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CONTENTS OF NUMBER 26


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THE INSTITUTE OF CETACEAN RESEARCH

POSSIBLE MIGRATION ROUTE OF THE GRAY WHALE ON THE COAST OF JAPAN

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ABSTRACT

The gray whale occured on the south coast of Wakayama and Kochi prior to the turn of the century. The calving ground of this stock was possibly in the Seto Inland Sea. It migrated to and from the feeding ground in the Okhotsk Sea, along the east coast of Japan. With the increasing industrial development and boat and ship traffic this stock of the gray whale was driven from the Inland Sea and probably joined to the Korean stock or even to the California stock. A case of stranding of the blue whale is also reported.

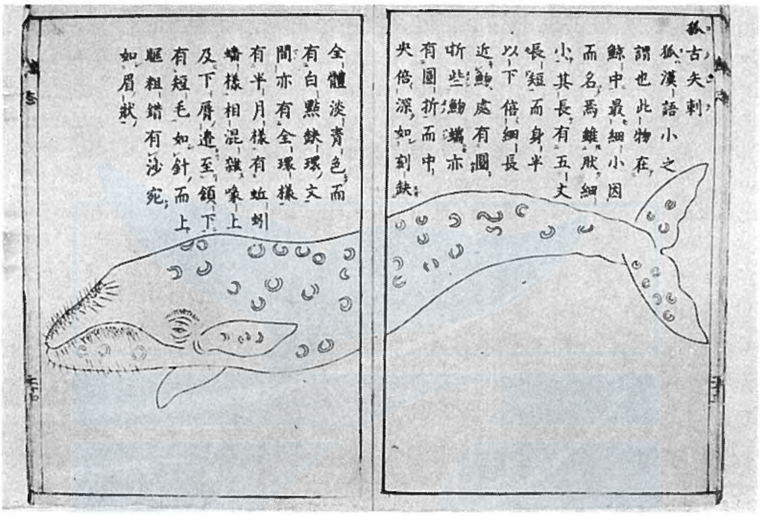
INTRODUCTION

Occurrence of the gray whale on the coast of Japan is described by many authors of old Japanese books and picture scrolls of whales. In Geishi (The treatise of the whale), written by Jiemon Kandoriya of the castellany of Wakayama in 1758 and printed in 1760, which is the earliest printed monograph of the cetacea in Japan, is shown a drawing of Kokujira with a brief description (Fig. 1). This whale is drawn rather slender, but it has a series of knobs instead of a dorsal fin and bears many circular and semicircular scars on the surface of the body and tail flukes. It has bristles spreading over the entire head. He also describes that this species is the smallest among whales. He has a reason because the minke whale was not taken in these days (see Table 1).

Kiyonori Otsuki (1773–1850), a famous scholar in the Tokugawa era, left an undated manuscript on whales and whaling, entitled Geishiko (A draft of a history of the whale). It remained unpublished till 1925, when it was printed in a series of various collections in Sendai. It is by far the most systematic survey of whales and whaling that was written in the Tokugawa period (Hawley, 1958). In this book he notes that Kokujira has baleen plates of white in color. Other descriptions agree in general with those in Geishi, but he mentions the body form of Kokujira is more fat than the drawing in Geishi and gives two figures of Kokujira which resemble more to the gray whale (Fig. 2).

From the above it may safely be concluded that Kokujira is identical with the gray whale (*Eschrichtius robustus*) and it had occurred in the past at least on the coast of Wakayama. Further there remains some statistical data which show Kokujira or the gray whales were taken on the coast of Kochi, southern part of Shikoku, by the so-called net whaling prior to this century.

Modern whaling was introduced to Japan in 1897. Operation of this type of whaling was firstly conducted on the east coast of Korea under the permission of the said government. After several years it was introduced to the coast of Kyushu, Kochi and Wakayama, gradually replacing the net whaling, and then to the northeast coast of Japan and off Hokkaido. But there is no record of the gray whale taken by modern whaling on the coast of Kochi and Wakayama, except one reported by Andrews (1914), refered from records of whaling company. This whale, a male of 40 feet long, was taken at Oshima, Wakayama, on 9 February 1910.



狐
古失剌
狐漢語小之
謂也此物在
鯨中最細小因
而名焉雖然細
小其長有五丈
長短而身半
以下倍細長
近鰭處有圈
斫些[illegible]亦
有圓折而中
央倍深如刻缺

全體淡青色而
有白點缺環文
間亦有全環樣
有半月樣有蚯蚓
蟠樣相混雜像上
及下脣邊至頷下
有短毛如針而上
髭粗錯有沙窕
如眉狀

Fig. 1. Kokujira in Geishi, 1760. Cited from Hawley, 1958.

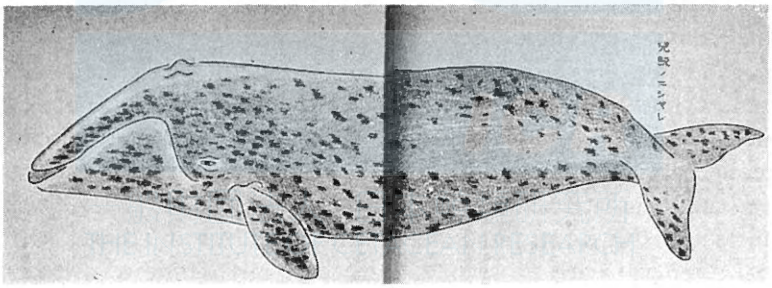


Fig. 2. Kokujira in Geishiko (Share).

In April of the year he stayed at Oshima, but no gray whale was observed at this landstation by him (Andrews, 1916). On the other coast of Japan the gray whale was taken rarely, as reported by Mizue (1951). What happened with the gray whale on the coast of Japan? This problem is discussed in this paper in relation to the supposed calving ground of this species.

CATCH OF THE GRAY WHALE IN THE DAYS OF NET WHALING

The method of taking whales by net was invented by Kakuemon Taiji in 1677 at Taiji of the castellany of Wakayama (now Wakayama-ken), and then it spread to fishing villages on the south and west coast of Japan, including Shikoku and Kyushu, where whales came in shore in winter.

This method is a combined method of driving, netting and harpooning. When a whale was sighted by Yamami (watch on the hill), they make a signal informing species, position and swimming direction of the whale with flags or rockets. Various kinds of boats waited and went into action in orderly fashion as soon as the commander gave the order. The basic organization of whaling fleet was as follow.

> Sekobune (for driving and killing whales). One group of about ten boats or more, 13 m long and 2.2 m wide with 8 oars, occasionally with sail. Crew consists of 15 men.
>
> Amibune (netting boats). One group of about 6 boats, 13 m long and 3.5 m wide with 8 oars. Crew of 10 men.
>
> Mossobune (tug boats). A group of 4 boats, nearly same as Sekobune but with a little broader beam. Crew of 13 men.

Sekobunes drive the whale to the place called Amiba (netting place) near the shore, producing underwater sounds with wooden hammer, where Amibunes are waiting to set the nets. Net is set sometimes two or three-fold in order to prevent the whale's escape and to check its action by entanglement.

Various kinds of harpoons, made of iron, were used. Their weights are not heavy and usually 1.0–2.0 kg in weight. Attached with harpoon a slender wooden pole and a rope with float at its end. Harpoons are thrown high up in the air so that they drop on the back of the whale from the air. When the whale has been sufficiently weakened by a number of harpoons, and later by the help of heavy swords thrown to the thorax, a sailor swims and climbs up on it and makes a hole at the blowholes with his knife in order to pass a rope through it. Then the whale is wound by several strands of rope around the body in order to tie the whale body between two Mossobunes before the whale was finally killed. Then it is stabbed at the heart with long swords.

In this way not only the right whale but also the balaenopterid whales were taken by the net whaling. This type of whaling was conducted by villagers forming groups. In these days two groups were in operation on the coast of Kochi and four groups in Wakayama. Shibusawa (1930) gives catch statistics of Ukitsugumi, one of these groups in Kochi, during 22 years from 1875 to 1896, by species of whales (Table 1). As seen in this table 64 whales or 17 percent among the total of 370 whales taken during this period were gray whales. From this table it is clear that the gray whale was hunted regularly at least until 1896 in these regions, as stated briefly by Nishiwaki and Kasuya (1970).

Further Hattori (1888) presents some data on details of operation and sighting of whales by the same whaling group in three years of 1880, 1882, and 1883 (Table

2). A total of 43 gray whales were sighted in these years, in which 12 were taken, 24 escaped from taking and 7 were not pursued due to unfavorable weather.

In general the rate of the catch against total whales sighted is very low and this is thought to be the main reason why the net whaling could survive more than 200 years. Among whale species other than the gray in Table 1 were also taken later by the modern whaling on the coast of Kochi and Wakayama.

TABLE 1. CATCH OF WHALES BY UKITSU WHALING GROUP, 1875–1896.
(Cited from Shibusawa, 1939)

Year	Blue	Fin	Bryde's	Humpback	Right	Gray	Total
1875	3	—	4	2	1	1	11
1876	2	2	5	6	—	2	17
1877	—	—	3	19	—	11	33
1878	3	—	4	4	6	1	18
1879	1	—	2	9	3	7	22
1880	5	1	8	2	1	6	23
1881	1	—	5	10	2	5	23
1882	3	—	2	4	—	3	12
1883	—	—	3	7	1	3	14
1884	5	1	2	1	2	1	12
1885	4	1	4	5	2	3	19
1886	1	9	3	6	—	1	20
1887	5	—	4	13	—	4	26
1888	1	3	4	6	—	1	15
1889	2	—	7	4	—	2	15
1890	—	3	4	—	—	1	8
1891	5	—	—	9	—	1	15
1892	2	—	3	1	1	1	8
1893	4	—	1	3	1	4	13
1894	1	—	4	3	1	1	10
1895	2	1	5	6	—	3	17
1896	5	2	4	6	—	2	19
Total	55	23	81	126	21	64	370

Note: Japanese name of the above whale species in these days are:
Blue whale—Nagasukujira, Fin—Nosokujira, Bryde's—Iwashi or Katsuokujira, Humpback—Zatokujira, Right—Semikujira, Gray—Kokujira.
But now the blue whale is called Shironagasukujira, and the fin Nagasukujira. Iwashikujira means usually the sei whale, but Iwashikujira in these districts is possibly the Bryde's whale.

SUPPOSED CALVING GROUND IN THE SETO INLAND SEA

Shindo (1970) proposes the " east Kyushu migration route " of whales. He is a clinical doctor, but concurrently a historian and has much interest on whales and whaling, especially on whales in the Seto Inland Sea. His conclusion is based upon his study of tombs and memorials of whales and old documents concerning these whales. He also visited villages and made interviews with people concerned.

In old days it was a general custom to errect a tomb or a memorial when a whale stranded on the beach or occasionally killed by fishermen, like human being following after buddhism. These tombs or memorials are most abundantly remaining on the northeast coast of Kyushu and west coast of Shikoku (Fig. 10). Among 34 tombs or memorials, he investigated all over Japan, 15 are situated in these districts. They were errected within a period of about 100 years from 1809 to 1907. It is suggested from these facts that whales have passed frequently this strait and some of them were killed occasionally or stranded.

TABLE 2. SIGHTING AND WHALING OPERATION BY UKITSU WHALING GROUP, 1880, 1882, AND 1883.
(Cited from Hattori, 1888)

	Year	Blue	Fin	Bryde's	Humpback	Right	Gray	Total
1880:	Catch	5	1	7*	2	1	6	22*
	Escaped, A	1	2	5	—	—	4	12
	„ B	9	3	15	4	2	8	41
	„ C	—	—	—	—	—	—	—
	Not operated, D	5	6	4	4	4	3	26
	„ E	14	—	3	5	—	—	22
	Total, sighted	34	12	34	15	7	21	123
1882:	Catch	3	—	2	4	—	3	12
	Escaped, A	3	—	6	2	—	4	15
	„ B	4	2	11	1	4	1	23
	„ C	—	—	—	—	1	—	1
	Not operated, D	3	1	4	3	4	1	16
	„ E	2	—	1	6	—	—	9
	Total, sighted	15	3	24	16	9	9	76
1883:	Catch	—	—	3	7	1	3	14
	Escaped, A	1	—	6	5	—	2	14
	„ B	9	—	22	16	—	5	52
	„ C	—	—	5	—	—	—	5
	Not operated, D	3	—	2	26	—	3	34
	„ E	5	1	6	46	—	—	58
	Total, sighted	18	1	44	100	1	13	177

* One whale difference from Table 1.
Escaped, A—breaking net, B—beneath net, C—round net.
Not operated, D—due to rough weather, E—offshore.

He (1968) also ascertained that Beppu-wan, a small bay on the northeast coast of Kyushu, was a calving ground of whales. Fishermen applied in vain several times for permission of whaling to the local government. These documents are remaining, but the reason of the rejection has not been made clear. Coming of whales to this bay has lasted until about 1887. With regard to the whale species he notes as Nagasukujira, mainly based on old papers left in Usuki, a city facing to a small bay next to Beppu-wan, and where a memorial of a stranded whale remaining. The story of this stranding is described later in this report.

Waters around Iwaijima, Yamaguchi-ken, was also a calving ground of whales.

This is supported by Higashi (1944), who writes " Nearby waters of Iwaijima was a calving ground of Nagasukujira and 60–70 whales have gathered yearly in these waters. Sometimes dead calves were washed ashore ". In Onoda, a city located westward of Iwaijima in Yamaguchi-ken, whaling was conducted in small scale in winter with hand harpoons and without using net. The whaling group was consisted of 15–20 fishing vessels. The whale species is not known, but most of them were accompanied by calves. The whaling group was dissolved in some years around 1877.

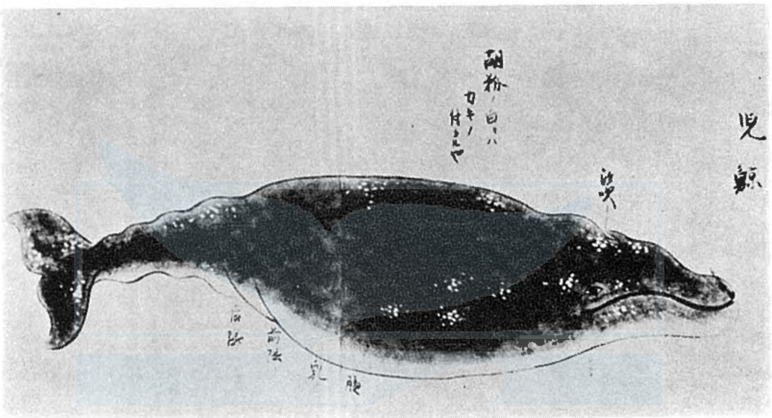


Fig. 3. Kokujira in Yakuyoki, Kawanoe. First whale.

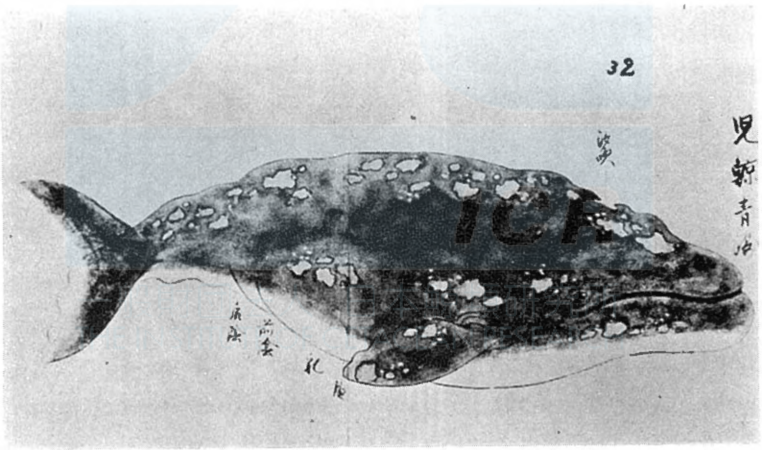


Fig. 4. Kokujira in Yakuyoki, Kawanoe. Second whale (Aosagi).

Above are the basis why Shindo (1970) proposes the " east Kyushu migration route " of whales. He concludes that there are good evidences of whales coming into Beppu-wan and came in shore of the south coast of Yamaguchi-ken and the purpose of this migration was for calving. For the whale species he notes the possibility of the balaenopterid whales, but this is hardly be thought. No baleen whales other than the gray whale give birth to a calf in such shallow coastal waters. It is highly possible, therefore, that the Shindo's proposal of migration route is only applied for the gray whale. There is a possibility of other species entering into the Seto Inland Sea through this passage, but it is not for calving. In fact a skull of a balaenopterid whale was dug out from sea bottom off Onoda in 1926. This skull was identified as a minke whale by Dr. T. Ogawa (Shindo, 1968).

Shindo (1968) reports two gray whales were taken at Kawanoe, Ehime-ken, in 1864. The official records or diary of the local government (Yakuyoki) in these days are still being kept at the city library. The first whale was taken on 20 February 1864 by nets and harpoons. This whale came in shore of the city several days before the hunting was done, during which period villagers prepared catching equipment. Shortly after the catch of the first whale the second whale came and this whale was taken on 26 February of the same year.

Attached with the official records there remains sketches of two whales (Figs. 3 and 4). Both are without doubt the gray whale, having several knobs instead of a dorsal fin and the head is small and not arched, unlikely to the right whale. The first whale was marked with white color on the dark gray of the body the infection of barnacles, but lacking the pale patches. The second whale bears pale patches all over the body, in addition to the barnacles. The body length of the first and the second whales were recorded as having 4 Hiro (1 Hiro approximately 1 Fathom) and 6 Hiro respectively. This length does not mean the total length, because it was a custom in Wakayama and Kochi to measure the length of the whale body from the blowholes to the insertion of the tail flukes. In any case the first whale was smaller and younger than the second whale. The first whale is noted as Kokujira, but the second whale as Kokujira or Aosagi. Two types of Kokujira were noted in these days. One is Aosagi and another is Share, but the difference between two types is not clearly described in most of the old books. Should the first whale grouped as Share, then the difference is based on the color pattern of the whale body caused by the infection of barnacles, or it can be said that Share is younger than Aosagi. Both whales are thought to be females, because teats are noted in addition to navel, genital grooves, anus and blow holes in their right positions.

One scapula from one of these whales has been preserved. It has been kept at Hachiman shrine in the city (Fig. 5). There is a custom in Japan to donate Ema to a shrine in memory of big event or from some other reasons. Usually Ema is a painting on a wooden plate. In this case a scapula was used instead of wooden plate. At the center of the scapula a big Japanese (or Chinese) character which means a whale is written with powdered gold. On both sides and below this character a brief descriptions of this whale is also written with paint by small characters. This Ema has been hanged more than a hundred years on the wall of the shrine with other wooden Emas.

These two whales were the only whales taken at Kawanoe in the history, but at Takuma, a small town east of Kawanoe, whaling had been conducted with nets and harpoons annually, taking about three whales in average, at least in a period from 1889 to 1897. The species of whale are not known, but the size of whales is said to be 5–7 Hiro, which are the comparable size with the Kawanoe whales.

Fig. 5. Left scapula of the Kawanoe whale.

OBSERVATION OF SCAPULAE AND OTHER BONES

Shindo (1970) reports a scapula, a tympanic bulla and one of ribs of the stranded whale at Usuki also have been preserved in the city. These are private posession of persons living there. I had a short trip in April 1974 to Usuki and Kawanoe in order to examine these bones. It may be of some interest to note here the story of the stranded whale briefly. The village of Odomari, now included in Usuki city, constructed fishing harbor (Fig. 6) in 1868, but the cost has remained as a big burden of debt. On 1 February 1870 a big whale came into the harbor and finally stranded. This whale was sold, after being dismembered by all hands of the villagers, and the amount of money earned could cover all of the cost needed for the construction of the harbor. The villagers constructed a memorial (Fig. 7) and on 1 February of the following year they held a buddhistic ceremony for the whale. Since then the ceremony is being held on 1 February every year, including 1974.

On arrival at Odomari, Usuki city, I knew that another scapula has also been preserved at a family. They also said some of the baleen plates of the whale were remained until about five years ago, when they were finally burned, not knowing the value of such precious sample. In Table 3 measurements of the scapulae of the Usuki and Kawanoe whales are shown, together with measurements of other authors. The scapula of the Kawanoe whale (Fig. 5) agrees in general with the descriptions by Andrews (1914), being intermediate between the wide, low blade of *Balaenoptera* and the high, narrower and more symmetrically fan-shaped scapula of *Eubalaena*. The superior margin is quite evenly convex and the glenoid border is almost straight except for a short concavity where it rises from the glenoid fossa. The acromion is wide, but it is not expanding towards its distal end, contrally to the description of Andrews and the photograph shown by Nishiwaki and Kasuya (1970). But this is thought to be caused by abrasion of the extreme end. The coracoid is thick and massive and directed somewhat upward from the margin of the glenoid fossa. The external face of the scapula is quite strongly concave. This scapula is smaller than that reported by Andrews (1914), but larger than those reported by Nishiwaki and Kasuya (1970). The former whale is an old male of 1250 cm long, and the latter is a young female of 900 cm in length. This scapula is thought to be taken from the second whale, and the size of this whale is possibly between the two lengths.

Fig. 6. Odomari fishing harbor, Usuki city. A big whale entered into this harbor and finally stranded in 1870.

The scapulae of the Usuki whale (Fig. 8) differ from that of the Kawanoe whale, being more broader and less massive, as shown in the table expressed by thickness of the superior margin of the fan. The acromion and the coracoid are shorter than in the Kawanoe whale. The external face is quite different from the Kawanoe whale, having no concavity, a characteristic feature of the gray whale. On the rear surface it has several shallow grooves radiating from the center of the fan. Without doubt these scapulae came from one of the balaenopterid whales. The tympanic bone, 129 mm in length, is broken at its margin, but this also suggest this and the outline of this bone resembles to that of the blue whale from the North Pacific (Fig. 9). The remaining rib is thought to be one of the latter half ribs. Its head is rounded and it measures 147 cm in straight line, but its distal end was cut off by knife. This bone has lesser value for the identification of the species.

After returning to Tokyo I sent three baleen plates, each one from the blue, fin and Bryde's whales, to Usuki for their identification, not informing them the species. They told me the color of the baleen plates was black, but the scapulae are without doubt not from a right nor a humpback whale, and there is less possibility of the sei whale in these regions. The reply was that the whale was a blue whale. Tomilin (1957) describes the ratio of breadth of the scapula against the height is 1.5–1.6 in the blue, 1.65 in the fin, and 2.0 in the sei whale. This value of the Usuki whale is around 1.6 and very close to the value for both blue and fin whales.

Fig. 7. Memorial of the big whale at Odomari.

In conclusion above the Usuki whale was possibly a blue whale and this was a rare case of the stranding of this species. The size of the scapulae are relatively small. The body length of this whale was recorded as having 15 Hiro which means roughly 75 feet (2250 cm.). This is clearly too big, even if this means the total length. Possibly the size of this whale was smaller than 20 m and probably around 17 m. The sex of this whale was male, because there remains a record that both eyes, penis, and bones in the loin (pelvic bones?) were burried beneath the memorial, sealed in a pot.

TABLE 3. MEASUREMENTS OF SCAPULAE OF THE USUKI AND KAWANOE WHALES.
(in mm)

Measurements	Usuki whale		Kawanoe whale	Gray A		Gray B
	Right	Left	Left	Right	Left	
Greatest breadth	980	970	990	757	761	1125
Greatest height	615	600	740	495	514	856
Length of acromion, inferior	260	220	290	193	190	335
Breadth of acromion, distal end	121*	120*	139	132	145	180
Length of coracoid	40	55	100	58	62	146
Length of glenoid fossa	235	220	210	253	245	268
Thickness of superior margin						
at anterior end	29	29	27			
at middle	9	8	15			
at posterior end	42	44	52			
Ratio of breadth against height	1.59	1.62	1.34	1.53	1.48	1.31

* Greatest.
Gray A. Cited from Nishiwaki and Kasuya, 1970.
Gray B. Cited from Andrews, 1914.

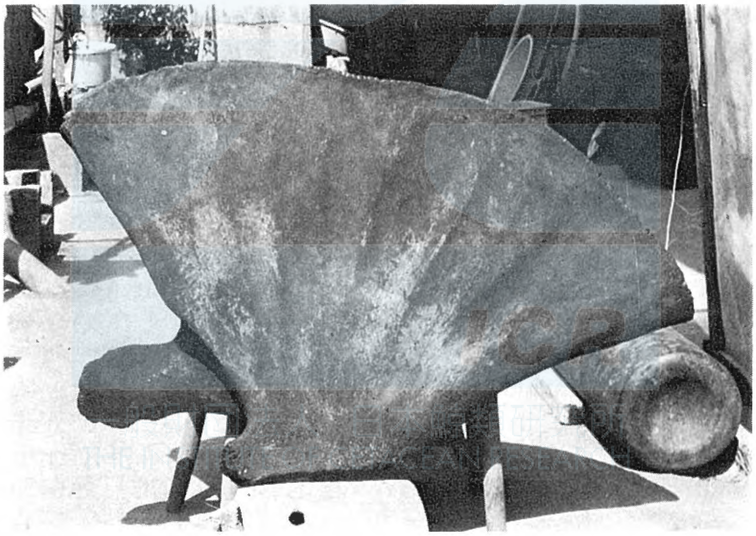


Fig. 8. Right scapula of the Usuki whale.

DISCUSSION

Although practically nothing was described by Andrews (1914), Mizue (1951) and Rice and Wolman (1971), the gray whale occured on the coast of Wakayama and Kochi in the days of the net whaling as already stated. It is possible that they entered into the Seto Inland Sea for calving, along the west coast of Shikoku. Their calving grounds were at least in the Beppu-wan and on the south coast of Yamaguchi. Possibly some of them then turned to east and reached as far as Kawanoe and Takuma. There is less possibility that the whale entered into the Seto Inland Sea along the west coast of Wakayama. One reason for this is the fact that no tomb or memorial is remaining on the west coast of Wakayama and east coast of Shikoku. Fishermen who engaged in the net whaling believed that whales come straight from off Shionomisaki, the southmost point of Wakayama, to the coast of Shikoku. Supposed migration route is shown in Fig. 10.

Fig. 9. Tympanic bulla of the Usuki whale.

With the increasing of industrial development along the coast of the Seto Inland Sea and boat and ship traffic the species has been driven from there since some time prior to this century. This might be the most possible explanation why practically no gray whale has been taken by modern whaling on the coast of Japan. Mizue (1951) reports, after investigating available catch records of whaling companies in seven years from 1911 to 1932, three were taken at Ayukawa and one at Nemuro, Hokkaido. Nishiwaki and Kasuya (1970) describe two recent occurences off Wakayama.

The feeding ground of the Japanese stock of the gray whale was probably in the Okhotsk Sea as in the case of the Korean stock (Rice and Wolman, 1971). The migration route to and from the feeding ground was possibly on the east coast of Japan, as already stated by Nishiwaki and Kasuya (1970). After driven from the calving ground in the Seto Inland Sea it probably has joined to the Korean stock. Further a possibility of joining to the California stock in the Bering Sea can not be denied. The original size of this stock is thought to be small and less than a thousand at the largest.

At Omijima, a small island on the north coast of Yamaguchi, or in the Sea of Japan, the gray whale was also taken in the days of the net whaling (Kimura, 1956). There remains catch records during a period from 1802 to 1850, by species. Annual catch, inclusive of all species, was fluctuated from one to fifteen whales.

The total catch during this period was consisted of the fin (38%), the humpback (34%), the right (19%), and the gray whale (9%). The catch of the gray whale has decreased since 1812. A question remains whether these gray whales belong to the Korean stock or they are stragglers from the Japanese stock.

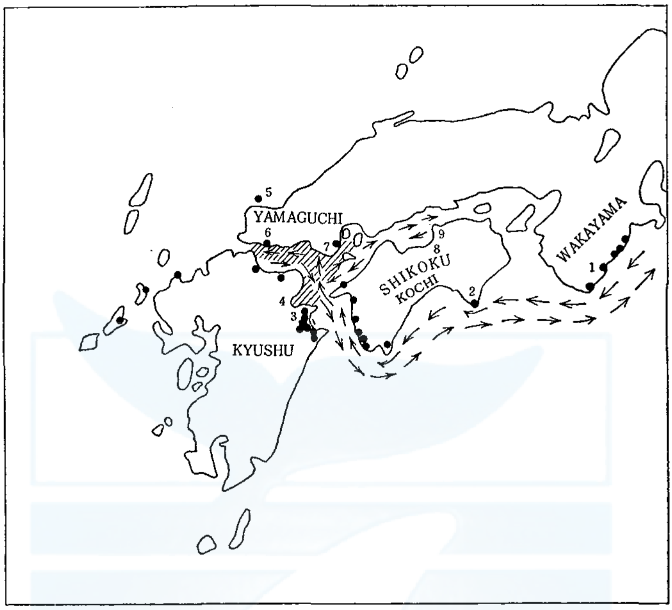


Fig. 10. Possible migration route of the gray whale on the coast of Japan.
Hatched area: Supposed calving ground.
Black dots: Positions where whale tombs or memorials located.
Names of the places refered to in the text are following.
1. Taiji 2. Ukitsu 3. Usuki 4. Beppu
5. Omijima 6. Onoda 7. Iwaijima 8. Kawanoe
9. Takuma

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Sincere thanks are due to Dr. N. Shindo who helped me greatly in this study. He joined my trip to Usuki and Kawanoe and made all possible arrangements for me. My thanks are also due to Mr. S. G. Brown of the Institute of Oceanographic Sciences, England. He gave me the old Japanese book, he found at an old book store in London, and from which Table 2 in the text was refered.

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POSTSCRIPT

After completion of the manuscript I read a paper on the Korean stock of the gray whale by Bowen (1974). The author states that the 1968 specimen (Nishiwaki and Kasuya, 1970) resembled members of the California stock in morphological features, without mentioning the character in question. As seen in Table 3 the ratios of breadth against height of scapulae in three specimens of the gray whale are: the Kawanoe whale 1.34, Gray A (Nishiwaki and Kasuya, 1970) 1.48–1.53, and Gray B (Andrews, 1914, Korean stock) 1.31. Thus in this respect the Kawanoe whale resembles more to the member of the Korean stock than the whale reported from the coast of Japan. But the latter whale is a young female and this is thought to be a difference due to the growth.

As regards the distribution of the Korean stock Dr. K. Uchida (1964) describes a gray whale sighted by him towards the end of May 1930 on the west coast of Korea, in the Yellow Sea, at a position close to 38°N.

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A TAXONOMIC STUDY OF THE MINKE WHALE IN THE ANTARCTIC BY MEANS OF HYOID BONE

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ABSTRACT

Hyoid bones of the minke whale in the Antarctic were studied from the standpoint of taxonomy, comparing those in the North Pacific. A distinction was noted in the length and thickness of the stylohyals. Greatest height of the ankylosed bone of basihyal and thyrohyals as well as the height at middle of the right and left wings are greater in the specimens from the Antarctic than in those from the North Pacific. But there is a possibility that this is a difference according to age of the whale. Hence samples from the Antarctic are biased towards older ages and those from the North Pacific towards younger ages, no conclusion was reached in this respect.

INTRODUCTION

The minke whale in the Antarctic, though most closely related to *Balaenoptera acutorostrata*, differs from the latter in having flippers of a uniform pale gray colour instead of showing the characteristic white band of the true minke whale. Furthermore the baleen of *B. acutorostrata* is of a uniform yellowish-white colour whereas the baleen of the minke whale in the Antarctic is white at the front of the series and gray and white at the back (Williamson, 1959, 1961; Utrecht and Spoel, 1962; Kasuya and Ichihara, 1965; Ohsumi *et al*., 1970).

Williamson (1961) describes that it is uncertain whether they (*B. bonaerensis*) represent a true species, or a subspecies of *B. acutorostrata*, but Utrecht and Spoel (1962) and Ohsumi *et al.* (1970) report that *B. bonaerensis* is a synonym of *B. acutorostrata*, mainly based on studies on the external characteristics.

In this report the hyoid bones of the minke whales in the Antarctic are compared with those of the North Pacific (*B. acutorostrata*) from the taxonomic standpoint, following after the method adopted by Omura (1964).

MATERIAL

In the 1971–72 whaling season Dr. Seiji Ohsumi went to the Antarctic on board Jinyo Maru, a minke whaling expedition. He collected hyoid bones from 25 minke whales and made them at our disposal. These whales were taken in the Antarctic area IV and the sex and body length of each whale are shown in Appendix Table.

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No. 26, 1974, 15–24

MEASUREMENTS

After extraction of oil and cleaning measurements of various parts were made. These are compared with those from the North Pacific, cited from Omura (1964). There is rather a wide difference in body length of samples between both hemispheres. Samples from the Antarctic range from 710 cm to 980 cm in length, with an average of 850 cm, whereas those from the North Pacific are from 500 cm to 768 cm and in average 624 cm. Thus samples from the Antarctic are biased towards older ages and those from the North Pacific towards younger ages, which should be born in mind in direct comparison.

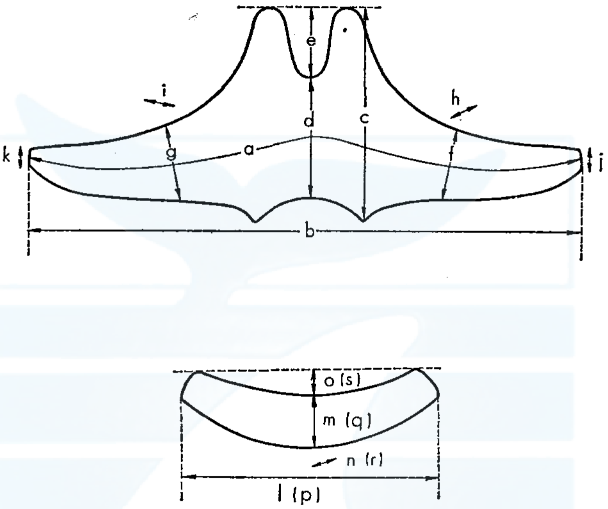

Fig. 1. Showing positions of the measurements.

The following measurements were made on each hyoid bone collected (see Fig. 1).

A. Ankylosed bone of basihyal and thyrohyals.

- a. *Overall length.* Curved length measured along the outer surface and passing centers of basihyal and thyrohyals.
- b. *Straight length.* Straight length between tips of right and left wings.
- c. *Greatest height.* Greatest height between tips of the anterior and posterior projections of the basihyal.
- d. *Height at center.* Height measured at the center of the bone.
- e. *Forward notch, depth.* Depth of the notch between right and left forward projections of the basihyal.
- f. *Height at middle of wing, right.* Height measured at middle between the center of the basihyal and tip of right wing.
- g. *Height at middle of wing, left.* Height measured at middle between the center of the basihyal and tip of left wing.

h. *Thickness at middle of wing, right.* Thickness of right thyrohyal on the line of measurement f.

i. *Thickness at middle of wing, left.* Thickness of left thyrohyal on the line of measurement g.

j. *Height at distal end, right.* Height of right thyrohyal at its distal end.

k. *Height at distal end, left.* Height of left thyrohyal at its distal end.

B. Stylohyal.

l. *Total length, right.* Straight length between tips of right stylohyal.

m. *Height at middle, right.* Height at middle of right stylohyal.

n. *Thickness at middle, right.* Thickness of right stylohyal on the line of measurement m.

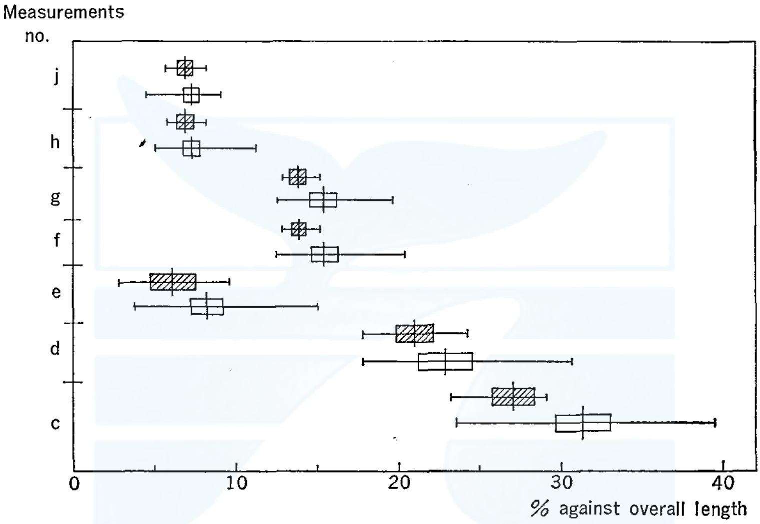

Fig. 2. Measurements of various parts of the ankylosed bone of basihyal and thyrohyals of the minke whale, expressed as percentages against its overall length. For measurements no. see text. Horizontal line indicates ranges of measurements, vertical midline the arithmetic mean, square the 95% confident limits of the mean. Square with hatched lines denotes samples from the minke whale from the North Pacific and white square those from the Antarctic.

o. *Degree of curvature, right.* Greastest distance between the straight line passing the most prominent parts of right stylohyal and its forward surface.

p. *Total length, left.* Straight length between tips of left stylohyal.

q. *Height at middle, left.* Height at middle of left stylohyal.

r. *Thickness at middle, left.* Thickness of left stylohyal on the line of measurement q.

s. *Degree of curvature, left.* Greatest distance between the straight line passing the most prominent parts of left stylohyal and its forward surface.

Results of these measurements are shown in Appendix Table, together with the serial number of the whale, sex, and body length.

These measurements were then calculated of their percentages against overall length in the case of the ankylosed bones of the basihyal and thyrohyals. For the stylohyals also percentages against overall length were calculated for total length, but in other measurements percentages against the length of stylohyals were calculated. Further for each measurement the arithmetic mean, its standard deviation and 95% confident limits of the mean were calculated.

DISCUSSION

The results of the calculations are shown in Figs. 2–4, comparing with those from the North Pacific. As seen in these figures differences are noted between the minke whales from the different oceans in the following measurements:

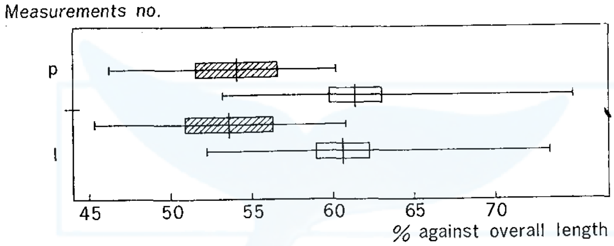

Fig. 3. Measurements of stylohyal of the minke whale, expressed as percentages against the overall length of the ankylosed bone of basihyal and thyrohyals. For explanation see Fig. 2.

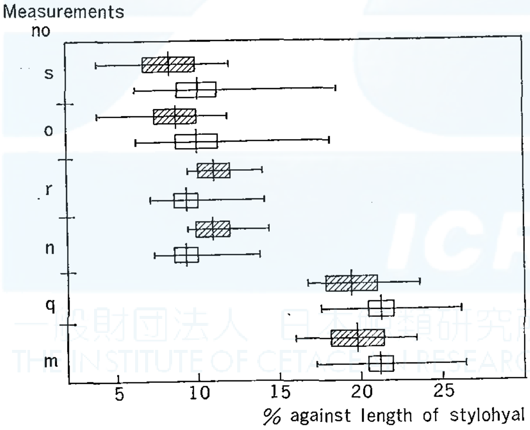

Fig. 4. Measurements of various parts of the stylohyal of the minke whale, expressed as percentages against its total length. For explanation see Fig. 2.

A. Ankylosed bone of basihyal and thyrohyals (Fig. 2).
   c. Greatest height.
   f. Height at middle of wing, right.
   g. Height at middle of wing, left.

B. Stylohyal (Fig. 3, Fig. 4).

l. Total length, right.
p. Total length, left.
n. Thickness at middle, right.
r. Thickness at middle, left.

In the other measurements 95 % confident limits are overlapping each other and they cannot be said as distinct. In conclusion above the minke whales in the Antarctic have more higher combined bone and larger and thicker stylohyals, hence more massive hyoid bones than those in the North Pacific.

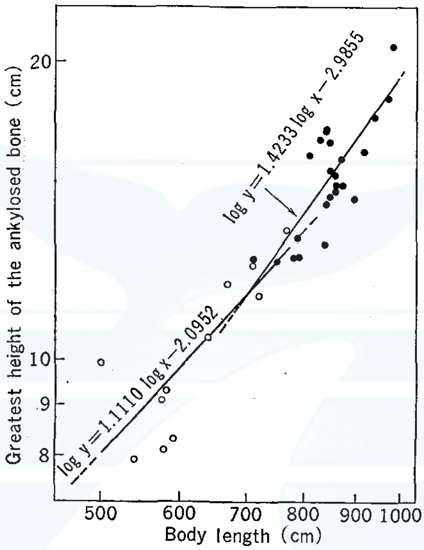

Fig. 5. Relative growth of the greatest height of the ankylosed bone of basihyal and thyrohyals and body length of the minke whale. Circles indicate minke whales in the North Pacific and black dots those from the Antarctic.

As already stated average body lengths of the sample whales are widely different between the two oceans. More larger or older whales were sampled from the Antarctic than from the North Pacific. The reason for such discrepancy in body length should be sought in the segregation of the minke whales according to the size or age. Samples from the North Pacific were collected at Ayukawa on the east coast of Japan where sexually mature animals are far less than in the waters of higher latitudes (Omura and Sakiura, 1956). Also in the Antarctic similar segregation by age groups was noted in males (Ohsumi *et al.*, 1970). Consequently there is a possibility that the above noted differences in hyoid bones are in fact due to differences according to age.

In Fig. 5 the greatest heights of the ankylosed bone of basihyal and thyrohyals have been plotted logarithmically against body length of whales. In the figure different symbols were used for the minke whales from both hemispheres. This figure shows that there are significantly different gradients for regressions of log height of the bone on log length between whales from the different oceans, and the lines of regression intersect at the body length of 709 cm.

In Figs. 6 and 7 relative growth of the height at middle of wing of the combined bones and body length are shown. In these cases two regression lines in

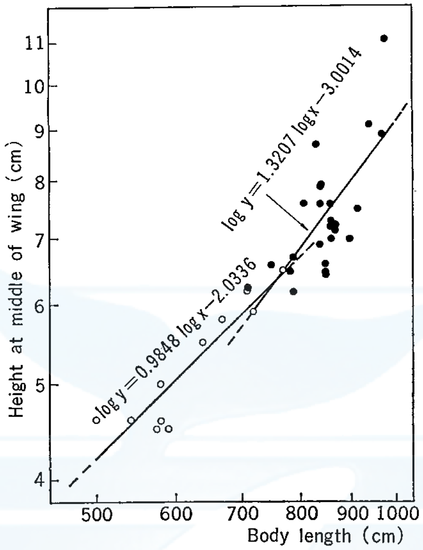

Fig. 6. Relative growth of height at middle of right wing of the ankylosed bone and body length of the minke whale. For symboles see Fig. 5.

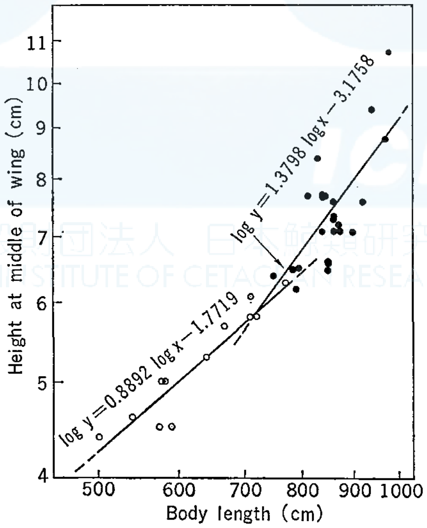

Fig. 7. Relative growth of height at middle of left wing of the ankylosed bone and body length of the minke whale. For symbols see Fig. 5.

each figure intersect at a body length of 761 cm (right side, Fig. 6) and 727 cm (left side, Fig. 7) respectively. Ohsumi *et al.* describe that the sexual maturity of the minke whale in the Antarctic is attained at a body length of 710 cm in male and 790 cm in female. According to Omura and Sakiura (1956) in the minkes on the coast of Japan these lengths at sexual maturity of male and female are 660–690 cm and 720 cm respectively.

One possibility, therefore, is that the antero-posterior growth of the combined bone becomes greater proportionally after the attainment of the sexual maturity. But this cannot be concluded at present due to lack of sufficient materials. More materials, i.e. in the case of the minke whale in the Antarctic samples from immature animals and in that in the North Pacific more samples from mature animals, are needed.

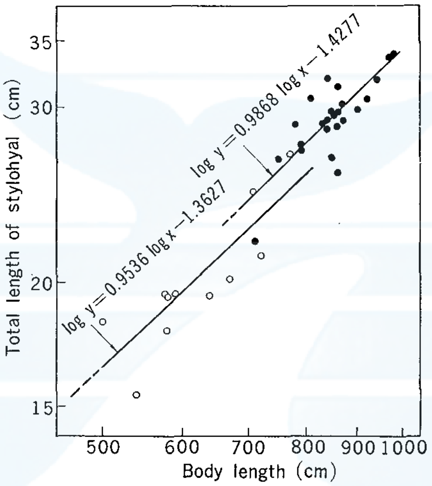

Fig. 8. Relative growth in length of right stylohyal and body length of the minke whale. For symbols see Fig. 5.

In Figs. 8 and 9 relative growth of the stylohyal and body length are shown. As clearly seen in these figures two lines of regression are nearly parallel and we may safely conclude that the minke whale in the Antarctic has more longer stylohyals than the minke in the North Pacific, though there is rather a wide individual variation.

We are not in a position, however, to conclude at present whether the minke whale in the Antarctic, *Balaenoptera bonaerensis*, represent a true species, or a subspecies of *B. acutorostrata*, as stated by Williamson (1961). Further studies especially on the skull and other postcranial bones are needed in order to reach a more definite conclusion.

Omura (1964) made a key to the genera and species of mystacoceti by means of hyoid bone. In the key he separates *B. acutorostrata* from *B. borealis* and *B. edeni* by percentage of the greatest height of the combined bone against its overall length.

The critical proportion is 29 percent and those less than this value was assigned to *B. acutorostrata* and others to *B. borealis* and *B. edeni*. *B. bonaerensis* has more greater value than this and the key should be or should not be revised in this respect, depending upon the final conclusion.

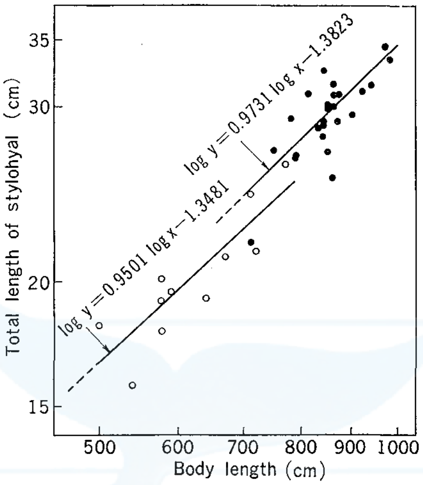

Fig. 9. Relative growth in length of left stylohyal and body length of the minke whale. For symbols see Fig. 5.

ACKNOWLEDGEMENTS

Our sincere thanks are due to Dr. Seiji Ohsumi who collected hyoid bones of the minke whale in the Antarctic for the present study. The crew of Jinyo Maru and the staff of Taiyo Gyogyo K.K. are deeply acknowledged for their cooperation in sampling and also in transportation of the material.

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APPENDIX TABLE. MEASUREMENT OF HYOID BONE OF THE MINKE WHALE IN THE ANTARCTIC.

Serial no.	Body length (m)	Sex	Measurement in mm*																		
			a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s
71J2721	7.1	F	364	334	127	98	21	62	61	30	29	34	34	220	46	23	18	219	45	22	19
71J2692	7.5	F	446	404	125	86	38	66	64	32	30	38	38	266	55	21	25	271	56	20	26
71J0188	7.8	F	459	425	127	88	37	65	65	30	30	43	45	288	54	22	35	292	55	22	35
71J2849	7.9	M	489	452	126	87	40	67	65	32	31	35	35	274	62	20	17	276	63	21	18
71J2685	7.9	F	414	399	132	105	24	62	62	29	30	36	33	271	47	23	30	275	48	23	28
71J2727	8.1	F	478	451	161	106	52	76	77	38	36	48	49	306	62	32	25	311	64	31	25
71J2323	8.3	F	450	420	166	138	23	87	84	42	41	41	41	285	63	34	33	286	65	33	30
71J2324	8.4	M	503	435	131	107	19	76	77	32	31	32	32	289	59	23	33	289	62	24	31
71J0157	8.4	F	466	438	171	96	70	79	77	42	41	34	37	275	61	38	50	280	62	37	52
71J0312	8.4	F	433	405	171	129	35	79	77	35	36	33	31	318	64	30	52	324	60	33	55
71J0459	8.4	F	477	425	143	90	43	69	71	34	34	32	32	285	55	29	27	287	57	30	24
71J0174	8.5	M	522	475	164	111	49	65	66	30	29	30	29	294	61	24	37	298	66	26	36
71J2415	8.5	F	502	462	147	94	52	65	65	38	39	39	41	267	62	24	17	272	63	24	18
71J2793	8.5	M	514	491	155	113	40	66	66	31	32	35	39	294	61	30	41	302	60	30	45
71J2322	8.6	F	427	397	153	123	31	73	73	38	37	37	36	257	59	34	22	256	60	36	21
71J0165	8.6	F	506	460	148	97	46	72	73	31	32	29	30	294	67	23	25	299	70	23	26
71J2373	8.6	M	471	438	124	96	27	70	71	24	26	36	37	286	65	25	23	308	65	25	26
71J2667	8.6	M	507	453	150	99	46	76	76	47	46	41	41	315	69	35	23	316	70	36	25
71J2197	8.7	F	505	460	151	105	43	71	72	34	34	44	41	300	67	29	33	307	68	30	34
71J2228	8.7	F	480	435	159	121	38	73	71	31	31	29	30	290	61	20	18	292	64	21	18
71J0145	9.0	F	503	454	145	106	35	70	71	38	41	37	38	297	62	27	24	296	62	27	23
71J0154	9.2	F	511	479	162	104	49	75	76	32	32	39	41	306	63	24	19	312	62	22	20
71J0276	9.4	F	485	433	176	147	22	91	94	39	40	47	44	318	84	29	23	314	82	27	24
71J0458	9.7	F	556	489	184	130	44	89	88	46	46	51	53	335	69	27	43	346	67	28	47
71J2883	9.8	F	543	493	207	157	48	111	107	40	40	38	40	339	63	27	33	336	64	28	39

* For measurement number see text.

EXPLANATION OF PLATES

All the photographs were taken from the ventral side.

PLATE I

The ankylosed bone of basihyal and thyrohyals of the minke whale from the Antarctic.

Fig. 1.	specimen 71J2721	Fig. 8.	specimen 71J2324
Fig. 2.	specimen 71J2692	Fig. 9.	specimen 71J0157
Fig. 3.	specimen 71J0188	Fig. 10.	specimen 71J0312
Fig. 4.	specimen 71J2849	Fig. 11.	specimen 71J0459
Fig. 5.	specimen 71J2685	Fig. 12.	specimen 71J0174
Fig. 6.	specimen 71J2727	Fig. 13.	specimen 71J2415
Fig. 7.	specimen 71J2323	Fig. 14.	specimen 71J2793

PLATE II

The ankylosed bone of basihyal and thyrohyals of the minke whale from the Antarctic.

Fig. 15.	specimen 71J2322	Fig. 21.	specimen 71J0145
Fig. 16.	specimen 71J0165	Fig. 22.	specimen 71J0154
Fig. 17.	specimen 71J2373	Fig. 23.	specimen 71J0276
Fig. 18.	specimen 71J2667	Fig. 24.	specimen 71J0458
Fig. 19.	specimen 71J2197	Fig. 25.	specimen 71J2883
Fig. 20.	specimen 71J2228		

PLATE III

Stylohyals of the minke whale from the Antarctic.
For explanation see PLATE I.

PLATE IV

Stylohyals of the minke whale from the Antarctic.
For explanation see PLATE II.

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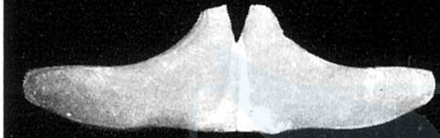

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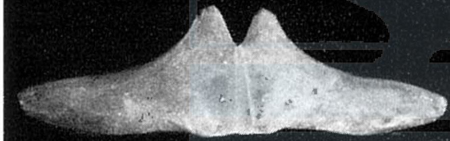

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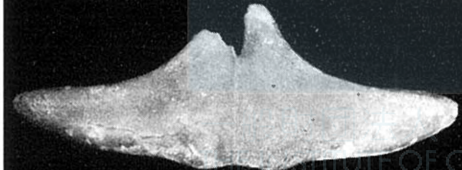

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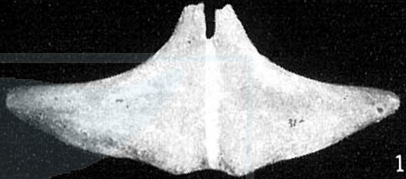

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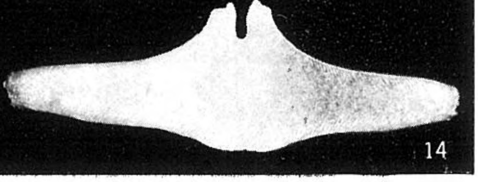

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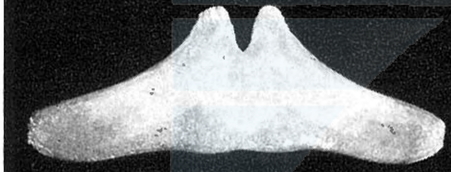
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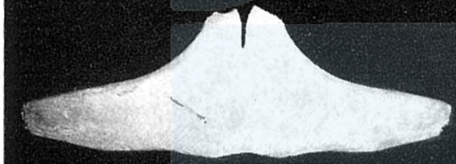
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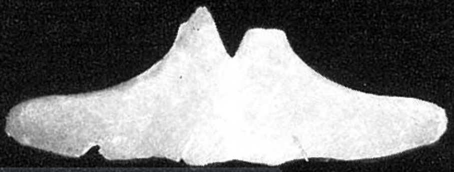
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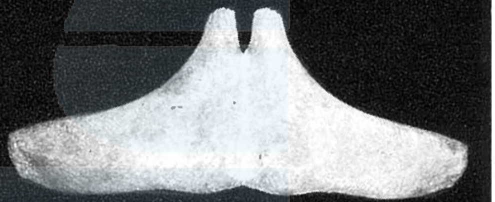
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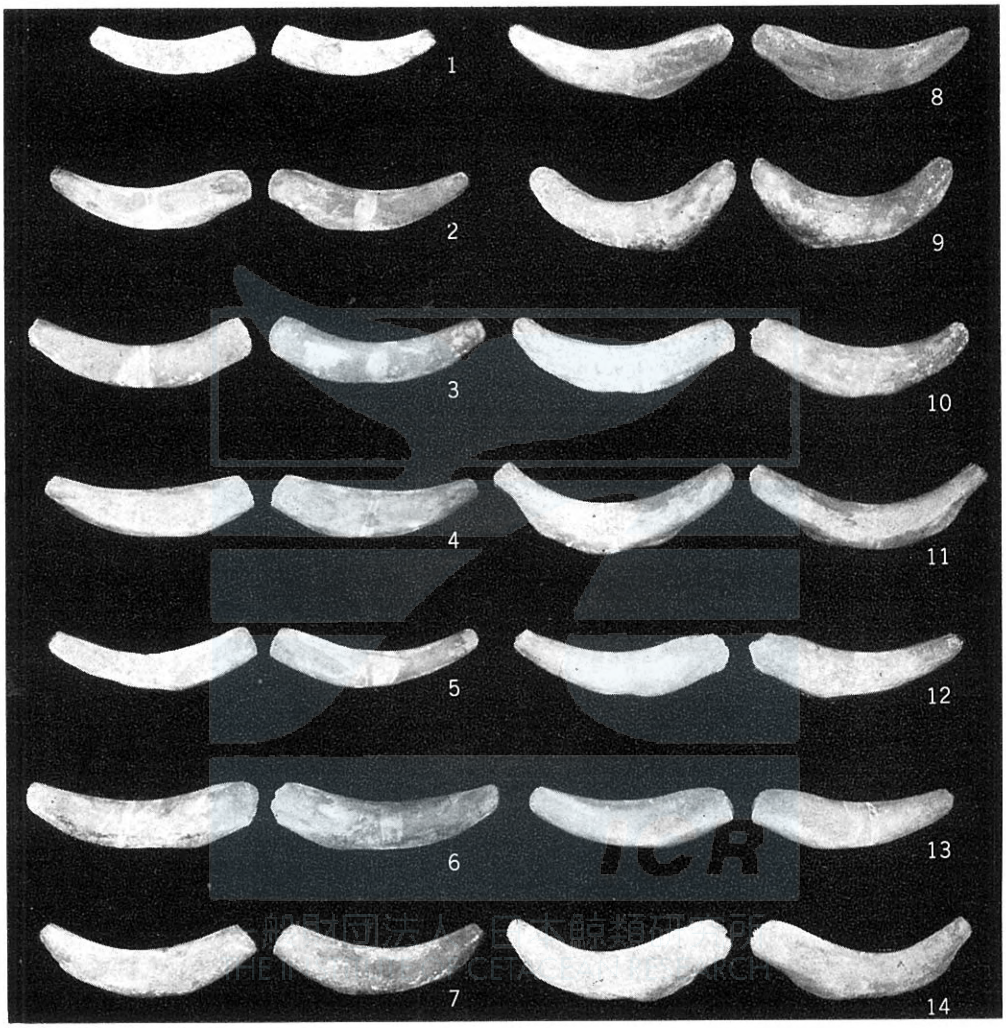
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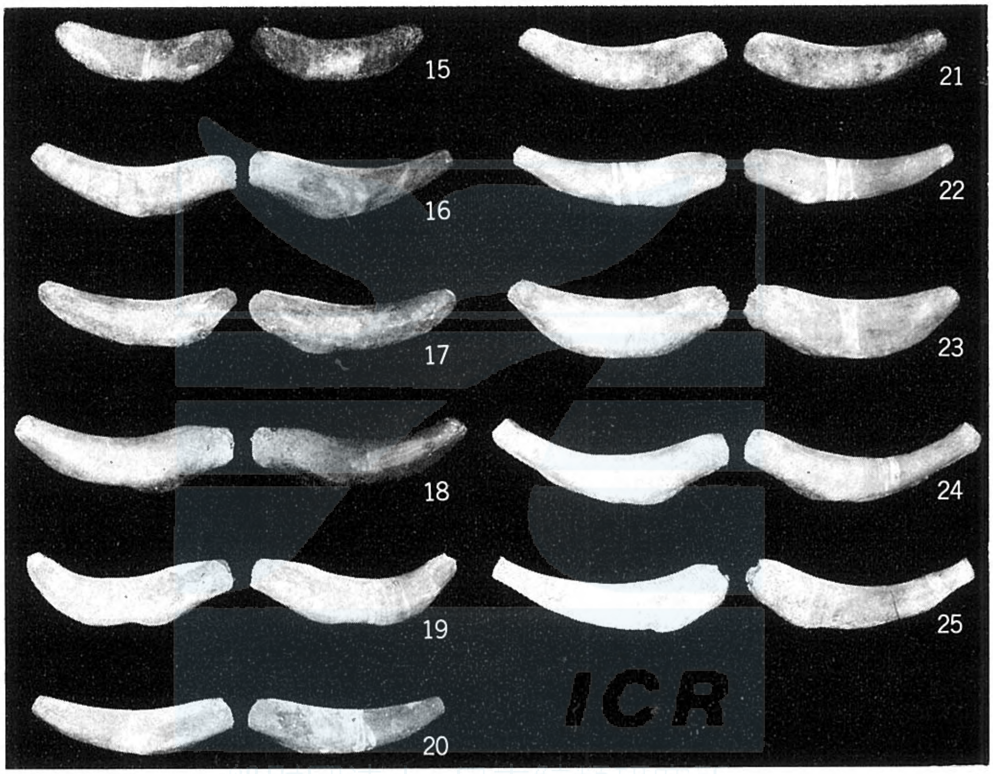
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FOOD AND FEEDING ECOLOGY IN THE SOUTHERN SEI WHALE*

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ABSTRACT

The sei whale is an important stock of whales which has currently been hunted in the Antarctic region taking over the decreased catch quotas of fin whale. However, its biology and ecology as a whole are poorly studied being compared with those in another whale species due to relatively recent development in commercial whaling.

This study aims to add some habitual and ecological knowledge on the food and feeding in southern sei whale being based on the materials obtained by the Japanese floating factories and by the research ships through 1967/68 to 1971/72 seasons.

The sei whaling ground is formed throughout the circumpolar seas, but it is centered approximately between 40°S and 50°S under the surface sea temperature of about 8.0~18.0°C, particularly in a zone along the Subtropical Convergence of under 10°C or more in temperature where more than 70% of whales is caught.

A total of 23 species of food organisms was found, of which the following species being arranged with the order of importance consisted main foodstuff of sei whale: *Calanus tonsus*, *Euphausia vallentini*, *Parathemisto gaudichaudii*, *Calanus simillimus*, *Euphausia superba*, *Drepanopus pectinatus*, *Clausocalanus laticeps*, and *Euphausia lucens;* and, the following 7 species were newly known as sei whale food in the Antarctic region: *C. tonsus*, *Cl. laticeps*, *Thysanopoda actifrons*, *E. diomedeae*, *E. lucens*, *Penaeus* sp. and *Scomberesox saurus* though *Penaeus* sp. is still doubtful in identification. However, *C. tonsus* of copepodite V stage was fed by more than 70% of 600 animals examined, and its nutritional importance along with its influence on the formation of whaling ground would be distinct. The food organism changes successionally with the shift in whaling ground from northern extreme along 40°S toward south by following the order of copepods, small sized euphausiids or amphipods, then again euphausiids.

The baleen plates furnished in a row as feeding structure of filtering apparatus are formed by the various sized baleen plates which are furnished with 0.93~1.4 plates/cm, and the figures do not vary with the body length and the sex. The averaged number of bristles on the baleen plate was 45.5 bristles/cm. An example of a total area for the filtering apparatus was 3.59 m^2 in the animal of 14.4 m in body length, and relative ability in filtering the water by a row of baleen plates was considered to be placed somewhere between that in balaenopterid whales other than sei whale and balaenid whales.

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Comparison of the filtering ability in sei whale with others revealed the sei whale to be poor in those ability being 1/5 of the fin whale, and 1/8 of the bolting silk cloth GG54 (0.33 mm mesh aperture, 46% in porosity).

The analysis on the fulness of stomach contents by hours revealed that 20~30% of their amounts reduced within 5~6 hours, from which it is supposed that the sei whale feeds fully once in a day. The amount of stomach contents usually found in fully repleted sei whale was 150~200 kg but was less than 100 kg when they were consisted by *Calanus tonsus*. The daily ration in sei whale was calculated as 4.43% of body weight by using the formulation; Heart weight ×100/body weight · 1/daily ration≒0.11 (const.), then average sized sei whale requires about 900 kg of food daily. The figures both amout of stomach contents and daily ration in sei whale lead to a consideration that the whale would hardly be filled its nutritional requirements by *C. tonsus* food alone, that is, the whales seem to be kept under starvation to some extent in the natural environment.

A possible population density in *C. tonsus* patches being based on both the amount in the stomach and the filtering ability was calculated as approximately $10^3 \sim 10^4$ inds./m^3, and it was proved in this calculation that feeding by skimming type would be much advantageous for sei whale than by swallowing or gulping type feeding. After examining on the net samples of *C. tonsus* patches being composed of similar population structure, it was proved that the population density under patchiness was 2.4×10^4 inds./m^3, which agreed quite well with the figures assessed by the theoretical calculation.

The distribution of whales in connection with the environmental conditions would be understood by a high concentration of phosphate along with the presence of rather deeper layered thermocline where larger standing crops of organisms were found. However, since the swarming of zooplankton into patchiness would be essentially important character as the food of whales, none of organisms which widely occur with larger biomass such as tunicates and chaetognaths induce the concentration of whales. The geographical distribution of *C. tonsus* may essentially be influenced by the physico-chemical conditions of the sea. They may, however, be of no use for considering on the causation of swarming phenomenon of, say, the patchiness of prey organisms since aggregating habits in animal including zooplankton seem to be strongly controlled or released by some less known biological factors such as the density effect under crowding.

CONTENTS

1. INTRODUCTION

The way to the modern pelagic whaling from the early North Atlantic whaling in Spitzbergen through those sperm whale whaling by the American ships in the south seas was a story of exploring the unknown seas by mankind who pursued for the undeveloped stock of whales which move in search of rich food concentrations in the vast ocean. In the ecological views it was a activity of mankind to increase the knowledge by the aid of accumulated experiences on the breeding and feeding behavior of whales, since those two are the essentially important factors in controlling the whale movements in the sea.

The famous whaling grounds which are formed during warmer season have been found where rich accumulation of food organisms is expected, or whale movements and the formation of whaling ground were recognized generally as a function of the distribution of food organisms in the sea. For instance, Scoresby (1820) in his cruise to the East Greenland waters early noticed that a " small crustaceans " was fed by the bowhead whale *Balaena mysticetus*, which indicates the whaleman at that time had been interested in whales food in relation to the whale movements although his observation was not biologically tangible. According to Collett (1886), however, the food of sei whale caught in Varangerfjord, Finmark in July 1885 was consisted of *Calanus finmarchicus* and of also *Euphausia inermis*, and they might be an important diet of sei whale in some seasons while fishes were less available as their food. Collett (1912) suggested an importance of the oceanic front as whaling ground where rich planktonic organisms occur due to confront the warm Atlantic and cold Arctic waters, and later Lillie (1915) called the sei and blue whales in the North Atlantic would be a " plankton feeder ". In the North Atlantic the distribution pattern of herring and euphausiids, or and copepods during fishing season closely relates to the movements of baleen whales which feed on those organisms. Concerning with feeding habits of baleen whales, it has been also known that they follow to two different ways to collect the food organisms, say, " skimming " and " swallowing " or " gulping " by boltering the body while feeding, and they are so shy and agile when there are no foodstuff in the stomach (Ingebrigtsen, 1929).

Returning from the 2nd exploring voyage into the southern seas during 1772–1775, Captain J. Cook brought an information that the bulk of pinnipeds and whales were accumulated in the Ross Sea region, and since then the Antarctic region became an indispensable whaling ground after passing several tenth years as heavy sealing places (Fraser, 1964). When C. Darwin made a famous voyage on boad of the H.M.S. " Beagle ", he sighted of many whales in the vicinity of Tierra del Fuego, South America where the surface of the sea was discolored into red-brown by the huge swarming of small crustaceans (Darwin, 1906). At this sight he (Darwin, 1906) thought that those swarming crustaceans must be the food of whales. According to Hinton (1925), Hamilton in his investigations at South Georgia had took note the importance of planktonic " swarming life " as Risting early had pointed out the matter in relation to whales food. It is important to take into account that the movement of whales had been considered as a function of food available there, especially as its distinct distributional pattern of so-called the plankton patchiness (Hardy and Gunther, 1935), and these recognitions of whales and their movements in connection with food organisms must be highly valuated ecologically apart from a qualitative knowledge on the whales food by species. In the investigation on southern whale stocks, much are owe to the works done by the Discovery Committee, especially to its bulk of results having been accumulated, and also to the establishments in methodology for biological examination of whale carcasses (e.g. Kemp *et al*, 1929; Hardy, 1967). In the matter of whales food, the records of the stomach contents by defining the size of food organisms present an important materials for considering geographical distribution of food organisms and their distribution pattern (Mackintosh and Wheeler, 1929; Marr, 1962; Mackintosh, 1973). By examining the stomach contents of blue and fin whales in the South Georgia whaling ground and in Nathal, South Africa, Mackintosh and Wheeler (1929) found only *E. superba* as a pricipal foodstuff, and has long been believed that only above species was the food organisms of southern baleen whales (Harmer, 1928, 1931). However, *E. superba* population which is actually fed by the whales is consisted of both matured adults and small or medium sized immature and adolescent individuals, and they occurred different ways by the places, seasons and by the kind of whale species which prey upon them. By noticing these difference, Norwegian whaleman called them from their experiences as " blue whale krill " for small sized *E. superba* and " fin whale krill " for larger sized one. This would be analogous in the case of *Meganyctiphanes norvegica* and *Thysanoessa inermis* which occur in the Norwegian waters, and they have called them as " stor-krill " and " smaa-krill " respectively. These also suggest that the seasonal movements of whales and their spring run close to their own shore have been considered in connection with the characteristic occurrence of food organisms. Hamilton who conducted biological observations on whale carcasses in 1913–14 season at South Georgia found "shrimp" in the stomachs of fin and humpback whales (Hinton, 1925). It is note worthy that Hamilton clearly separated them from usual krill, and this leads to a supposition that his " shrimp " might had not been larger *E. superba* but Galatheid shrimp such as *Munida gregaria* (Matthews, 1932; Dawbin, 1955; Tabeta and Kanamaru, 1970). In 1913–14 season at South Georgia a total of 90 sei whale was caught (Hinton, 1925). There were, however, no notable biological observations on this species except a mere note as " plankton eating species " since sei whale had less commercial value at that time. The food habits of sei whale have not known well until recent years by reason of little catches as above mentioned (Mackintosh, 1947). During the whaling seasons from 1960/61 to 1964/65 a total of 1223 sei whale was caught at South Georgia whaling ground, and food organisms such as *Parathemisto gaudichaudii*, *Electorona* sp. were newly found in addition to *E. superba* (Brown, 1968). He (Brown, 1968) also mentioned on the feeding habits of sei whale being based on the observations on the stomach contents.

With development of pelagic whaling operation in contrast to declining in principal whale stocks, the whale species commercially hunted for were greatly changed from fin to sei whales after 1964/65 season. This caused also the geographical change and expansion of the whaling ground itself, and the knowledge on the biological characters of sei whale gradually increased in relation to the needs for stock assessment. The kind of food organisms of southern sei whale which known recently in addition to *E. superba* are:- *Euphausia vallentini* (Marr, 1956; Mackintosh, 1960), *E. crystallophias* (Marr, 1956), *Thysanoessa macrura* (Nemoto and Nasu, 1958), *E. recurva*, *E. diomedeae* (Bannister and Baker, 1967), *Parathemisto gaudichaudii* (Nemoto, 1962a), *Calanoides acutus* (Peters, 1955), *Drepanopus pectinatus* (Tanaka, 1964), *Calanus propinquus* and *E. frigida* (Pervushin, 1968), *C. tonsus* (Best, 1967; Kawamura, 1970a), *Clausocalanus laticeps* (Kawamura, 1970a) and so forth.

In this report more several species of food organisms would be added. Among those above mentioned records, one by Best (1967) would be interesting since his materials were obtained in South African waters far outside from the so-called feeding ground in southern oceans. He (Best, 1967) reported a total of more than 44 species of food organisms in sei whale stomachs. Although the principal food was represented by a small number of species such as *Calanus tonsus* and some euphausiids, his result suggests us that sei whale would feed on even the organisms which do not swarm patchily in those temperate waters. Nemoto (1959) early suggested that some copepods would be fed by the sei whale in some place in the Antarctic region, but his suggestion was proved earlier than was expected as I have described above. Recent study on the food and feeding habits of whales tends towards the analysis of both the formation of whaling ground and whale movements along with the distribution of their food organisms (Slepzov, 1955; Nemoto, 1957, 1959; Pervushin,

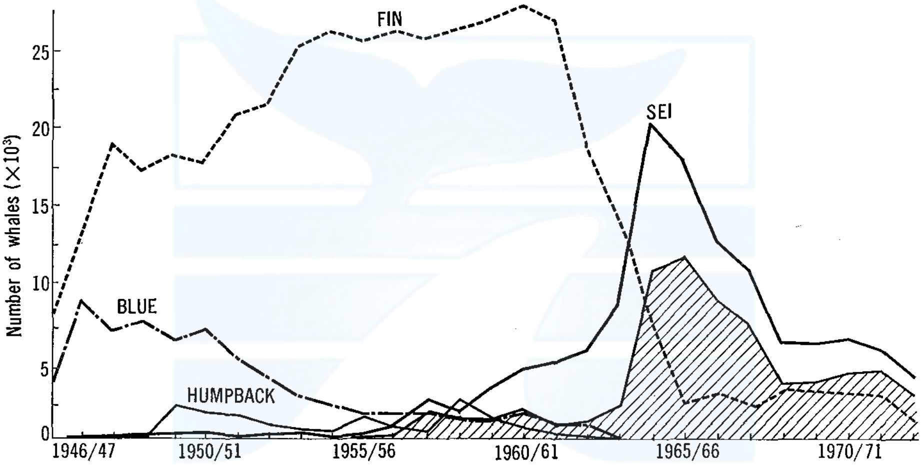

Fig. 1-1. Total catch of fin, blue, humpback, and sei whales in the Antarctic pelagic whaling during the past 28 seasons. Catch of sei whale by the Japanese fleets is shown by the hatched area. Whales taken under special permit after 1966/67 season; 3 humpback whales in 1971/72, 7 blue and 5 humpback whales are excluded.

1968; Kawamura, 1973a), and nutritional physiology based on feeding rate of whales (Klumov, 1961; Sergeant, 1969; Nemoto, 1970; Kawamura, 1970a, 1971a).

Commercially important whale species in the Antatctic region have been blue, fin, sei, humpback, right and minke whales respecitvely. However, recent status of some those stocks are not always kept under hopeful level, and only three of them are currently opened for regal catches. Fig. 1–1 demonstrates the number of catches in the Antarctic by species after 1945/46 season. The figure of the fin whale clearly shows its distinct importance among the total catches but it was took over by the sei whale since 1964/65 seasons. In these figure the history of the Antarctic whaling could be seen in another way as a history of shifts in commercially important species such the circumstances as shown schematically in Fig. 1–2. The Discovery Committee aimed to manage and control the Antarctic whale stocks under scientific basis (Kemp *et al*, 1929). In the days of blue and fin whaling, Matthews (1938) noted the forth comming situation that large catch effort would be added onto sei whale in the furture, and stressed the necessity of biological investigation on this species as much as possible. When we consider the present whaling status his anticipation must be greatly valuated. In 1964/65 season the total number of sei whale catch (19874 animals) exceeded that of fin whale, and showed 63.3% among total catch in that season. In 1971/72 season the minke which

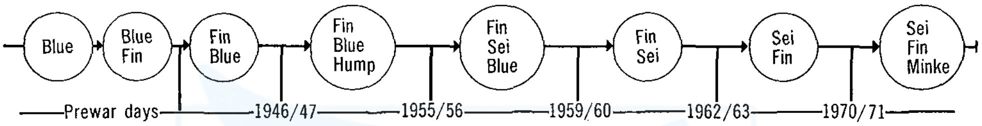

Fig. 1–2. A rough figure showing the change in whale species which have been caught in the Antarctic.

TABLE 1-1. CATCH OF SEI WHALE AMONG TOTAL ANIMALS IN THE PAST 28 ANTARCTIC SEASONS EXPRESSED IN PERCENTAGE FIGURES.

Seasons	Percentage	Seasons	Percentage
1945/46	+	1959/60	8.9
1946/47	+	1960/61	11.1
1947/48	+	1961/62	12.7
1948/49	+	1962/63	18.3
1949/50	0.3	1963/64	28.6
1950/51	1.2	1964/65	63.3
1951/52	0.1	1965/66	71.9
1952/53	0.4	1966/67	61.2
1953/54	0.8	1967/68	68.7
1954/55	0.4	1968/69	50.3
1955/56	0.8	1969/70	49.0
1956/57	2.2	1970/71	50.9
1957/58	6.6	1971/72	47.4
1958/59	3.9	1972/73	39.3

'+' less than 0.1 percent

had not entirely been regarded as commercially exploitable resources turned to some importance for whaling by the pelagic floating factories, and 3000 animals were caught successfully although it was still exploratory whaling. Under these circumstances in the Antarctic whaling as having been mentioned above the purpose and reasons which made me study the sei whale could be summerized as follows:-

1) Food and feeding habits in the animals can be generally recognized as a whole as one of the most important event along with their breeding behavior throughout their life history. The baleen whales are very characteristic in ecological niche through marine food chains where the very primary herbivorous organisms are connected directly with the animals in the highest trophic levels. In connection with these circumstances the sei whale was in need of knowledge about its food and feeding habits and ecology since these factors in general strongly relate to the change of animal population and the movements of whales.

2) Catch of sei whale in enormous numbers began relatively recently, and the biological characters were poorly known particularly in sei whales. There have been done almost no observations and analysis on sei whales food but a brief discusion by Nemoto (1962) since then the main whaling ground in the Antarctic region shifted to further northern waters up to the Subantarctic region.

3) In connection with the shift and vast expansion in the region of main whaling ground, several kind of food organisms began to occur newly in the diet of sei whale (e.g. Kawamura, 1970a).

4) It is hoped to recognize the mechanisms of formation of whaling ground not only by the hydrodynamical process but also biologically through the food conditions of baleen whales.

5) It is expected to make clear the actual distribution characters of planktonic food organisms, especially their uneven distribution in the feeding places through the formation of dense swarms so-called plankton patchiness, which seems to be ultimately responsible for the formation of feeding spot of whales.

6) The knowledge of patchy distribution of some planktonic organisms would be useful for developing the plankton fisheries (e.g. Hempel, 1968; Parsons; 1972).

7) The study of sei whale food is desirable to be conducted while larger number of catch of this species would be expected since the history of shifting the whale species which have been commercially hunted teaches us the importance of properly partinent investigations.

2. MATERIAL AND METHOD

The material used for analytical treatments were obtained from various source, namely, pelagic whaling both in the Antarctic and North Pacific, and some were from land based whaling in the Japanese coastal waters. One of others were obtained in the cruises on board of the research ships. The material can be divided into two principal categories, namely, row material of both whale food and plankton samples, and data in the field chiefly compiled by the Fishery Agency, Ministry of Agriculture and Forestory and by the personnel on the floating factories. Although the material and the method of analysis in particular will be discribed more in detail elsewhere in the following each sections, the principal sources of material obtained are as follows:

The stomach contents of sei whale caught in the Antarctic waters were collected continuously through 1967/68 to 1971/72 seasons by the Japanese floating factories and those materials were treated chiefly for examining the kind of food organisms, their geographical and seasonal distribution. Some results obtained on the material in 1967/68 season concerning to the food habits of sei whale has already been reported by the author (Kawamura, 1970a).

In the seasons of both 1967/68 and 1971/72, I was on boad of the floating factories, " Nisshin Maru " of Taiyo Gyogyo Co. and " Tonan Maru No. 2 " of Nippon Suisan Co. respectively, and engaged in general biological observations of whale carcasses as routine work and also collected the samples of the first stomach contents of sei and fin whales.

In the course of this study I made theoretical estimation on the population density of *Calanus tonsus*, the principal prey crustacean of the sei whale, when it forms the patches being based on both the amount of this organism found in the first stomach and relative filtering ability in the row of baleen plates (Kawamura, 1971a). To prove this result I cruised down into southern waters off Western Australia in 1971/72 season on boad of M.S. " Eihô Maru " of Hôkoku Suisan Co., and made quantitative sampling of *C. tonsus* by spotting its patches in the surface waters. After finishing these investigations, I moved to the F.F. " Tonan Maru No. 2 " as above mentioned when both ships met each other on high seas.

The row materials concerning to examining the relation between the distribution of whales and of their prey zooplankton along with sea conditions were obtained in 1968/69 season by the R.V. " Hakuhô Maru " during her KH 68-4 cruise down to the Antarctic (Ocean Research Institute, University of Tokyo, 1970). With this material a quantitative and qualitative study on the food organisms of sei whale in the Pacific sector of the Antarctic and Subantarctic waters was made, and at the sametime the distribution of sei whale and the occurrence of the DSL in relation to that of physico-chemical elements in the region were discussed. A part of these results were preliminary reported (Kawamura, 1969a; 1970b, c; Kawamura and Kureha, 1970).

Mechanisms of feeding as a function of the structure of filtering apparatus of sei whale and its food habits were also studied. In order to estimate the capacity of oral cavity in sei whale the amount of air used for making afloat the whale carcasses was measured on the whale boat, " Toshi Maru No. 18 " which belongs to the Nisshin Maru fleet of Taiyo Gyogyo Co. in the summer of 1969 when she engaged in the North Pacific whaling operation, and a row of baleen plates was collected too by that fleet to assess its relative filtering ability of the water. Whether or not the whale vomits its stomach contents under continuous chasing was an important matter which have to be clarified when we consider the amount of stomach contents in carcasses, and the observations for this purpose were made by six whale boats, of which each two belonged to K. K. Kyokuyo, Taiyo Gyogyo Co. and Nippon Suisan Co. respectively (Kawamura, 1971a).

To know the daily ration of sei whale theoretically the heart weight which was proposed by Sergeant (1969) as a useful index for this purpose was weighed in 1970/71 Antarctic season at the floating factories, " Tonan Maru No. 2 " and " Nisshin Maru No. 3."

There is bryde's whale *Balaenoptera edeni* Anderson (Olsen, 1913), which is very similar to sei whale dealt in this study though the former has currently been separated clearly as completely different species (Omura, 1966). According to Omura (1966) the bryde's whale distributes in the offshore waters of South Africa, Brazil, Japan and western Australia, and a considerable number of this whale was caught in the north-western North Pacific in recent operations. Japanese whalemen have been noticed some specific differences by calling it as the sei whale of " southern origin " or " southern type " which means the warm water species, but it has not been treated separately in the old catch statistics of Japanese coastal whaling. The bryde's whale are usually found in the warm waters of sea temperature higher than 20°C and its food habits also differs to some extent from the sei whales (Omura and Nemto, 1955). Best (1970), on the other hand, observed two allopatric forms in this species in the South African waters, namely, " inshore " form which distributes in the waters within 20 miles of the coast whereas the " offshore " form is found 50 miles or more from the coast. They differ each other in some biological characters such as external appearance, breeding and feeding habits.

Accordingly, it is supposed to be caught the bryde's whale along with the bulk of sei whale catch especially in the whaling area III in the Antarctic since the sea conditions in that area are much complicated, and sei whale is widely pursued for by the whaling fleets. Of 945 sei whales taken by the Russian fleets in 1972/73 season 5 bryde's whales were included (Intern. Whal. Stat., 1973). However, the morphological and ecological characters of bryde's whale as mentioned above are well known currently by the whalers, and sei whale treated in this study can be considered as *B. borealis* Lesson exclusively.

3. BIOLOGICAL OBSERVATIONS OF WHALES

The Japanese whaling fleets which engage in the Antarctic and North Pacific whaling operate under an obligation to record and collect the materials of every whale carcasses treated after the instructions of whaling inspectors on boad; the actual items and the way of the observations are essentially based on those established by the Discovery Committee (see Mackintosh and Wheeler, 1929). The personnel who engages in this scheme is a governmental whaling inspectors and some deck workers of the whaling company, and the following items are observed: that is, whale species, sex, body length, foetus (body length and sex if present), stomach contents (kind of organisms by rough grouping, the amount of food and freshness), condition of mammaly gland whether lactating in any degree or not, and its thickness), thickness of blubber, weight of both testes, number of corpora albicans and corpora lutea (but they are collected for later examination if counting them on the deck was impossible), collection of the ear plug on every carcasses and the stomach contents about every tenth of carcasses if any food present. In addition to these, the position, date and time of catch and treatment as supplemental data. All these data are compiled in the *seibutsu-chosa-daicho*, a kind of official field note of the Fishery Agency, which can be reffered for statistical analysis.

The data treated in this study other than those obtained on row materials, chiefly based on this field note. The position of catch, however, is not actual but represented by the noon position of the mother ship. Accordingly, the positions of catch may differ to some extent particularly those in the morning and evening. It is, however, recognized empirically that the difference in the position is within tenth miles, and none of those seems to cause any confusion in analysing the data except particular cases such as the catch occurred fairly close to the convergence zone.

It is recognized anatomically and histologically that the stomach of whale is composed of four compartments arranged in series: the first compartment or stomach with no digestive glands, being a kind of dilated sack of the oesophagus origin to the fouth stomach by the extraordinarily developed ampulla (Slijper, 1958a; Hosokawa and Kamiya, 1971). The second and the third stomachs are real gastric compartments provided with digestive glands. Accordingly, the stomach of whale carcasses is usually examined only on the first stomach since the contents remain being undigested for long time and the second or the thrid stomachs are examined only when there was no food remains in the first stomach. In this case, however, the condition of the stomach contents is recorded as " empty " (=0) in the field note above mentioned.

The food conditions of the first stomach in the whaling ground give an important suggestions for whalers to judge whether or not the whaling ground is under suitable sea conditions as long lasting whaling ground. In the observations on the kind of food organisms in the field, the following rough calssifications and abbreviations are adopted as have been described previously by Nemoto (1959) and Kawamura (1970a), namely, ' Calanus ' (Ca), 'Amphipoda ' (Am), ' Euphausia ' (Eu), ' Fish ' (F), ' Squid ' (Sq), ' Munida ' (Mu) and so forth. Since the stomach contents are consisted of so many species of food organisms, it is hard to distinguish all of them after the classifications especially in ' Calanus ' and ' Euphausia ', then both of which actually mean copepods and euphausiids respectively. As for ' Euphausia ' the group is divided into three sizes by the body length; ' Large ' (L) for larger than 5 cm, ' Medium ' (M) for 4–5 cm, and ' Small ' (s) for smaller than 4 cm., and they are recorded by one of a dominant forms in the official record. This definition for classifying the size of euphausiids was supposedly adopted after the way having been employed by the Discovery Committee. In those days there had not been the problems of mixing the food organisms with more than two species since only *E. superba* had consisted of foodstuff in higher latitudes (Mackintosh and Wheeler, 1929). As mentioned before the sei whale is currently the most important species, and they seem to prefer copepods or small sized euphausiids such as *E. vallentini* being found in more northern waters. It may hard to distinguish these kind of small euphausiids from young *E. superba* or from some another euphausiids species expressed as ' Eu-S ' in the data record. However, it is possible with considerable preciseness by reffering the result obtained on row food materials to identify the kind of food organisms in those field record. There are no euphausiid species that correspond to the body length of ' L ' and ' M ' in the northern North Pacific, but the occurrence of ' L ' and ' M ' of *Euphausia* was recorded in 1969 season, and was proved later by examining the row materials collected that they were a kind of Sergestid shrimp, *Sergestes similis* Hansen (Kawamura, 1970d; Omori *et al*, 1972). This fact suggests that the observations by defining the size as ' L ', ' M ' and ' S ' would be still methodologically efficient for the field work.

One of another items of observations is the fulness of stomach with food against the capacity of stomach itself. This is recorded by five different degrees along with the freshness; these are, ' empty ' (0 %), ' r ' (less than 25 %), ' rr ' (25～50 %), ' rrr ' (50～75 %) and ' R ' (75～100 %) respectively. The freshness of food organisms therefore usually corresponds well to the fulness of stomach by its order such as ' R ' for ' F ', very fresh.

Food organisms as row material were collected on the every tenth of flensed carcasses when the stomach contents were kept under good freshness for the later examination in the laboratory. The collection of row material, however, is also conducted to make the material characteristic in time and space when the kind of food organisms seemed different from others, when the floating factory changed its position, and when the sei whale was caught sporadically during the period of fin whale hunting in higher latitudes. A considerable part of this study is greatly based on the statistical material having been compiled like this way by the Japanese floating factories during 1967/68 to 1971/72 seasons.

TABLE 4-1. THE ANTARCTIC WHALING AREAS ROUND THE SOUTH POLE CAP.

Area	Longitude	Main land and ocean included
I	120°W- 60°W	Eastern Pacific, South America, Folkland Is.
II	60°W- 0°	South Georgia Is., South Sandwich Is.
III	0° - 70°E	Bouvet Is., Marion Is., Crozet Is.
IV	70°E -130°E	Kerguelen Is., Heard Is., Western Tasman Sea
V	130°E -170°W	Tasman Sea, New Zealand
VI	170°W-120°W	Central Pacific

4. RECENT CATCH AND WHALING GROUND OF SEI WHALE

4-1. *An outline of the whaling ground*

The Japanese pelagic whaling in the Antarctic region is operated under the regulations by the IWC's arrangements, by the recommendations under the Antarctic Teaty, and by the measures of Japanese Government. Under these circumstances, four species of baleen whales, *i.e.*, fin, sei, minke and sperm whales are hunted.

The whaling place is found throughout the whole circumpolar seas but it is divided longitudinally into six whaling areas, from I to VI(Table 4–1). These whaling areas were defined being based on the catch statistics of the blue whale for the purpose of clarifying its sub-populations or stock units by the sea areas (Hjort and Ruud, 1932; Mackintosh, 1942). The whaling areas defined thus seem to well represent the stock unit of whales especially in blue and humpback whales whereas they seem rather less convenient for sei and fin whales. It is, however, still con venient to compare the catch statistics of sei whale with those other whale species.

Fig. 4–1 shows the distribution of whaling ground along with the whaling areas where the Japanese floating factories have operated through past five seasons, 1967/68 to 1971/72. In recent whaling with quite larger number of sei whale catch, most of whaling ground is found in the zone along the Subtropical Convergence between 40°S and 50°S, and little number of sei whale is caught along with larger number of fin whale in more higher latitudes, south of 50°S in the areas IV and VI. In the area VI a southerly expansion of the Subtropical Convergence toward higher latitude is very distinct particularly in the east of New Zealand but sea conditions in this area as whaling ground of sei whale do not differ much on the whole from other areas of mid-latitudes. In contrast to those situations the whaling ground close to the pack-ice in the south of 60°S as whaling in 1940's to 1950's when a larger number of blue, fin and humpback whales were caught (e.g. Nishiwaki and Hayashi, 1950; Nishiwaki and Oye, 1951; Mackintosh, 1965; Nasu, 1966). Comparing with those distribution pattern in the whaling grounds, it is clear that the sei whale is caught in the far northern waters north of the Antarctic Convergence, and its whaling ground could be considered as the " Subantarctic " whaling ground instead of the historical "Antarctic " whaling ground.

The whaling activity was most heavily conducted in the areas III, IV, and V throughout the Antarctic whaling grounds, and the areas I, IV in the south of Australia and a part of the area V seems rather less important as sei whaling ground due to a monotonous sea conditions there along with a prevaliling bad weather especially in the area I. Since the bulk of the catch in the southern zone between 45°S and 50°S is consisted of fin whale almost exclusively, and the proportion of sei whale catch among them is so little that the distribution of sei whaling ground in the southern zone does not always represent well the status of sei whale distribution. The center of sei whaling ground can be seen in general close to the northern boundary of the subantarctic region being related to a hydrodynamical upwelling (Nasu, 1966) and the bottom topography.

4–2. *Catch distribution*

Fig. 4–2 shows the number of sei whale caught during 1966/67 to 1968/69 seasons by the Japanese floating factories being arranged in five degree square of both latitude and longitude. The region where the floating factories operated usually correspond to the whaling ground itself, and the latter represents the region where large number of sei whale have been spotted by the scouting boats belonging to the fleet. Accordingly, the whaling ground itself could be considered to agree with the distributions of sei whale with high population density. However, it must be also taken into consideration that there are the case of small catch by artificial reasons due to weather condition, geographical position, and less catch effort on sei whale due to balancing relation with the period of fin whaling. It is clear in Fig. 4–2 and Table 4–2 that the sei whale is caught chiefly in the Subantarctic waters between 40°S and 50°S as a whole, and the 5 degree squares with catch more than 100 animals distribute in the narrow zone along both north and south sides of the Subtropical Convergence. The sei whale catch in the south of the Antarctic Convergence is seen in the areas IV to VI but the actual number of catch was relatively small except those in the area IV. The bulk of catch in the area IV is found in 52°–53°S, the northern waters of Heard Island, and a 5 degree squares between 80°–85°E seem to be a particular case. The most distinct trends of northerly shift in the distribution of whaling ground is found in the areas II to IV between Folkland Islands and the Indian Ocean sectors, and the location of these whaling grounds well agree with the mean position of the Subtropical Convergence (Deacon, 1937). The catch of sei whale in such waters as to be considered warm temperate region greatly owe to the formation of feeding place by the dense swarms of *Calanus tonsus* in the surface during mid-December to January, on which the sei whale feed voraciously. The fin whale, on the other hand, usually preferably feeds on euphausiids and supposedly enters into the more higher latitudes in early austral summer. It could, therefore, be considered a habitat segrigation in both fin and sei whales. In those days when blue and fin whales were hunted exclusively, the catch of sei whale in February and March was quite sporadic (Hinton, 1925). However, by examining a long-term catch distribution, it is noticed that

TABLE 4–2. NUMBER OF SEI WHALES CAUGHT AND ITS PERCENTAGE FIGURES (ITALICS) BETWEEN EACH 10 DEGREES OF LATITUDE IN THE ANTARCTIC.

Latitude (S)	66/67	67/68	68/69	69/70	70/71	71/72	72/73
40°–50°	8775 *71.0*	5114 *49.0*	4178 *72.4*	5112 *87.4*	5644 *91.8*	5329 *97.7*	3633 *94.0*
50°–60°	2270 *18.4*	3373 *33.0*	870 *15.1*	212 *3.6*	186 *3.0*	105 *1.9*	151 *3.9*
60°–70°	1315 *10.6*	1863 *18.0*	722 *12.5*	528 *9.0*	321 *5.2*	21 *0.4*	79 *2.1*

TABLE 4–3. CATCH OF SEI WHALE BY MONTH.

	Whaling season									
	63/64	64/65	65/66	66/67	67/68	68/69	69/70	70/71	71/72	72/73
Dec.	552	1001	3202	3168	1812	2358	2435	2760	2348	1347
Jan.	3204	7116	5701	3615	3351	1779	2055	1958	2098	1681
Feb.	2451	7690	5579	3673	3055	1484	792	875	540	488
Mar.	1867	3870	2923	1880	2113	694	570	520	441	346
Apr.	182	161	153	24	19	—	—	38	28	1
Total	8256	19838	17558	12360	10350	5770	5852	6151	5445	3864

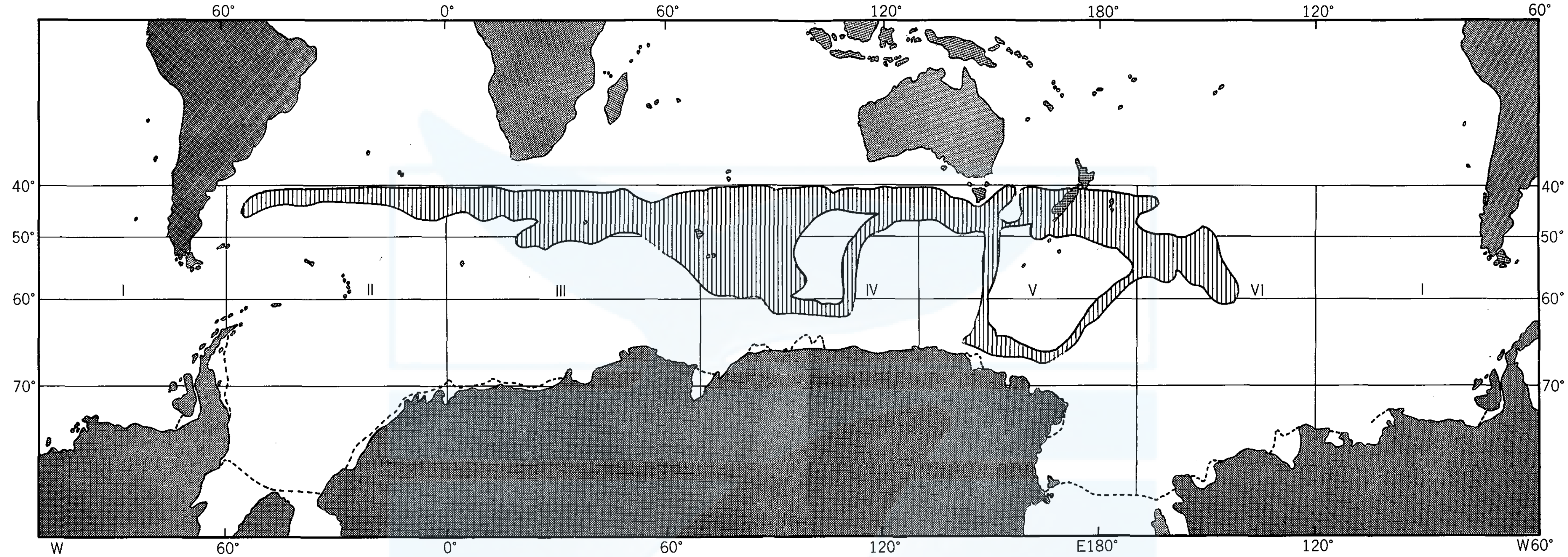

Fig. 4–1. The Antarctic whaling ground occupied by the Japanese floating factories during the seasons from 1967/68 to 1971/72.

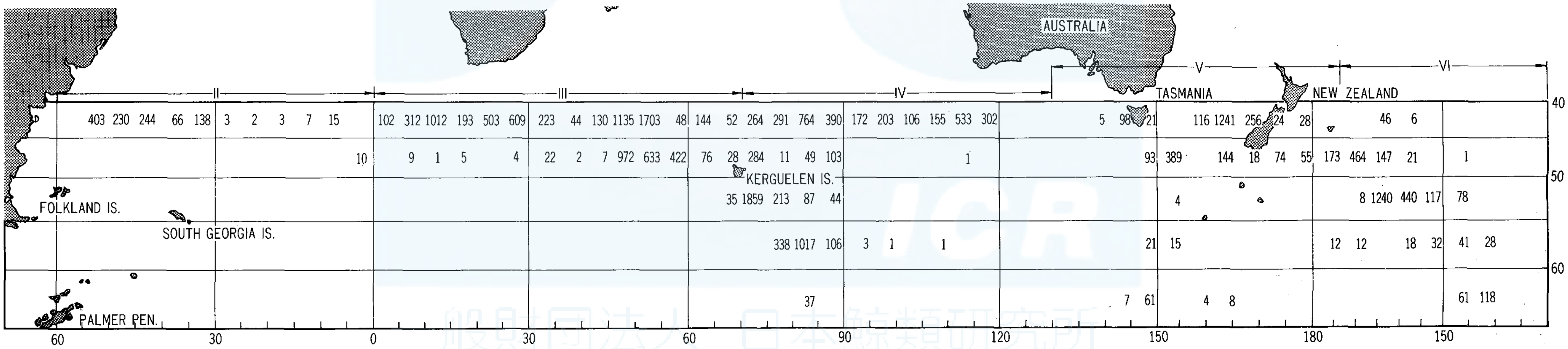

Fig. 4–2. Number of sei whales caught by the Japanese floating factories in every 5 degree squares of the Antarctic whaling ground during the seasons from 1966/67 to 1968/69.

there are some catch of sei whale in higher latitude south of 70°S in the Ross Sea region of the areas V and VI (Kashida, 1972; Omura, 1973).

As season goes by the feeding place formed by *C. tonsus* will fade out due to their wintering migration down to some deeper waters, and the sei whale moves into more colder region where several kind of cold water food organisms of copepods, amphipods and euphausiids occur in swarms. The representative species of those waters are *Calanus simillimus*, *Euphausia vallentini*, *E. superba*, and *Parathemisto gaudichaudii*. In recent whaling operations, however, the whale species of being hunted shifts almost to fin whale in these cold waters after catching such vast number of sei whale in the northern waters as to fill the catch quota for the season. By considering both the number of monthly catch as shown in Table 4–3 and the surface temperature of the whaling ground under about 3°∼4°C in March, it is suggested that the region in higher latitudes as above mentioned would be far outside from the usuall distribution range of the sei whale.

The catch of sei whale by pelagic whaling during the seasons of 1931/32 to 1968/69 is shown in Table 4–4 by separating each whaling areas. A fairly little catch in the areas I and VI would be due to the treatments of total banning of the catch up to 1962, and relatively small in stock size there (IWC, 1969; 1970), and also due to some difficulties in an actual operation by ill weather condition. The most distinct catch is seen in the areas II where one of the most productive regions in the Antarctic, say, South Georgia and Folkland Islands waters, are included. In 1964/65 season, a total of about 2000 sei whale was caught in this area. It has been reported that the cold Weddell Current extends northward distinctly, and this would be responsible along with a complexity in bottom topography for quite high standing stocks of zooplankton which causes high potentials in availability of food organisms for both whales and pinnipeds (Hardy and Gunther, 1935; Ommanney, 1936; Mackintosh, 1934, 1937; Marr, 1962). However, a quite heavy catch in this whaling area might possibly caused a considerable local decline in the population of sei whale, and the catch was actually very poor when two Japanese floating factories operated again in 1969/70 season. This fact suggests a little rcovery in sei whale stock up to today (IWC, 1970), andt herefore the sei whale is caught principally in the whaling areas IV and V in recent operations.

TABLE 4–4. TOTAL CATCH OF SEI WHALE IN SIX WHALING AREAS DURING THE SEASONS FROM 1931/32 TO 1969/70.

Area	Number of animal	Percent
I	3708	3.6
II	42109	40.6
III	20776	20.0
IV	12774	12.4
V	15066	14.5
VI	9207	8.9
Total	103640	100.0

The schematic distribution of sei whale based on the position and the number of catches indicate that there are trends of efficient catch particularly in the regions under some complexity in bottom topography which responsible for arrousing the upwelling under the distinct meandering of the Subtropical Convergence. These general features in distribution patern of sei whale are comparable to those food organisms, that is, the dense swarms or aggregations into the patches in *C. tonsus* (see section 11). Mentioning on the formation of whaling ground in the North Pacific, Nemoto (1957, 1959) and Nasu (1963, 1966) pointed out the close relationships between the distribution of food organisms and the upwelling by various origins and the situation in the Antarctic region seems to be essentially analogous in the structure of whaling ground formation.

4–3. *Surface sea temperature in sei whaling ground*

The distribution of surface sea temperature of sei whaling ground in the areas II-VI during 1969/70 season is demonstrated in Figs. 4–3a∼4–3f, but the general sea conditions in the areas V and VI of the same season has already been reported by Nasu and Masaki (1970). The surface sea temperature treated here was observed at the ship's noon position during the period of whaling operation being measured by electric thermometer which has its sensor on the ship's bottom about 10 meter depth. There are so much measurements of sea temperature in actual operation, but most of them are hardly obtainable for outside use except one as mentioned above.

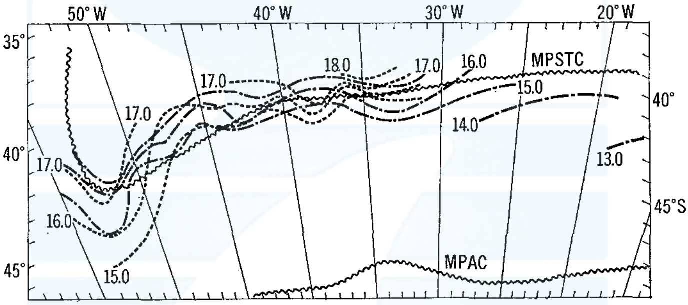

Fig. 4–3a. Surface temperature in the Area II, December, 1969. Solid line indicates the isotherm in the first decade of a month, and dotted and chain lines indicate those in the middle and last respectively. Both MPSTC and MPAC are the mean positions of the Subtropical Convergence and those of the Antarctic Convergence.

Fig. 4–3a∼Fig. 4–3f cover the region between Folkland Islands and western Australia, that is, 55°W∼120°E, and this region represents the principal sei whaling groud in recent operations. An outline of the monthly temperature distribution is as follows:

December (*Figs.* 4–3*a*∼4–3*b*): Since the whaling ground of baleen whales is opened in nearly mid December the material treated here covers late half of the month. The sei whaling ground spreads over in latitudinally narrow zones along 40°S, and the temperature of 15°~18°C occupies exclusively even in the areas II (Fig. 4–3a) and IV (Fig. 4–3b). The whaling ground in Folkland region may be formed by an oceanic front which originates from both the cold Folkland Current and the warm Brazil Current. Accordingly, the coeanic front distinctly extends northward at 50°~55°W longitudes, and its position agrees in general with the mean position of the Subtropical Convergence in summer (Deacon, 1937). In the whaling ground off southwest Australia the sea temperature principally showed between 14°C and 16°C. The distribution pattern of isotherms does not differ much in general within the same month exept a slight southerly shift about 1° latitude on the whole in late December. This indicates the gradual grow of warming conditions toward south during this month. Discussing on the sea conditions of sei whaling ground in the areas II and VI in 1969/70 season, Nasu and Masaki (1970) concluded that the sei whaling ground in the area II was formed in the waters north of the Antarctic Convergence with temperature higher than 4.5°C, but it was found also between 8°C and 10°C in the area VI. A slight temperature differences in the whaling areas also found in the Folkland region and in the southwestern Australia region where the difference was 1°~2°C in the center of the whaling ground. These suggest that there are some different hydrological conditions for the formation of whaling ground among those areas.

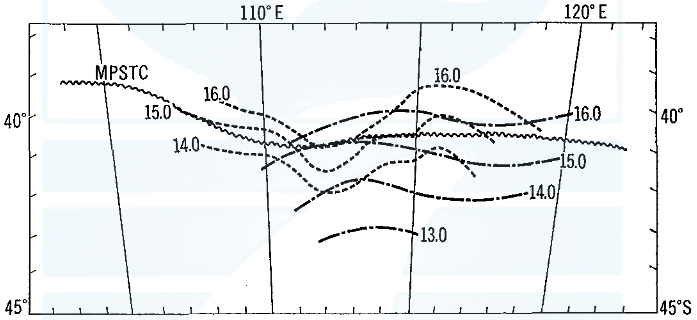

Fig. 4–3b. Surface temperature in the Area IV, December, 1969. Legends as in Fig. 4–3a.

January (*Figs.* 4–3*c*~4–3*d*): Following to December the whaling was operated through the areas II to IV. In accordance with northerly extension of the Subtropical Convergence beyond 40°S between 10° W and 15°E, the principal whaling ground was covered with 15°~17°C waters during first half of January in the Folkland region whereas it was 11°~14°C in the area III. In the area IV there found 14°~16°C waters close to the Subtropical Convergence zone in January. In the regions south of South Africa between 10°E and 30°E, however, the distribution of sea temperature showed rather complicated features supposedly due to the formation of local fronts, some of which must have been formed by a confronting both the warm Agulhas Current and the cold Benguela Current. These hydro-

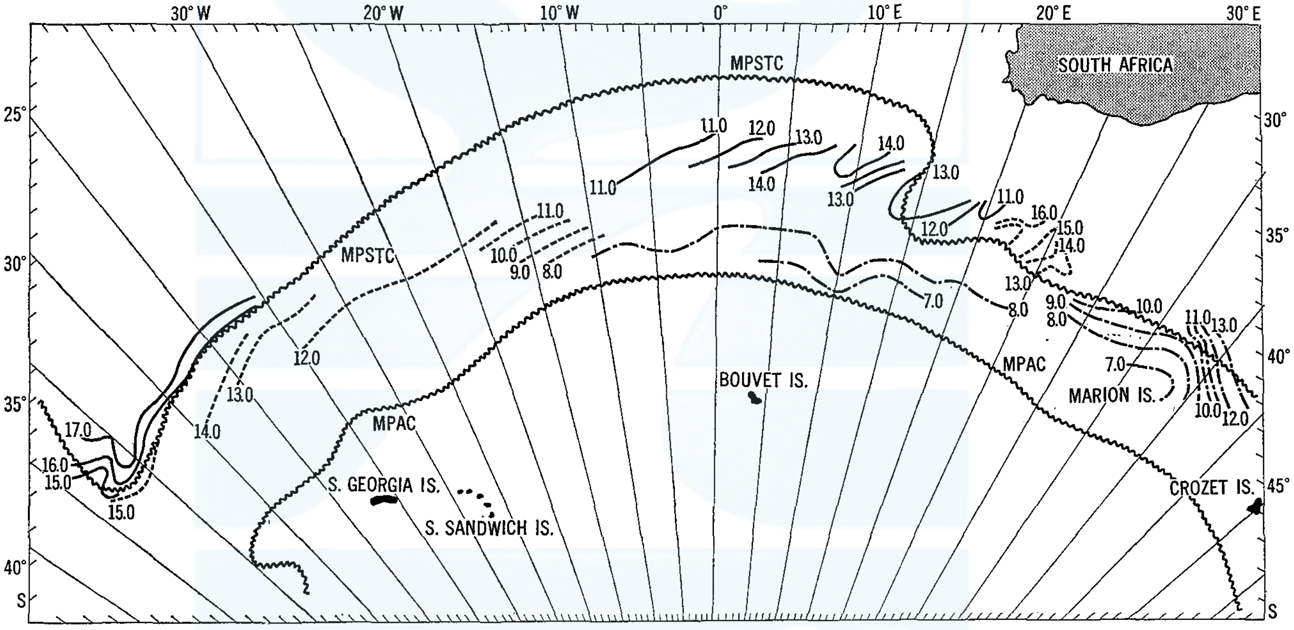

Fig. 4–3c. Surface temperature in the Areas II and III, January, 1970. Legends as in Fig. 4–3a.

logical condition would be responsible for high productivity due to upwelling in the region where forms another fertile whaling ground far outside from those in the Antarctic region especially in the western coast of South Africa (e.g. Best, 1967). By refering the Fig. 4–2 it is noticed that the regions of high density in the catch number of whales in early January are found in relatively warmer waters in the north of the Antarctic Convergence up to 40°S., and the center of heavy catch lies in the zone of temperature above 14°C. The expansion of warmer conditions towards the south is weakened gradually toward late January although there are still slight trends getting warmer as being seen in the behavior of 8°C isotherms at 10°W. However, the temperature of the main whaling ground during January showed 8°∼13°C on the whole.

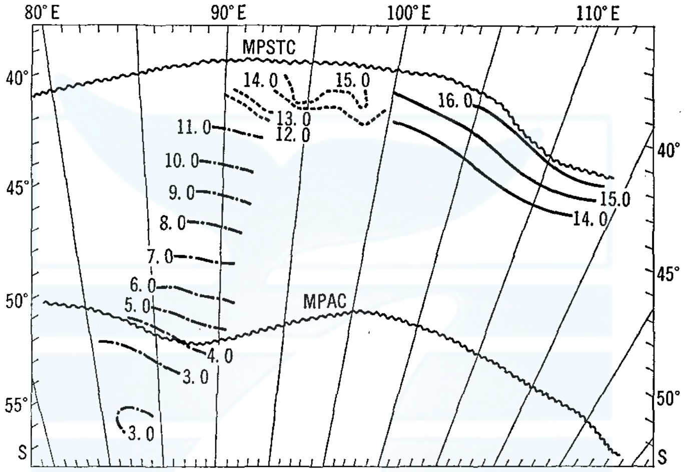

Fig. 4–3d. Surface temperature, January, 1970. Legends as in Fig. 4–3a.

February (*Fig. 4–3e*): There was no whaling activity in the area II in February, but the area II and a part of the area IV where involve Marion, Crozet and Kerguelen Islands has been formed a well staple whaling ground through past several seasons. In contrast to northern positioning of whaling ground close to 40°S during December to January, it is found rather mid to higher latitudes with 45°∼46°S as its center in February. The 7°C isotherms along 35°E was found near to 45°S in late January, and it still continued shifting down to about 47°∼48°S in early February. The southerly shift of the isotherms, however, decreased gradually during mid to late February as observed in the feature of 7∼8°C isotherms at 40°∼50°E and at 60°E, and the sea condition seems as a whole to be in the state of those typical one of mid summer. The whaling ground is found in the temperature of 7°∼10°C, which was slightly colder than that prevailed in preceding month but agreed with the result obtained by Nasu and Masaki (1970).

In view of the kind of food organisms which is responsible for forming principal sei whaling ground, the areas II and VI during December to January would strongly be due to the mass occurrence of copepod, *C. tonsus* whereas more cold water species such as *E. vallentini*, *C. simillimus* and *P. gaudichaudii* are responsible in the areas III and IV. The whaling ground in the area IV along 80°E is usually under very cold sea conditions with temperatures of 4°～6°C, where much fin whales are caught than the sei whale. The principal food organisms are consisted of *E. superba* and *P. gaudichaudii*, but they were replaced to *D. pectinatus* in the slightly northern waters under the temperature of about 7°～9°C.

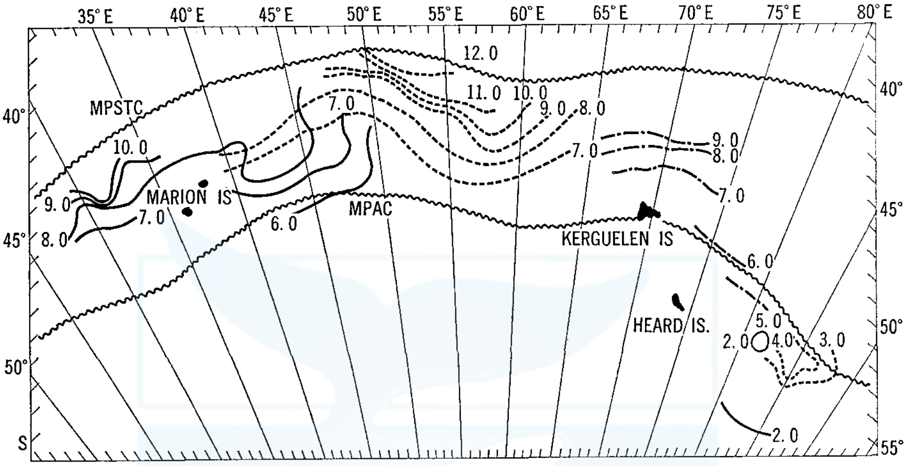

Fig. 4–3e. Surface temperature, February, 1970. Legends as in Fig. 4–3a.

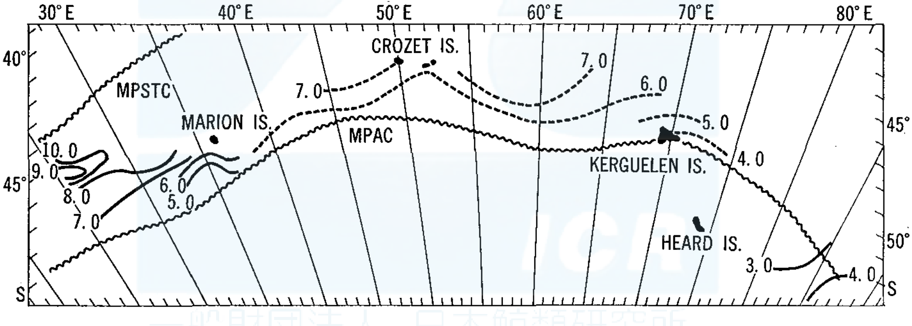

Fig. 4–3f. Surface temperature, March, 1970. Legends as in Fig. 4–3a.

March (*Fig.* 4–3*f*): The catch of sei whale distinctly decreases in March in the recent operations. In the regions of Marion, Crozet and Kerguelen Islands there was a sign of retreating the warm water toward north particularly in the region between 70°～75°E. The sei whaling ground was formed under relatively colder sea conditions of 4°～7°C but the catch of sei whale was very little in contrast to that of fin whale (Table 4–3).

Studying on the food habits of sei and fin whales of the North Pacific Ocean, Nemoto (1957) reported a distinct preference to copepod food in sei whale. In the Antarctic region, on the other hand, the large standing stocks of copepod species is usually found in relatively warmer waters in the north of the Antarctkc Convergence (Kawamura and Hoshiai, 1969; Kawamura 1969b; 1970a, b; Kawamura and Kureha, 1970). Accordingly, the principal sei whaling ground during December to March is found usually in the northern zones of the Subantarctic region, and then it would be hardly expected a bulk of feeding concentrations of sei whale population in the regions south of the Antarctic Convergence even in the midst of austral summer.

5. FOOD OF SEI WHALE

In order to know the kind and distribution of food organisms of sei whale a total of 462 food samples was collected from the first stomach of 462 animals. The 462 food sample is comprised of both the 117 samples collected in 1967/68 season and the 345 in 1969/70. These row material geographically covers for the most Antarctic

TABLE 5-1. FOOD ORGANISMS OF SOUTHERN SEI WHALE CAUGHT DURING 1967/68 TO 1971/72 SEASONS.

COPEPODA	*Calanus simillimus* GIESBRECHT
	Calanus tonsus BRADY
	Clausocalanus laticeps FARRAN
	Drepanopus pectinatus BRADY
AMPHIPODA	*Parathemisto gaudichaudii* GUERIN
	f. *compressa*
	f. *bispinosa*
	f. *intermediate*
EUPHAUSIACEA	*Euphausia superba* DANA
	Euphausia vallentini STEBBING
	Euphausia lucens HANSEN
	Euphausia diomedeae ORTMANN
	Euphausia similis G. O. SARS
	Thysanoessa vicina HANSEN
	Thysanoessa gregaria G. O. SARS
	Thysanopoda actifrons HOLT & TATTERSALL*
FISHES	*Gymnospelus nicholsi* (GILBERT)**
	Myctophum subasperum (GUNTHER)**
	Scomberesox saurus (WALBAUM)
	Notolepis castsi DOLLO**
	Vinciguerria attenuata (COCCO)
	Gonostomatid fishes**
DECAPODA	*Penaeus* sp.***
OTHERS**	*Cleodora sulcata* (PFEFFER)
	Clione antarctica E. A. SMITH
	Eukrohnia hamata (MÖBIUS)

* Although the bipolarity of this species is reported, the occurrence is doubtful.
** The species gathered to feed on amphipods or copepods, and are not important as a staple food of sei whale.
*** Doubtful in identification.

whaling areas, say, the areas II∼VI, and gives us well the general knowledge concerning to the distribution of food organisms within the circumpolar seas exept a sector which involves the eastern Pacific and the Folkland Islands region.

5–1. *Kind of food organisms*

Although the food habits of sei whale in 1967/68 season has been reported previously (Kawamura, 1969b, 1970a, 1971b), some of which were also treated in this report to make the scheme more clear in detail. In the previous repeort (e.g. Kawamura, 1969b), it was pointed out that the sei whale principally feeds on copepods such as *C. tonsus* more preferably than euphausiacea in accordance with the distinct northerly shift in the center of sei whaling ground through recent operations. The kind of food organisms along with those admixed by a chance are enlisted by species in Table 5–1. As having been mentioned above the food organisms in Table 5–1 can be considered to cover the almost all foodstuff of the sei whale which distributes within the circumpolar seas in the south of 40°S. By comparing with the foodstuff known in the northern North Pacific and Bering Sea, (Nemoto, 1957, 1959), Kawamura (1973a) showed that those in the Antarctic region seem to be quite monotonous as a dietary environments for baleen whales, *i.e.*, the Antarctic environment lacks some micronectonic organisms such as the fishes molluscs, and crustaceans like Sergestid shrimp (Omori *et al.*, 1972). Although Nemoto (1962a, b) early reported the newly known food organisms as found in sei whale stomachs, the principal foodstuff of sei whale in the Subantarctic waters is consisted of both copepods and small sized euphausiids, and this fact is far different from the previous recognitions of depending solely on euphausiids. The following species could be considered as newly known food orgnaisms in the Subantarctic and Antarctic regions in addition to those reported previously. They are: *C. tonsus**, *Clausocalanus laticeps*, *Thysanopoda actifrons*, *Euphausia diomedeae*, *E. lucens*, *Penaeus* sp. and *Scomberesox saurus*.

Among those food organisms given in Table 5–1, the following four species might be the most important throughout the Subantarctic waters from their distinct occurrence in the sei whale stomach: *C. tonsus*, *C. simillimus*, *E. vallentini*, and *Parathemisto gaudichaudii*. In addition to these species both *Clausocalanus laticeps* and *Drepanopus pectinatus* could be considered to be particularly important in a local sea regions.

Nemoto (1962a) early suggested that *E. similis* which had not been reported as whales food would be found in the whale stomach when the whaling ground shifted to another place in the future, since *E. similis* forms dense swarms in the surface water. By examining the foodstuff of minke whale, *Balaenoptera bonaerensis* caught in 1967/68 season, I found the occurrence of *E. similis* as food in several number of animals (Ohsumi *et al*, 1970) and again in sei whale caught in 1969/70

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* Salinikov (1953, Table 4) described *C. tonsus* as a food of baleen whales in the North Pacific waters. However, it is obvious in the studies by Tanaka (1954, 1956) that Salinikov's *C. tonsus* must be separated from the so-called *C. tonsus*, the endemic species in the southern hemisphere. *C. tonsus* was also reported as sei whale food from the Cape Province, South Africa (Best, 1967) but I enlisted the species again in this report since Cape Province is located at about 33°S being far outside from the Antarctic region proper.

season. These facts strongly suggest that the food organisms of baleen whales would supposedly form the dense swarms or aggregations into patchiness. These results lead to a consideration that the southern saury, *Scomberesox saurus* and *Penaeus* sp., both were found in this study, also seem to form the swarms in the surface waters. A little number of myctophid fishes, chaetognatha, and pteropods were also found as contaminants. They must have been fed by a chance when they gathered in the surface waters in search of their prey organisms such as copepoda and euphausiacea, and have little importance as sei whale food. This kind of mixture not only occur in the mid latitudes but also occur in more higher latitudes.

TABLE 5-2. COMPOSITION OF FOOD ORGANISMS IN THE STOMACHS OF THE SOUTHERN SEI WHALE 1967/68.

Kind of food organisms	No. of whales examined
C. tonsus (CV & Female)	23
C. tonsus (CV)—*P. gaudichaudii* f. *compressa* (Female)	1
C. tonsus (CV)—*P. gauchichaudii* f. *bispinosa* (Female)	1
C. tonsus (CV & Female)—*E. vallentini* (Female & Juvenile)	2
C. tonsus (CV & Female)—*E.* sp. (Furcilia)	2
C. tonsus (CV)—*E. vallentini* (Female)—*E. hamata*	1
C. tonsus (CV)—*P. gaudichaudii* (Female)—*E. vallentini* (Male, Female & Juvenile)	1
C. tonsus (CIV & CV)—*E. hamata*—*Clione antarctica* & *Cleodora sulcata*	1
C. simillimus (CV & Female)	4
C. simillimus (CIV & CV)—*Drepanopus pectinatus* (Juvenile)	3
C. simillimus (CV)—*E. vallentini* (Male, Female & Juvenile)	2
C. simillimus (CV)—*E.* sp. (Male & Furcilia)	1
C. simillimus (CV)—*P. gaudichaudii* f. *compressa* (Male & Female)	2
C. simillimus (CV)—*P. gaudichaudii* f. *bispinosa* (Female)	2
C. simillimus (CV)—*G. nicholsi*	1
C. simillimus (CV)—*P. gaudichaudii* f. *compressa* (Male & Female)—*E. vallentini* (Juvenile)	1
D. pectinatus (Male, Female & Juvenile)	4
D. pectinatus (Juvenile)—*C. simillimus* (CIV, CV & Female)	2
C. laticeps (Female & Juvenile)	2
P. gaudichaudii f. *compressa* (Female)	9
P. gaudichaudii f. *bispinosa* (Female)—f. *compressa* (Female)	18
P. gaudichaudii f. *bispinosa* (Female)—*E. vallentini* (Male & Juvenile)	1
P. gaudichaudii f. *compressa* (Male & Female)—*P. gaudichaudii* f. *bispinosa* (Male & Female)—*E. superba* (Male & Female)	1
P. gaudichaudii f. *compressa* (Female)—*gaudichaudii* f. *bispinosa* (Female)—*E. vallentini* (Male, Female & Juvenile)	1
P. gaudichaudii f. *bispinosa* (Female)—*E. vallentini* (Juvenile)—*C. simillimus* (CV)	1
Euphausia superba (Male, Femal & Juvenile)	14
E. superba (Male, Female & Juvenile)—*Myctophum subasperum* & *Gymnospelum nicholsi*	1
E. vallentini (Male & Female)	10
E. vallentini (Juvenile)—*D. pectinatus* (Juvenile)	1

Degree of dominancy is on decrease from left to right in the left column and the dominant forms of each organisms are shown in parentheses.

Note: CIV—the fourth copepodites, CV—the fifth copepodites.

According to Brown (1968) the sei whale caught in the South Georgian waters had fed on *Electorona subasper* and *E. normani* along with *E. superba*, and he (Brown, 1968) called them as " occasional occurrence ". By discussing the diel vertical distributions of those myctophid fishes, Brown (1968) also supposed that the bulk of sei whale feeds actively in the evening since those fishes usually come up near to the surface in the night. It might, however, rather difficult to know the active feeding time of sei whale like this way since there are also the fact that the sei whale does not seem to feed at any definite time of a day but feed whenever there are a foodstuff available (Kawamura, 1970a).

5–2. *Composition of the stomach contents*

As mentioned before the most important food organisms for sei whale in the Subantarctic and Antarctic waters are *C. tonsus*, *C. simillimus*, *P. gaudichaudii*, *E. vallentini* and *E. superba*, whereas in Saldanha Bay, South Africa there has reported more than fourty five food species; seven euphausiids, twenty of copepoda, six of amphipoda, four of fishes, six of pteropoda and some others such as megalopa larvae, and *Vellella* sp. (Best, 1967). However, there were only 8∼9 species which seemed to be actually indispensable as food of sei whales there. The most of other species might have found as " occasional occurrence ", though

TABLE 5–3. COMPOSITION OF FOOD ORGANISMS IN THE STOMACHS OF THE SOUTHERN SEI AND FIN WHALES, 1969/70.

I / II	*Calanus tonsus*		*Calanus simillimus*		*Drepanopus pectinatus*		*Euphausia lucens*		*Euphausia vallentini*		*Euphausia superba*		*Euphausia diomedeae*		*Parathemisto gaudichaudii*		*Notolepis castsi*	
	Sei	Fin	Sei	Fin	Sei	Fin	Sei	Fin	Sei	Fin	Sei	Fin	Sei	Fin	Sei	Fin	Sei	Fin
C. tonsus	203*	3													1			
C. simillimus			5**		1													
Th. vicina	2																	
Th. gregaria	1									1								
Th. sp.	1	1																
E. lucens	3						2	1										
E. vallentini	1								10	38								
E. superba											8	8						
E. similis										1								
E. diomedeae														1				
Th. actifrons	1																	
P. gaudichaudii	19		1							1				1	20	2		
Penaeus sp.	4																	
S. saurus	1																	
V. attenuata	1																	
N. castsi																		1

I & II: Order of dominancy.

* Including a mixture with *Pseudochirella* sp. in the Order II.

** Including a mixture with a few individuals of *P. gaudichaudii, E. vallentini, Th. gregaria* and *E. hamata* in the Order II.

Best (1967) did not give the quantitative data, and they usually recognized as non-swarming species. Consequently, the foodstuff in the South African waters also seems rather monotonous as feeding environment for the sei whale.

The stomach contents of beleen whales are formed essentially with only one species of food organism as many previous works have been stated. In order to know an actual states of stomach contents in the Antarctic sei whale, the results of examination on the stomach contents obtained both in 1967/68 and 1969/70 seasons are given in Tables 5–2 and 5–3. It is shown in both tables that the somach contents of sei whale are composed characteristically of monospecific populations particularly in copepods and euphausiids. This fact suggests that the sei whale prey almost exclusively on the swarming organisms. The result in 1967/68 season covers only the whaling areas III and IV. Since there were no distinct differnce

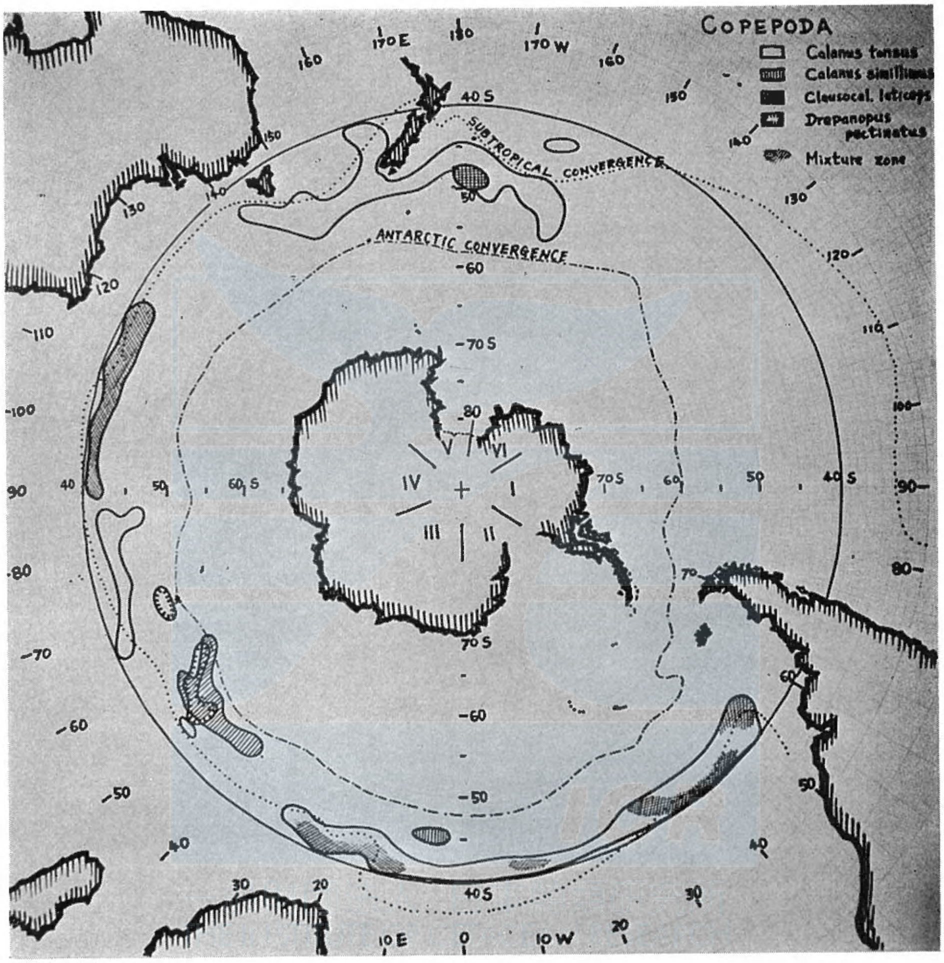

Fig. 5–1. Geographical distribution of the food copepods for sei whale in the Antarctic.

being observed in longitudinal expansion of the sea throughout the circumpolar seas, it may be well represented even by the samples obtained in limited whaling areas. In Figs. 5–1, 2 and 5–3 some leading species as sei whale food are indicated on the above right as the figures legend. It is observed in the figures that the geographical distribution of each food species overlaps each other in many regions.

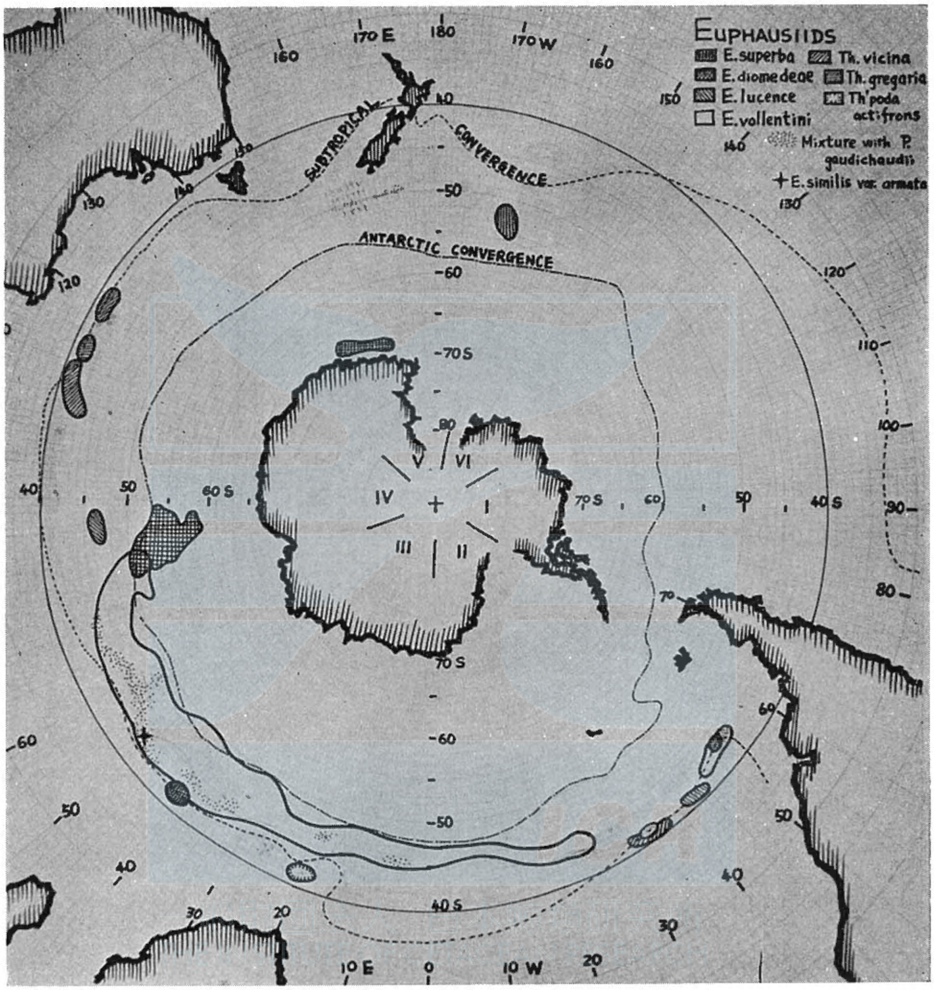

Fig. 5–2. Geographical distribution of the food euphausiids for sei whale in the Antarctic.

However, it does not mean the occurrence under an admixed pouplation but they are a monospecific population being isolated each other. These relationships would be clearly recognized by refering the composition of stomach contents given in Tables 5–2 and 5–3 where most stomach contents were consisted of only one species. The important foodstuff of sei whale are *C. tonsus*, *C. simillimus*, *P. gaudichaudii*, *E. superba* and *E. vallentini*, and each of them forms a monospecific stomach contents themselves although their distribution does not always isolate from each other. Table 5–4 shows a monospecific characters of the stomach contents of sei whale on the basis of five major food organisms. Throughout the areas II to VI as observed in both 1967/68 and 1969/70 seasons, it is clear in the table that a quite few examples of stomach contents had contaminated with one or more numbers of food species in addition to those constitutes the major body of the stomach contents. These trends are most distinct among the stomach observed when *C. tonsus*, *P. gaudichaudii* and *E. vallentini* constituted the sei whale food where more than 72 percent of stomachs were monospecific. Thus the tables above mentioned show a distinct monotonous composition in the foodstuff of southern sei whale, which leads to a consideration that the sei whale feeds exclusively on the swarm forming

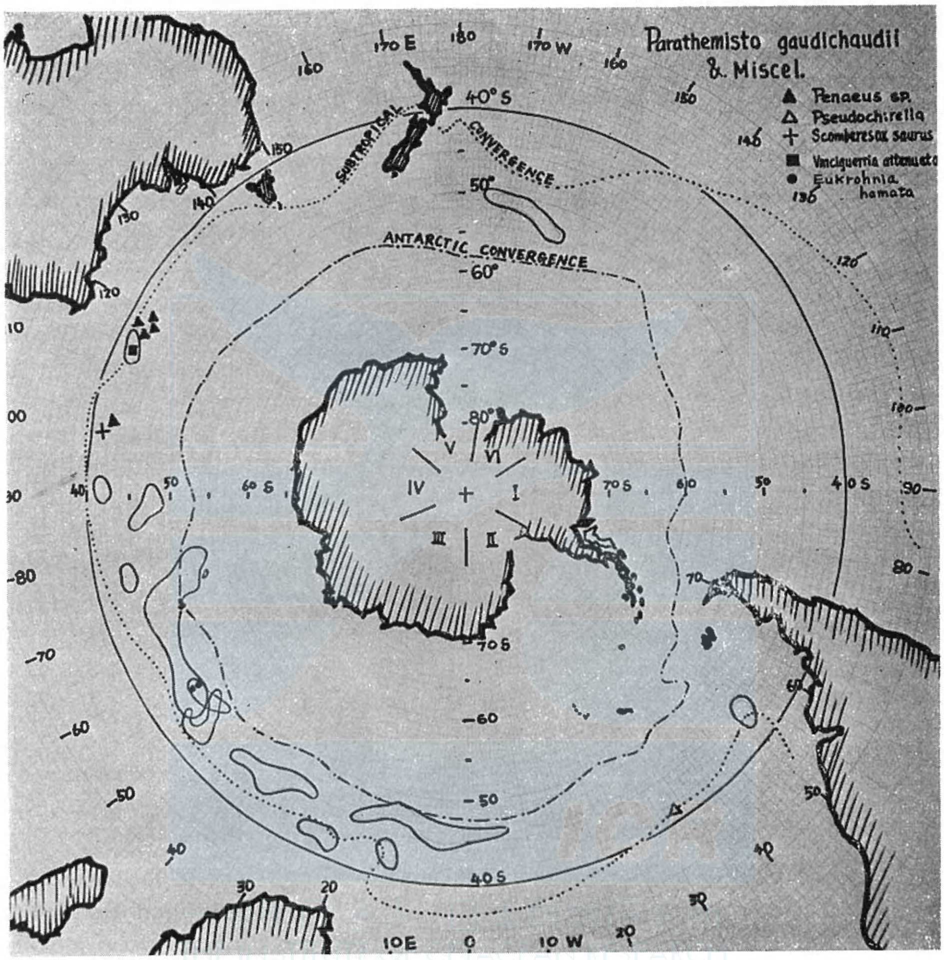

Fig. 5–3. Geographical distribution of the food amphipod, *Parathemisto gaudichaudii*, and other miscellaneous foodstuff for sei whale in the Antarctic.

organisms. It was also known that the number of species contaminated does not exceed more than two, and they also never exceed the major species in quantity, except when the fishes were contaminated; that is, the food of sei whale usually formed with a species which occurs dominantly in the sea concerned. As far as the individual numbers observed are concerned, the sei whale in the Antarctic waters feed selectively with prefering orders of copepoda—euphaussiid, amphpoda, or both of them—other crustaceans, and then fishes or squids as has been reported in the North Pacific sei whale (Nemoto, 1957; 1959). However, the food preference in sei whale varies to some extent by the case. For instances, they feed chiefly on *E. lucens*, *E. recruva* in the South African waters, and copepods such as *C. tonsus*, *C. carianatus*, *Clausoclanus arcuicornis* f. *major* follow to the former (Bannister and Baker, 1967; Best, 1967). Although the " selection " by the kind of food organisms in baleen whales is still in need of more discussion, there seems to be no other ways to believe it possible by adding more facts observed in the North Atlantic baleen whales where Howell (1930) described the selective feeding habits with the orders of small shrimps, anchovy, smelt, and then mackerel. In the Antarctic waters, on the other hand, many sei whale actually feeds on *C. tonsus* at first then *P. gaudichaudii* or *E. vallentini* and finally *E. superba* notwithstanding the fact that there must be exist so rich distribution of *E. superba* in the higher latitudes when they entered into the southern feeding place in early summer. According to my unpublished data the surface swarms of young euphaudiids and amphipods are observed often in the Subantarctic waters of relatively higher latiturdes, but they never found in the stomach contents of sei whales there. They feed exclusively on the adult forms of *E. vallentini* or *P. gaudichaudii*. However, it is still unknown that these are due to the size of food organisms as particles. By examining the sei whale food and feeding in South Georgian waters, Brown (1968) reported a opposite opinion that there were no facts to believe the selective feeding habits in sei whale.

TABLE 5-4. MONOSPECIFIC DEGREE IN THE STOMACH CONTENTS OF SEI WHALE IN FIVE MAJOR SPECIES OF FOOD ORGANISMS.

Species		No. of monospecific samples	No. of mixed samples	No. of species mixed		No. of samples examined	Monospecific samples (%)
				1	2		
Calanus tonsus	1967/68	23	9	6	3	32	71.9
	1969/70	203	34	34	—	237	85.6
Calanus simillimus	1967/68	4	12	11	1	16	25.0
	1969/70	4	2	1	1	6	66.6
Parathemisto gaudichaudii	1967/68	27	4	1	3	31	87.1
	1969/70	20	1	1	—	21	95.2
Euphausia superba	1967/68	14	1	—	1	15	93.4
	1969/70	8	—	—	—	8	100.0
Euphausia vallentini	1967/68	10	1	1	—	11	91.0
	1969/70	10	—	—	—	10	100.0

As shown in Table 5–1 the most important food organisms of the sei whale was copepods but an actual feeding habit of sei whale seems slightly more complicated when *Penaeus* sp., *Scomberesox saurus*, and several another organisms occur locally as being found in 1969/70 season. The feeding habits of sei whale can be considered as a whole that they feed on any kind of swarm forming organisms which dominantly occur within their migratory regions. Bannister and Baker (1967) have also been pointed out on this character by examining the feeding of baleen whale at Durban. However, it must be noted that both chaetognatha which does not swarm into so-called patchiness, and tunicates which is not preferable organisms, are avoided at least by sei whale notwithstanding the fact that they usually occur quite abundantly in the feeding place of baleen whales.

5–3. *Geographical distribution of food organisms*

Since considerable large number of sei whale is caught by the floating factories, it is hardly possible to examine or collect the row materials of the somach contents on every carcasses. So the the food samples are usually collected with some intervals in time and space such as every tenth of carcasses, or every shifts in noon position of the fleets. As mentioned in the foregoing section the kind of food organisms are recorded on the every carcasses regardless the collecting samples. By comparing both row and data materials together, it is possible to figure out the general geographical distribution of food organisms. The results are shown in Figs. 5–1 to 5–3, each of which represents the distributions of copepods, amphipods, and euphausiids respectively.

In the overall distributions of copepod food, *Calanus tonsus* not only occurred dominantly in the south of 40°S covering vast circumpolar regions throughout the areas II to VI, but also was fed most frequently in the region. Its occurrence as sei whale food well agrees with the distribution of patches in the surface waters under close relation to the Subtropical Convergence (see also section 11). As has mentioned in the foregoing section, it must be noted that only swarm forming organisms could be fed by the sei whale, *i.e.*, the distribution of *C. tonsus* as described above supposedly present a little different figures from those known as geographical distribution range of this species. The biomass usually found in its patches is maintained such high density as to be hardly comparable to that known in general, and has been considered to be a characteristic niche in the marine ecosystem. Since the whaling in the Antarctic region is opened in the south of 40°S the northern boundary in the distribution of *C. tonsus* in Fig. 5–1 does not show its natural habitat but artificial. The center of rich distribution of *C. tonsus* is usually found in the vicinity of the Subtropical Convergence (e.g. Kawamura and Hoshiai, 1969) but its northern most boundary may extends beyond upto 30°S or thereabouts.

According to Brodskii (1964) *C. tonsus* occurs under the temperature of 5°∼15°C, and its rich occurrence is observed between 8.5°C and 12.3°C off Otago Peninsula, New Zealand (Jillett, 1968). In this study the surface sea temperaure at which *C. tonsus* occurred as food of sei whale during December was between 9.5° and 18.0°C. Judging from feeding percentages by sei whale the most preferable temperaure for this species was supposed to be 9.0°∼13.0°C, and these sea conditions correspond to the Deacons' mean temperature of the Subtropical Convergence during austral summer (Deacon, 1937).

A distinct southerly extension in the distributions of *C. tonsus* down to 55°S between 160° and 170°W longitudes would be comparable to the southerly shift of the Subtropical Convergence. Actually, the Subtropical Convergence at 170°W in 1968/69 season was located in the vicinity of 55°S latitude (Ocean Res. Inst., 1970).

In the plankton communities of South Georgian waters including northeast Weddell Sea and Scotia Sea, *C. tonsus* does not occur (e.g. Mackintosh, 1934; Hardy and Gunther, 1935), since these regions are influcenced under a northward movement by the cold Weddell Current lower than 5.0°C. In general *C. tonsus* distributes abundantly throughout the subantarctic regions so as to be fed by the sei whale under relatively warmer conditions, *i.e.*, 10°∼15°C, and no other kind of organisms which are comparable with *C. tonsus* as whales food were found. In this point of view *C. tonsus* could be considered ecologically most important species being comparable with *C. plumchrus* or *C. finmarchicus* in the northern hemisphere.

Following to *C. tonsus* the secondly important food copepoda is *C. simillimus*. However, as it is seen in the distributions, *C. simillliums* occurred in the Indian sector where both Crozet and Kerguelen Islands, and also a part of Atlantic sector are involved. So the occurrence of *C. simillimus* is considered rather local and hardly comparable with that of *C. tonsus* as food of sei whale. This species distributes on the whole in the slightly southern waters than *C. tonsus* with the distribution center between 45° and 50°S. It is note worthy that the distibutions of *C. simillimus* and *C. tonsus* is closely located geographically but never overlaps each other. In contrast to rather earlier occurrence through December to January in *C. tonsus*, *C. simillimus* occurred mostly around February. Accordingly the sea temperature when they occurred was also different: *C. simillimus* food was found under the temperaures of 5.0°∼9.1°C in 1967/68 season. According to the distributions of copepods obtained by the Japanese Antarcic Research Expedition (Kawamura and Hoshiai, 1969), the successive occurrence of *C. tonsus* was replaced with *C. simillumus* at about 45°S in the southern waters of South Africa, when the surface sea conditions were 7.5°C with salinity of 34.07‰. These facts suggest that the lower most temperature for *C. tonsus* distribution may be 7.0°C or thereabout whereas it may be the higher most temperature for *C. simillimus*. Although both *C. tonsus* and *C. simillimus* are the Subantarctic species, the former could be regarded as northern warmer water species while the latter as southern cold water species.

D. pectinatus occurred only in the waters around Kerguelen and Crozet Islands. In the waters in the vicinity of Crozet Islands distribution of this species agreed well with that of *C. simillimus* but not in Kerguelen waters where none of *C. simillimus* occurred at all. Nemoto (1962) also reported *D. pectinatus* as sei whales food only in the waters around Kerguelen Islands. Kerguelen Islands is located on the Kerguelen—Gausberg under water ridges and forms a shallow depth zones which are rarely found in the high seas in the Antarctic region. The characteristic occurrence of *D. pectinatus* as above mentioned may supposedly due to a local hydrological conditions caused by a kind of upwelling of deep waters in the Indian-Atlantic Basin.

Clausocalanus laticeps is one of newly found food species in the Pacific sector of around 180° meridian. Although its distribution area agrees with that of *C. tonsus*, *C. laticeps* occurred as monospecific population without mixing with any other food species. Among the euphausiid species shown in Fig. 5–2, both *E. vallentini* and *E. superba* are the most important species in the feeding percentages and large shares as biomass in a stomach contents. In the mid-latitude zones the euphausiid food represented almost exclusively by *E. vallentini*. Nemoto (1961) added this species in the dietary list of southern baleen whales after finding its occurrence as food of pygmy blue whale, *B. musculus brevicauda* (Ichihara, 1961: Omura *et al*, 1970) in the Kerguelen waters. Mackintosh (1960) had early suggested an ecological importance of *E. vallentini* when there had not been any scientific evidences on the role of this species among marine food-chains. In the areas II and III *E. vallentini* is fed in a narrow zone between 45° and 47°S but in the areas II and IV, the Indian sector, this species was frequently found under admixing with *P. gaudichaudii*. Although the most *E. vallentini* as the case in copepods is usually fed during December, its distribution centered in rather southern waters within the Subantartic zone. A completely isolated occurrence of *E. vallentini* was seen in the southeastern waters off New Zealand. Since its distribution is clearly isolated from that of *C. tonsus*, *E. vallentini* could be considered a typical Subantarctic species, and these facts agree with the result by Nemoto (1962a), in which he suggested that the distribution pattern of *E. vallentini* as whales food seems to agree to some extent with the distributions of shallow zone by continental shelf and under water ridges. In the environs of New Zealand particularty in its eastern regions the continental shelf develops well, which might be responsible both for the upwelling and a local swarming phenomena by *E. vallentini*.

As the whaling season proceeds the sei whaling ground also shift gradually toward south. In accordance with this shift the food organisms of sei whale also changes into *E. superba* which distributes in the waters south of the Antarctic Convergence, a representative of the whales food in the region. However, it seems rather less important as sei whale food since relatively small number of sei whale migrates into the higher latitudes in the south of the Anatrctic Convergence. Other euphausiids species such as *E. lucens*, *E. similis*, *E. diomedeae*, *Thysanoessa vicina*, *Th. gregaria* and *Thysanopoda actifrons*, were also found in slightly northern regions than *E. vallentini* as sei whale food, but their occurrence was quantitatively small and rather sporadic. In this sence they seem less important as sei whales food. According to Nemoto (1957), *Th. macrura* was one of other kind of important species as a food of fin, blue and humpback whales but none of individuals of *Th. macrura* was found in the sei whale stomachs in this study. Nemoto (1957) also had not found its occurrence in sei whale. These facts are characteristic when compared with the case in *E. superba* since *Th. macrura* also distributes in the waters near to ice-pack (Nemoto, and Nasu, 1958). One of a possible explanations is that *Th. macrura* shows rather sporadic and local distributions than *E. superba* in addition to its habitat in higher latitudes.

Parathemisto gaudichaudii, one of the most important food organisms for sei whale which widely distributes in the Subantarctic waters with the center between 45° and 50°S, *i.e.*, relatively southern waters near to the Antarctic Convergence (Fig. 5–3). Accordingly its general features of the distribution resemble with that of *E. vallentini*. However, it would be noticed by comparing the distribution character with *E. vallentini* that the occurrence of *P. gaudichaudii* as food of sei whale is much sporadic, that is, *P. gaudichaudii* forms the patches so as to be fed by the whale but distributes sporadically. *P. gaudichaudii* occurred most distinctly in the Indian sector of the areas III and IV where the bottom topography is complicated by the presence of many islands such as Kerguelen, Crozet, Marion and Heard Islands. So its distribution resembles to that of *E. vallentini*. Although Nemoto (1962) found *P. gaudichaudii* in the stomach contents of fin and pygmy blue whales, this food species would supposedly be preferred much in sei whale from the general selecting feeding habits of baleen whales. The general agreements in the distribution of both *E. vallentini* and *P. gaudichaudii* suggest a possibilities of their co-existing in time and space. Actually they occurred in the food of sei whale by admixing each other in some sea regions of the Indian sector (see Fig. 5–2).

Penaeus sp., *Scomberesox saurus*, *Vinciguerria attenuata* and some other kind of myctophid fishes occurred in relatively larger quantities but were found to be less important since they were considered as the contaminants mixed with the principal food zooplankton populations. Among those above mentioned organisms, Genus *Vinciguerria*, a kind of gonostomatid fishes, would be regarded relatively important since it forms a potential foodstuff of the skip Jack, *Katsuwonus pelamis* at times in the Pacific Ocean (Kubota and Kawamura, 1972).

5–4. *Latitudinal change in the distribution of food organisms*

In 1967/68 season two of four floating factories operated relatively widely through latitudinal zone, and the materials obtained from those two fleets made it possible to analyse the change in geographical distribution of food organisms in terms of the feeding percentages. The general features of latitudinal change in the Indian sector is demonstrated in Fig. 5–4 and those in the Pacific sector along with the Tasman Sea region is in Fig. 5–5. The feeding percentages are expressed by the ratio of the number of animals with food in the first stomach against the total number of animals examined. " Calanus " in the figures does not mean the Genus *Calanus* in taxonomical sence but represent the copepod although most of the case in " Calanus " is represented by *C. tonsus* and *C. simillimus* (Tables 5–2 and 5–3).

In both figures it is noticed clearly that " Calanus " food being represented by *C. tonsus* and *C. simillimus* occurs exclusively in the waters south of 40°S, down to amidst of the Subantarctic region of about 47°S *i.e.*, the northern half of the Subantarctic waters of the main sei whaling ground of the copepod rich waters. Getting closer to southern region of the Subantarctic waters close to 50°S., the representative food organism gradually changes to small-sized euphausiids such as *E. vallentini*, but *P. gaudichaudii* was also fed by the whale in some places under both monospecific composition and mixture with *E. vallentini*. *P. gaudichaudii* increased gradually in the share of occurred food organisms toward the Antarctic Convergence. In the south of the Antarctic Convergence the dominancy of *E. vallentini* in a stomach contents replaced with *P. gaudichaudii* but the latter is again replaced gradually with euphausiids of adult and adolescent forms of *E. superba*. In the waters south of 65°S 1-year group of *E. superba* occurs sporadically in the stomach of sei whale. Thus the occurrence of the food organisms distinctly changes in latitudinal direction. It is note worthy that these successive changes occur within the narrow zone of about 20° degrees of the latitudes.

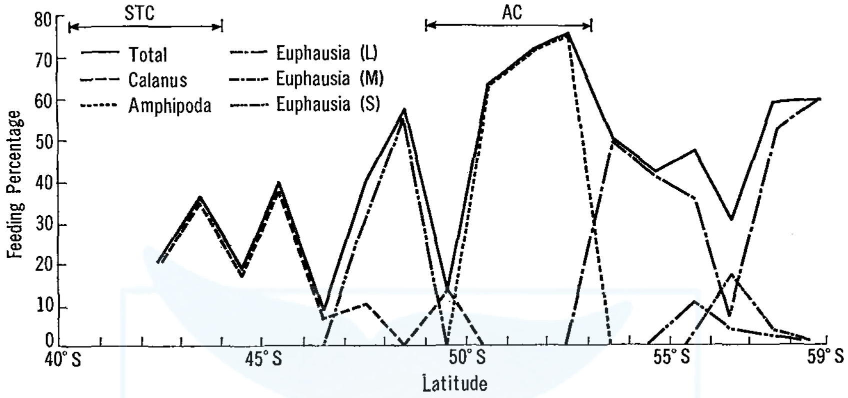

Fig. 5–4. Latitudinal change in the occurrence of food organisms for sei whale in the Indian sector of the Antarctic. STC: Subtropical Convergence, AC: Antarctic Convergence.

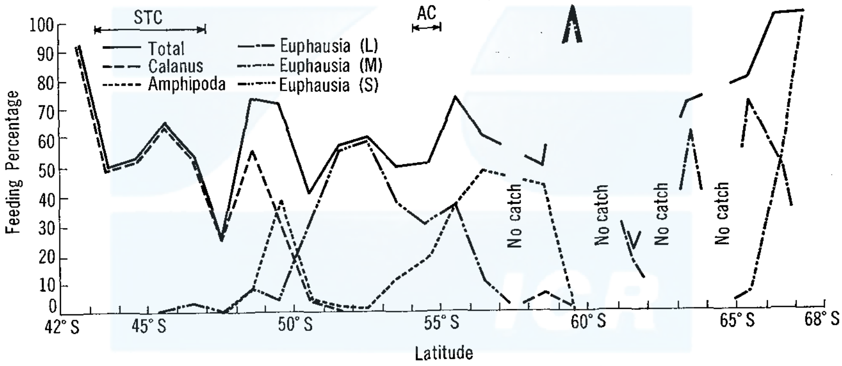

Fig. 5–5. Latitudinal change in the occurrence of food organisms for sei whale in the Pacific sector of the Antarctic and in the Tasman Sea region. STC: Subtropical Convergence, AC: Antarctic Convergence.

The food organisms of sei whale in the waters of the both Subantarctic and Antarctic occurred toward higher latitudes in the order of copepod, euphausiid, amphipod, and then again euphausiid. In the waters north of the Antarctic

Convergence *E. vallentini* was fed more preferably than *P. gaudichaudii* notwithstanding the fact that the former is less abundant than *P. gaudichaudii* in the region, and feeding on *P. gaudichaudii* by the whale was distinctly increased in the south of the Antarctic Convergence (Fig. 5–5). According to Kane (1966), *P. gaudichaudii* distributes most abundantly in the waters around the Antarctic Convergence especially in its northern side. These facts lead to a consideration that the sei whale feeds more preferably on euphausiids than amphipods while the former seems to be less abundant than the latter in the region concerned as a function of selective feeding habits, although it is still unknown whether the food selection is caused by mechanical process or some kind of biologically potential preferance. It may also be possible that the selection of the food organisms in feeding habits would released only when rich food organisms were available in the region. The selective feeding haibts in sei whale also corelate to the distribution pattern of the food organisms whether they form the patchiness or not.

5–5. *Distribution of food organisms by the whaling area*

As mentioned in the foregoing section, the food organisms of sei whale changes one to another in a narrow latitudinal zone. The general circumpolar hydrological conditions in the surface waters of the Antarctic Ocean shows rather monotonous

TABLE 5-5. FEEDING PERCENTAGE (ITALICS) AND ACTUAL NUMBER OF WHALES IN THREE MAJOR FOOD ORGANISM GROUPS BY THE WHALING AREAS III TO VI IN 1967/68 SEASON.

Area & Sector	Kind of food organisms						Empty	Food/ Total	No. of inds. Total
	Calanus	Amphipoda	Euphausiid			Unknown***			
			L	M	S				
Areas III & IV	207*	191	115	23	59	—	919		1518
(Indian Ocean)	*13.64*	*12.58*	*7.58*	*1.52*	*3.89*	—	*60.54*	*39.46*	
Areas IV & V	357**	73	61	17	203	—	537		1248
(Tasman Sea & Pacific Ocean)	*28.61*	*5.85*	*4.89*	*1.36*	*16.27*	—	*43.03*	*56.97*	
Areas V & VI	888	70	—	—	575	9	1008		2550
(Pacific Ocean)	*34.82*	*2.75*	—	—	*22.55*	*0.35*	*39.53*	*60.47*	

* Includes *Drepanopus pectinatus*.

** Includes *Clausocalanus laticeps*.

*** Not examined.

features (Deacon, 1937), that is, the hydrological conditions are less variable by the whaling areas in contrast to those in latitudinal direction. In order to figure out the change in the occurrence of food organisms by the whaling areas, the composition figures were given in Tables 5–5 and 5–6. In the tables the occurrence of food organisms by each whaling areas were expressed in feeding percentages along with the number of animals examined. To make comparison with the case of fin whale its figure was also given in Table 5–6. The kind of food organisms expressed in the tables would be known by refering the foregoing sections. Both large (L) and medium (M) sized euphausiids represents the 1- or 2-year group of

E. superba and small (S) sized one is represented mostly by *E. vallentini* or *E. lucens* in mid-latitudes and by the young *E. superba* in higher latitudes. Only *P. gaudichaudii* corresponds to amphipods (Am).

The feeding percentages in 1967/68 season showed 52.3% on an average and those in 1969/70 was 48.6% through the whaling areas II to VI whereas fin whale showed 58.6%. Their percentage figures suggest that an approximately 50% of sei whale caught in the whaling operations carries food contained stomachs. The feeding percentage of fin whale was slightly higher than that of sei whale. The feeding percentage by the whaling areas in both 1967/68 and 1969/70 seasons varied 39.46~61.22%, which suggests the different feeding conditions to some extent by the whaling areas. In the feeding percentages by the kind of food organisms, " Calanus " (=copepods) food showed only 13.64% in the Indian sector of the areas III and IV in 1967/68 season while they increased gradually toward the Pacific sector where the feeding percentage attained at 34.82% (Table 5–5). The " Calanus " food through the areas II to IV in 1969/70 season showed a quite high percentage being higher than 60% in the area II whereas they decreased about one half in the areas III and IV.

TABLE 5-6. FEEDING PERCENTAGE (ITALICS) AND ACTUAL NUMBER OF FIN AND SEI WHALES IN FOUR MAJOR FOOD ORGANISM GROUPS BY THE WHALING AREAS II TO IV IN 1969/70 SEASON

Area	Species of whales	Calanus	Amphipoda	Euphausiid			Fish*	Unknown**	Empty	Food/Total	No. of inds. Total
				L	M	S					
II	Sei	675 *60.32*	2 *0.18*	— —	— —	8 *0.71*	— —	— —	434 *38.78*	61.22	1119
	Fin	6 *30.00*	— —	— —	— —	6 *30.00*	— —	— —	8 *40.00*	60.00	20
III	Sei	233 *29.68*	61 *7.77*	— —	— —	42 *5.35*	2 *0.26*	1 *0.13*	446 *56.82*	43.18	785
	Fin	12 *1.10*	4 *0.37*	— —	— —	486 *44.67*	1 *0.09*	— —	585 *53.77*	46.23	1088
IV	Sei	579 *35.76*	47 *2.90*	34 *2.10*	1 *0.06*	6 *0.37*	— —	2 *0.12*	950 *58.67*	41.33	1619
	Fin	9 *1.34*	— —	445 *66.12*	16 *2.38*	18 *2.67*	— —	1 *0.15*	184 *27.34*	72.66	673

* *Notolepis castsi.*
** Not examined.

These results as observed in both seasons suggest that " Calanus " food might be relatively less important in the Indian sector especially in the environs of Crozet Islands. The relatively low feeding percentages of " Calanus " food in these waters well agree with the result obtained by Pervushin who studied on the materials during 1961/63 to 1964/65 seasons (Pervushin, 1968). On the other hand, a relatively high percentages in the areas II of Folkland Island sector and the areas V and VI indicate a potentential importance of " Calanus " food in those regions. However, the " Calanus " food can be regarded potentially important diet for the sei whale whereas they seems less important for the fin whale throughout the whaling areas. The general trends to feed more on euphausiids than copepod in fin whale are clearly seen in Table 5–6.

Although the importance of " Calanus " food for sei whale may be quite evident in general, the fullness of the first stomach with " Calanus " food proved less than 50%, and none of fully repleted stomachs were observed. This fact indicates that the population density in terms of the biomass in " Calanus " food would be less than that in euphausiids and amphipods even when they aggregated densely to show the patchiness. Copepods as food of sei whale have been well known early (*e.g.* Collett, 1886; Ingebrigtsen, 1929; Nemoto, 1957; 1959; Kawamura, 1970a, b) and their more importance for southern sei whale than any other organisms is proved in this study. Accordingly it would be possible that the sei whaling at least in December to January was determined primarily by the distribution of " Calanus " food.

Different from " Calanus " food, amphipods (*P. gaudichaudii*) was fed by 12.58% of sei whale in 1967/68 season and by 7.8% in 1969/70 season. These figures are rather lower when compared with the case of " Calanus " food. Among the whaling areas concerned relatively high feeding percentages were observed in the Indian sector of the areas III and IV in both seasons. However, the feeding percentages in 1969/70 season leveled cosiderably lower than in 1967/68 season as well as having been noticed in " Calanus " food. These phenomena are still not proved yet, but supposedly due to the variation in geographical distribution along with year to year fluctuations in the population size of the food organisms. The low feeding percentages in 1969/70 season also agree with those observed in euphausiids. Since these trends are quite similar through the three kinds of food organisms, it is supposed that they must had not been influenced under the environmental control onto their developmental stages.

Large and medium sized euphausiids, say, *E. superba* had been fed quite little by the sei whale in 1969/70 season. The feeding percentages showed only 2.16% for large sized euphausiid in the area IV whereas it was 7.6% in the Indian sector of 1967/68 season. The latter was the highest feeding percentages through both seasons. In 1967/68 season euphausiids showed relatively higher feeding percentages than copepods and this relationship reversed in 1969/70 season. A relative low feeding percentage in large and medium sized euphausiids supposedly due to the geographical location of main sei whaling ground, and the varations between whaling seasons would be due to the environmental factors which are responsible for the development of young copepods. The sei whale might have fed on *E. superba* when copepods such as *C. tonsus* was poorly available. Studying on the food of baleen whales in the North Pacific, Nemoto (1959) concluded that there must be both *Calanus* rich year and euphausiids rich year in those region. A similar phenomena may be considered in the Antarctic whaling ground.

In small sized euphausiids, however, the general circumstances seem different to some extent. Different from large sized euphausiids the small sized one is chiefly represented by *E. vallentini* and *E. lucens*, and their feeding percentages in the Pacific sector of the areas V and IV showed 22.6%, a relatively high ratio though it decreased gradually toward the west through Tasman Sea, Indian sector and then Atlantic sector respectively. In 1969/70 season the feeding percentages were distinctly low throughout the areas II to IV, and no areal variations were observed. The occurrence of small sized euphausiids may also be related to the abundance of copepods as having been suggested in the large sized euphausiids.

According to Baker (1954) the circumpolar distribution of zooplankton in the Antarctic region shows a monotonous features on the whole through the three oceans whereas they distinctly change in the north-south direction, and both of these circumstances agree well with the general hydrological conditions. The geographical changes in the feeding percentages of sei whale also agree as a whole with the results reported by Baker (1954). A local but distinct occurrence of *C. simillimus* and *P. gaudichaudii* in the sei whale food agrees too with their general distribution patterns, that is, the distribution of food organisms does not differ from that of zooplankton.

6. DISTRIBUTION OF WHALES, AND ITS RELATION TO PHYSICAL, CHEMICAL AND BIOLOGICAL ENVIRONMENT FACTORS

Studying on the food and feeding of sei whale caught in the 1967/68 and 1969/70 seasons, it was considered that the regions where feeding ground is formed in the Subantarctic zone would closely related to the characteristic features in the distribution of food organisms. For instances, the feeding ground being formed by the copepodite V stage of *C. tonsus* during early summer diminishes gradually as to their seasonal vartical migration into the deeper waters (Jillett, 1968), and these environmental changes make the whale move into more higher latitudes in search of another foodstuff such as *C. simillimus*, *E. vallentini* and *P. gaudichaudii*. Thus, the geographical shift in the whaling ground closely relates to the ecological characters in the distribution of food organisms.

6–1. *Distribution of whales and the environmental factors in the Pacific and Antarctic Ocean*

Apart from the biological examination on whale carcasses, the oceanographical investigations along with plankton sampling and whale sighting were made during the KH–68–4 cruise of the R. V. "Hakuho Maru" of the Ocean Research Institute, University of Tokyo, and a part of biological works made in this cruise have already been reported (Kawamura, 1969a, 1970b, c; Kawamura and Kureha, 1970). Leaving Tokyo on November 14, 1968, the research cruise of KH–68–4 was made along two transections, *i.e.*, 170°W from 30°N down to 70°S and 155°E from 38°S to 70°S. The track along 170°W crossed in the midst of main sei whaling ground where one of the Japanese floating factories operated for two successive seasons through 1967/68 and 1968/69 (Ocean Res. Inst., Univ. Tokyo, 1970). A total of 61 oceanographic stations were occupied during the cruise, and the plankton collection from 150 m depth upto the surface was also conducted routinely with the North Pacific standard net, and also several series of divided hauls from great depths with the Petersen type vertical closing net. Of approximately 9,000 miles cruise 2,100 miles of the track was sighted for counting the number of whales and seabirds.

The number and the kind of whales sighted along 170°W were demonstrated in Fig. 6–1 along with the profile of the environmental factors. In general the distribution of whales shows close relation to the bottom topography in the feeding place (Nemoto, 1957; 1958), but the depth along the track covered by the R. V. "Hakuhô Maru" varied between 2,000 and 3,000 m, and possibly no influences on the distribution of whales. It would be noticed in Fig. 6–1 that the distinct accumulations of whales were found in the south of 30°S especially in the Subantarctic region between 30°S and 50°S. A rather less number of sighted whales between 50°S and 60°S was supposedly due to rough surface of the sea by stormy weather.

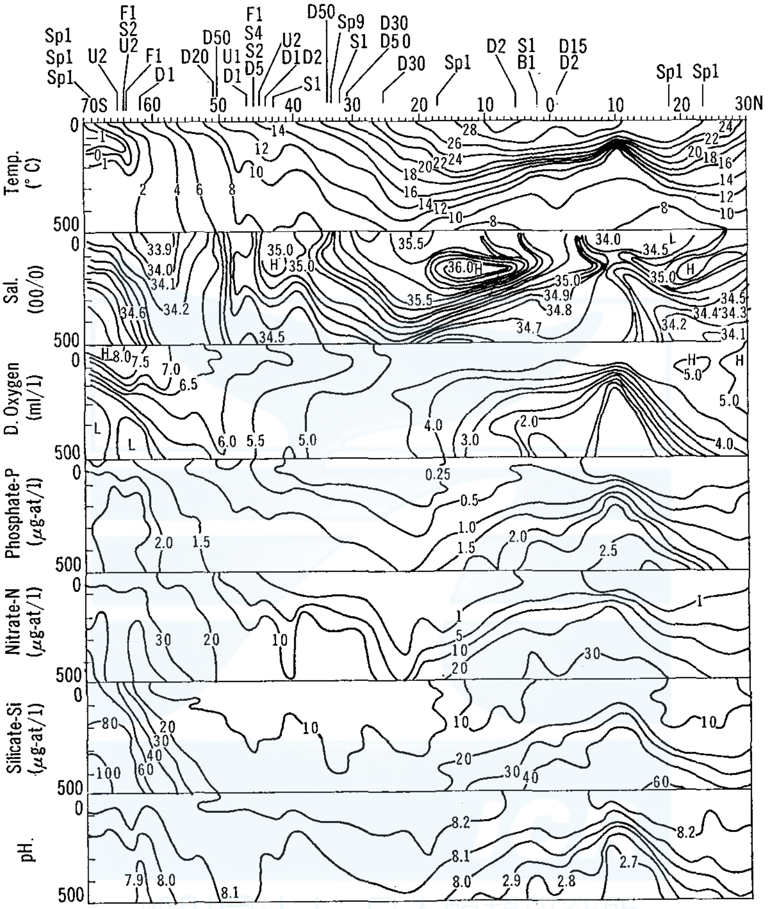

Fig. 6–1. Whales sighted and profile of the environmental factors along 170°W, 30°N~70°S during Nov. 22, 1968 to Jan. 19, 1969. Sp: sperm, B: blue, F: fin, S: sei, D: small toothed, U: unidentified.

An approximate physicochemical conditions in the Subantarctic waters along 170°W were; 10°~20°C (temperature), 34.5~35.5‰ (salinity) and 0.25~0.5 μg-at/l (phosphate) and 5.5 ml/l (dissolved oxygen) respectively. On the characters in chemical properties of the Subantarctic regions, Rochford (1961) demonstrated 35.4‰ of salinity and 0.2~0.4 μg-at/l in phosphate as its indicators in the waters off Western Australia, and he distinguished the water masses under the names of "south transitions zone". By taking these results into considerations it would be noticed that relatively denser consentration of whales are located not in the midst of the Subantarctic waters but in rather northerly located transition zone between warm and cold waters. As clearly noticed in the distribution pattern of the environmental properties, those transition zone corresponds to the upwelling zone of rich zooplankton standing stocks. In the south of 60°S, the proper of the Antarctic region, a great number of whales distribution was also found.

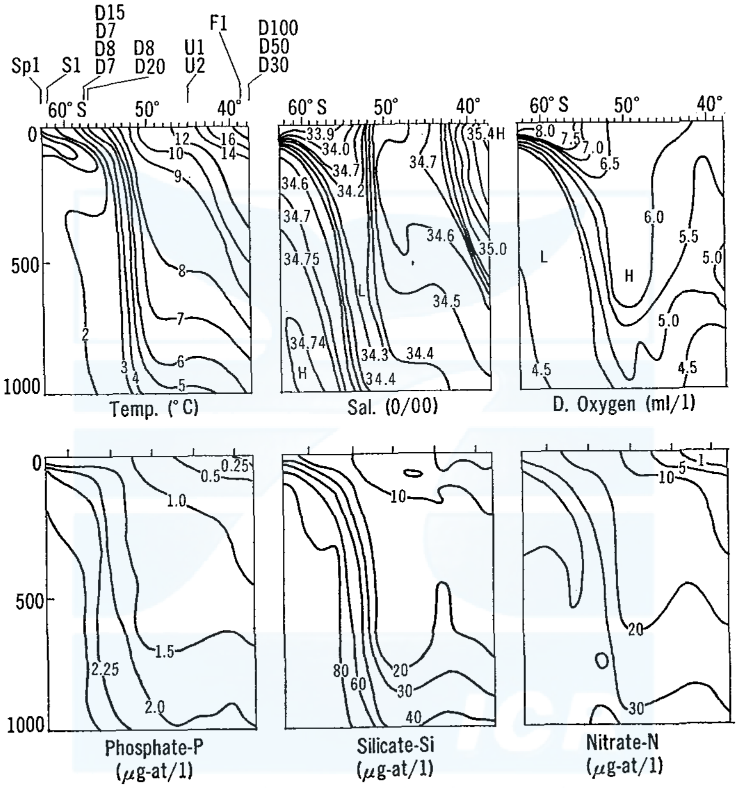

Fig. 6–2. Whales sighted and profile of the environmental factors along 155°E, 63°S~38°S during Jan. 23 to Feb. 1, 1969. Abbreviations of whale species are as given in Fig. 6–1.

On the other hand in the Antarctic and the Tasman sea regions along 155°E longitude, the whales were spotted only twice for sei and fin whales, which showed a poor distribution of whales in general (Fig. 6–2). The relationship between the distribution of whales and the environmental factors in this region was less clear than those in 170°W. However, relatively rich distribution of whales was found in the Antarctic and Subantarctic waters, particularly in the transition zone of northern waters.

Apart from the Antarctic regions it was note worthy that there were also distinct accumulations of whales in the region of equatorial divergence between 10°N and 10°S, where a quite high concentrations of zooplanters were found (Fig. 6–3). The zooplankton in this region would possibly be supported by the high primary productivity due to upwelling (Nasu, 1972) which provides a quite rich accumulation of tuna (Sette, 1955). Although it is recognised in general that the baleen whales do not feed much or entirely in the tropical seas (*e.g.* Mackintosh, 1965), but those above mentioned results lead to a consideration that the whales would potentially be in search of foodstuff even in those warmer waters.

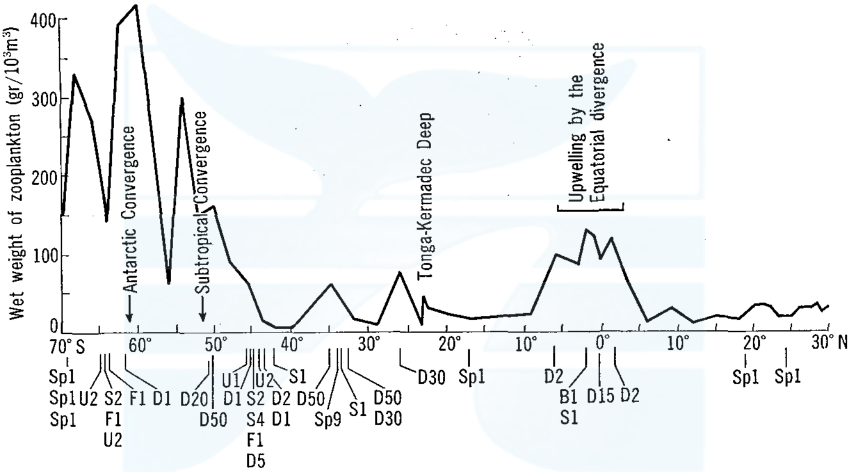

Fig. 6–3. Whales sighted and wet weight of zooplankton in the upper 150 meter of the water column between 30°N and 70°S along 170°W during Nov. 22, 1968 to Jan. 19, 1969. Abbreviations of whale species are as given in Fig. 6–1.

Whales sighted at 40°~50°S might have been on their migration toward south since most of them were spotted in the early January. According to the catch records in the past 40 years (Omura, 1973), some individuals of the sei whale spotted at higher latitudes in early summer are supposed to be as the stranger from over wintered population.

In summerizing the above mentioned results both baleen and toothed whales distribute in more favourable environments of the sea, where the feeding conditions as having been indicated by the zooplankton abundance would be the most important role not only in the Antarctic region but also in the tropical seas.

6–2. *Whaling ground of sei whale and the distribution of zooplankton*

The whaling grounds of sei whale both in 1967/68 and 1968/69 in the areas V and VI of the Pacific sector were shown schematically in Fig. 6–4, and the distribution of food organisms found in the stomach of sei whale caught in the above mentioned whaling grounds were demonstrated in Fig. 6–5. Black spots on the meridians of 170°W and 155°E in the figures represents the oceanographic observation stations occupied by the R. V. "Hakuhô Maru" during her 1968/69 cruise. The track by the "Hakuhô Maru" crossed over the whaling grounds although the main body of whaling ground in 1968/69 season located somewhat eastward. The mean position of both the Subantatctic and Antarctic Convergences are indicated by the solid lines along with those observed by the R. V. "Hakuhô Maru."

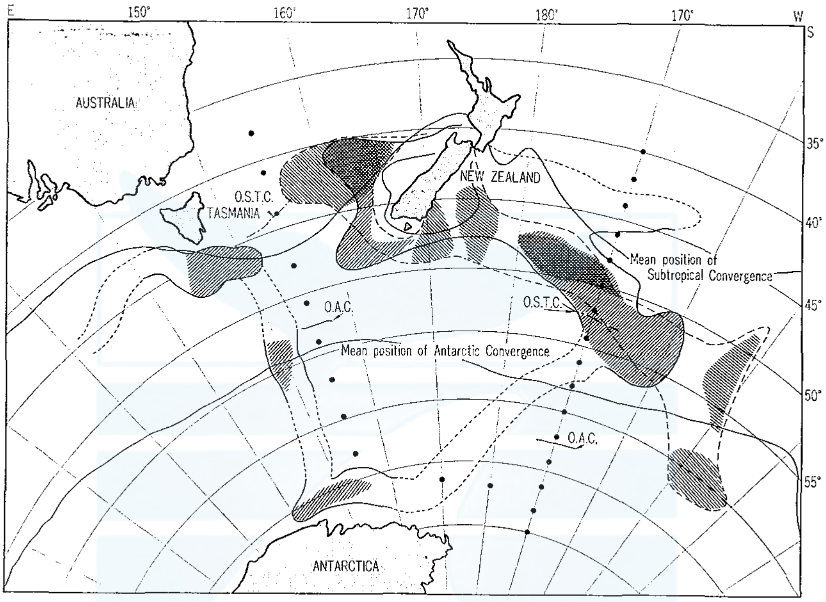

Fig. 6–4. Whaling grounds of sei whale in the Antarctic, Areas V and VI. Shade by hatch indicates the region where the sei whale was heavily catched. Black spot shows the position at which plankton sampling was made by the R. V. Hakuhô Maru during her KH-68-4 Cruise in 1968/69. O.S.T.C., O.A.C.: Observed positions of the Subtropical and Antarctic Convergence.

The whaling ground of sei whale in these regions is formed in the north of the Subantarctic waters with its center along the Subtropical Convergence and its transition zone. These hydrological conditions do not differ much from those in the Folkland region (area II) and the Indian sector (areas III and IV).

The food organisms which occur regularly in the whaling ground around New Zealand are *C. tonsus*, *Clausocalanus laticeps*, *E. vallentini*, *E. superba* and *P. gaudichaudii* among which *E. superba* is found only in the vicinity of Balleny Islands. This species seems less important as sei whale food being compared with other food species. Both *E. vallentini* and *Clausocalanus laticeps* as well as *E. superba* showed local occurrence. In Fig. 6–5 it is considered that the whaling ground of the areas V and VI is largely formed solely by *C. tonsus*.

On the other hand the quantitative distributions of net zooplankton species which were collected by the Norpac net at each stations were demonstrated in Figs. 6–6 to 6–12. In Fig. 6–6 it was observed that the approximate number of individuals of *C. tonsus* population was 10^4 inds./1000 m^3 along the 170°W whereas it was 10^5 inds./1000 m^3 along 155°E. The figures of $10^4 \sim 10^5$ inds./1000 m^3, can be considered quite distinct in abundance as the distribution density of copepods, and are still more higher density than that of *C. tonsus* in New Zealand waters where they showed 0.52~83.5 inds./m^3 (Jillett, 1968). The general features

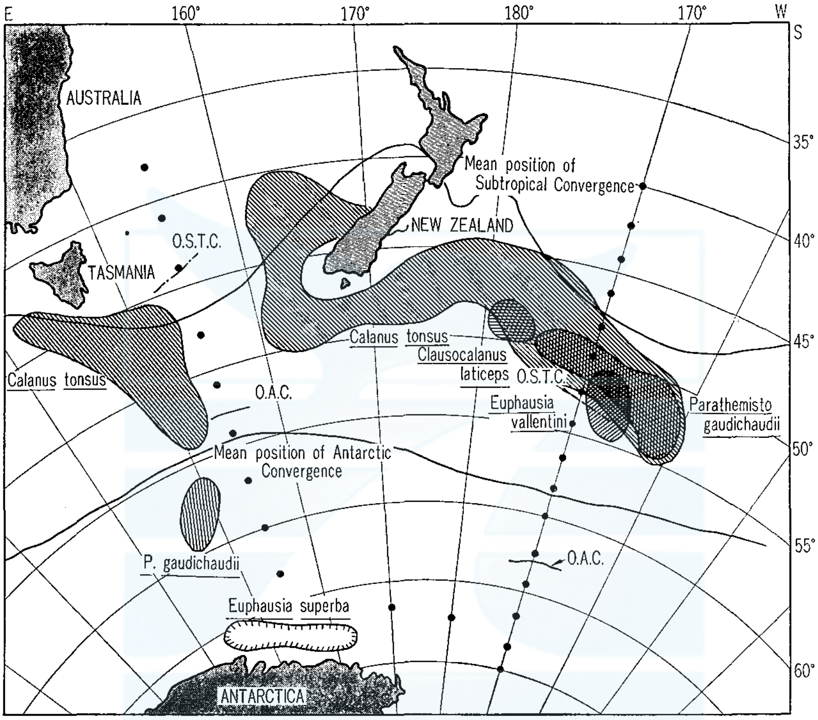

Fig. 6–5. Distribution of the food of sei whale in the Areas V and VI, 1967/68. O.S.T.C., O.A.C.: Observed positions of the Subtropical and Antarctic Convergences.

of the *C. tonsus* distribution in Fig. 6–6 correspond well to the characteristic distribution of whaling ground shifting rather northerly or southerly close to the Antarctic Convergence at 170°W and 155°E respectively.

C. simillimus was one of an important food plankton for sei whale in the Indian sector of the area III, but none in the area V. A considerable number of species, however, occurred in the net samples throughout the Subantarctic region with the individual density of $10^3 \sim 10^5$ inds./1000 m^3 or more (Fig. 6–7). The most *C. simillimus* population occurred was represented by the copepodite stages II and III along with adult forms while *C. tonsus* population was almost exclusively by the copepodite V, that is, the food of sei whale. Accordingly, it would be possible that their life history differs each other. *C. simillimus* is generally recognized as

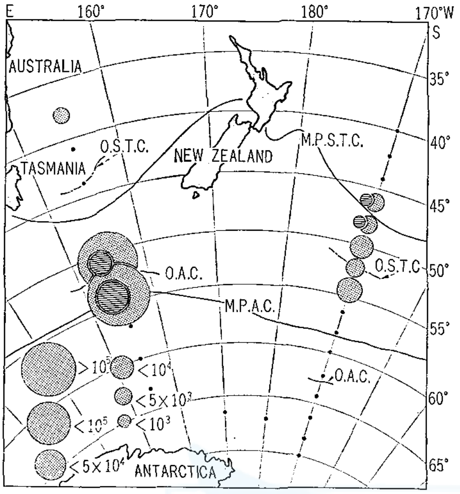

Fig. 6–6. Quantitative distribution of *Calanus tonsus* in the whaling area V, 1968/69. MPSTC: Mean position of the Subtropical Convergence, MPAC: Mean position of the Antarctic Convergence, OSTC: Observed position of the Subtropical Convergence, OAC: Observed position of the Antarctic Convergence. Copepodites under IV are shown by the hatch.

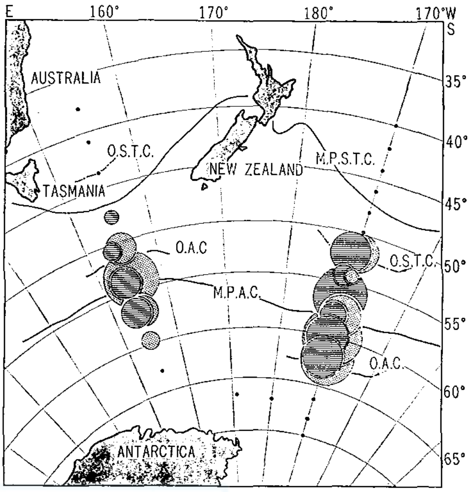

Fig. 6–7. Quantitative distribution of *Calanus simillimus* in the whaling Area V, 1968/69. Legends as in Fig. 6–6.

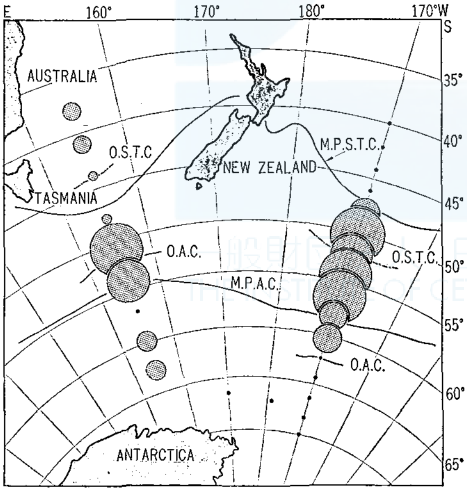

Fig. 6–8. Quantitative distribution of *Clausocalanus laticeps* in the whaling Area V, 1968/69. Legends as in Fig. 6–6.

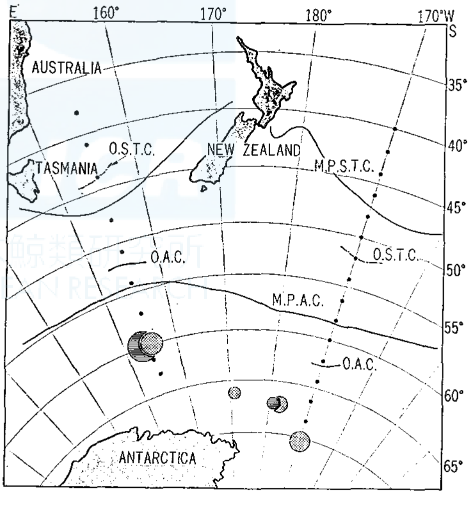

Fig. 6–9. Quantitative distribution of *Calanus propinquus* in the whaling Area V, 1968/69. Legends as in Fig. 6–6.

the Subantarctic species (Hardy and Gunther, 1935, Vervoot, 1951, 1957; Tanaka, 1960; Brodskii, 1964), and the center of distribution in this species were found relatively in the southern waters than *C. tonsus* and does not occur in those transition zone proposed by Rochford (1962).

As it was described by Brodskii (1964), *C. simillimus* distributes in the waters around the Antarctic Convergence being centered between 50°S and 60°S. It was the Kerguelen—Crozet regions of 43°∼50°S that *C. simillimus* occurred in the sei whale stomach in late January to mid February. In the environs of Crozet Islands where the surface sea temperature during December to January was 9.0∼13.4°C, *C. tonsus* occurred as food of sei whale and it was replaced with *C. simillimus* in the waters of 5.0°∼9.1°C. These facts lead to a consideration that *C. tonsus* would be rather northern warm temperate species in contrast to *C. simillimus*. According to Kawamura and Hoshiai (1969) the boundary at which the distributions of both *C. tonsus* and *C. simillimus* replaced one to another was found at 45°S in the area between Cape Town and the Showa Base in Antarctica. The surface sea temperature and the salinity at 45°S were 7.6°C and 34.07‰, respectively. Since *C. simillimus* does not occur under the conditions of low salinity lower than 33.88‰, it would hardly be possible that *C. simillimus* occurs as food of sei whale in the higher latitudes south of 60°S. Accordingly, *C. simillimus* would be fed by the whale in the waters of 45°∼50°S where relatively warmer water prevails although its distribution is positioned still southward than the case in *C. tonsus*. Therefore, the distribution pattern of *C. simillimus* is considered to be somewhat similar to that of between *C. propinquus* and *Calanoides acutus*.

As the season goes by the copepodites II and III population of *C. simillimus* in January develops gradually to copepodites III to IV while *C. tonsus* population of copepodite V migrates into deeper waters (Jillett, 1968), and the feeding place for sei whale being formed by this species diminishes gradually. Then *C. simillimus* forms the feeding place following to *C. tonsus* but it is somewhat local phenomenon; none of *C. simillimus* was fed by sei whale in the waters around 155°E while a considerable number of *C. simillimus* occurred in net samples.

It was 1967/68 season that *Clausocalanus laticeps* was recorded first in the food of sei whale (Kawamura, 1970a). This species, as shown in Fig. 6–5 was fed by the whale in the same region as *C. tonsus*, and therefore this species as food of sei whale has not such importance as to *C. tonsus* because of its quite local occurrence. However, *C. laticeps* population occurred under monospecific composition with high population density, and was considered locally important foodstuff for sei whale. *C. laticeps* distributes in the vincinity of the Subtropical Convergence, a slightly northern species, and they occurred abundantly in the Pacific sector proper than in the Tasman Sea region. Although this species distributes upto far north off Australia along the 155°E meridian, the population density showed 5×10^2 inds./1000 m^3 at most. So the biomass of this species in the sea might be rather small due to its body length. As a food of sei whale *C. laticeps* occurred in the waters around Antipodes Island, 50°S, 175°W∼180°, and the distribution of this species agreed well with that obtained on the net plankton samples. Therefore, it is supposed that *C. laticeps* forms dense swarms in the surface waters as well as other food species. In the South African waters near Cape Province, *Clausocalanus arcuicornis* was fed by sei whale (Best, 1967). It was proved by this facts that at least genus *Clausocalanus* would swarm into the patches as well as *Calanus* species, and formation of the patchiness would supposedly be the general distribution characters throughout the genus.

Both *Calanus propinquus* and *Calanoides acutus* have not been recorded as the food of baleen whales in the food materials collected by the Japanese floating factories (Nemoto, 1959; 1962a; Kawamura, 1970a). However, Peters (1955) reported *C. acutus* as the food of sei whale during the German whaling operations in 1930's, and later Pervushin (1968) described both *C. propinquus* and *C. acutus* as the food of the baleen whales. According to Ottestad (1932; 1936), *C. acutus* and *C. propinquus* are typically endemic species of the Antarctic waters, and they occurred only within the colder regions in the south of the Antarctic Convergence (Figs. 6–9 and 6–10). In many locations these two species occured being accompanied with *Rhincalanus gigas* or dense vegetation of diatoms. Comparing with both species *C. acutus* was more dominant than *C. propinquus* but the former was represented by younger individuals of copepodites II to IV. Since *C. acutus* and *C. propinquus* distribute with a little numbers in the far southern waters apart from the main whaling ground of sei whale, it would be quite possible that none of those two species occur in the diet of sei whale. However, Pervushin (1968) reported their occurrence in the stomach contents of sei whale in the area III of Crozet Islands and its environs although the case might be quite extraordinal. By summerizing the results on the distribution of those two species along with those reported

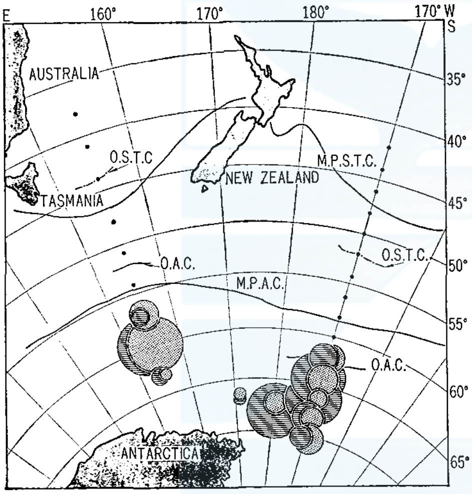

Fig. 6–10. Quantitative distribution of *Calanoides acutus* in the whaling Area V, 1968/69. Legends as in Fig. 6–6.

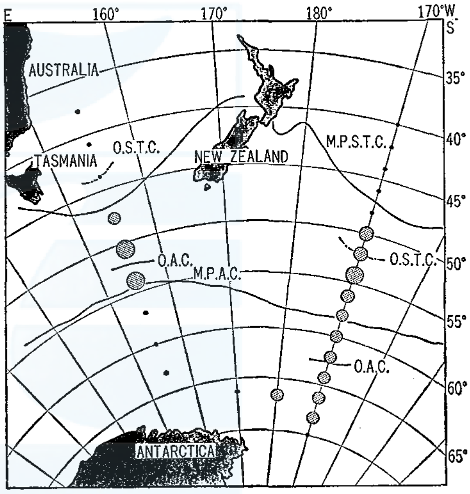

Fig. 6–11. Quantitative distribution of *Parathemisto gaudichaudii* in the whaling Area V, 1968/69. Legends as in Fig. 6–6.

previously (Mackintosh, 1934, 1937; Ottestad, 1932, 1936; Hardy and Gunther, 1935; Vervoot, 1951, 1957; Tanaka, 1960, 1964; Andrews, 1966; Kawamura and Hoshiai, 1969), the northern most boundary in their distribution would on the whole be somewhere between 50° and 60°S except the case in the Indian sector where it was 47°43′S, at 76°48′E (Vervoot, 1957). It seems therefore curious that both *C. acutus* and *C. propinquus* occurred as the food of sei whale in the Crozet Islands regions since the feeding by whale itself essentially requires an abundant distribution so as to form the patches. In this respect both *C. acutus* and *C. propinquus* may possibly be fed to some extent by the baleen whales in some locally limited time and place, but it may also be impossible them to form the staple feeding ground for whales since those two species occur usually by accompanying the thick diatom population of *Thalassiothrix antarctica* along with totally poor standing stocks themselves.

Since *P. gaudichaudii* is provided the strong ability of swimming by its pleiopods (Kane, 1966; Nemoto and Yoo, 1970), many adult forms of this species would have avoided from the net collection. *P. gaudichaudii* population occurred in net samples of this study were excusively consisted of small immatured individuals with body length less than 10 mm. In the Subantarctic waters south of New Zealand Hurley (1961) and Kane (1962) made zooplankton collections, and found that amphipods in those waters were mostly represented by the larval and immatured young individuals. Their net avoidance during net hauling would be obvious.

A relatively small number of *P. gaudichaudii* occurred regularly in the waters between 50° and 60°S along 170°W, where the individual density showed about 10^2 inds./1000 m^3 whereas they showed much poorer but steady density throughout the 155°E. It is supposed that the center of distribution would be around the Antarctic Convergence. The results obtained by Kane (1966) in the area III by R.R.S. "Discovery II" and those by Hurley (1961) and Kane (1962) in the Pacific region agree in general with the present study.

In the row materials of the stomach contents of sei whale the most individuals of *P. gaudichaudii* were represented by the large sized individuals of adult and possibly adolescent forms. This is largely different from the population obtained by the net. However, it was observed that the general characters of the distribution in both populations do not differ much. So it could be said that none of the habitat segrigations are possible in adult and young immature forms.

It has been reported that a little number of *P. gaudichaudii* occurred in the stomach contents of blue and fin whales as an admixture among *E. superba* population (Nemoto, 1959; 1963). However, the importance of *P. gaudichaudii* as food of baleen whales is much increased along with the proportional increase of sei whale in the total catches. In this respect *P. gaudichaudii* seems to be indispensable food for sei whale especially in the Indian sector of the Antarctic (Table 5–4). According to Nemoto (1959) the fin whale in the area V fed exclusively on *E. superba* whereas the bulk of sei whale fed on *P. gaudichaudii*. Following to *C. tonsus*, *P. gaudichaudii* as found in net samples distributed widely through the whaling ground as shown in Fig. 6–5. Since the net avoidance by euphausiids as well as

P. gaudichaudii may also be possible as Fleminger and Clutter (1965) have discussed on this matter, a quantitative treatments on the net samples in this study would be difficult. Fig. 6–12 demonstrates the distribution of euphausiids species occurred in the net samples. The populations of euphausiid were mostly consisted of young individuals of the furcilia stages, and a little number of adult forms. A total of thirteen species of euphausiids was identified, but it was only two or three species that were actually important as food of sei whale, *i.e.*, *E. superba*, *E. vallentini*, and *E. lucens*. In contrast to euphausiid populations in the net samples, those fed by the whale were mostly represented by both adolescent and adult forms. The furcilia and some corresponding individuals were consisted of many species, and therefore, the distribution of furcilia of euphausiids does not seem to have any direct relationship to the formation of feeding ground.

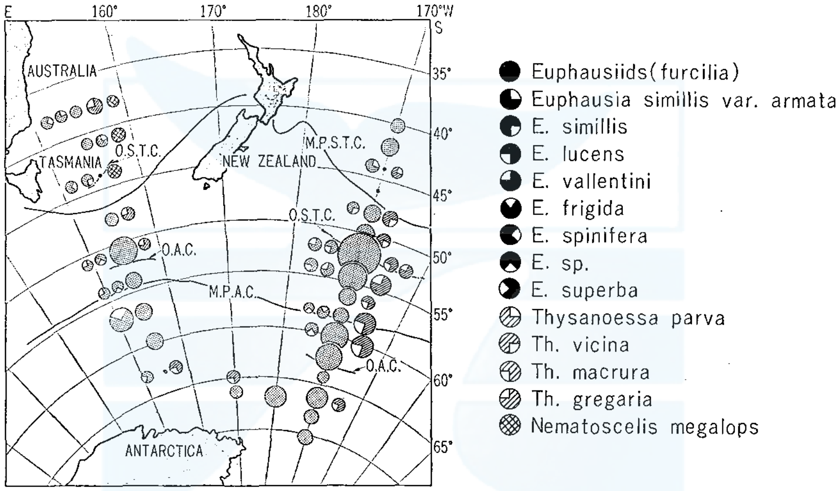

Fig. 6–12. Quantitative distribution of euphausiids in the whaling Area V, 1968/69. Legends as in Fig. 6–6.

E. vallentini, the main euphausiid species occurred at 52°S and 54°S along 170°W longitude, and again at 51°S and 54°S along 155°E. Although the number of individuals occurred was relatively small, the distribution pattern of *E. vallentini* in both whales stomach and net samples agreed well in the region along 170°W. *E. superba* also shown a similar relationships. In *Thysanoessa* populations, *Th. macrura* and *Th. gregaria* were distinct in their individual numbers. The former has been reported as the food of humback and fin whales in the areas I and VI (Nemoto and Nasu, 1958), and they (Nemoto and Nasu, 1958) suggested its importance as whales food particularly in the region of higher latitudes. The occurrence of *Th. macrura* in this study was recorded only in the south of 60°S, and this species may possibly be less important for sei whale which is essentially considered to be copopoda feeder in the mid-latitudes. None of *Th. macrura* was fed by the sei whale in the areas V and VI.

The biomass of euphausiids in terms of the number of individuals in the area

V showed $10^3 \sim 5 \times 10^3$ inds./1000 m^3, and there were no notably distinct differences were found between local regions. As mentioned before the net avoidance by euphausiids would be quite possible, and the euphausiids species as demonstrated in Fig. 6–11 might have been entangled by reason of their dominancy among zooplankters under those circumstances. If so, *E. vallentini* could be considered to have distributed abundantly in the southeast region off New Zealand, and in the Tasman Sea region. Supposing these circumstances the feeding on *E. vallentini* by the sei whale agrees with the general distribution patterns of *E. vallentini*.

In general the distribution of sei whaling ground can be seen as a function of the characteristic distribution of food zooplankters, and these corelations were more clearly observed in copepods. The organisms fed by the sei whale are represented by the patch forming species, and an agreement in the distributions between zooplankton and whaling ground strongly suggests that those food organisms aggregate so as to form the patches to some extent at least in some local regions throughout their geographical distribution range.

7. BODY SIZE OF *CALANUS TONSUS*

In the previous sections it has been discussed and proved that the zooplankters and micronekton as food of baleen whales have to be maintained such high population density as to aggregate into patchiness. This conception would be well recognized by refering to some previous reports (e.g. Collett, 1886; 1911∼12; Hinton, 1925; Mackintosh and Wheeler, 1929; Slepzov, 1955; Nemoto, 1957, 1959, 1962a, b; Marr, 1962; Mackintosh, 1973) although non-patch forming organisms would be fed at times when the whales migrate into the region far outside from the so-called feeding ground such as the case in the South African waters.

In the course of microscopic observations on the food organisms some differences in the body size of *C. tonsus* population by the whaling areas were noticed. *C. tonsus*, as has been described previously, is the most important foodstuff for the southern sei whale since it heavily aggregates in the surface waters during the first half of whaling season. In this respect the composition of body size in *C. tonsus* by the whaling areas was discussed in connection with its aggregating habits what it means ecologically.

7–1. *Composition of body size in C. tonsus population*

The materials examined were the stomach contents of sei whales which were caught in 1967/68 and 1969/70 seasons. A total of 5,706 individuals of *C. tonsus* was examined for this purpose, and the results were compiled by separating the month into three decades (Table 7–1). However, the materials were only available during mid December to mid January since the whaling operation for baleen whales is opened on 12th of December thereafter, and also the season for sei whaling lasts for only a month and half to somewhere around mid January due to a fading out of the feeding ground formed by *C. tonsus*.

As shown in Table 7–1 *C. tonsus* of copepodites IV–VI (female) occurred as food of sei whale. Since adult male of this species is usually said as to be mostly in deeper waters (Jillett, 1968), they hardly occur in the surface swarms and consequently, in the population of sei whale food. The body size was measured on the individuals being preserved in good conditions, and they were selected randomly. Then the number of measured individuals through copepodites IV–VI could be considered as to represent the composition of food *C. tonsus* population, and they are represented by the copepodite V stage, since it occupied for 81.9~98.4%, with the average of 89.7% in the whole of *C. tonsus* populations examined.

TABLE 7–1. MONTHLY OCCURRENCE OF *C. TONSUS* BY THE STAGES IN TERMS OF PERCENTAGE FIGURES. THE ACTUAL NUMBER OF INDIVIDUALS EXAMINED IS INDICATED BY PARENTHESES.

Stage	Mid-Dec.	Late-Dec.	Early-Jan.	Mid-Jan.	Total
C IV	1.6 (24)	0.83 (20)	1.73 (17)	0.62 (5)	1.16 (66)
C V	81.9 (1222)	88.5 (2135)	96.4 (956)	98.4 (797)	89.7 (5110)
C VI Female	16.5 (247)	10.67 (258)	1.87 (18)	0.98 (7)	9.14 (530)
Total	1493	2413	991	809	5706

In 1967/68 season the whaling was mostly operated in the areas III, IV and V, but the area shifted rather westward in 1969/70 season and the areas II, III and IV were occupied. The composition of body size of *C. tonsus* along with the average and the number of individuals were demonstrated by regions in Figs. 7–1 and 7–2, since the overall sea conditions as the habitat of *C. tonsus* are possibly variable by the sea regions (Hempel, 1968). The body size of each copepodite stages was: 2.7~3.0 mm in copepodite IV, 3.2~3.6 mm in copepodite V, and 3.7~4.0 mm in adult female respectively. The composition of body size in copepodite V showed a normal distribution pattern with highest frequency of occurrence at the midst of distribution range through the materials obtained in Folkland region to the east Indian sector region. In the general trends of the variation by the ocean sectors, the distribution range of the body size class widened gradually in the direction from the Atlantic sector toward the Pacific sector, though the most distinct example was in the Western Australian region. The body size of 3.5~3.6 mm usually showed high frequency of occurrence, but in the regions both south of Western Australia and South Africa as indicated by the letter of, D, H, J, K, M and N, the body size of high frequency was found between 3.0 and 3.2 mm. These kind

TABLE 7–2. AVERAGE SIZE OF *C. TONSUS* IN THREE DIFFERENT AREAS IN 1967/68 SEASON. NUMBER OF INDIVIDUALS EXAMINED IS GIVEN IN PARENTHESES.

Month Area		Mid-Dec.			Late-Dec.
		III, IV 66°~82°E	V 172°E~163°W	IV 83°~101°E	IV 82°~87°E
	C IV	—	—	—	2.80 (1)
Average size (mm)	C V	3.46 (294)	3.23 (111)	3.38 (78)	3.38 (1335)
	C VI (♀)	3.85 (76)	—	—	3.78 (110)

of difference as a biological character of each swarming *C. tonsus* populations suggests that they might come from a different population as the reproductive units. The pattern of body size composition following to that of the normal distribution lasts for a month or so without any changes within the composition. The female of copepodite VI is considered to follow the similar way as copepodite V although the former is much variable than the latter due to its poor number of materials. The high frequency of the occurence in the adult female was 4.0~4.2 mm and no differences in the body size compositions between the whaling areas were observed. This may possibly be due to their biological character of stopping the feeding activity in the copopodite VI stage as it has been known in *Calanus plumchrus* and *C. cristatus* (Minoda, 1971). In the populations in the Indian sector as indicated by the letters of C and G, the body size of high frequency of occurrence was 3.7~3.8 mm. In general the composition of the body size in the adult female showed the range between 3.4 and 4.8 mm, a rather wider range in the distributions than the case in copepodite V. The variations of this range was most distinct in the Atlantic sector.

TABLE 7-3. AVERAGE SIZE 'OF *C. TONSUS* IN THREE DIFFERENT AREAS IN 1969/70

Month / Area		Mid-Dec.			
		IV 109°~118°E	II 33°~43°W	II 37°~53°W	IV 110°~118°E
Average size (mm)	C IV	2.72(5)	2.78(2)	—	2.77(9)
	C V	3.13(21)	3.44(23)	3.56(4)	3.19(31)
	C VI (♀)	4.00(5)	4.11(19)	4.21(4)	4.01(15)
Average by month	C IV		2.75		
	C V		3.38		
	C VI (♀)		4.11		

7–2. *Discussion*

Jillett (1968) studied the seasonal distribution of *C. tonsus* in the waters off Otago Peninsula, New Zealand, and found that the *C. tonsus* population in the surface water during the summer was represented by the copepodite V stage. He (Jillett, 1968) also shown that *C. tonsus*, as a biological characters through Calanoida, has two generations annually, and that the copepodites from the second generation of current year mostly occupy the summer population, which must be the food of sei whale in the northern Subantarctic waters. The life history of *C. tonsus* suggests generally that the individual of the copepodite V from two different generations coexists at least during December. One comes from over winterd population and the other from developing population in current year. The coexistence of two size groups of copepodite V from different reproductive sources has been known in *C. finmarchicus* in the North Atlantic waters (Stormer, 1929, Barnes and Barnes, 1953; Colebrook, 1963), and Barnes and Barnes (1953) considered that the difference in size composition would be due to different populations, although there is a possibility of potential male and female.

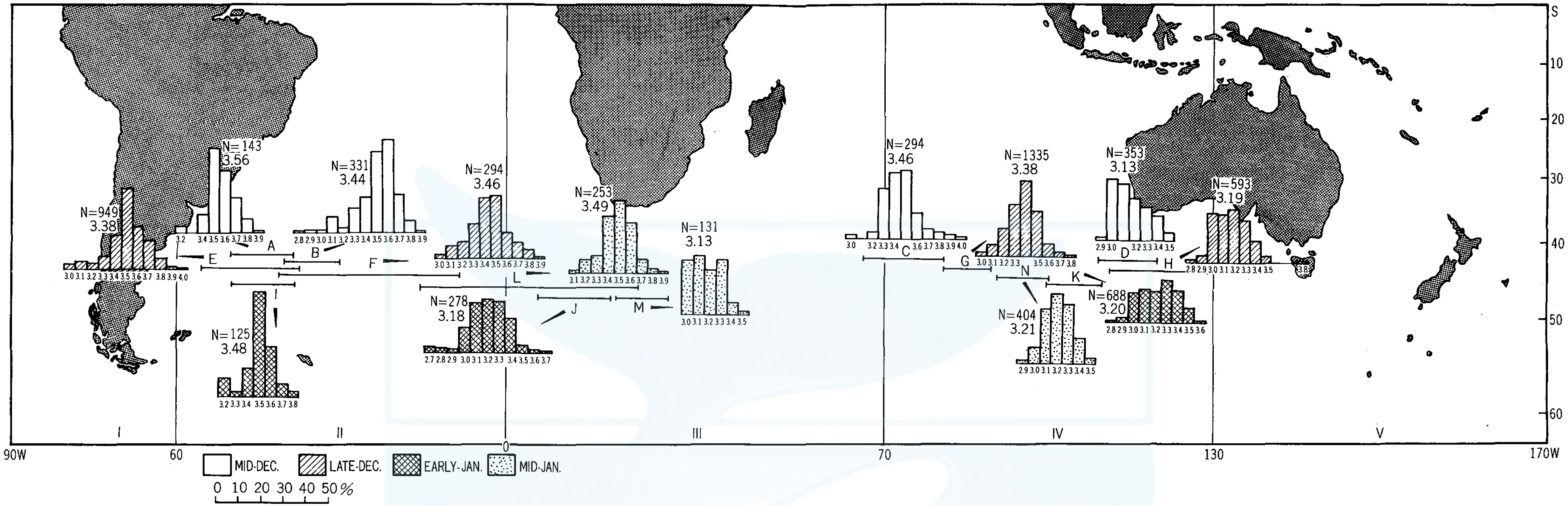

Fig. 7-1. Size composition of *Calanus tonsus* copepodite V in the whaling areas and months in 1969/70 season. Average body length is given above each figures, and an approximate longitudinal range from which samples were collected is shown by the capital A to K.

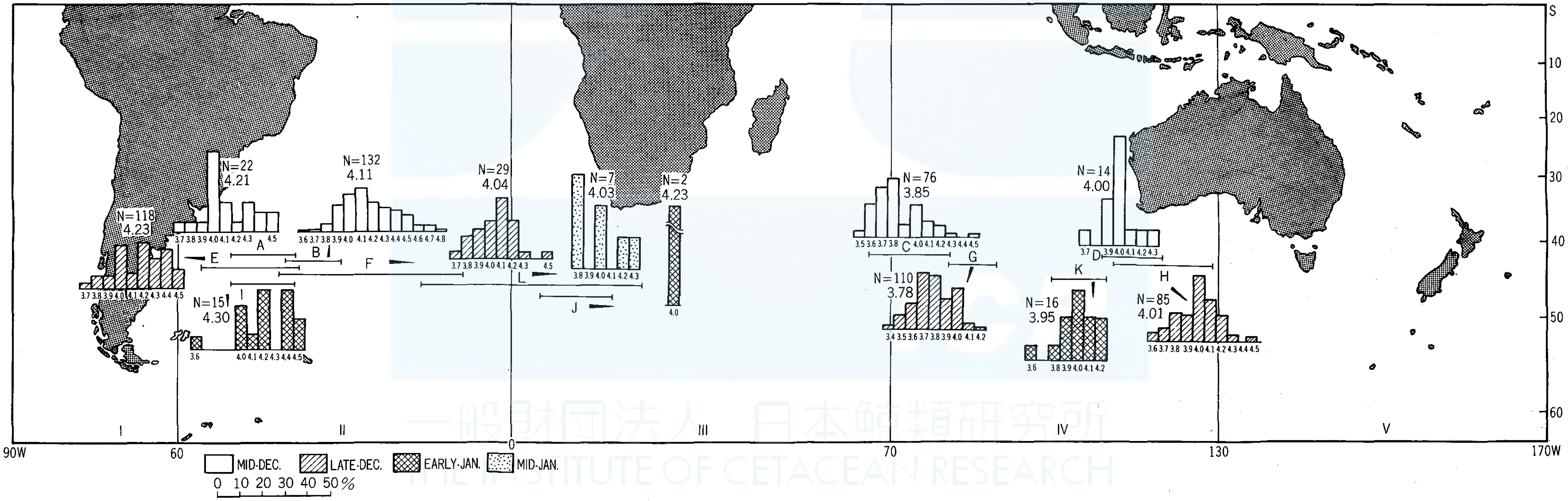

Fig. 7-2. Size composition of *Calanus tonsus* copepodite VI (female) in the whaling areas and months in 1969/70 season. Average body length is given above each figures, and an approximate longitudinal range from which samples were collected is shown by the capital A to K.

In this respects the differences in size composition of *C. tonsus* especially in the copepodite V stage suggest that they should come from the different reproductive populations. It is also suggested as a whole that those different size compositions which are the distinct biological character not as individuals but as the population, would be the result of having been isolated each other. A quite few occurrence of adult male in the surface population of *C. tonsus* is similar to the results by Jillett (1968). Those male occurred sporadically must be newly developed individuals in the current season, which made Jillett (1968) consider a possibility that the second generation would supposedly be due to a result by the parthenogenesis in the over wintered females. The small sized female populations found in the Indian Ocean sector are considered to be the result of different environmental conditions there, or of a complete isolation from the others. It is known in the British waters that a local difference in environmental conditions influences on the size of individuals which form a dominant population in those regions (Marshall and Orr, 1955). The geographical difference in body size in the Antarctic copepods also well known (e.g. Brodskii, 1964). Baker (1954) considered that many zooplankters would originate from the identical populations of species by species since they show rather monotonous circumpolar distributions. However, as Brodskii (1964) having been demonstrated in *C. tonsus* and other copepod species, there is a distinct geographical differences in the composition of body size as the local populations, and I have also shown these circumstances in the previous section of this report. Mackintosh in his recent report clearly shown that there should be several number of distribution centers under quite high population density in *E. superba* while it shows a typical circumpolar distributions (Mackintosh, 1973). The above mentioned facts indicate that the zooplankton in the Antarctic waters distributes quite unevenly under the general circumstances of circumpolar distributions, and that their occurrence with different body size compositions in various sea regions would perhaps belong to different reproductive populations somewhat likely to a "stock unit".

SEASON. NUMBER OF INDIVIDUALS EXAMINED IS GIVEN IN PARENTHESES.

Late-Dec.		Early-Jan.			Mid-Jan.		
II	II	IV	III	II	IV	III	II
8°~46°W	36°~54W	99°~110°E	0°~19°E	40°~51°W	90°~100°E	19°~27°E	14°~52W
—	2.60(1)	2.50(1)	2.89(1)	3.00(2)	—	2.91(3)	2.80(1)
3.46(10)	3.38(31)	3.20(23)	3.18(11)	3.48(5)	3.21(13)	3.13(6)	3.49(10)
4.04(8)	4.23(16)	3.95(7)	4.23(3)	4.30(2)	—	—	4.03(3)
2.69			2.83			2.86	
3.34			3.29			3.28	
4.09			4.16			4.03	

The largest and the smallest body sizes in female *C. tonsus* measured in this study were 4.8 mm and 3.6 mm respectively, while the former by Brodskii (1964) was 4.25 mm (female) and 3.40 mm (male). Although it is known that the body size both in copepodites V and VI (female) shows latitudinal variations as a whole, the body size seems to differ to some extent between the individuals from sei whale food which have had been formed the patchiness and those taken by the net haul which must supposedly been in a sporadic distribution without forming the patchiness.

7–3. *Patchiness of C. tonsus and the density effects*

The body size of *C. tonsus* in Table 7–4 was based on the row materials which were collected by the net haul along with many other zooplankters. On the other hand, *C. tonsus* being fed by the sei whale as has given in Tables 5–2 and 5–3, occurred as mono specific composition, which suggests that *C. tonsus* population as whales food might possibly have been in an aggregation, to show the patchiness. Both *C. tonsus* populations, mentioned above therefore, can be considered to be ecologically unidentical to show some differences in the size composition and the averaged body size. The food *C. tonsus* population seems rather larger if not entirely in the body size of individuals.

TABLE 7–4. BODY SIZE OF THE SOUTHERN SPECIES, *CALANUS TONSUS* BRADY REPORTED PREVIOUSLY BY THE DIFFERENT WORKERS.

Author	CV	CVI (♀)	CVI (♂)
Brodskii (1964)*		3.40–4.25	3.30–4.15
Tanaka (1956)	3.27–3.47	4.07–4.24** 3.66–3.75***	
Tanaka (1960)	3.39–3.69		
Vervoot (1957)		3.69–4.05	

* 3.71 mm on an average.
** Size at higher latitudes.
*** Size at lower latitudes.

The patchiness of zooplankton has been observed but a little. Studying on the food of blue and fin whales in the South Georgian waters, Mackintosh and Wheeler (1929) stated that *E. superba* occurs by a monotonous composition of same year class or same developmental stages since the species forms such patchiness separately as to be fed by the whales. Hardy and Gunther (1935), and Mackintosh (1966) reported the results of their observations on the behavior of *E. superba* under patchy aggregations in Cumberland Bay, South Georgia, and described as " There appeared some guiding ' principle '—almost as if there was some leader in command of the whole ! " (Hardy and Gunther, 1935). Mackintosh (1966) also described later that the patches of *E. superba* moved in a cluster as if they were an amoeba like organisms as a whole, and the patch was quickly reorganized within tens seconds after disturbance. These characters of *E. superba* patches as a kind of animal aggregations strongly suggest their something socialized structure within the patches as the theme having been suggested also by Clutter (1969) in Mysidacea. In general the features of the plankton patches can be comparable though not anologous with the aggregations in the insects such as the reproductive aggregation by male mosquitoes (Kawamura, 1971c). An ecological homology in a plankton patchiness could be imagined by the fact that the empty shells of *E. superba* were collected abundantly in a net haul (Marr, 1962). This indicates that the development of the individuals proceeds simultaneously among almost all members of the patches.

The patchiness of zooplankton can be considered as one of the distinct characters in the distribution of animals. Difference in generations could be responsible for variable body size composition but on the otherhand it should be considered that there must supposedly be some ecological benefits for aggregating into patches through the density effect. For example, it is well known fact in aggregating insects that the population density closely related to their relative growth rate (e.g. Ishida, 1952; Uchida, 1952; Fujita and Uchida, 1952; Takahashi, 1956), in which the density effect would role positively (Chauvin, 1962). In the population of cockroach, *Blatella germanica* the overall growth rate as the unit of population is more enforced quickly by keeping close the intervals between individuals (Ito, 1959; Ishii, 1970). This kind of function by the density effects have also been indicated in Mysidacea population (Clutter, 1969). In the zooplakton population under aggregations, the population density is usually kept quite high; *E. superba* shows one individual per cubic inch (Marr, 1962), and he described them as "jostling one another" under patchiness. Swarming *E. pacifica* shows 1∼2 cm of intervals between individuals (Komaki, 1967). These facts leads to a supposition of tactile stimuli, that is, touching each other by the body or by the antennules would possibly occur to some extent during their swimming (Kawamura, 1971c). The differences in body size composition in *C. tonsus* populations could be explained by this kind of density effect through their social behavior, but the scheme will be discussed more in section 11 where the *C. tonsus* patches were treated on the basis of field observations and row materials obtained by net haul.

8. FEEDING APPARATUS OF SEI WHALE

A quite characteristic adaptation in baleen whales is their specialized feeding apparatus to collect a bulk of zooplankton and some micronektons. The baleen plates or whalebone as feeding apparatus has developed in various ways by species in place of the tooth, and no similar feeding structures are found in any of other kind of animals. The baleen plates being arranged in a row on the upper mandible are quite functional for gathering rather scattered foodstuff along with the specialization of oesophagus to form the first stomach which functions as a depositing sac for swallowed foodstuff (Hosokawa and Kamiya, 1971). In this respects a row of baleen plates is indispensable apparatus for the baleen whales actually functions whereas the teeth are not so functional in many toothed whales. When they were lost or heavily damaged by some desease or by an accident, a daily nutritional requirements would hardly be filled. Rice (1961, 1969) reported the rudimentary baleen plates in sei whale due to some microbial desease, and it caused the blubber of the whale quite thin from the insufficient food intake.

The amount of stomach contents under full repletion closely related to feeding habits of whales and to the population density of the food organisms, say, the patchiness of zooplankton. Since the patchiness of food zooplankton hardly be studied by the net haul as has been pointed out by Mackintosh (1966), one of an approaches to studying the plankton patchiness would be found in the stomach contents of baleen whales. In this point of views Klumov (1961), Kawamura (1970b, 1971b), and Omori *et al.*, (1972) reported on the population density of food organisms being based on the stomach contents of whales, and found a hardly believable high population density of zooplankton under the patchiness, which would never be obtained or known by the net haul investigations. In regard to this circumstances it would be necessary to know the ability in filtering the water by a row of baleen plates in sei whale.

8–1. *Oral cavity*

A row of baleen plates furnished on the upper mandible functions in collecting the food organisms. This would be fairly comparable character with the sperm whale whose lower jaw is fully functional against the upper jaw. The baleen plates however would be functional actually with the supplemental aid by the lip on lower mandible. After Ingebrigstsen's suggestion on the feeding habits in baleen whales, Nemoto (1959) described on this scheme under three different feeding types of baleen whales: swallowing or gulping type, skimming type, and the combined both swallowing and skimming. Then the shape of the lip which is characteristic by species closely related to the feeding type above mentioned. Both right and bowhead whales are furnished with so largely developed lips which are indispensable for their feeding by skimming off the food contained water continuously, while balaenopterid whales are furnished with the poorly developed lip since they collect the the foodstuff by swallowing the water although the lip of sei whale relatively well developed among them. In California grey whale, the benthos feeder (Rice and Wholman, 1971), the lip is rather poorly developed. It is worth taking into account that the sei whale follows after both feeding types according to the conditions of the distribution of food organisms.

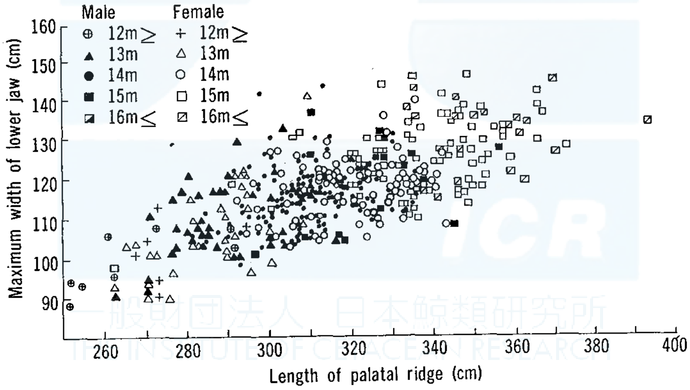

Fig. 8–1. Relationship between the length of upper jaw and the maximum width of lower jaw in sei whale.

In this respect the size of both upper and lower jaws were measured in connection with the potential ability in collecting the foodstuff. The relationships between the sizes of upper and lower jaws against the body length of whales are demonstrated in Figs. 8–1 and 8–2. The size of oral cavity varied to some extent among the individuals examined, but it grows larger and larger in accordance with the growth in body length. Dominacy of the female in the size of larger than 330 cm of upper jaw in sei whale and also 470 cm in fin whale is due to their biological character that the female grows much larger than the male, and the former is preferably caught largely than the latter. In bryde's and minke whales the proportional length of the skull is larger in the female than the male (Omura, 1966; Ohsumi *et al.*, 1970). The sei whale which closely relates taxonomically to bryde's whale showed considerable variations in the maximum width of lower jaw against a definit length of the upper jaw, and in a definit width of lower jaw against the upper jaw length. The variations were more distinct in the latter. These variations relating to the size of oral cavity along with the number of baleen plates indicate a manifold character of baleen whales in their feeding mechanisms and in the ability of collecting the foodstuff.

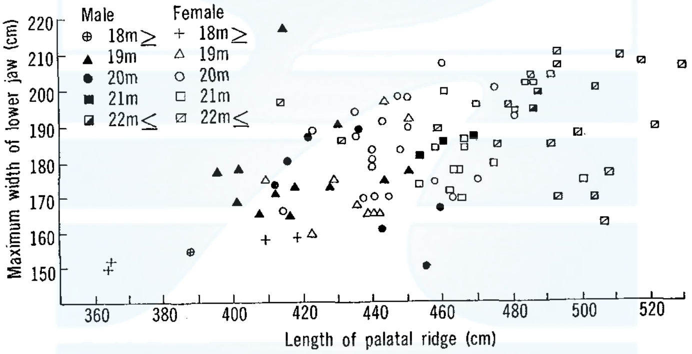

Fig. 8–2. Relationship between the length of upper jaw and the maximun width of lower jaw in fin whale.

8–2. *Baleen plates*

The number of the baleen plates in sei whale varies somewhere between 300 and 350 plates on one side, and two folds of this number of baleen plates functions actually for collecting the food. However, the number of baleen plates varies by the individuals and also by the observer (Williamson, 1973), since they are deformed into a kind of hair-like bristles near at the tip of rostrum and are randomly arranged. The density of the baleen plates furnished in a row varies with the positions of the mouth (Fig. 8–3, Table 8–1). The baleen plates (=bristles or hair) near the rostrum were counted 1.4 plates/cm on average while they were 0.93 plates/cm at their maximum length as indicated by the arrow in Fig. 8–3, and they again showed a high density in the posterior part close to the angle of gape.

The relative ability in filtering the water per unit area of the inner surface of the apparatus is a function of meshes formed by the woven bristles. The meshes are kept so as to show a definite filtering ability at any part of the apparatus, since the overall ability for retaining the foodstuff might greately reduced if the filtering ability was randomly variable by the part of the apparatus due to different mesh sizes in its inner surface.

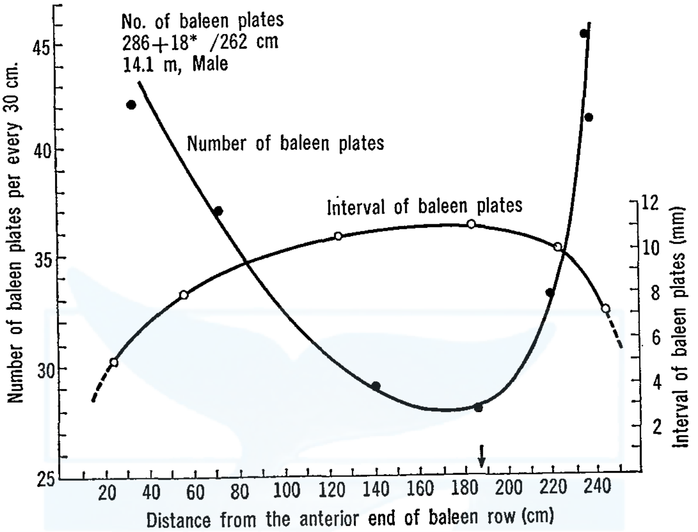

Fig. 8–3. Variation of the number of baleen plates in sei whale. Arrow shows the spot where maximum length of baleen plates was found. (*bristles)

TABLE 8–1. INTERVALS OF EACH BALEEN PLATES AT THEIR MAXIMUM LENGTH IN THE NORTH PACIFIC SEI WHALES.

Body length (m)	Sex	Interval (mm)	Thickness of baleen plate (mm)	Room between baleen plate (mm)
11.6	M	9.20	2.2	7.0
12.3	M	9.78	2.2	7.56
13.2	M	11.60	2.15	9.45
14.1	M	11.11	2.2	8.91
14.3	F	9.29*	1.7*	7.59*
14.4	F	9.40	2.5	6.90

* Measurement on dried material.

The length of each baleen plates is usually measured along their outer margin but it is the length along the inner margin to the base of palatal ridge that actually affects on the total surface area of the filtering apparatus. As shown in Fig. 8–4 the unfolded shape of filtering apparatus varied by the animals along with their body length as a whole. Although the animals examined in Fig. 8–4 were caught in the coastal waters of Japan, those unfolded shape is considered to be the same with the animals throughout the oceans. The position of the maximum width does not coinside with the position of the maximum length of baleen plates, but is found at rather posteriorly of about 66.4~69.5% in the total baleen row length, at which the highest part of the lips of lower jaw is positioned. These general arrangement seems as a whole to function effectively in collecting the foodstuff as much as possible particularly when the whale feeds by skimming the food contained water with its mouth half opened.

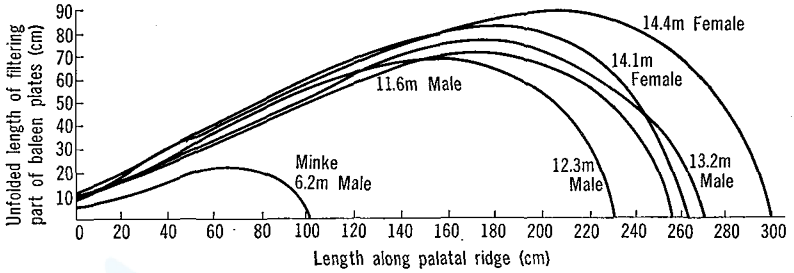

Fig. 8–4. Unfolded figures of the filtering apparatus of sei and minke whales.

8–3. *Bristles on baleen plates*

The bristles furnished on the inner margin of baleen plates form the fine meshed structure as demonstrated in Plate I, and actually retains the foodstuff which have been skimmed off. The inner margin of the baleen plates is furnished with the bristles (Plate I, fig. 1), and the whole surface of filtering apparatus is covered by this meshes although the number of bristles are considerably reduced at the tip of baleen plates (Plate II, fig. 1). Ruud (1940, 1945) examined the baleen plates

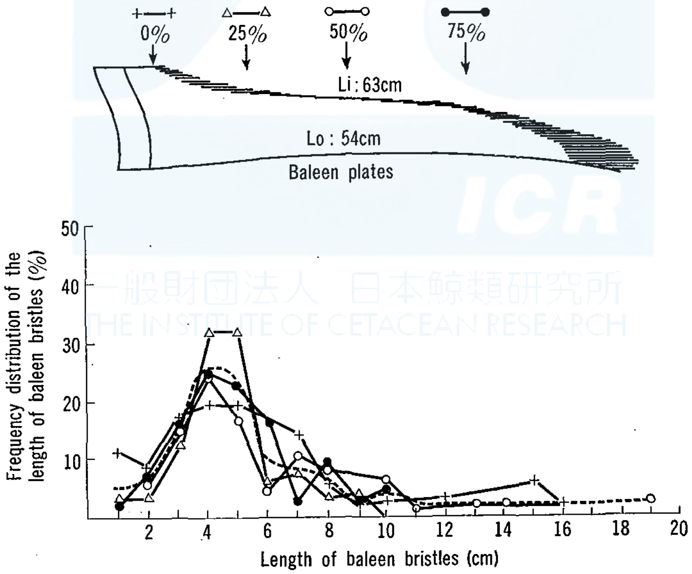

Fig. 8–5. Composition of the length of baleen bristles in 14.3 m sei whale caught in the North Pacific in 1968.

TABLE 8–2. MEASUREMENTS ON THE BALEEN

Location of catch	Body length (m)	Sex	Length of baleen plates*		Lo/Li
			Lo	Li	
N. Pacific	14.3	F	54.0	63.0	1.17
Japan, coastal (off Kinkazan)	13.5	M	42.5	54.0	1.27
,,	12.3	M	43.0	52.0	1.21
,,	11.6	M	44.0	53.0	1.21

* Length along outer edge of baleen plates (Lo), and those along inner edge (Li).

** Diameters of baleen bristles measured at the base (Db), middle (Dm), and at the tip (Dt).

of fin whale in detail and described that they are made of chitinous tissue which is somewhat likely to a kind of fused bandage of many bristles. So the diameter of the birstles do not differ between wet and dried materials.

The length of the bristles varies with the part on the inner margin. Fig. 8–5 shows the frequency of occurrence in the bristles length in a sei whale of 14.3 m, and the actual figures were given in Table 8–2. The number and the length composition of the bristles per unit length along the inner margin showed that relatively longer lengthed bristles were poorly found. The length of the bristles was measured at four parts, and was found that 3∼5 cm long bristles were most dominantly furnished. Accordingly the meshes in the surface of the filtering apparatus are chiefly formed with these length of bristles. It is clearly noticed that the length of the bristles did not show characteristic differences at any part of the inner margin. These suggest that the filtering ability in sei whale would be the same at any part of the apparatus.

Table 8–2 represents relative abundance of the baleen bristles, their length and diameter. Although the triangle shaped baleen plates are well known, the length along the inner margin of baleen plates is longer about 1.2 times than the outside so as to form relatively larger surface of filtering area. The distribution density of the bristles was 50 bristles/cm with the average of 45.5 bristles/cm, and this density does not vary with the sex and the body length of whales. The shape of a bristle itself seems rather slightly tapered: the diameter is larger at its base than the tip. However the variation in diameter is such slight as to make them represent the mean diameter at the mid point of the bristles.

8–4. *Area of filtering apparatus*

The total inner surface area of the filtering apparatus in five animals of different body lenth was measured from the unfolded figures as shown in Fig. 8–4, and the results were given in Table 8–3. However, the filtering area given in Table 8–3 is approximate figures, since an overall shape of the filtering apparatus shows a quite complexed features by the curved surface.

The surface area of the filtering apparatus was 2.37 m^2 in 11.0 m individual and was 3.59 m^2 in 14.4 m individual. Then those areas seem to increase after a geometrical progression (Fig. 8–6). However, it is clearly observed that the surface

PLATES AND BRISTLES OF SEI WHALES.

No. of baleen bristles/cm				Average length of bristles (cm)				Average diameter of baleen bristles (μ)**		
75%	50%	25%	0%	75%	50%	25%	0%	Db	Dm	Dt
44	49	63	36	5.6	6.1	5.2	6.4	250	167	141
	54				4.2			168	108	106
	37				4.4			155	114	93
	42				4.6			157	114	85

TABLE 8-3. AREA OF FILTERING APPARATUS OF SEI AND MINKE WHALES CAUGHT IN THE COASTAL WATERS OF JAPAN, MAY, 1971.

Species of whale	Body length (m)	Sex	Lk* (cm)	Ld* (cm)	Length along outer edge of baleen plates (cm)	Area of filtering apparatus combined both sides (m^2)
Sei	11.6	M	268	256	291	2.37
Sei	12.3	M	236	228	261	2.13
Sei	13.2	M	—	271	330	2.64
Sei	14.1	M	—	262	300	2.89
Sei	14.4	F	—	300	330	3.59
Minke	6.2	M	—	102	114	0.29

* Length of a row of baleen plates along the upper jaw.

** Strait length from the anterior end of baleen plates to the posterior end of them.

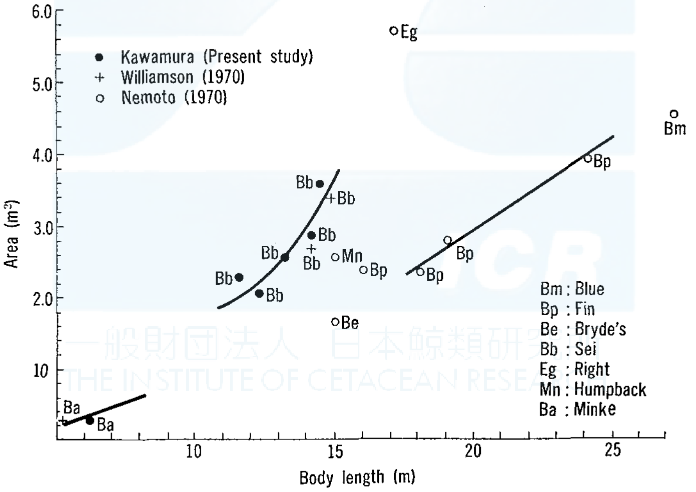

Fig. 8-6. Area of filtering apparatus in baleen whales.

area of filtering apparatus in sei whale is considerably larger in contrast to the body length of animals. These sei whale's characteristics are quite interesting when we compare the feeding habits of both sei and right whales with those of another balaenopterid whales: the former two feed after skimming type with well developed filtering apparatus while the latter feed after swallowing type with poorly developed apparatus. The area of filtering apparatus in sei whale showed moderate figures between right whale and another balaenopterid whales. This fact will be reasonably recogniged by supposing that the sei whale feed after the types of both skimming and swallowing. In balaenopterid whales other than sei whale on the other hand, the area of filtering apparatus changed rather linearly against the body length. In regard to these above mentioned facts it could possibly be considered that the feeding ability of the baleen whales would develop after geometrical progression since the body weight of whales is porportional to cube root of the body length (Nishiwaki, 1950) whereas the food requirement in terms of the daily ration is linearly proportional to the body weight (Sergeant, 1969, Table 4).

9. FILTERING ABILITY IN THE ROW OF BALEEN PLATES

In any types of feeding method the food contained water is pushed outside by the current pressure or by the co-operated functions of oral cavity, ventral grooves, and tongue. In sei whale as mentioned before the foodstuff is collected chiefly by skimming the food contained waters, and the filtering ability in the feeding apparatus may greatly affects on the overall ability for sieving the foodstuff.

9–1. *Porosity in the meshes of filtering apparatus of sei whale*

The porosity, the mesh openings in filtering apparatus in terms of percentages was calculated, and the figures were given in Table 9–1 along with those known in the bolting silk cloth for the comparison. The netting of the filtering apparatus in baleen whales is structured by the following elements: the intervals between each baleen plates (Fig. 8–3), the thickness of bristles in diameter, and the length of the bristles. As the measurements of these elements were given in previous section, the calculation was made by using them (Table 9–1). Since the meshed filtering apparatus in whales is formed with some thickness due to entangled bristles,

TABLE 9-1. POROSITY OF FILTERING APPARATUS OF SEI WHALE, WHICH IS FORMED BY THE BALEEN BRISTLES. (MEASUREMENTS AT THE MAXIMUM LENGTH OF BALEEN PLATES AND THOSE AT THE MIDDLE PART OF THE BALEEN PLATES ALONG INNER MARGIN).

Body length (m)	Sex	Location of catch	Total length of baleen bristles (mm)	Interval of baleen plates (mm)	Mean diameter of bristles at Dm*** (mm)	Porosity (%) Possible thickness of filtering apparatus (mm)				
						1	2	3	4	5
11.6	M	Japan coastal	1942	9.20	0.114	72.6	86.3	90.87	—	—
12.3	M	„	1111	9.78	0.114	81.97	90.98	93.99	—	—
13.5	M	„	2285	11.60*	0.108	77.0	88.5	92.33	—	—
14.3**	F	N. Pacific pelagic	3000	9.29	0.167	1.0	55.0	70.00	77.5	82.0

* Measurement from 13.2 m, male.

** Measurements on the dried material.

*** Measurements at the middle part of baleen bristles.

five cases of the thickness between 1.0 and 5.0 mm were supposed for the calculation. In sei whale, however, the actual thickness is considered about 1.0~2.0 mm (Plate I, fig. 4 and Plate II, fig. 2). The above mentioned thickness along with the intervals increase thicker and wider with the increase in body length although the length of the bristles also grow longer.

The porosity which is usually examined in bolting silk cloth for plankton net (e.g. Anraku and Azeta, 1966) varied between 77.2% and 88.6% by the body length of sei whale concerned. Since the baleen plates and the bristles examined were damaged to some extent due to ill treatment, the actual figures of the porosity would be slightly more lower values. However it is note worthy that the overall figures of the porosity do not seem to vary with the body length, say, the porosity is nearly constant regardless the body length of whales.

By comparing the porosity in ballen plates with that in plankton net, the former showed distinctly larger percentages than the latter (Plate II, fig. 2).

TABLE 9-2. POROSITIES OF JAPAN BOLTING SILK CLOTH COMMONLY USED IN PLANKTON COLLECTION.

Kind of bolting cloth	Mesh aperture (mm)	Open area* (%)
XX 13	0.094	23.0
XX 7	0.193	40.0
GG 54	0.334	46.0
GG 32	0.630	58.0
GG 20	0.926	60.0
Pylen #60	0.350	38.0
Larva net (Cremona+Pylen #60)	—	50.0**

* Data by the Nippon Bolting Cloth Co., Ltd. (S. Ueno pers. com.).

** Anraku and Azeta (1966).

9-2. *Relative filtering ability in a row of baleen plates*

In order to know an actual filtering ability in a row of baleen plates, the filtering ratio was measured experimentary after the similar ways employed in plankton net. The experiment was conducted at the offshore region in Suruga Bay on boad of the R. V. "Tansei Maru" of the Ocean Research Institute, University of Tokyo. The general arrangements of the experimental instrument are shown in Plate III. The dimensions of the instruments were 48.6×23.4×91.0 cm. A flowmeter was mounted on the inside of the instrument at about 1/3 distance posteriorly from the mouth opening. A row of baleen plates was mounted on the bottom of the instrument (Plate III, fig. 2). The slits between the mounted baleen plates and the instruments, which may cause a leakage were filled with 5.0 cm thick of uretan foam (Plate III, figs. 1 and 2). The surface of the filtering apparatus through water passed away in the experiment had an area of about 23.4×54.0 cm. The two 10.0 kg of lead weights were mounted on the both outsides of the instrument, which was towed by bridle. Before experiment a filter made of bolting silk cloth GG 32 (0.63 mm mesh opening, 58% in porosity) was attached on the mouth of the instrument so as to reduce the volume of passing water down to about 1/3.

By this treatment the water entered into the instrument was well filtered off without causing any overflowing. The experiment was conducted in Suruga Bay when the depth was 426 m by towing the instrument vertically from 200 m to the surface at the speed of 1∼1.2 m/second. The volume of water filtered by the row of baleen plates was calculated by the flow-meter's readings.

The results were given in Table 9–3. The relative filtering ability in baleen plates of both sei and fin whales showed rather poor when compared with those in the bolting silk cloth: the ability in sei whale was approximately 1/8 of GG 54 (0.33 mm mesh openings) while the fin whales' was 1/5, and still more, it may be interesting that those relative ability was poorer than the finely meshed XX 13 bolting silk cloth which can retain most of the representative diatoms in the sea. From this experiments it can be safely stated that the filtering ability in sei and fin whales, and possibly in any baleen whales is astonishingly poor than those in the bolting silk cloth. The filtering ability might reduced to some extent by ill treatment in mounting the row of baleen plates on the instrument, and even we take these circumstances into account the results of 1/5∼1/8 against the bolting silk cloth are astonishing enough, that is, the filtering apparatus of baleen whales never exceeds in the ability of filtering off the water than in the plankton net.

TABLE 9–3. FILTERING ABILITY OF THE BALEEN PLATES IN SEI AND FIN WHALES AND THOSE OF JAPAN BOLTING SILK CLOTH.

Exp. No.	Item	No. of flow-meter revolution/200 m	Relative ability
1	Calibration	1842	17.55
2	GG 32	610	5.81
3	GG 32+GG 54	893	8.50
4	GG 32+XX 13	648	6.18
5	GG 32+Sei*	105	1.0
6	GG 32+Fin**	184	1.75

* 14.3 m., female, caught in the North Pacific on July 18, 1969 at 45°–04′ N, 171°–37′ W.

** 16.8 m., female, caught in the North Pacific on August 1, 1969 at 47°–55′ N, 157°–10′ W.

These results give us some fundamentally important evidences concerning on the scheme of food and feeding habits in baleen whales: that is, there have been two suppositions in connection with the population density of food organisms and the amount of stomach contents acutually found (Klumov, 1961; Kawamura, 1970b). They are: 1) the daily rations of baleen whales would be filled by their extraordinal ability in collecting the foodstuff, and the ability have to be maintained under a quite excellent functions, or 2) the food organisms have to distribute with very high population density of such extent as hardly impossible to know it by means of an ordinal method being employed in plankton samplings by the net.

Those above mentioned results lead to a consideration that the food organisms would distribute under a quite dense population in the sea to fill the daily food requirements of whales rather easily by those poorly developed filtering ability in the row of baleen plates.

10. AMOUNT OF THE STOMACH CONTENTS AND THE POPULATION DENSITY OF FOOD ORGANISMS

The amount of the stomach contents in three species of the baleen whales has been reported previously though it was rather preliminary (Kawamura, 1968b, 1970a). The predator-prey relationships which involve the baleen whales would be a characteristic scheme in the food chains of the sea, since the secondary producer are directly connected with the consumers of the highest level in the ecological niche, that is, the energy flows quite effectively in the economy of the sea. Klumov (1961) made a calculation and described theoretical population density of zooplankton basing on the amount of stomach contents which were actually measured, and he concluded that the food requirement by the whale would hardly be filled fully with the population density of zooplankton being widely found in the sea. After the scheme of Ivlev's " feeding rate " (Ivlev, 1961), Sergeant (1969) confirmed on the daily ammount of food consumed by the whales which has been reported previously would be an appropriate figures, and Kawamura (1970b; 1971b) has discussed on the population density of copepod, *Calanus tonsus* in relation to the amount of this food organism in the first stomach of southern sei whale. Prior to further examination on the population density of food zooplankton, the feeding habits such as feeding cycle, feeding method, amount of stomach contents, speed in digestion, were examined.

Most of whales usually spotted in the whaling ground are considered to be under the movements in search of food, and such whales as being under feeding activity in high seas are rarely sighted even by the whalers who had been engaged in whaling for many years. These fact indicates that the whales feed intermittently within rather shorter hours. Under these circumstances the observations by Ingebrigtsen (1929) on the feeding behavior in North Atlantic sei whale must be an important. According to Ingebrigtsen's observations the sei whale under feeding shows rather dull and only pays a little attention to the surroundings. Far later, Gunther (1949) reported a similar aspects in the southern fin whale, in which he (Gunther, 1949) described that the fin whale continued its feeding without paying any attention to the approaching ship and was easily marked. The whales fully repleted with food also show a similar behavior. When they are under starvation, however, they are quite shy and agile, and can hardly be approached within the shooting distance. The sei whale quickly moves around in the surface with its mouth half opened when they are under feeding (Ingebrigtsen, 1929; Scoresby, 1820; Kawamura, 1972), and it is this occasion that bolting behavior was observed (Andrews, 1909; Gunther, 1949) though the whale sometimes feeds without bolting its body (Millais, 1904–1906). In humpback whale it is also known that the whale makes its food organisms aggregate into dense shoals by moving around them so as to enable feeding himself more effectively (Howell, 1930).

On the other hand, the balaenopterid whales other than sei whale feed by swallowing the food contained water. However, the feeding type employed by the whale is not always fixed but varies with case by case. In the North Pacific relatively larger sized fishes such as the pacific saury, pacific cod, mackerel, sardines and some squids are fed by the baleen whales in addition to the planktonic crustaceans (Nemoto, 1957; Kawamura, 1973a). Feeding by skimming type which seems to be largely employed by sei whale may possibly be less effective against these kind of well swimming food organisms. The sei whale, therefore, is considered to feed by rather combined ways of both skimming and swallowing types, and this supposition would be supported by the following fact: the variation or the change in feeding method is known even in some plankton eating fishes. For example, both biting and filtering types are employed in anchovy by the size of the prey organisms and their population density in the sea (Leong and O'connell, 1969).

The foodstuff swallowed is preserved temporalily in the first stomach, and this kind of function is characteristic in baleen whales among the marine mammals. Studying on the anatomy of the first stomach of whales, Hosokawa and Kamiya (1971) concluded after discussing on its ecological recognition that there might be need to deposit the food as far as the food is available since the whales in their feeding place have been faced the competition with the others for a limited amount of foodstuff.

Under these above mention circumstances, the observations on the amount of food organisms in the first stomch would be an important materials in connection with the feeding habits of whales and the distribution ecology in the food organisms such as their patchiness and the population density. However, Betesheva (1955), Nemoto (1957) and Bannister and Baker (1967) have pointed out that the whales under chasing would possibly vomit their stomach contents supposedly from fatigue after long and continuous chasing. If this occur actually, the amount of the stomach contents which is found in carcasses would be greatly decreased, and therefore, before going further the matter was examined and discussed in the following section.

10–1. *Influence of chasing time to stomach contents*

Prior to further discussion on the amount of food in the first stomach, it was examined and discussed that to what extent the chasing by catcher boast influences on the amount of stomach contents due to vomit. This however have been discussed fully in the previous report (Kawamura, 1970e, 1971a), then I will redescribe here only an abstracts and conclusions by quoting my previous reports.

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 being chased and sperm whale vomited most frequently (16.8%) whereas sei and fin whales were 1.1% and 0.78% respecitively (Table 10–1). The diet of the whales concerned was consisted of boarfish, squids, copepods and euphausiids. It was often observed that the whales likely to vomit out more larger sized foodstuff such as boarfish than that of copepods and euphausiids. 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 (80%)

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. There are one possibility left behhind 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, 1958a).

TABLE 10-1. NUMBER OF WHALES OBSERVED BY SIX CATCHER BOATS WHICH PARTICIPATED IN THE NORTH PACIFIC WHALING OPERATIONS IN 1969.

Floating factory		Kyokuyo Maru No. 3		Tonan Maru		Nisshin Maru		
		Catcher boats participated (day/month)						
Duration of operation		Kyo Maru No. 12 (18/V–25/VII)	Kyo Maru No. 15 (6/V–18/VIII)	Konan Maru No. 25 (19/V–24/VII)	Konan Maru No. 26 (24/V–8/VII)	Toshi Maru No. 17 (16/V–4/VIII)	Toshi Maru No. 18 (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

* Sperm whale was not observed expect Kyo Maru No. 15 and Toshi Maru No. 18.

10–2. *Amount of stomach contents*

The amount of the stomach contents was measured on the animals which were appeared to be fully repleted with food. For the measurement in the field a basin of known volume was used to remove the stomach contents completely from the opened stomach, and the amount was calculated by multiplying the number of basin which was required for the complete removal. Since the stomach contents removed by this way contain the water to some extent, the weighing of a basin-full organisms was made after draining away the water. I have reported on the amount of the stomach contents in three southern species of baleen whales (Kawamura, 1970a). It is however, considered necessary to give the results for further discussions, I redescribed here a part of descriptions in the previous report.

In the Antarctic, as I showed in a brief note (Kawamura, 1968b) the amount of stomach contents of 14 sei whales which fed on *Calanus tonsus*, *Parathemisto gaudichaudii*, *Euphausia superba* and *Euphausia vallentini* was measured (Table 10–2). The weighing of stomach contents were carried out on the stomachs being judged as

" full " by eyes, and full data including fin and minke whales were given in *Appendix*. The highest value observed was 228.0 kg of *Parathemisto gaudichaudii*, which was fed by 15.2 m of male, while it was only 68.0 kg in the *Calanus tonsus* food. Nemoto (1962b) mentioned that there was a quite well agreement between the weight and the degree of replation of stomach judged by eyes. However, as shown in *Appendix* there were considerable variations in the case of the Antarctic sei whale. It can be said in general that the whales caught before 0900 hours carry somewhat fresh and large amount of stomach contents, and the proportional weight of water gradually increases toward noon due to digestion.

TABLE 10-2. AN AVERAGE AND THE MAXIMUM AMOUNT OF STOMACH CONTENTS OF SEI AND FIN WHALES CAUGHT IN THE ANTARCTIC OCEAN.

Species of whale	Body length (m)	Sex	No. of whale examined	Average		Maximum	
				Total weight (kg)	Volume (l)	Total weight (kg)	Volume (l)
Sei whale	13.0–13.9	Female	2	171	202	182	204
		Male	0	—	—	—	—
	14.0–14.9	Female	2	118	149	141.3	180
		Male	5	116	140.4	154.6	200
	15.0–15.9	Female	1	152	200	152	200
		Male	3	159.2	208.5	228	312
	16.0–16.9	Female	1	196.5	255	196.5	255
		Male	0	—	—	—	—
Fin whale	18.0–18.9	Female	0	—	—	—	—
		Male	1	301.3	391	301.3	391
	20.0–20.9	Female	1	567	700	567	700
		Male	0	—	—	—	—
	21.0–21.9	Female	0	—	—	—	—
		Male	2	510	700	885	1000
	22.0–22.9	Female	1	133	238	133	238
		Male	0	—	—	—	—

It has long been the obscure mystery or the matter of interest how much the baleen whales take food in a day. According to Nemoto (1959) Collett (1912) early estimated the amount of food taken by the Atlantic blue whale, and showed that they had taken at least 1,000 liters of euphausiids. Betesheva (1954) showed that the North Pacific sei whale can feed 600 kg of squids or 50∼370 kg of *Calanus plumchrus*, while Best (1967) given 59 kg of zooplankton from South African waters, and 175 or 305 kg of krill for Antarctic sei whales (Brown, 1968). There are some more data about this problem which has been accumulated on the whales of northern hemisphere though most of them were on fin whales (e.g. Nishimoto, *et al.*, 1952; Nemoto, 1959; Klumov, 1961). Nemoto (1959) demonstrated that the fin whales of 57 feet in the northern North Pacific fed on 759.0 kg. of Alaska pollack and found a considerable variations in the amount of stomach contents (91.0∼759.0 kg) notwithstanding the fact that the majority of all stomachs concerned were repleted as " full " by eyes. His result also suggests that the weight of stomach contents filled with copepods usually very little than those by fishes or euphausiids.

The highest and averaged amount of stomach contents show that the males of both sei and fin whales likely to feed on much food than the females though feeding percentage seems to be high in the female (Brown, 1968). It is noticed that the stomach is hardly repleted when the whales feed on copepods than fish or euphausiides. This fact leads to a consideration that the larger the size of food organisms, the larger amount of stomach contents is expected. Such a tendency is also shown in the North Pacific fin whales (Nemoto, 1959, Table 24). From my result I may describe the following weights as an approximate amount of stomach contents usually seen in the Antarctic (Table 10–3).

TABLE 10–3. AMOUNT OF FOOD USUALLY FOUND IN THE FIRST STOMACH OF ANTARCTIC BALEEN WHALES.

Species of whale	Kind of food organisms	Amount of food usually found
Sei whale	Copepoda	less than 100 kg
	Amphipoda	150–250 kg
	Euphausiids	150–200 kg
Fin whale	Euphausiids	300–900 kg
Minke whale	Euphausiids	30 kg

By comparing these values with those obtained by other workers (e.g. Klumov, 1961; Brown 1968), the amount of stomach contents of sei whale in the Antarctic does not differ so much from those obtained in the northern North Pacific.

10–3. *Daily variation in feeding activity*

Although the daily variation in feeding activity in terms of the percentage figures is rather well known in fin whales while not in sei whale, and in this point of views Kawamura (1970a) studied on sei whale. Since several facts found in his report are considered to be suggestive on this matter, a section of the results were redescribed: It has been known that the feeding activity of baleen whales in a day in terms of the percentages varies in general with a bimodal curve which has a maxima in the early morning and in the evening (Nemoto, 1957, 1959). One of his results (Nemoto, 1957) suggests that baleen whales somewhat actively feed twice a day in many cases though each patterns of feeding activity are variable with the kind of food partaining to their diurnal vertical movement, seasons, latitudinal positions, or sometimes with the bottom topography of whaling grounds. Sometimes, however, the baleen whales show a evidence suggesting to feed only once a day (Nishiwaki and Ohe, 1951). In any case, it is considered to be quite important to accumulate the evidences on the feeding habit of baleen whales especially of sei whales in relation to estimating the nutritional budget among the food webs in their feeding grounds. However, it is also nesessary to figure out the feeding patterns of baleen whales by theoretical and experimental methods by assuming such a feeding model as Klumov (1961) instituted for this purpose.

The daily change of feeding activities in terms of the percentages of the stomach with food against the whole number of stomach examined is supposed to be affected chiefly by the diurnal vertical migrations of food organisms, because the most of all food organisms listed in Table 5–1 were known as to show a quite distinct diurnal vertical migrations in the South Georgian whaling ground (Mackintosh, 1934, 1937; Hardy and Gunther, 1935; Ommanney, 1936). Accordingly, it is necessary to examine the whales food by the species since each food organisms has their own peculiar migratory patterns in a day. The hourly change in the feeding activity of sei whale in the whaling areas III, IV and V is demonstrated in Fig. 10–1. It is noticed in the figures that a quite high feeding percentages are observed in the early morning, and no distinct recovery occurs in the evening. It is also noticed that the most causative organisms to bring on the daily variation of feeding activity are chiefly responsible in the case when amphipoda, large sized euphausiids or " Calanus " were fed. Medium or small sized euphausiids seems to be fed whenever they are available. The upper and lower extremes of feeding percentages were 57 percent and 28 percent in the areas IV and V, and that in the areas III and IV were 82 percent and 25 percent respectively. The general trends of feeding activity of sei whale in the Subantactic waters differ considerably from those of fin and sei whales obtained in the northern North Pacific where it varied between 0 to 100 percent in most cases (Nemoto, 1957). This may be attributed partly to the differences of the kind of food organisms taken in both whaling grounds. From the figures, it is naturally considered that the most of sei whales in the Antarctic heavily take a dense population of food once in the morning possibly by ' swallowing ' or ' skimming ', and take a relatively scattered poor population of food organisms by ' skimming ' during the daytime towards the evening, as the manner described by Ingebrigtsen (1929) and Nemoto (1957, 1959).

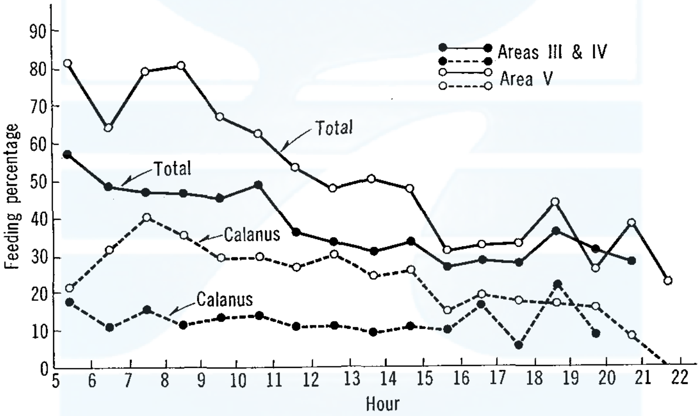

Fig. 10–1. Feeding percentage of sei whale in the whaling Areas III, IV, and V, 1967/68.

The components of the " Calanus " food are represented by two dominant species, *Calanus tonsus* and *Calanus simillimus*. In the Indian sector of the Antarctic a considerable number of both *Calanus tonsus* and *Calanus simillimus* occurred as principal food source of sei whale while only *Calanus tonsus* was observed in the Tasman Sea and in the Pacific sector of the Antarctic (area IV and V). Since there are considerable differences in the behaviour of diurnal vertical migration between *Calanus tonsus* and *Calanus similimus* the extent of the repletion of stomach contents by the time was also differed between those two copepod species (Fig. 10–2). Those differences due to diel migratory habits of food organisms have also been known in decapod crustacean, *Sergestes similis* which is locally important food of sei and fin whales in the North Pacific (Omori *et al.*, 1972). In both *Calanus tonsus* and *Calanus simillimus*, the repletion of stomach was relatively small with the quantity of food less than 50 percent during the daytime. It is noticed clearly that the almost fully repleted stomachs (" rrr "~" R ") with *Calanus tonsus* occurred more frequently than *Calanus simillimus*, and the former was fed with a same feeding percentages during the daytime while the bulk of *Calanus simillimus* was exclusively fed only in the evening. This fact would be the result from being exactly followed to the differences of the migratory habits of both species. According to Hardy and Gunther (1935), *Calanus simillimus* is regarded as one of the quantitatively important copepods in the South Georgian waters, and this species shows a distinct diurnal vertical migration as well as *Drepanopus pectinatus*; the bulk of *Calanus simillimus* population begins upward movement at about 1700 hours in the evening and reachs to 10~20 m depth at 1800 hours. They remain at the surface layer during the night then begin to move into the deep down to about 100 m depth in very early morning, at least 02~03 hours. This behavior leads to a consideration that there would be only a chance for sei whale to feed on *Calanus simillimus* in the evening throughout a day. It is interesting to find that the stomach of " full " occurred very frequently in the evening so as to support the consideration of feeding ' once ' in a day.

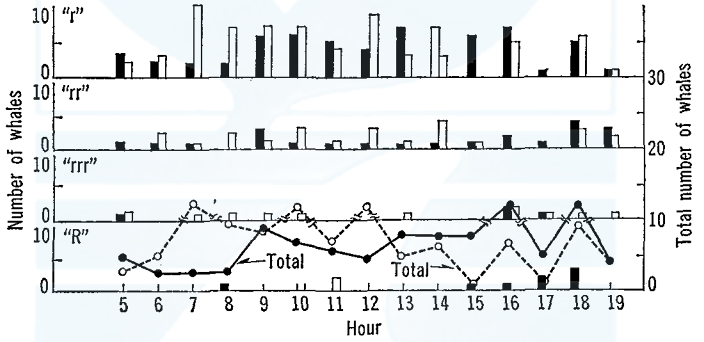

Fig. 10–2. Number of whales fed on *Calanus simillimus* (black colum and solid line), and *C. tonsus* (vacant colum and broken line) by the four different degrees in stomach fulness. Degrees of fulness are as follows: ' r ' less than 25 percent, ' rr ' 25–50 percent, ' rrr ' 50–75 percent, ' R ' 75–100 percent.

Calanus tonsus, on the other hand, is a comparable species to *Calanus plumchrus* in the northern North Pacific, and this species of at least in the copepodite stage V is recognized in general to show no such a distinct diel vertical migration as *Calanus simillimus*. Judging from its hydrological and taxonomical affinities to *Calanus plumchrus* (Tanaka, 1954, 1967; Jillett, 1968), it might presumably be considered that *Calanus tonsus* of 5th copepodite stage does not show any distinct diel-vertical migration. The occurrence of " full " stomachs with *Calanus tonsus* during the daytime suggests a quite well availability of this foodstuff in the surface waters so as to be fed by the sei whale throughout a day.

In summarizing the above mentioned results, it would possibly be said that the sei whale feeds whenever the foodstuff is available within a reasonable spacial range, and therefore its diel feeding pattern so far as it is expressed by the feeding percentages concerned may be different by the kind of migratory habits of its food organisms. Concerning to these food habits of sei whale, a recognition on the ecological means of the first stomach by Hosokawa and Kamiya (1971) as mentioned in the begining of this section would be well understood. Baleen whales in Patagonian waters (Matthews, 1932) and humpback whale in New Zealand waters (Dawbin, 1956) eat but little food, and later, Bannister and Baker (1967) considered that the whales under those circumstances would have to feed whenever there some amount of accumulations of food organisms to fill their nutritional requirements.

10–4. *Possible cause induces a decrease in the fulness of stomach contents*

The number of animals well repleted with food decreased along with the duration of chasing extends over 40 minutes regardless the kind of food organisms (Kawamura, 1971a). 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 chasing during midday until it was shortened again in the evening. There observed to present two different kinds of varing 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. 10–3). The duration of chasing time which corresponds to the degree of the fulness of stomach seems to be shortened from the morning toward the 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 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 squids or boarfish. This may be the result partly due to the 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.

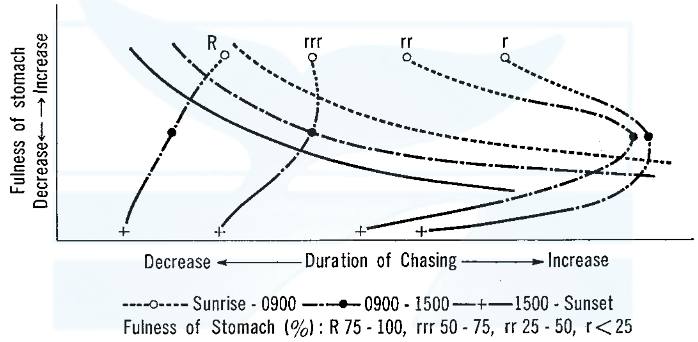

Fig. 10–3. Schematic curves showing regressive tendency of the fulness of stomach contents along with the duration of chasing in three different time bands. Curves with circle and cross by four different degrees of the fulness of stomach show a shift of those degrees toward lesser direction of the fulness with the lapse of time from sunrise to sunset.

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 (Tobayama) 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.

10–5. *Daily ration in sei whale*

It is interest to know the amount of food required by a whale per day, say, the daily ration. It has long been subjected to determine the daily ration in smaller whales in captivity (e.g. Takahashi, 1961; Tobayama and Tamura, 1964). In larger whales, however, the daily ration has hardly been determined with preciseness although there were some assessment being based on the analysis of the fulness and its daily changes (Nemoto, 1957, 1959; Kawamura, 1970a). However, after examining on the daily rations as function of body weight in small cetaceans, Sergeant (1969) described the following equations which might be applicable to larger whales. Firstly, the feeding rate is defined:

$$\text{Feeding rate} = \frac{\text{Food per diem}}{\text{Body weight}} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

The feeding rate which was found in smaller cetaceans varied 5.26∼13.67 with 8.26 on average, and the values were somewhat constant regardless the species and the age of animals. Then the following equation was introduced.

$$\frac{\text{Heart weight} \times 100}{\text{Body weight}} \cdot \frac{1}{\text{Feeding rate}} = 0.11 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

The heart weight as a factor of the equation was found since its weight well indicates the extent of activity of animals through their metabolisms. According to these formulations Sergeant (1969) concluded that feeding of 2.0∼2.5 tons per day in ordinally sized blue whale would be appropriate, and therefore the whale have to eat fully twice a day. However, the relationships between heart weight and feeding rate in larger whales are still little known when compared with another mammals (Ridgway, 1966; Ridgway and Johnston, 1966). To make the matter more clear I examined the heart weight of sei whales which were caught by the floating factories, "Tonan Maru No. 2" and "Nisshin Maru No. 3" in 1970/71 Antarctic season and the results were given in Tables 10–4 and 10–5. The weight of animals were calculated after the following formulae by Omura (1969), Ohsumi (1969), and Ohsumi *et al.* (1970):

Sei whale $W = 0.0016L^{2.43}$
Fin whale $W = 0.00024L^{2.9}$
Minke whale $W = 0.04655L^{2.31}$

where W is the weight of animals in 10^3 kg, and L is the body length in feet but in meter in minke whale.

The heart weight/body weight in connection with body length and sex did not differ much (Fig. 10–4). The difference in the latter was only 0.16‰, and was almost no difference in the former which was in such body length as to be caught regally by whaling, but some variations by age have been known in smaller cetaceans

(Kleinenberg, 1956; Slijper, 1958b). Table 10–5 was given under combined figures of both sexes, and the following was found in sei whale.

Heart weight/Body weight = 0.00487 ....(3)

Although Sergeant (1969) found the figure 0.00404 in this relation, the above described figure would be considered more appropriate since it was derived from more larger number of materials. Basing on the above described figures, the feeding per diem in sei whale is calculated by the equations (1) and (3) as follows:

TABLE 10–4. BODY AND HEART WEIGHTS OF THE ANTARCTIC SEI WHALE BY THE DIFFERENT BODY SIZES.

Body length (m)	Sex	Body weight (ton)	Heart weight (kg)	Heart/Body (‰)	Average	No. of whale examined
12.1	Male	8.94	53.2	5.95	5.95	1
	Female		45.2– 60.0	5.06–6.71	5.89	2
12.4	Male	13.25	41.0– 65.1	3.09–4.91	4.09	4
	Female		58.0– 70.0	4.38–5.28	4.78	4
12.7	Male	—	—	—	—	—
	Female	14.09	62.0– 66.8	4.40–4.74	4.57	2
13.0	Male	14.89	61.2– 86.0	4.11–5.78	4.59	9
	Female		56.0– 75.0	3.76–5.04	4.43	3
13.4	Male	15.72	62.0– 72.0	3.94–4.58	4.22	5
	Female		75.0– 89.0	4.77–5.66	5.22	2
13.6	Male	16.56	70.0– 92.0	4.23–5.56	4.59	4
	Female		74.0– 89.0	4.47–5.37	4.92	4
14.1	Male	17.51	90.0–106.0	5.14–6.05	5.60	2
	Female		76.2–106.0	4.35–6.05	5.43	4
14.3	Male	18.42	68.0– 93.3	3.69–5.07	4.56	7
	Female		86.0–110.0	4.67–5.97	5.06	4
14.5	Male	19.35	86.4– 97.0	4.47–5.01	4.79	3
	Female		83.0– 99.0	4.29–5.12	4.64	5
14.8	Male	20.35	78.5–117.0	3.86–5.75	4.60	6
	Female		90.0–126.0	4.42–6.19	5.10	4
15.1	Male	21.40	97.0–101.0	4.53–4.72	4.66	3
	Female		94.0–126.0	4.39–5.79	5.02	6
15.6	Male	22.40	110.0–114.0	4.91–5.09	5.00	2
	Female		99.0–125.0	4.42–5.58	5.15	3
15.7	Male	23.55	—	—	—	—
	Female		98.0–142.0	4.16–6.03	4.91	10
16.2	Male	24.75	—	—	—	—
	Female		102.5	4.14	4.14	1
8.4*	Male	5.38	21.3	3.96	4.21	1
8.1*	Male	4.96	22.2	4.47		

* Minke whale.

Feeding per diem = 0.0443×Body weight ....(4)

Then the daily ration in ordinally sized sei whale can be considered about 4.4% of body weight (Fig. 10–5), and that in fin and minke whales was 0.0407 and 0.384 respectively. The overall figures through baleen whales therefore would be somewhere between 3.8% and 4.4%. These results as a whole agree with those by Klumov (1963) whose figures were 3.0~4.0% though he expressed it by the biomass basis, say, gr.-food/kg-muscle weight of animals. The food per diem demonstrated in Fig. 10–5 shows relatively higher food requirement in sei whale, and it gets lower gradually in fin and then in minke whales. A quite high food

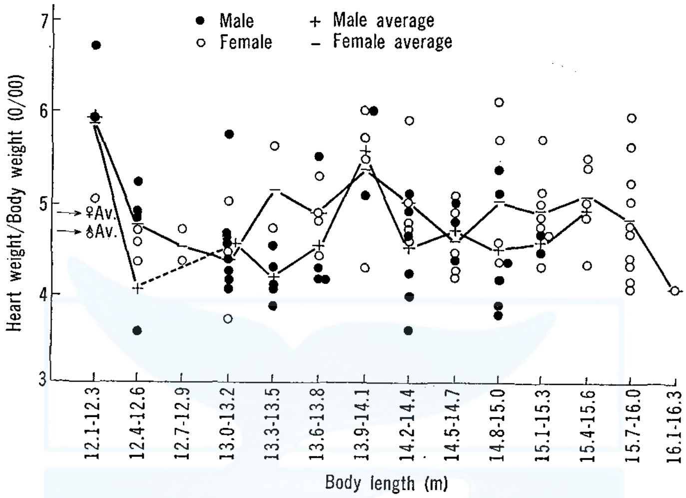

Fig. 10–4. Heart weight and body weight ratios in southern sei whale.

TABLE 10–5. BODY AND HEART WEIGHTS OF THE ANTARCTIC FIN WHALE BY THE DIFFERENT BODY SIZES. BOTH MALE AND FEMALE ARE COMBINED.

Body length (m)	Body weight (ton)	Heart weight (kg)	Heart/Body (‰)	Average	No. of whales examined
17.3	29.33	105.6–156.0	3.60–5.32	4.35	7
17.6	31.05	102.0–193.0	3.29–6.22	4.78	4
17.9	32.45	134.0–150.0	4.13–4.62	4.35	3
18.2	34.20	132.0–205.0	3.86–5.16	4.60	9
18.5	35.85	138.0–185.0	3.85–5.16	4.61	5
18.8	37.54	144.0–200.0	3.84–5.06	4.55	8
19.1	39.30	136.0–179.4	3.46–4.57	4.00	10
19.4	41.25	158.0–224.0	3.83–5.43	4.35	8
19.7	43.25	165.0–220.0	3.82–5.09	4.52	5
20.0	44.99	158.0–239.0	3.51–5.31	4.28	12
20.3	47.25	185.0–245.0	3.92–5.19	4.57	7
20.6	49.20	196.0–280.0	3.98–5.69	5.05	7
20.9	51.40	160.0–258.0	3.11–5.02	4.06	10
21.2	53.60	195.5–278.0	3.65–5.19	4.46	8
21.5	55.7	206.0–350.0	3.70–6.28	5.03	8
21.8	57.9	235.0–258.4	4.06–4.46	4.22	3
22.1	60.8	180.0–330.0	2.96–5.43	4.22	8
22.5	63.2	203.0–379.0	3.21–6.00	4.27	7
22.8	65.4	240.0–375.0	3.67–5.73	4.94	3
23.1	68.1	276.0–343.0	4.05–5.04	4.43	3

requirement in right whale along with similar trends in sei whale indicates that their difference from fin and minke whales would be due to the feeding types; skimming in the former whereas swallowing in the latter.

The amount of the first stomach contents which has been reported in sei whale is given in Table 10–6. It is observed in the table that the amount of food in the stomach of ordinarily sized animal, *i.e.*, 15~24 tons of sei whale is 200 kg or thereabout when they feed on planktonic crustaceans. It could also be said as a whole that the amount in the stomach decreases with the size of food organisms, and those amounts actually measured are considerably low when compared with the daily ration. If we follow to the daily ration in sei whale of 18 tons in body weight, the animal requires about 800 kg of food daily, and the stomach of this animal have to be fully repleted three to four times in a day. However, it seems hardly pos-

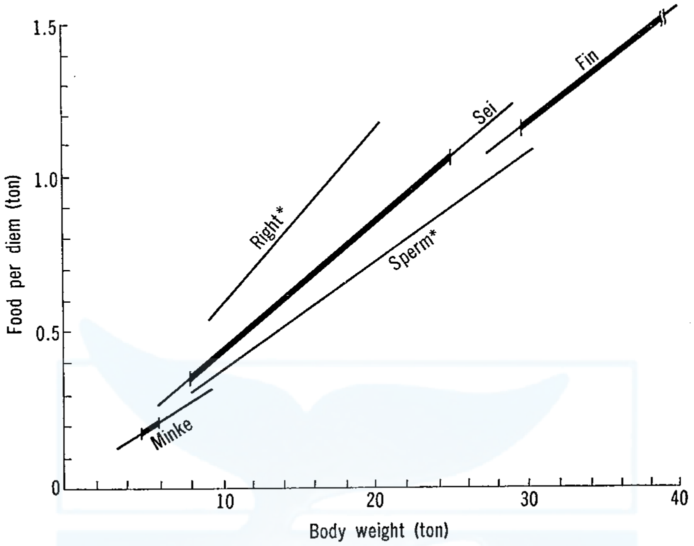

Fig. 10–5. Theoretical amount of food per diem in southern sei, fin and minke whales.

TABLE 10–6. AMOUNT OF STOMACH CONTENTS OF SEI WHALE.

Kind of food	Amount of food (kg)	Locality	Author
Calanus tonsus	54.0	Antarctic	Kawamura (1970)
Parathemisto gaudichaudii	57.6–200.0	Antarctic	„
Euphausia vallentini	79.1–149.6	Antarctic	„
Enphausia superba	128.7–149.6	Antarctic	„
Euphausia superba	175.0–305.0	S. Georgia	Brown (1968)
Zooplankton	59.0	S. Africa	Best (1967)
Calanoida	300.0	N. Pacific	Klumov (1963)
Pacific saury	500.0	N. Pacific	„
Calanus plumchrus	50.0–370.0	N. Pacific	Betesheva (1954)
Squid	620.0	N. Pacific	„

sible for the animal to feed 800 kg of *Calanus* within several hours because *Calanus* remains in the surface only a few hours in the morning and evening. Therefore, the sei whale would have to eat even rather scattered food organisms which might have remained in the surface being apart from the main body of the migrating population. According to Best (1967) the sei whale in South African waters fed zooplankton being consisted of many species, and a considerable number of them were supposed to be non-aggregating species. This fact suggests that the sei whale can feed even those rather scattered food organisms by skimming type of feeding. It may be considered anyhow that daily ration of about 800 kg would hardly be taken by the sei whale from its filtering ability and the population density of available food organisms.

TABLE 10-7. THE HIGHEST NUMBER OF FOOD COPEPODS PER 1000 M³ OF WATER IN THE UPPER 150 METER DEPTH OBTAINED BY THE NORTH PACIFIC STANDARD NET IN THE SOUTHERN WATERS OF CENTRAL PACIFIC AND TASMAN SEA IN 1968/69.

Species		Highest number of individuals by each stages through all stations occupied ($\times 10^3$)	Highest number of individuals in a haul by species ($\times 10^3$)
Calanus tonsus	female	4.53	—
	male	0.51	—
	C V	118.28	12.13
	C IV	249.58	250.58
	C III	39.86	39.86
	C II	2.60	2.60
Calanus simillimus	female	8.10	8.06
	male	6.72	6.72
	C V	60.40	60.44
	C IV	190.73	190.73
	C III	186.69	56.41
	C II	72.30	10.75
Calanoides acutus	female	1.64	1.64
	C V	38.07	35.57
	C IV	51.84	75.63
	C III	103.63	46.09
	C II	51.84	31.07
	C I	89.94	89.94
Calanus propinquus	female	1.17	1.17
	male	0.97	0.39
	C V	4.27	4.27
	C IV	6.95	1.55
	C III	11.45	—
Clausocalanus spp.*	female & male	3179.62	—
Metridia gerlachei	female & copepodites	384.17	—
Rhincalanus gigas	copepodites & C I～C VI	56.41	—

* *Clausocalanus laticeps* & *C. paululus.*

10–6. *Estimation of population density in the food organisms*

One of the most important food organisms of sei whale in the southern whaling ground is copepods, especially *C. tonsus* and *C. simillimus*. An ecological importance of these two are comparable to *C. cristatus* and *C. plumchrus* in the North Pacific region.

The amount of food organisms in the stomach would be the result of functions of both feeding ability of whales and the population density of food organisms. Studying on the baleen whales in the Fareast seas, Klumov (1961) stated that the amount of stomach contents could not be understood unless the food organisms distribute such high density as to be hardly known by the net sampling in the sea. In the southern sei whaling ground the food organisms distribute with the density as given in Table 10–7 and 10–8. The figures in the tables were obtained by the plankton net hauls through 27 stations in the Tasman Sea and in the Pacific Ocean, and the population density in each copepod species does not show that of under aggregations. The wet weight of copepods were obtained from the stomach contents which were completely consisted of mono-specific population. On the other hand, the amount of stomach contents was given in *Appendix*. The amount of copepod food was larger in the North Pacific than in the South African and the Antarctic waters. The availability of foodstuff seems in general to be high in the North Pacific.

TABLE 10–8. THE HIGHEST NUMBER OF INDIVIDUALS OF EUPHAUSIIDS AND AMPHIPODS PER 1000 M^3 OF WATER IN THE UPPER 150 METER DEPTH OBTAINED BY THE NORTH PACIFIC STANDARD NET IN THE SOUTHERN WATERS OF CENTRAL PACIFIC AND TASMAN SEA IN 1968/69.

Species	Individual number ($\times 10^3$)	Remarks
Euphausia simillis var *armata*	0.26	Immature
Euphausia simillis	0.054	Immature
Euphausia lucens	0.001	female
Euphausia vallentini	2.81	female
Euphausia frigida	1.41	Immature male
,,	1.41	Immature female
Euphausia spinifera	1.11	female
Euphausia superba	0.47	Immature
Euphausia sp.	0.45	Immature
Euphausiids furcilia	59.48	
Thysanoessa parva	0.30	Immature
Thysanoessa vicina	1.09	Immature
Thysanoessa macrura	8.10	Immature
Thysanoessa gregaria	7.80	
Nematoscelis megalops	0.11	female
Parathemisto gaudichaudii	0.21	female, f. *compressa*
,,	0.26	female, f. *intermediate*
,,	3.42	Juvenile

The quantitative distribution of food zooplankton in the subantarctic waters varied between 15.10 and 426.12 gr./1000 m^3 in wet weight (Kawamura and Kureha, 1970). Since the composition of whales food usually found is monospecific, the highest figures in the poplation density in net haul samples was given by separating each species (Tables 10–7). A distinct occurrence of copepodites IV and V in *C. tonsus*, and adult *Clausocalanus laticeps* agrees with the composition of the stomach contents although *C. simillimus* differed in this respect. Both *C. acutus* and *C. propinquus* showed a quite slight occurrence as none of them were found in the stomach contents. The figures in euphausiids are quantitatively less important due to net avoidance. However, the dominancy of an important food species; *E. vallentini* is indicated. The population density of food organisms was estimated as follows under two feeding types particularly in the case of *C. tonsus*, one of a leading foodstuff in the southern feeding ground:

Swallowing

The 14.4 m sei whale caught in the Antarctic feeds at least 54.0 kg of *C. tonsus* of copepodites IV and V (Table 10–6), and the average body weight of *C. tonsus* is 1.2 mg/individual. (Table 10–9). Accordingly, a total of 54.0 kg. of food *C. tonsus* corresponds to 45×10^6 individuals. In order to obtain this number of *C. tonsus* under the population density of 262.7×10^3 inds./1000 m^3 which was the highest figures actually found (see Table 10–7), a total of 171.2×10^3 m^3 of water have to be filtered off by the whale. The volume of water in a gulp in fin whale is supposed about 6.0 m^3/30 sec. (Klumov, 1961) whereas in average sized sei whale (14.5 m: Intern. Whal. Statistics, 1969) the volume of engulped water would be somewhere between 2.0 and 3.0 m^3/30 sec.

TABLE 10–9. WET BODY WEIGHT OF FOOD COPEPODS COLLECTED FROM THE FIRST STOMACH OF SEI WHALES CAUGHT IN THE INDIAN SECTOR OF THE ANTARCTIC.

Species	Stage	Weight measured (mg)	No. of individual		Body weight (mg)	State of material
			Normal	Damaged*		
Calanus tonsus	C V	200	155	26	1.19	
	C V	200	151	33	1.20	
	C V	1000	595	83	1.57	Moderately digested
	C V+VI female	500	256	105	1.66	Moderately digested
Calanus simillimus	C V	500	541	144	0.82	
	C V+VI female	500	745	226	0.58	
Clausocalanus laticeps	female	20	96	71	0.15	Heavily digested
	female	20	110	75	0.14	Heavily digested
	female	20	186	57	0.09	
Drepanopus pectinatus	female	200	587	358	0.26	Heavily digested
	female	20	139	89	0.11	Moderately digested

* Damaged individuals are supposedly lost their body fluids, and they were regarded as one half of those undamaged individuals in the wet weight.

To examine these figures more clearly the volume of air which was sent into the oral cavity to make the animal afloat was measured (Fig. 10–6), and the average volume of air used in fin and sei whales was 10.4 m³ and 8.95 m³ respectively. In Fig. 10–7 the dots far above from main body would be due to a leakage of air. Since the above mentioned air was pressured 3 to 4 times higher than natural pressure, those amount of air in fin and sei whales could be converted into 2.6~3.5 m³, and 2.24~2.98 m³ respectively. It is clear that these figures agree well those above mentioned. Therefore, a total of 54.0 kg. of *C. tonsus* could be obtained in 5.5×10^2 hours, say, 23 days ! As it is noticed in Table 10–6, the amount of the stomach contents in sei whale sometimes attains at 500~600 kg, and their theoretical daily ration was 800 kg. Then if we assume 300 kg. of copepod food as their possible daily ration since an availablity of copepod food would be considerably poor than the others, a total of 54.0 kg. of stomach contents fills only 1/6 of the daily requirement in sei whale. Accordingly, it could be supposed that the population density of *C. tonsus* under an aggregation must be found somewhere between 3.4×10^7 and 5×10^7 inds./1000 m³ (Fig. 10–7).

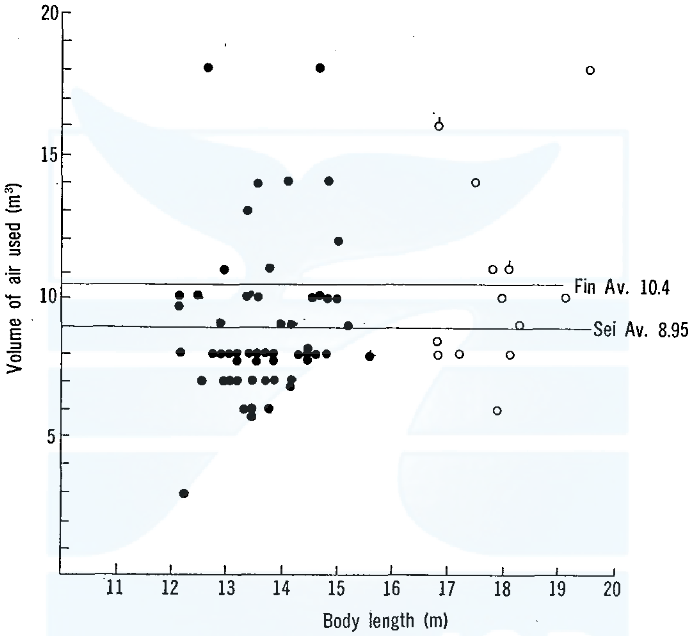

Fig. 10–6. Volume of air used to make afloat the carcasses of sei and fin whales.

According to Minoda (1958) the highest population density found in his study in *C. plumchrus* in the North Pacific was 395×10^3 inds./1000 m³, and later the another case revealed as 631×10^3 inds./1000 m³ (Fac. Fish. Hokkaido Univ., 1963). Comparing these figures with the density of 367.8×10^3 inds./1000 m³ in *C. tonsus*, it is noticed that the population density in both cases agrees quite well while those two are the phenomena in far separated regions each other. These facts indicate that the upper extreme of population density in copepods would be about up to 4×10^5~6×10^5 inds./1000 m³ throughout the world seas though rarely found. The estimation described above seems quite high density which may almost unbelievable but it is the patchiness of plankton that gives those high level of the population density.

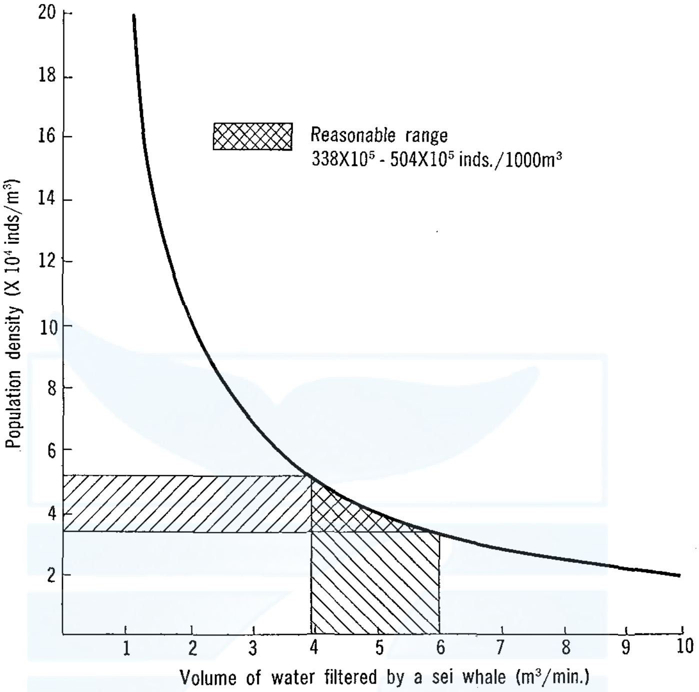

Fig. 10–7. Theoretical estimation of the population density of *Calanus tonsus* patches which fulfill the 54.0 kg of *C. tonsus* within 4 hours.

Skimming

The feeding type actually and most frequently employed by the sei whale is not swallowing but skimming (Scoresby, 1820; Millais, 1904–1906; Ingebrigtsen, 1929). The sei whale collects foodstuff by filtering continuously the food contained sea water with the mouth half opened. The right and bowhead whale feed by skimming exlusively while sei whale does not always but frequently.

As it has examined previously a relative filtering ability in the row of baleen plates in sei whale was 1/2.2 against fin whale (Kawamura, 1971a). A total surface area of the inner surface of filtering apparatus in sei whale was about 3.6 m^2, and the filtering coefficient was 0.167. By these figures a sei whale can filter off 6.0 m^3 of water effectively by swimming for 10 meters. One of possible and acceptable parameters in regard to feeding by skimming would be; 3 knots in swimming speed, 4 hours in feeding duration and a total of 300 kg of food organisms is fed. Then the population density of food organisms which fills enough above mentioned parameters must be 2.13×10^3 gr./1000 m^3, that is, 1.8×10^7 inds./1000 m^3. This figure as the order of density agrees well with the both estimations.

According to Zenkevitch (1963) the biomass of zooplankton standing stock during the summer in the Okhotsk Sea and Bering Sea rarely shows more than 1.0 gr./m^3, and those exceeds 3.0 gr./m^3 would only be found in a limited region of the northern Okhotsk Sea. Kurile region also rarely yields 1.0 gr./m^3 of zooplankton (Klumov, 1961). In the Pacific sector of the Antarctic the biomass of zooplankton was usually between 0.5 and 2.0 gr/m^3, and that more than 2.0 gr/m^3 was rarely found. One of the biomasses of *C. tonsus* in the subantarctic waters ever found was 0.2～0.5 gr./m^3. (Dolgencov, 1970).

By comparing these figures with those estimations in *C. tonsus*, the biomass or the population density in *C. tonsus* as food of sei whale seems considerable higher numbers than those obtained by the net haul investigations. Those density in food *C. tonsus* would still under estimated since the 300 kg. of stomach contents which was assumed in calculation should be doubled or more. However, it should also be took in account that those extremely dense population would possibly be found only when *C. tonsus* aggregates into the patches. Manteufel (1939) stated 9.0 gr/m^3 of population density in *Calanus* sp., then the biomass of about 21.3 gr/m^3 (1.8×10^4 inds/m^3) in *C. tonsus* population as estimated could be considered quite possible.

The population density of *C. tonsus* required to fill the 300 kg. of stomach contents by swallowing type feeding was 3.4×10^7～5×10^7 inds./1000 m^3 whereas it was 1.8×10^7 inds./1000 m^3 in skimming type. Comparing these figures it could be supposed that the feeding by skimming type would be more effective to collect the same amount of foodstuff. The scheme would also support the facts previously known that the sei whale feeds almost always by employing the skimming type feeding in the whaling ground.

11. SWARMS OF *CALANUS TONSUS* BRADY

As has been mentioned in the previous sections, it was strongly suggested that the population density in *C. tonsus* must be maintained at least in such the order of 10^3～10^4 individuals per cubic meter when they swarm into the so-called patches as to be fed by the sei whale (Kawamura, 1971d). However, the population density described above was an estimation being based on the amount of *C. tonsus* in the first stomach of whale carcasses and the filtering ability in a row of baleen plates as a function of feeding in sei whale. The theme therefore, was in need of being substantiated by the further evidence in the field, since the general features of swarming copepods under patchiness along with their population density had been known quite a few, while those swarm forming phenomena in copepods themselves had been known in early 1800's in the North Atlantic waters, and have been relatively well documented (e.g. Marshall and Orr, 1955).

In the following section I will describe some additional evidences on the swarming of *C. tonsus* in the surface waters. *C. tonsus* is a typical endemic species in the Subantarctic waters and considered to be important in a role of marine ecosystems of the southern waters. However, it is still unknown whether there were any socialized relationships among the swarming *C. tonsus* individuals. The swarming *C. tonsus* populations are exclusively consisted of stage V copepodites with a little mixture of adult females. A possible causations of surface swarming behavior may perhaps be similar to those in mysids (Clutter, 1969) though there must be some another pattern-forming agencies in copepods.

An uneven and spatial distribution of plankton species has been well known (e.g. Hardy, 1936a, b; Barnes and Marshall, 1951; Cassie, 1959a, b, c, 1960). However, some recent works (Wiebe, 1970; Kuwabara *et al.*, 1971)on this matter seem to give some confusion in the term of the plankton patchiness: Wiebe (1970), for instance, defined the " patches " or " patchiness " when the overall concentrations of zooplankters under multispecies composition exceeded a central value in a data set, which necessarily induce such a quite much occurrence of the " patches " as about 200 patches per a grid of about 100×100 m squares. These kind of " patchiness " are, however, considered rather usual phenomena as a distribution pattern widely seen in any localities of the sea. On the other hand, the plankton patches under considerations may be something different from those above mentioned, and also may possibly be different from those quite large scaled spacial distribution such as treated by Cushing (1962), but identical to those dense monospecific aggregations into swarms or rafts which by Marr's expression, scattered in a plane keeping 1/3∼1/4 miles intervals of " krill-less " sea. As mentioned in the previous sections, the composition of patch forming plankton population is monospecific as known in *Euphausia superba* (e.g. Hardy and Gunther, 1935; Marr, 1955) or in copepod, *Calanus finmarchicus* (Bainbridge, 1952; Kitou, 1956), which make the sea discolored by enormous number of swarming plankton species in the very surface.

11–1. *Zooplankton swarms as whales food*

The swarming organisms as whales food have had been well recognized early among British whalers in those sperm whaling days in the southern seas, and the " Brazil banks ", according to Beale (1839), is " only discolorations of water caused by myriads of animal culæ which perhaps form the sustenance of the common black whale's food; that consisted of " squillæ " and other small animals ", and Beale (1839) also called them as " submarine pastures ". During the cruise on boad of the H.M.S. " Beagle," Darwin (1906) sighted a fairely well discolored waters by a huge number of copepod-like minute organisms, and considered that they must have been the food of whales and seabirds. Apart from recognizing the swarming phenomena of plankton species, Klumov (1961) brought out a subject under ecological considerations concerning to plankton patchiness that the daily food requirements of baleen whales would never be filled by the standing stocks of zoplankton known in the Kurile region even by their uppermost extremes, and concluded that the food zooplankton parhaps be maintained with a density of at least about 1500∼2000 mg per cubic meters. An approach to know the population density in whale's food zooplankton involved an important indications, and later Omori *et al* (1972) made an estimation on the population density in swarming

Sergestes similis in the northern North Pacific.

At least the following zooplankton species except copepods have been observed directly as to form a dense swarms or so-called patches apart from those uneven or spatial distributions of plankton species: *Euphausia superba*, *E. crystallorphias* (Marr, 1962), *E. pacifica* and many others (Komaki, 1967), *E. nana*, *E. similis Thysanoessa inermis*, *Th. raschii*, *Th. spinifera* (Nemoto, *et al.*, 1969), Mysid, *Metamysidopsis elongata* and *Acanthomysis* sp. (Clutter, 1969), *Mysidium columbiae* (Steven, 1961), Galathea, *Munida gregaria* (Matthews, 1932; Tabata & Kanamaru, 1970), *Pleuroncodes planipes* (Boyd, 1967), macruran, *Sergestes lucens* (Omori, 1969) and *S. similis* (Omori *et al.* 1972). The number of patch forming plankton species would be doubled or more when we take into account the indirect evidences of swarming such as the food of baleen whales, among which amphipods, *Parathemisto gaudichaudii* is distinct. In these patch forming species the population density under swarming is usually maintained quite high, say, 1 ind./inch^3 in *E. superba* (Marr, 1962), 100 crabs/m^2 in Galatheid shrimp, *P. planipes* (Boyd, 1967), or animals swim as close as 1～2 cm one to another in *E. pacifica* (Komaki, 1967). Patchiness in mysids are relatively well known as mentioned before. Recent biosociological study on the swarms of mysids, *M. elongata* and *M. columbiae* (Clutter, 1969) much contributed to our knowledge on the aggregations of zooplankton particularly on swarming mechanisms along with possible but indicative biological cusations of the aggregation agencies such as density or grouping effects, role of sensory organs or underwater vibrations and pheromones (e.g. Laverack, 1962; Horridge, 1966; Ryan, 1966; McLeese, 1973; Dahl *et al.*, 1970a, b).

11–2. *Material and method*

The freezer ship M. S. "Eihô Maru" (1153 ton) which was chartered by the Nippon Suisan Co. Ltd., participated to the Antarctic whaling operation in 1971/72 season, and made a exploratory fishing and scouting for whales on her way down to the whaling ground. During her cruise in the south- to southwestern waters off Western Australia in December 11～26, 1971 when she was engaged in scouting about for sei whales in advance of comming season, many patches of discolored waters by dense aggregations of copepods, *Calanus tonsus* Brady were observed in the surface waters. Japanese whaleman calls them as "Uki-esa", a floating whale's food. The cruise track and the general hydrography are shown in Fig. 11–1. The ship cruised by following up the waters chiefly along the 12.0°～14.0°C isotherms since high concentrations of sei whales are usually expected under these sea conditions by the whaler's experience.

The surface swarms of *C. tonsus* which distributed within the range of about 2 miles of both sides of the ship's track were possible to distinguish by their dark brownish, sometimes blick like reddish discoloration from the surrounding waters, and the plankton sampling was conducted under inducement by the watchers who were on the upper deck, since the margin or the boundary of swarms was hardly visible in closer distance from foredeck. Marr (1962) suggested upon the decrease in detecting ability of the plankton patches when it is partly cloudy weather by

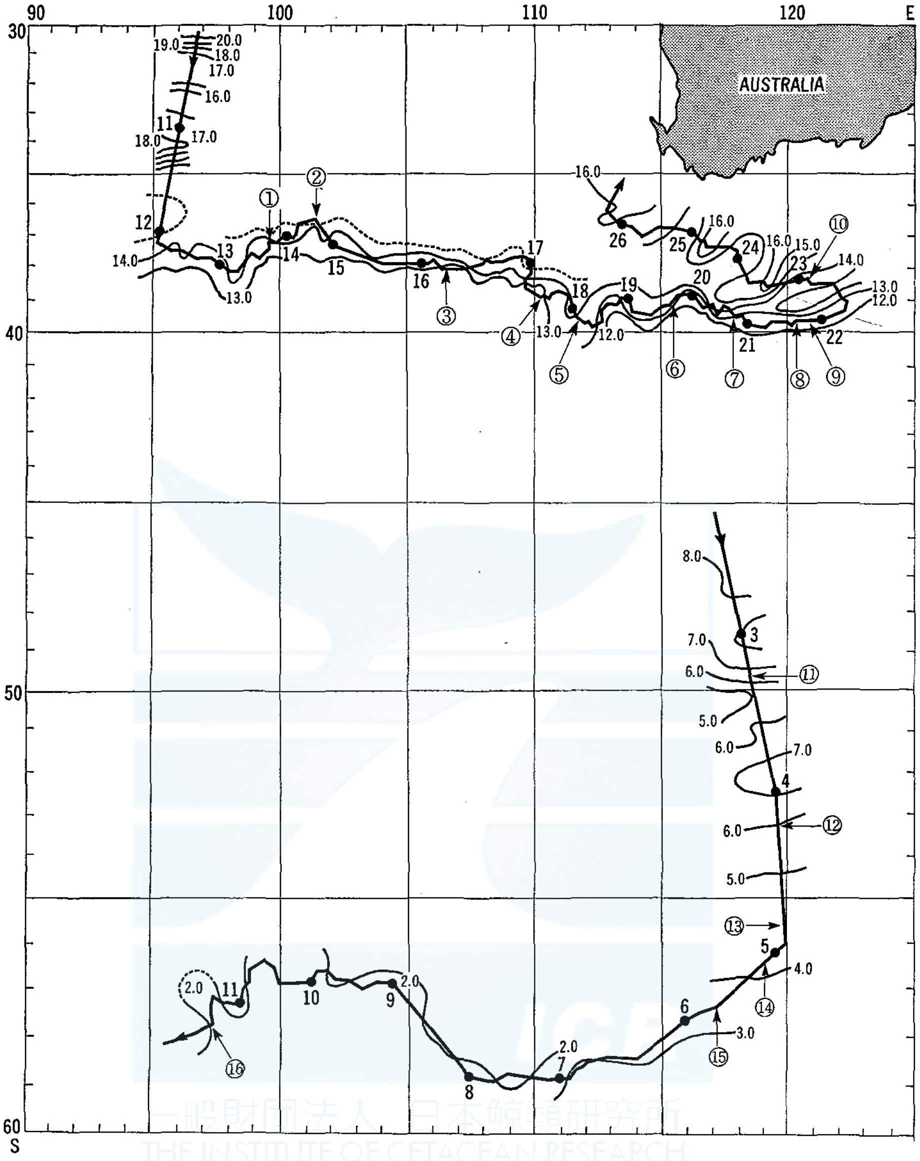

Fig. 11–1. Track of the Eihô-Maru with approximate isotherms along the ships cource during Dec. 11∼26, 1971 and Jan. 2∼11, 1972. Black spot represents the ship's noon position. Numerals with arrow shows the serial number of patches sampled as details are given in Tables 11–3 and 11–5.

confusion with the shades of cloud on the sea surface. However, it was usually over cast or cloudy throughout this investigation, and any hard difficulties in spotting the *C. tonsus* patches were not noticed. The number of surface swarms which occurred along the ship's cource were counted usually by three watchers.

While the ship cruised at the speed of about 10 knots, the shape and an approximate size of *C. tonsus* patches that passing through by the ship's course were also determined as exact as possible by the author on the upper deck. As the eye level at the upper deck was relatively low (ca. 8 meters high above the sea level) there was some difficulties to figure out exact shape of patches which spread out far beyond in the surface waters where large swells and waves prevailed. The shape of patches was determined by observing meandering margin of the patches at least from three different directions, *i.e.* front, side and back as ship passing through by them. The margin of far opposite side from the ship could be sometimes determined when the margin of the patches was on the top or on the slope of swells and waves.

The swarming *C. tonsus* was collected by two kinds of sampler; the high speed underway plankton catcher which was slightly modified from its initial model V (Motoda, 1959): 5.0 cm diameter in mouth opening, 72.7 cm overall length, Japan bolting silk cloth GG 54 netting (ca. 0.33 mm mesh apertures), and the RGS flow-meter was mounted inside the sampler for estimating the volume of water filtered by the sampler. The another one was Petersen type vertical closing net (Kawamura, 1968a), having 70 cm mouth opening with pylen #24 netting (ca. 1.0 mm mesh apertures). The former was used exclusively for estimating the population density itself, and the latter was for the relative abundance and qualitative analysis of swarming population.

Towing of the sampling gear was made usually at the speed about 2～3 knots by slowing down the ship's speed by keeping some distance before hand from the swarm in question. When the ship seemed to have crossed over the margin of the swarm and positioned inside, the sampling gear was thrown out in the sea. The duration of towing varied from several tenth seconds to several minutes according to the ship's speed and the size of each swarms. In most cases the gear was took in while the net seemed to be still amid of the swarms since the purpose of sampling was focussed chiefly on to know the population density of swarming *C. tonsus* as precicely as possible. Thus, ten samples from *C. tonsus* patches were obtained during December 14 to 23 (see Fig. 11–1). Apart from these sampling on swarms surface tows for ten minutes with under way plankton catcher were made routinely every day, usually at 1000 and 1600 hours (LMT) as far as when there were no surface swarms on the ship's passage. This sampling offered materials to know the standing stocks of copepods and other zooplankters during daytime as the overall plankton population of background waters.

The quantitative treatment on the samples obtained by the underway plankton catcher was made by the flow-meter readings by comparing them with those in calibrations, and 80～90 percent of filtering coefficient under 2 knot towing was adopted for the samples obtained by Petersen type vertical closing net.

The population density, however, varied considerably even within the identical swarm judged by the pattern of discoloration, and those observed between many other swarms. The underway plankton catcher might have been towed through non-swarming waters more or less, which would make the figures on population density small by dilution. So the results obtained were also variable by the patches and the observed population density of *C. tonsus* must be considered as the " at least " figures.

11–3. *General hydrology in the investigated region*

As shown in Fig. 11–1 the region investigated spreads over between the latitudes of 30°S and 40°S, and between the longitudes of 95°E and 122°E. The ship had not equipped any research instruments, and the depth record of temperature was not known. The general pattern of isotherm distribution was figured out by refering to Rochford (1962) since the data obtained by the "Eihô Maru" was too fragmentary and insufficient to show the overall pattern in temperature distribution. The ship, however, took a cource mainly along the isotherms of about 12.0°∼14.0°C in search for sei whale. The isotherms of these temperature are usually concerned as a bounday between the Subtropical region and the Subantarctic region, say, the Subtropical Convergence. The most of surface swarms of *C. tonsus* were found in this region. The isotherms run for west-east direction roughly parallel to the latitudinal lines although they showed rather complicated features in the waters south of Western Australia where the tongue-like warm waters intrude considerably from the north to make the surface temperature relatively high. According to Rochford (1962) the area in question can be regarded as the South Transision Zone where distinct change in salinity is characteristic.

11–4. *Shape, color, and size of C. tonsus swarms*

As it is shown in Fig. 11–2 the shape of *C. tonsus* patches was manifolds. However, they can be roughly classified into three types of the shape, *i.e.*, meandering stream or streak bands, spindle shape, and quite irregular shape with many tongue-like protorusions. The shape of patches can be said in general that they are different to some extent in their complexity from those previously reported in the patchiness of southern and northern euphausiids (Marr, 1962; Nemoto *et al.* 1969). Some of them were stream like shape being kept very long for several miles as having been called the " plankton stream " (Nemoto, 1962). Most of the patches were formed in the very surface so as to perhaps be easily deformed by the wind and wave actions to show quite irregularity as some figures shown below in Fig. 11–2. It is noticed in the figure that the *C. tonsus* patches keep more or less definite shape when the sea surface conditions were smooth enough under slight wind. Movements of the whole body of patches as suggested in some euphausiids (e.g. Nemoto, *et al.* 1969) were unknown.

Orientation of patches in connection with the relative wind direction and force were: the longer axis of patches against the wind direction kept at the angle of about 90°, or the longer axis kept nearly parallel to the wind direction, and or incoherent by the mixed characters of the two formers. There seem, however, some another causes such as swells, tidal current or even the action by the Langmuir circulations (Langmuir, 1938; Scott *et al.* 1970; George and Edwards, 1973) to be present other than the wind action. The following fact is also note worthy when we consider what causes the plankton patchiness, that is, *C. tonsus* patches kept tightly even in the rough sea conditions such as the wind force 5 which seems rough enough to disturb the swarms. Mentioning on the patchiness of *Euphausia superba*, Hardy (1936b) pointed out that their patches were kept under the sea condition up to at least the wind force 7.

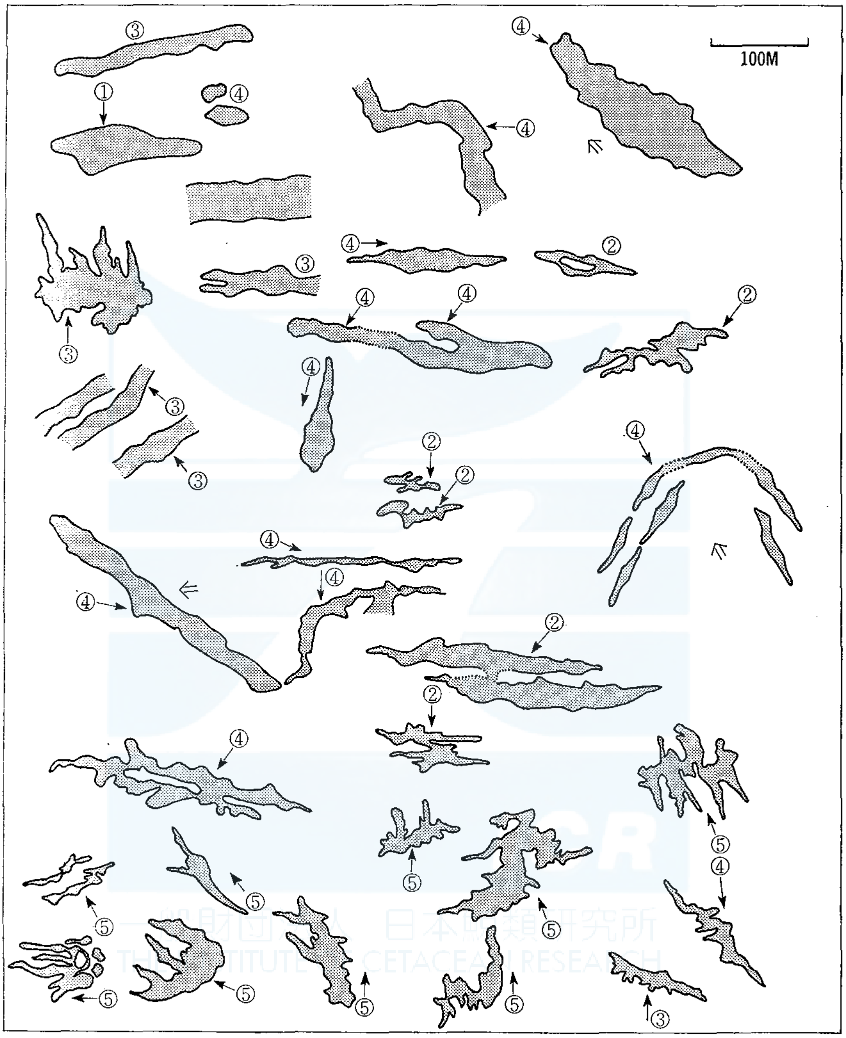

Fig. 11–2. Rough sketches of *Calanus tonsus* patches. Arrows and numeral in the circle show the wind direction and the force.

Sometimes a discoloration of waters by swarming was distinct, but it varied considerably by patch to patch, or by part to part of even in the identical patch. There were void or extremely poorly distributed spots in the midst of the patch through which clear blue water was seen. It is also observed that there were clear water whenever the discolored water was smashed and turned by the ship. This seems to be due to " hop and sink " movements as observed in *C. finmarchicus* swarms (Bainbridge, 1952). He (Bainbridge, 1952) observed it within 12 inch depth, and the above facts suggest that the dense swarms in *Calanus* must be found within very thin layer of the surface. The variations in discoloration character were seemed to be caused maily by the variable change in population density of swarming *C. tonsus*, followed by the character of at what depth the center of swarms is kept in the surface layer.

The distinct difference in the size of *C. tonsus* patches from those of euphausiids was much widely spreading out in the former. Most usual size having been known previously in euphausiids were several tenth meters in diameter (Marr, 1962; Ozawa *et al.* 1967, 1968; Nemoto, *et al.*, 1969), while those in *C. tonsus* were hundred to several hundreds meters in their longer axis. One of the longest sizes under stream like patches showed the length of about several miles. Kitou (1956) also reported 15 miles long patches of *Calanus finmarchicus* in the North Pacific. This kind of difference in size might be caused something by nature of organism itself because the sizes of swarming in patchiness have been known characteristic by the plankton species concerned, *i.e. Parathemisto* and *Salpa* sp. usually show 3 miles wide (Hardy, 1967), and Galathea shows much larger size than *Euphausia superba* (Ozawa *et al.* 1967).

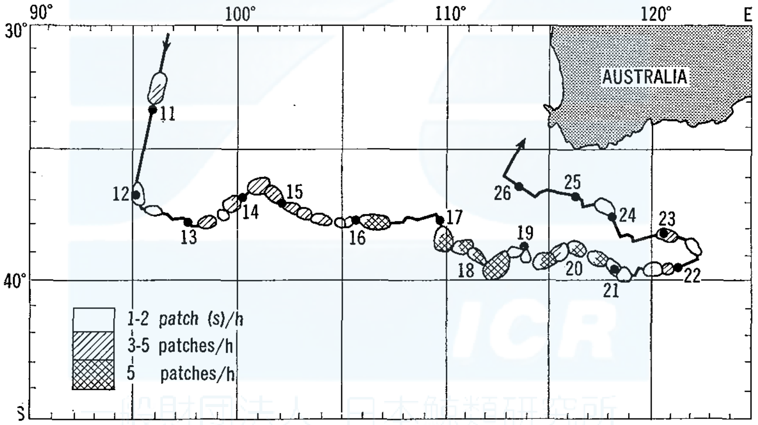

Fig. 11–3. Schematic map showing the distribution of patches of *C. tonsus* during Dec. 11∼24, 1971.

11–5. *Distribution of C. tonsus swarms*

The number of patches occurred within about 2 miles of both port and starboad sides along the ship's cource were recorded. As mentioned before the number of patches, however, must be regarded as " at least " or round numbers since the patches of poorly discolored had perhaps been overlooked when they were far enough from the ship to be detected by binoculars.

Fig. 11–3 demonstrates the general features of the occurrence of *C. tonsus* patches which distributed along the ship's track during December 11∼24, 1971. The patches occurred every day during that period though the frequency in terms of the number of patches per hour was most distinct during Dec. 16∼20 when the sea temperature was in 13.0°∼14.0°C. However, a complete absence in some definite region during Dec. 16∼17 cannot help to be said curious because any unusual sea conditions in temperature were not observed in the region.

The highest number of patches per hour was recorded between 1600 and 1700 hours on Dec. 16 when it was 21 patches/hr. On the way down to the south after calling Fremantle, Western Australia on Dec. 31, the ship again crossed over the swarm rich area of Dec. 20 at the position between 115° and 116°E longitudes with the time lag of 11 days and 15 hours. The sea temperature was 14.6°C when crossed the previous track. However, none of signs showing the presence of *C. tonsus* swarming were observed in this time.

As it is noticed in the poor occurrence on Dec. 11 and Dec. 24, the *C. tonsus* patches usually do not occur in the region where the sea temperature of high above 16.0°∼17.0°C prevails (see Table 11–1). According to Brodskii (1964) and Jillett (1968), *C. tonsus* occurs at the sea temperatures between 5.0°∼15.0°C in the southern waters, and both Kawamura and Hoshiai (1969) and Kawamura (1970b) also confirmed those temperature as possible conditions of their habitat. Accordingly the distribution range of *C. tonsus* as a function of sea temperatures concerned would be considered as relatively wide ranged. However, the main body of early summer concentration of sei whale which exclusively feeds on *C. tonsus* patches (Kawamura, 1970a) in the Subantarctic waters is found at the temperature of 10.0°∼16.0°C accompanying distinct temperature gradient (Nasu and Masaki, 1970). These fact and Table 11–1 suggest that *C. tonsus* prefers somewhat warmer waters, and its patch would not have been formed much in the waters south of 40°S and in the waters under the temperature of higher than 16.0°C.

TABLE 11–1. SEA TEMPERATURE AND THE NUMBER OF *C. TONSUS* PATCHES OCCURRED.

Sea temperature (°C)	No. of patches
11.0–11.9	4
12.0–12.9	46
13.0–13.9	117
14.0–14.9	49
15.0–15.9	4

To know the relationship between the occurrence of patches and the sea temperature more precisely, Fig. 11–4 was arranged. As mentioned before, *C. tonsus* patches occurred most frequently during Dec. 14∼20, and the trends of sea temperature change by hours in connection with the occurrence of patches during those period were distinct; a very frequent occurrence of patches can be expected under the small-scaled variable temperature change. The sea temperature in the figure represents the value measured every hour, but it varied very frequently

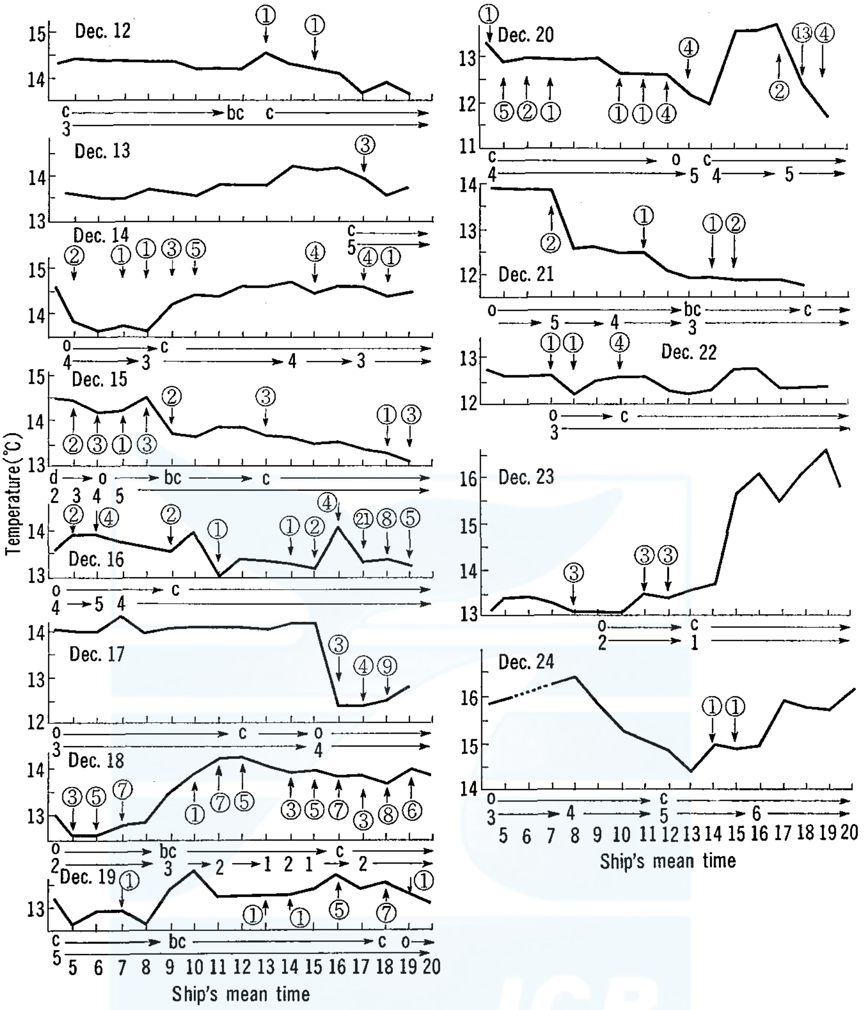

Fig. 11–4. Sea temperature and the occurrence of *C. tonsus* patches along the ship's track during Dec. 12∼24, 1971. Arrow shows the time of occurrece and the numeral encircled shows the total number of patches occurred in every one hour.

TABLE 11-2. TEMPERATURE VARIATION WITHIN VERY SHORT TIME.

Date	Time (SMT)	Temperature change (°C)
Dec. 17	1520–1600	14.5 ∼ 13.3
	1620–1730	14.2 ∼ 12.3
Dec. 18	1300–	Very frequent change within the range of 0.2∼0.3
Dec. 20	1200–1220	12.3 ∼ 14.7 ∼ 12.0
	1350–1640	11.9 ∼ 14.8 ∼ 15.1 ∼ 11.9
	1700–	11.9 ∼ 11.7
Dec. 21	0700–0800	14.8 ∼ 11.9 ∼ 12.4

through hours to hours as an example given in Table 11–2. This suggests that the occurrence of patches would be closely related to the characters of sea temperature distribution especially to the small-scaled local hydrological structures, which something likely to micro-distribution of plankton as demonstrated by Cassie (1959). Poor occurrence of the patches during Dec. 23～24 would be attributed to an unfavourable high temperatures for swarm formation, and those on Dec. 12～13 should be noted as the result of monotonous hydrological conditions possibly due to relatively poor temperature gradient.

The conditions of sea surface in terms of wind force varied from class 1 to 5 throughout the investigation though the most was in the class 3 to 4. During Dec. 16～20, when the patches appeared frequently, the wind of class 4 or 5 prevailed. This fact suggests that *C. tonsus* patches never be dispersed or scattered away at least under these roughness of the sea surface.

11–6. *Frequency distribution by hour*

Fig. 11–5 demonstrates the frequency distribution of *C. tonsus* patches by every observed hour. A total of 220 patches was counted. As far as the figure concerned, the diel variation of occurrence makes us confirm that *C. tonsus* patches which were consisted of almost exclusively by the copepodite stage V likely to move vertically, and a considerable number of patches come up to the very surface in the evening between 1700 and 1800 hours. It is also shown that there are two other peaks in frequency distribution: early morning and daytime, although they are hardly comparable to those found in the evening. By analysing the feeding habits of southern sei whale which feeds on *C. tonsus* exclusively, Kawamura (1970a) considered that *C. tonsus* of copepodite stage V does not make any diel vertical migration. So it seems disagree with the above results each other. It is, however, considered that *C. tonsus* patches move slightly down to such the depth, say, 1 or 2 meters under the surface during daytime as to be hardly detected by eyes but still

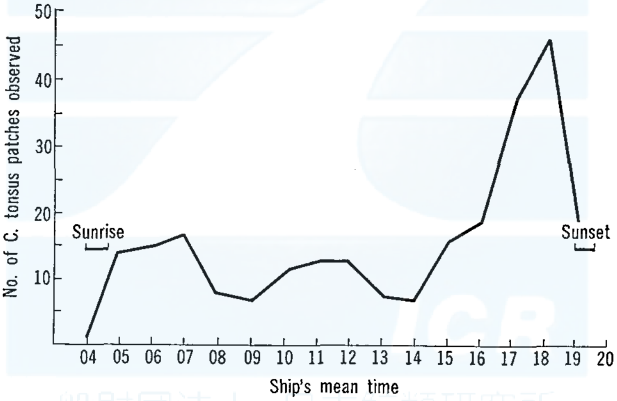

Fig. 11–5. Frequency distribution in the number of *C. tonsus* patches, Dec. 11～24, 1971.

remaining within the enough depth to be fed by the sei whale. This vertical movements in whale's food can be recognized as "Uki-esa", a floating food and "Soko-esa," a bottom food which were introduced by the Japanese whalers. They are not scattered away but still keeping swarm during daytime since the routine sampling by underway plankton catcher at 1000 and 1600 hours did not show any trends of their dispersal which may cause poor occurrence of *C. tonsus* patches during daytime.

The poor occurrence both in 0800~0900 hours and 1300~1400 hours corresponds to 3~4 hours of the time lag from astronomical twilight at 40°S in December (Japan Maritime Safety Agency, 1971) in the former and 4.7~5.9 hours for the latter. This fact suggests that the light condition in or under the surface varies considerably with both cases, and that the vertical movements of *C. tonsus* patches may possibly not correspond to the light condition. Those small scale movement of patches would also differ from patch to patch themselves. The patches of *E. superba* likely to occur more frequently both in the morning and evening, and those by Galathea are distinct in the daytime (Ozawa *et al.*, 1967). The manifold charactors of movements by the kind of patch forming organisms make us confirm that the behavior of *C. tonsus* patches above mentioned may be, as Cassie (1960) suggested, by some internal behavior patterns within the species.

11–7. *Population density in the C. tonsus patches*

In the study on the food and feeding habits of southern sei whales, it was estimated theoretically that the population density in *C. tonsus* patches have to be maintained at least in the order of 10^4 individuals per cubic meter (Kawamura,

TABLE 11–3. PATCHES OF *CALANUS TONSUS* AND *PARATHEMISTO*

No. of patches	Date	Position		Time (SMT)	Sea temp. (°C)	Weather	Wind direct. & force
		Lat. (S)	Long. (E)				
1	Dec. 14	37–14	99–36	0801–0811	13.6	O	NNW 3
2	Dec. 14	36–26	101–21	1845–1856	14.87	C	NW 3
3	Dec. 16	37–56	106–39	1730	13.54	C	ENE 4
4	Dec. 17	38–37	110–07	1820	13.21	O	ENE 4
5	Dec. 18	39–31	111–56	1556–1558	13.80	C	NNW 1
6	Dec. 20	38–59	115–21	0715	13.49	O	S 4
7	Dec. 21	39–21	117–57	0729–0730	12.13	O	SSE 5
8	Dec. 22	39–36	120–22	0720–0722	12.90	O	SE 3
9	Dec. 22	39–54	120–54	1029–1032	13.10	C	SSE 3
10	Dec. 23	38–19	120–48	1107–1108	13.0	O	ESE 2
11	Jan. 3	49–40	118–35	1906–1916	6.24	BC	NW 4
12	Jan. 4	53–09	119–35	1600	5.60	F	NW 6
13	Jan. 5	55–40	119–57	0740–0744	4.20	F	NNW 3
14	Jan. 5	56–22	118–50	1500–1505	4.00	D	NNE 5
15	Jan. 6	57–17	117–07	0341–0350	3.40	O	SSW 5
16	Jan. 11	57–14	97–03	2029–2035	2.20	R	ENE 5

1) Petersen Type Vertical Closing Net (Kawamura, 1968a).

2) Simple Underway Plankton Catcher (Motoda, 1959).

1971a). One of the purposes of the investigation on *C. tonsus* patches was to get an evidense which directly supports those theoretical estimations.

Table 11–3 presents the details of ten *C. tonsus* patches which were sampled actually, and the quantitative results on the samples were given separately. In the most of sampling in the field, the plankton catcher was towed as to cross over the patches in their short axis. The duration of net towing varied from several tenth seconds to several minutes since individual density varied both vertical and horizontal plane even within the identical patch in addion to the variation of patch sizes. As it will mentioned later, the patches were composed of almost solely by *C. tonsus*, and the number of individuals in a haul was determined by sub-sampling a small fraction of materials such as 1.0 gram or so.

The individual number of *C. tonsus* patches per cubic meter of water varied considerably by the patches: 330 inds./m^3 as the lower extreme and 23,680 inds./m^3 followed by 21,165 inds./m^3 as the upper extremes. So the individual density found in this study was in the range of 10^2 to 10^4 inds./m^3. Some of these figures would not represent an exact density because the sampling method employed in this investigation was in danger of failure in quantitative treatment due to the irregularity of individual distribution within the patch and also due to those variables in vertical section against the definite sampling level in the water. Accordingly the population density within the patches always tends to be under estimated as Fraser (1962) mentioned the difficulty on this matter. The population density of $2\times10^4\sim3\times10^4$ mg/m^3, which is equivalent to about $3.8\sim5.7\times10^3$ mg dry weight/m^3 (after dry/wet weight ratio of *C. tonsus* by Bradford, 1972) would be

GAUDICHAUDII WHICH WERE SAMPLED BY THE NET.

Kind of net used	Kind of patch organism	Approx. size of patches[3]	No. of individuals per		Wet weight per	
			haul	m^3	haul (mg)	m^3(mg)
PVCN[1]	*Calanus tonsus*	40×500	144633	670–761[4]	177900	848–937[4]
„	„	30×120	146545	623–701[4]	212690	905–1018[4]
SUPC[2]	„	10×500	4750	23680	5890	29362
„	„	10×400	2884	—	4710	—
„	„	100×300	16720	21165	27500	34810
„	„	10×150	266	3446	—	—
„	„	60×500	1525	6277	2990	12305
„	„	150×100	5035	8626	9500	16274
„	„	6×500	167	330	—	—
„	„	100×1000	123	350	—	—
PVCN	*Parathemisto gaudichaudii*	unknown	1688	8–9[4]	5800	27–31[4]
„	„	„	389	36–41[4]	—	—
„	„	„	565	7–8[4]	—	—
„	„	„	353	3–4[4]	—	—
„	„	„	2100	8–9[4]	32300	129–145[4]
„	„	„	4273	3–4[4]	91900	72–81[4]

3) Width×Length (m).
4) Upper and lower extremes of 80% and 90% fiiltering coefficiencies of the PVCN when towed at the speed of 2 knots.

agreeable when compared with the previous estimations of between $3\sim6\times10^4$ inds./m^3 (Kawamura, 1971d), and the result of 9×10^3 mg/m^3 in *Calanus* (Manteufel, 1939). The above results also well agrees to the figure obtained in *Calanus finmarchicus* patches by Kitou (1956), where 8,208 individuals per $0\sim1$ meter haul (ca. 2×10^4 inds./m^3) were recorded.

11–8. *Zooplankton abundance in the back ground waters*

To compare the quite large zooplankton standing stocks maintained by *C. tonsus* patches with those lying in the waters outside from the patches as a back ground, sampling by 15 minutes surface tow with underway plankton catcher was conducted twice a day during Dec. $11\sim26$, and the Petersen type vertical closing net was drifted at times after sunset as supplemental sampling.

Table 11–4 gives the figure that zooplankton standing stocks are very poor during the daytime when only $1\sim2$ individuals per cubic meter of water was found. The area investigated was so barren as a whole only maintaining organisms less than 10 mg/m^3 throughout the investigated period though they increased to about two folds or more in the night; $1\sim60$ mg/m^3. Comparing a poor occurrence both in the number of species and individuals during daytime, most samples in the night showed rather rich zooplankton communities by *C. tonsus* of stages V and VI of female, *Neocalanus gracilis*, *Euphausia lucens*, *E. recurva*, *Ostracods*, *Doliolum* sp. *Salpa* sp. and *Sagitta* sp.

TABLE 11-4. AVERAGED ZOOPLANKTON ABUNDANCE COLLECTED BY UNDERWAY PLANKTON CATCHER IN 15 MINUTES SURFACE TOW DURING DEC. 11~26, 1971.

Organisms	Abundance
Calanus tonsus Copepodite V	0–1 ind./m^3
Micro-calanoida	0–20 ind./m^3
Amphipoda or euphausiacea	0–1 ind./m^3
Doliolum or *Salpa*	0–0.1 gr/m^3

However, in the region concerned to this study it has been known as relatively poor in zooplankton population having been reported less than 25 mg/m^3 (Tranter, 1962), and euphausiids also distribute as poor as in the tropical region of the Indian Ocean (Baker, 1965). The region under consideration can be noted quite characteristic where food rich waters float like a islands or rafts in the ocean which would possibly give a quite different results in the estimation of plankton biomass by sampling condition whether the patch or a part of it were collected or not. Baker (1965) stressed on this matter while he was studying on *Euphausia vallentini*, one of the another important whale's food in the Subantarctic region.

The occurrence of *C. tonsus* patches can be considered to make the region quite characteristic as an ecological environment particularly for the predators in higher trophic levels such as *Scomberesox saurus*, Gonostomatid fishes (Kubota & Kawamura, 1972) in the pelagic waters and basking sharks *Cetorhinus maximus* in offshore waters (Bradford, 1972).

11–9. *Some biological characters in the C. tonsus patches*

The size composition of *C. tonsus* population which formed patches is demonstrated in Fig. 11–6 which was obtained by examining 1152 individuals in all. The size of *C. tonsus* in stage V copepodites through ten patches varied almost within the range of 3.2∼3.3 mm with an average 3.295 mm (N: 1141). There were no stage V copepodites smaller than 2.8 mm and those larger than 3.6 mm. In contrast to dominant occurrence of stage V copepodite (99.2 percent on average) the adult females occurred but very small numbers, 11 out of 1152 individuals. They varied between 3.5 mm and 4.1 mm with an average 3.764 mm, and their size distribution agrees well to that of the populations usually found in 40°S latitude (Brodskii, 1964) where it seems about 3.78 mm as his figures concerned. A fairly poor occurrence of adult females among patch forming population agrees to the result on the food analysis in sei whales (Kawamura, 1970a) and it is also similar to net samples obtained in circumpolar waters (e.g. Brodskii, 1964).

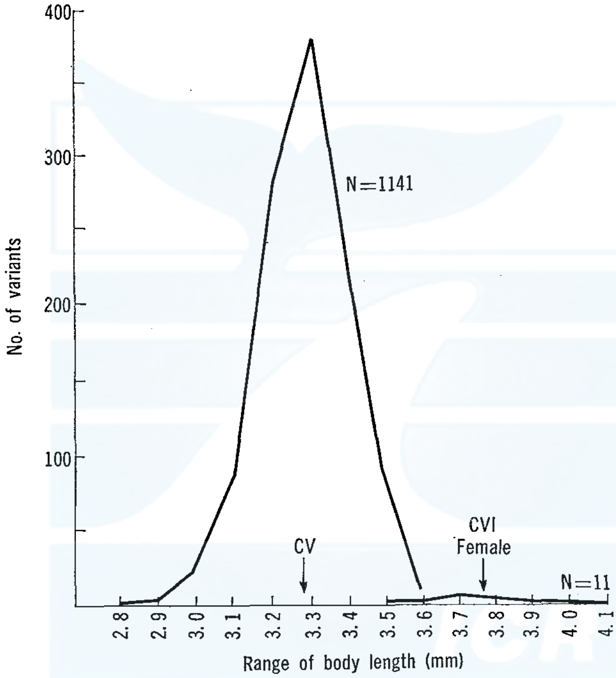

Fig. 11–6. Variability of the body length of *Calanus tonsus* which formed patches.

However, the size of *C. tonsus* by each patches as numbered 1 to 10 in Table 11–5 shows some interesting facts: the patches of Nos. 1 and 2 were consisted of relatively small sized individuals of 2.8∼3.4 mm with an average 3.18 mm and of 2.9∼3.5 mm with an average 3.28 mm respectively. In contrast to this figures, the patches of Nos. 3 to 10 were consisted of more larger individuals with the size of 3.1∼3.6 mm with an average 3.32 mm. There seems two possible explanations on the differe nce in size distribution of stage V copepodites of *C. tonsus*:

During the austral summer it is known that two generations of *C. tonsus* in stage V copepodites as summer population are present, that is, the individuals of previous year origin and that developed in the current season (Jillett, 1968), and differences in body length composition in the *C. tonsus* patches may be due to this breeding character. One of the anothers also could be considered. According to Brodskii (1964) there are latitudinal difference in body size of *C. tonsus*, and larger individuals are usually found in higher latitudes. So it is possible that the patches of Nos. 1 and 2 were relatively northern water origin accompanying with warm water species of zooplankton (see Table 11–5). These facts suggests that both the patches of Nos. 1 and 2 might have been isolated through their development from others of Nos. 3 to 10, which were possibly the offsprings from the same initial population stock.

TABLE 11–5. BIOLOGICAL CHARACTERS OF *CALANUS TONSUS* PATCHES.

No. of patches	Av. body size (mm)	Av. body weight (mg)	CVI ♀/CV (%)	Range of body size (mm)		Organisms occurred with *C. tonsus* (No. of inds./haul)
				CV	CVI ♀	
1	3.18	1.23	1.65	2.8–3.4	3.7–3.8	*Vellella vellella* (18) Amphipoda (36) *Cavolinia* sp. (1)
2	3.28	1.45	3.22	2.9–3.6	3.6–3.8	*Doliolum* sp. (473) and others*
3	3.34	1.24	0.77	3.1–3.6	4.0	—
4	3.35	1.63	0.87	3.1–3.6	3.8	*Thysanoessa* sp. (1) Amphipoda (2)
5	3.35	1.64	16.23	3.0–3.6	3.5	*Thysanoessa* sp. (7) & juv. (9) *Euphausia* sp. juv. (2)
6	3.28	—	—	3.0–3.5	—	—
7	3.39	1.96	0.78	3.0–3.7	4.1	Amphipoda (1)
8	3.25	1.89	—	3.1–3.5	—	—
9	3.30	—	—	3.1–3.6	—	Copepoda (3) Amphipoda (1)
10	3.27	—	—	3.1–3.5	—	—

* *Diphyes antarctica* (1), *Cavolinia* sp. (1), Combjelly (1), *Cyllopus* ?(1), *Euphausia* sp. juv. (6), Squid (1), and fish larva (1).

The geographical location where the patches Nos. 1 and 2 were collected was in the waters far west from the others, and relative abundance of adult females is large enough to distinguish them from another patches. The zooplankton species entangled along with a bulk of *C. tonsus* seem also to be something different between the patches Nos. 1∼2 and Nos. 3∼10. In the Nos. 1∼2 patches there were found some warm water species such as *Vellella vellella*, *Doliolum* sp. and *Cavolinia* sp. while these species were completely absent in the others. Similar facts showing a different biological characters by patches have been found in the population of *Euphausia superba* (Mackintosh and Wheeler, 1929; Marr, 1962), and these facts seem to be essential characters widely found in zooplankton swarms.

The average body wet weights also varied between 1.23 and 1.96 mg. through Nos. 1 to 10 patches. However, they showed no parallel relationships to the body length as noticed by comparing the patches Nos. 2, 4 and 8. The patch forming individuals must be different in their physiological conditions even in the same developmental stages.

It could be considered as a whole that the patches of *C. tonsus* keep their biological characters each other to some extent, and this means that they do not mingle each other for some long time, and that they are controlled by some biological functions to swarm or aggregate themselves, if not the patches and their biological characters could not be kept so distinctly under the continuous disturbance by strong winds and smashing waves. Marr (1962) mentioned that patches of *Euphausia superba* are maintained for long time through their life span, and rarely found mixed populations with the individuals in different developmental stages among the identical patches. Hardy (1967) also confirmed the similar evidence as a function of strong self-swarming behavior by euphausiids. In the neritic waters, the planktonic larvae of *Balanus* and *Mytilus* sometimes show a dense patchy distribution, but they dispersed over soon after as season proceeds (Raymont, 1963). The patches of euphausiids, or copepods found in the pelagic waters would be considered different in their biological nature such as socialized function through swarming behavior as Steven (1961) and Clutter (1969) confirmed it in the patches of mysid from those swarms by temporal zooplankton species.

11–10. *Possible cause of swarming in zooplankton*

The zooplankton does not evenly distribute throughout its habitat but distribute quite unevenly as has been known by an actual experience in the North Atlantic cod fishing grounds. The swarms or the patches of zooplankton could be seen as one of particularly distinct phenomena of spatial distribution, and those sighted by C. Darwin in the Antarctic region near to Tierra del Fuego might possibly be the plankton patches (Darwin, 1906). The swarming phenomenon in zooplankton has been documented to some extent by Mackintosh and Wheeler (1929) who studied on the food habits in baleen whales, and also by Hardy (1936a, b) in his investigations by the continuous plankton recorder. Hardy (1936a, b) also made it clear that the uneven distribution of zooplankton is not so special phenomenon but rather general characters as a whole, which made him criticise the recognition of even distribution of zooplankton by Hensen (1890). Through his studies on the uneven distribution in plankton population, Hardy (1936a, b) called " patchy distribution " or " patchiness " of plankton when they swarmed densely in a spacially limited region. For example, Hardy (1936a) found patchy distribution of *Salpa longicauda* when they densely swarmed with more than 30~50% larger in their population density to that of the back ground waters. The patchiness as one of a distribution patterns in animals, therfore could be considered a kind of sociality in animals, and Imanishi (1941) called the theme as specific synusia an ultimate pattern of population life as widely found in the insect communities. Imanish (1941) considers these monospecific swarms or aggregations in animal community would be somewhat unusual in their daily life, but the patchy distribution in organisms itself can also be considered rather usual distribution patterns since it is widely found throughout both animal and plant kingdoms.

One of the distinct examples of plankton patchiness is known in *E. superba* and *M. norvegica* populations, and they swarm such densely as to make the sea heavily discolored. It was this discoloration of the sea that has made whalers spot the whales and whaling ground. The *E. superba* population under patchiness is exclusively monospecific composition, and it also clearly formed independently by the individuals in the same developmental stages (Mackintosh, and Wheeler, 1929; Mackintosh, 1973). Therefore, the zooplankton swarming into patches differs in a sence from the patchy or uneven spatial distribution. The latter would be widely found in any kind of plankton communities. The *E. superba* patches are quite important ecologically since they are voraciously fed by the baleen whales while none of *Sagitta* spp. and pteropoda under similar patchiness are fed by the whales. What whales feed exclusively on swarming organisms which form the patches indicates that patch formation would be a staple distribution pattern through the evolutional ages since baleen whales must have adapted to develop specialized apparatus, the baleen or whalebone so as to utilize those patch or aggregation forming organisms.

In the northern North Pacific and Bering Sea, *Sagitta*, *Aglantha* and *Clione* sometimes show a distinctly larger biomass (Hokkaido University, 1962). In the southern seas *Sagitta* spp. also show a patchy distribution (Hardy, 1936a). However, a bulk of occurrence of these organisms is usually accompanied along with many other plankton species to show a complicated zooplankton communities though *Sagitta* occurs with patchiness. More recently, Wiebe (1970) observed on the small scale spatial distribution of zooplankton in detail and he called " patchy distribution " against the plankton biomass of about 2.6~5.1 times larger than the back ground, while Kuwabara *et al.* (1971) definited the patchy distribution as with the biomass larger than the overall median value in a series of samplings. These patchy distribution as definited above however may be similar but different from so-called plankton patches by aggregating or swarming of organisms in view of their community composition.

As it has been mentioned the population density in *C. tonsus* patches was maintained under somewhere between 10^3 and 10^4 inds./m^3. These figures would be larger, approximately several thousands to several tenth thousands times than the back ground waters, and this somewhat similar to the case in *E. superba* (Marr, 1962) and *M. norvegica* (Mackdnald, 1927) where it was larger about 200 to 300 times. Anyhow the zooplankton patches is quite important ecologically in the marine food chains. For instance, a squid, *Nototodarus sloani sloani* which distributes in New Zealand waters feeds on the swarms of both *Nyctiphanes australis* and *P. gaudichaudii*, and *Todarodes pacificus* also feeds on *E. pacifica* (Kawakami *et al.*, 1973; Kawamura, 1974b). These facts suggest an importance of the plankton patches other than the case in baleen whales since the squids supposedly distribute over the world oceans with great quantity.

For the convenience of further discussion on the patches in *C. tonus*, their biologically important characters are given as follows: 1) a horizontal expansion of the patches is at least several hundred meters, 2) the shape is usually recognized with the scale in horizontal plane, *i.e.* stream, round or oval shaped, 3) the patches and its shape firmly maintanined under a rough sea of 8.0～10.7 m/sec in wind speed and 5 class of waves, 4) patches occur most frequently under the temperature of 13.0～14.0°C, where distinct temperature gradient prevails, especially in the regions under varying temperature, 5) higher population density of patches is mostly found in the surface waters shallower than 1.0 m but some are in more deeper waters, 6) the population density under patchiness would be 10^3～10^4 inds./m^3, 7) the patches are composed of copepodite V though sometimes a little number of copepodite IV and adult female are mixed up, 8) biological characters of patch forming *C. tonsus* population are maintained for long period, 9) occurrence of patches varies with time in a day, 10) patches may show a slight diel vertical movements without any relations to underwater illumination. Among these characters, 3), 7) and 8) strongly indicate that the patches are neither formed by random variation in the distribution nor physical conditions of the water but purely biological causes of internal behavior to aggregate themselves.

Various discussions have been stated on the possible cause to make zooplankton swarm so densely, and the discussion could be divided into three opinions: one of them discussed the phenomenon as being a subject of zooplankton or organism itself, so the environment, have somewhat the secondary importance for it (*e.g.* Gurney, 1924; Russell, 1927; Hardy and Gunther, 1935; Watermann, 1958; Colebrook, 1960a, b), and the other considers an inorganic environments first such as current, circulation of the water, underwater illumination which directly influences on the formation of swarms (Fraser, 1936; Bogorov, 1938; Beklemishev, 1958), and the third is a combinations of the both above mentioned, and Colebrook (1960a, b) considered the surface swarming in *Daphnia hyalina* would supposedly caused by whirling movement of water and swarming behavior of *Daphnia* itself, whereas Russell (1927) insisted the purely biological factors of zooplankton to aggregate themselves after his observations on decapod larva. " Localize didtribution " in *M. norvegica* in the North Atlantic must be due to a seasonal change in an availability of foodstuff along with being chased by predator and with an effect by tidal currents. However, when we consider the biological characteristics of the swarming or patchiness in *E. superba* and *C. tonsus*, it does not seem to be caused by environmental conditions such as the current, upwelling, pack-ice and its melted water but caused primarily only by the subject of those organisms, that is, 1) a monospecific composition of swarming population is maintained for long period (Mackintosh and Wheeler, 1929; Marr, 1962), 2) each patches are composed of individuals in a definite developmental stages but it would possible to occur two kind of patches each of which composed of different developmental stages in the same sea region, 3) orientation of *E. superba* individuals within the patches is almost in the same direction and the patches are quickly reorganized after disturbance (Hardy and Gunther, 1935), and 4) patches are well maintained through even rough weather.

In this study I sighted at many *C. tonsus* patches even when the surface was very rough under the wave class 5, say, 8.0~10.7 m/sec in wind speed. According to Sakamoto (personal comm.) a theoretical current speed which is possible under the wave height of 1~5 m would be 62.5~140 cm/sec. Under these circumstances *C. tonsus* could not maintain those high population density unless they swim actively againt to the current. According to Marshall and Orr (1955) the swimming speed in *Calanus* was 0.42 cm/sec. in long ascent movement, and 1.32 cm/sec. in descent. Still more most *C. tonsus* patches occur in the convergence region where the water sinks to some extent, which would require to make *C. tonsus* move upward to keep their position within the surface layer. However, Jillett (1968) stated that the dense population in *C. tonsus* would be due to an accumulations caused by some current dynamics, and it is in these points that I disagree with his consideration.

If *C. tonsus* forms dense swarms or patches not by a enviroммental conditions but by its habits of gathering closely each other into an aggregation, there would be found some physiological and ecological benefits for them as Allee (1938) and Lorenz (1963) discussed beneficial effects in many kind of aggregating animals. The population density in *C. tonsus* patches was approximately $6 \times 10^3 \sim 2 \times 10^4$ inds./m^3 though the figures as plankton biomass still much less than *E. superba*. However, these above mentioned population density would be enough to make the individual under the patchiness touch each other while they jostling one another, and the explanation on the plankton swarming by some factors such as the structual features in a column of water, photo taxis, sensory for polarized light and grazing could not possibly keep the individuals so closely for long time. The antennule in crustaceans functions as a sensory organ (e.g. Dahl *et al.* 1970a, b), and the role of the frontal organ in *Calanus*, and the setae on the antennule themselves would function similarly. The stimulation induced by physical contact while jostling would release the behavior of swimming at least toward the surface (Rudjakov, 1970). Allee (1938), however, considered the absence of any kind of physical contact in copepod aggregations, but also suggested their social habits.

Apart from that above mentioned, one of another possible cause being proposed might be a chemosensory receptors furnished on the antennule although any kind of the receptor had not known yet in *Calanus*. However, its presence in brackish water amphipoda, *Gammarus duebeni* as receptor for sex pheromone (Dahl *et al*, 1970a, b) and in decapod crustacean, *Portunus sanguinolentus* (Ryan, 1966) must function as chemotaxis of a gathering attractant. The swarming in crustaceans particularly under monospecific compositions therefore might possibly benefit as the density or grouping effects in growth speed and shortening the larval period, such as known in a kind of cockroaches (Ishii, 1970; Chauvin, 1967) and in oligochaetes (Brinkhurst *et al*, 1972). According to Ishii (1970) the swarming and settling in a nauplii of *Balanus* sp. are controlled by chemical factors though only settling factor has been known to induce their aggregation and simultaneous settling on the bottom. Stimuli by physical contact through body touch would make copepods ascent toward surface (Rudjakov, 1970), which may explain the occurrence of densely aggregated *C. tonsus* population in the very surface waters. However, since the *C. tonsus* patches were found not only at the surface but also at several meters depth, some another causations to explain these circumstances have to be considered in the future. Bainbridge (1953) indicated the importance of vision and reotactic sence which might explain the animal aggregations, but it would be still in need of examinations to appropriate his indications at least on to *C. tonsus* population and other copepods since visual sence in these organisms is poorly developed. Learning and practising behavior found in the fishes may also be difficult to appropriate on to swarming in zooplankton.

12. GENERAL DISCUSSION AND CONCLUSION

The behavioral patterns of animals in time and space are so complicated features as to hardly be understood even their outlines. However, when we consider a movement of animals in view of the population ecology as a whole, they could be approached to some extent since they were mostly controlled by instinctive behavior of both breeding and feeding as has been pointed out by Elton (1927), and the whales do not differ essentially from another mammals but rather simple due to their seasonal migratory behavior between cold and warm seas. One of the current problems to which the population ecology faces would be to understand the structure and mechanisms of varying animal populations under the natural and artificial factors which affect on their population along with inter-specific factors. Food and feeding habits of animals much influences on the number and size of population through the marine food web. Elton (1927) suggested an importance of study on the prey-predator relationships in connection with the animal populations.

In baleen whales a minute crustacean animals had been known early as the main nutritional sources for the whales (e.g. Scoresby, 1820; Collett, 1929). However, it was until recent years that those food habits were considered from the view points of production ecology in which the secondary producer connected directly with the last consumer, say, a typically simple but effective shift in energy flows. At the sametime, the relationships around food would be an important role on controlling the overall population size of the predators such as, say, catch of anchovata and the population of pelican, whale stocks and the abundance of euphausiids (Kawamura, unpublished data). All these are in need of quantitative treatment in their preypredator relationships. Since the stock of whales is important among all, the study on their food and feeding habits have to be proceeded along with the whales itself.

The sei whale in the Antarctic region distributes along the Subtropical Convergence, and the food organisms in that region are consisted of somewhat simple zooplankton community although the oceanic conditions differ to some extent between the whaling areas. The important food organisms in the southern sei whaling ground are: *Calanus tonsus*, *C. simillimus*, *Parathemisto gaudichaudii*, *Euphausia vallentini*, and *E. superba*. The shift of whaling ground during a season is mostly to the features of the seasonal distribution patterns of food organisms such as disappearance of *C. tonsus* from the surface by its depth migration for wintering. In the formation of whaling ground the patchiness of zooplankton is important among all, since food organisms of whales are restricted in patch forming species. As has been mentioned in the previous sections, the plankton patches as a whole are distinctly characteristic population in general distribution and its movements being differed from the individuals outside the swarms. For example, patches of *E. superba* usually shows diel vertical migrations to some extent (Marr, 1962), while many patches occur in the surface layer throughout the night (Ivanov, 1970). The ecological importance of plankton patches would be understood when we consider their biomass as shown in *C. tonsus* patches where the biomass was $2\times10^4\sim3\times10^4$ mg/m^3 of water while it was only 25 mg/m^3 in the back ground waters. The patches of *C. tonsus* usually found under the temperature of 13.0°～14.0°C whereas the species itself is known to distribute under wide temperature range of 5.0°～15.0°C. (Brodskii, 1964). The whaling ground formed by *C. tonsus* therefore could hardly be recongized only by the characters of its general distribution unless the knowledge on the ecological characters of the patches was accompanied. The movements of whale within the feeding ground would be well understood by studying the causations which make the food organisms densely aggregate into the patches.

In the feeding types of baleen whales the filtering apparatus along with its mechanisms and the feeding ability were considerably different in sei whale from those in blue and fin whales. The sei whale can recognized characteristic in this point though all these three belong to balaenopteridae. The baleen plates of sei whale shows rather slim, and its bristles furnished on the inner margin of baleen plates are fine as comparable with those of balaenid whales. The meshes which cover the inner surface of filtering apparatus are quite fine with relatively larger filtering area among balaenopterid whales. In regard to a selective feeding habits in baleen whale (Nemoto, 1959; 1970), the sei whale prefers copepods at first then euphausiids or amphipods in the Antarctic waters though the latter two are replaced one to another by the regions concerned (Best, 1967; Kawamura, 1970a). A preference to copepods in sei whale also found in the North Pacific where *C. cristatus* and *C. plumchrus* are the staple food (Nemoto, 1959; 1957) although they are replaced by fish and euphausiids in more southern waters (Kawamura, 1973a). The food organisms of sei whale took over by *C. finmarchicus* in the North Atlantic (Collett, 1886). A boltering behavior is known well in fin and blue whales (Lillie, 1910; Gunther, 1949) but is less distinct in sei whale. These facts along with the feeding mechanisms, apparatus, and habits lead to a consideration that the sei whale is more closely related to right and bowhead whales. Nemoto (1959; 1970) however, thought the sei whale belongs to blue whale type feeding apart from right and grey whales types. But when the above mentioned circumstances on sei whale feeding are took into account, its feeding type would be rather much similar to that of the right whale.

The over specialization such as elongated teeth in narwhal, *Monodon monoceros* is usually seen to some extent throughout the order cetacea, and the development of the baleen plates could be considered as one of over specialization themselves (Howell, 1930). In this respect the gulping or swallowing type in feeding would be more general throughout many animals while the skimming type as employed in sei and balaenid whales would be an over specialization. As I have assessed in the previous section, the sei whale can collect more abundant foodstuff effectively by skimming the food contained water than swallowing, that is, the sei whale seems to have aquired skimming type feeding as an more advanced habits for collecting the foodstuff in marine biotope.

Marr (1962), Moiseev (1968) and several other workers assessed the stock size of *E. superba* being based on the consumption of *E. superba* by whales. Apart from the whales, Ryther (1969) also made an estimation of *E. superba* production from the view point of production ecology by supposing the energy coefficient of 10, 15, and 20% in the shifts of the trophic level, and criticized the above mentioned method as out of the discussion. Ryther's methodology itself is one of the subject in production ecology. However, it sometimes leads to a confusion or incorrect conclusions unless the biological characteristics such as the dietary habits of prey and predator were took into account. For example, *E. superba*, according to Barkley (1940) and Marr (1962) preferably feeds on diatoms, *Fragilariopsis antarctica*, and as a whole it seems to avoid larger or longer sized diatom and spinous diatomspecies. *E. superba* likely to strongly avoids the water dominated by *Thalssiothrix antarctica* (Kawamura, 1973b; 1974). However, the biological aspects of feeding babits such as food selection are omitted in the method by productivity which involves all of the organic carbon produced. Hasle (1969) reported abundant distribution of *Nitzschia* spp., *Fragilariopsis* and *Chaetoceros* diatoms in the Pacific sector of the Antarctic but they are supposedly less important as food of *E. superba*. This fact supports well a poor distribution of *E. superba* in that region (Mackintosh, 1973). Marr (1962) considered the gaps or voids in phytoplankton abundance between the waters with rich *E. superba* patches and those separating the patches would be due to grazing.

The animals which distribute dominantly with the bulk of biomass and usually in higher trophic levels likely to prey on zooplankton species particularly those aggregate into the patches. These animals, for instance, are anchovata, gonostomatid fishes such as *Viciguerria attenuata*, *Scomberesox saurus*, squids, seabirds, crabeater seal and whales. The role of those animals in the Antarctic ecosystem would be distinct than any other kind of organisms, but none of them studied yet except whales, and therefore the knowledge of food habits in those animals is considered to be strongly in need of further investigations. However, it has been known that the southern blue, humpback, minke and fin whales feed almost exclusively on *E. superba* though the fin whale utilizes copepods to some extent whereas the sei and right whales feed copepods preferably, though the latter feeds much on euphausiids other than *E. superba* and amphipods, *P. gaudichaudii*. When we take into account the ecological niche concerning to those prey organisms in quantitative and qualitative respects, it would be possible to suppose an outline of the structure of the ecosystem in the southern ocean: the organic production in the Antarctic regions proceeds as a whole under relatively lower trophic levels. Accordingly, the role of zooplankton in the southern ecosystem would be hardly comparable importance than that of any other places, and it seem to be almost impossible to understand the ecology such as the movements and the inter specific relationships among those important predators without studying on the swarming habits of their prey organisms.

The swarming habits in zooplankton however have been poorly studied particularly in the biological and ecological knowledge except several observations as an unusual distribution phenomena (e.g. Hardy and Gunther, 1935; Mackintosh, 1967). As it has been stated in the previous section, *E. superba* and *P. gaudichaudii* occur in patchiness which would be formed by the individuals of almost every developmental stages. On the other hand the patches in *C. tonsus*, *E. vallentini*, and supposedly in many another kind of copepods and euphausiids are formed by the individuals of some particular developmental stages such as the copepodite V in *C. tonsus*. The swarming into patches in *E. pacifica* (Komaki and Matsue, 1958; Komaki, 1967), *The. inermis* and *M. norvegica* (Bigelow, 1924; Macdnald, 1927) would be similar to the case in *C. tonsus* and *E. vallentini*.

Marr (1962) discussed on the possible cause which make *E. superba* aggregate so densely but he did not figure out decisive conclusions after examining particularly the effects by animal exclusion and the pack ice, and stated that the patchiness seems to spring from the lifelong habit of this species.

In the patchiness of *C. tonsus*, I have supposed a kind of density effects which would benefit on *C. tonsus* not as an individual but a population to be kept staple, since as mentioned before the aggregating or swarming phenomenon would be the subject of ethological habits in organism itself. However, the surface swarms of Galatheid shrimp, *Munida gregaria* seems to occur under some particular environments such as the depth or the front like structure of the waters (Tabeta and Kanamaru, 1970). *Pleuroncodes planipes* also swarms in the upwelling region accompanying the oxygen minimum layer (Anonymous, 1971). These facts however would possibly be a phenomena which seem as if it were the causation for aggregation or swarms, that is, a kind of pseudo-factor, and the patchiness of zooplankton would be induced purely by biological but still unknown agencies. Komaki (1967) and Kawamura (1971c) have pointed out that the development or occurrence of so-called patches by swarms would hardly be forecasted by the figures of ordinal physico-chemical environmental factors, that is, the swarming of zooplankton differs essentially from the red tides.

Mackintosh (1967) stated on the behavior of *E. superba* patches that each swarming individuals showed a synclonized swimming as if there were some leader particularly in command of the whole. Their behavior as mentioned above would be similar to " following reaction " in fish schools, which was proposed by Crook (1961). In the school of scombid fishes, the distance separating each individuals and the movements of the tail flukes are the important factors to keep the school tightly (Olst and Hunter, 1970). They (Olst and Hunter, 1970) also found that the school was specially well kept tightly when the distance between each fishes were one half of their body length. The population density in the patches of *E. superba* and *E. pacifica* show one individual per cubic inch or thereabouts (Marr, 1962; Komaki, 1967), and these facts make us suppose that the swarming in euphausiids would be similarly understood though the distance between the individuals within the patches must be more important in euphausiids than the fishes since visual sence is poorly developed in the former.

In the population of insects the density effects usually function in controlling the population size (Ito and Kiriya, 1971), but it is also known in some insect species that the density effects would be benefitial for promoting the relative growth rate by shortening the intervals between individuals, in which the density effects make each individuals shorten their larval period being induced by the promoted secretion of the moulting hormone possibly induced by tactile stimuli (Ishii, 1970). The density effects are particularly more strongly functional in the earlier stages of insect species (Chauvin, 1967). This fact indicates something analogy with the case in swarming *C. tonsus* population composed of the copepodites IV and V, and also the case in some temporal plankton species.

On the study of zooplankton patchiness, the followings are particularly hoped to be known in the future: the geographical and the vertical distributions, the seasonal change, change within short time period, population density and its structure, and the causations which trigger the behavior of swarming. In this study a small underwater plankton sampler (Motoda, 1959) was used in collecting *C. tonsus* patches, but the sampling gear seemed to be insufficient for the purpose of quantitative study since population density varied distinctly even within a patch. In this respect the continuous plankton recorder which revealed clearly the uneven distribution of plankton (Hardy, 1936a, b) must be revaluated. Wiborg (1971), on the other hand, found the population density of 4000 inds./1000 m^3 in *Th. inermis* and 5000 inds./m^3 in *Th. raschii* by towing the IKMT, and he (Wiborg, 1971) considered these high population density would be due to their patchiness. Omori (1965) and his colleagues (Omori *et al.*, 1965; Kawaguchi and Marumo, 1967; Kawaguchi, 1973) have successively used the large sized ring net of 160 cm mouth opening for collecting the micronektons, and proved that the net was considerably effective for patchily distributed organisms such as Sergestid shrimps (Omori, 1969; Omori *et al.*, 1972). These facts suggest that the larger sized towing net in its mouth opening would be more successive for collecting the fast moving or very locally swarming organisms.

SUMMARY

1. The food and feeding habits in southern sei whale, *Balaenoptera borealis* Lesson, which was caught during 1967/68 to 1971/72 seasons by the Japanese floating factories were studied. The observations were chiefly focussed on the distributions of prey organisms by species through which the formation of whaling (feeding) ground was considered biologically. One of another focusses was to figure out a comparative structural characteristics of the feeding apparatus along with the dietary habits in sei whale in connection with the patchiness of prey organisms.

2. The sei whaling ground in recent operations is found in the mid latitudes of the circumpolar seas, say, the Subantarctic waters of 40°∼50°S, where more

than 70 % of sei whale have been caught among all. The formation of sei whaling ground is closely related to the Subtropical Convergence, and the most important areas are the Indian and the western part of the Pacific sectors between 0° and 170°W.

3. The general hydrological conditions of the whaling ground was as follows: the favourable surface sea temperature was somewhere between 14.0°C and 18.0°C during December though it was 8.0°C~10.0°C by some whaling areas. As season proceeds the whaling ground shifts to higher latitudes where the temperature was 14.0°~16.0°C in January, 7.0°~10.0°C in February and then 4.0°C~7.0°C in March. The isotherm recede toward north with the speed of about 1.0°C/1° lat./month in the region concerned.

4. A total of 23 species or more of food organisms were found in the stomach contents of sei whale, and the following 8 species were most important components: *Calanus tonsus*, *C. simillimus*, *Clausocalanus laticeps*, *Drepanopus pectinatus*, *Parathemisto gaudichaudii*, *Euphausia vallentini*, *E. lucens*, and *E. superba*. There were 7 species of food organisms, *C. tonsus*, *Cl. laticeps*, *Thysanopoda actifrons*, *E. diomedeae*, *E. lucens*, *Penaeus* sp. and *Scomberesox saurus* which were newly known in this study as the sei whales food in the Subantarctic feeding ground though both *E. diomedeae* and *E. lucens* had been known as sei whales food in the South African waters.

5. The composition of the stomach contents was monospecific in more than 72 % of the animals examined, and those of mixture with two or more species were rarely found. It was indicated from this fact that sei whale feed on the prey which had so densely swarmed as to form the patchiness. *Doliolum*, *Salpa*, pteropoda and chaetognatha distribute abundantly in the region concerned, but none of them were the important components of the stomach contents. A selective feeding habits by species and size of the prey organisms were also observed in sei whale as has been known in fin whale. The sei whale feeds preferably on crustaceans than any other kind of foodstuff, and copepods were the most important among all. *C. tonsus* of copepodite V stage was the main food species in the southern waters.

6. The distribution of the food organisms changed latitudinally: *C. tonsus*, *C. simillimus* and *Clausocalanus laticeps* were the main composition of the stomach contents throughout the zone between the Subtropical Convergence and about 47°S, although they were took over by *E. vallentini* or *P. gaudichaudii* by the sea regions, and then by *P. gaudichaudii* almost exclusively between 50°S and the Antarctic Convergence. It was only *E. superba* that occurred in the stomach in the southern most whaling ground close to the Antarctica. These geographical change in the composition of stomach contents was a phenomenon which occurred within a narrow zone of 20 degrees in latitudes.

7. In the feeding percentages in terms of the number of animals with food against those examined, 28~59 % of animals in the Indian sector had carried the stomach contents whereas it was 25~82 % in the Pacific sector, and the availability of foodstuff would be considered higher in the Pacific. The scheme above mentioned by species was also varied with the whaling areas, that is, both *C. tonsus* and *E. vallentini* were dominant in the Pacific sector, while *P. gaudichaudii* and *E. superba* were

important food in the Indian sector and in the Tasman Sea area. However, preference to the kind of foodstuff in sei whale was focussed first on copepods and, euphausiids and amphipods were secondarily important. The feeding percentage by the species and seasons revealed that there might be both copepod rich year, and euphausiid or/and amphipod rich year.

8. Sighting investigations revealed that both baleen and toothed whales seem to take food even in the tropical seas, especially where upwelling along with abundant distribution of zooplankton prevails. The region of a relatively dense distribution of whales was indicated particularly by the distribution features of salinity and phosphate.

9. The sei whaling ground agrees on the whole with the abundant distribution of their food organisms particularly of *C. tonsus* and *C. simillimus*. Apart from this however, there was a local but abundant distribution of food organisms such as *D. pectinatus* and *Cl. laticeps*, and the whaling ground formed by these foodstuff hardly be spotted since there was no effective ways left behind to know very local occurrence of the plankton patchiness by plankton net haul.

10. *C. tonsus* population is composed of copepodite stages IV, V, and adult female, but the population is represented by copepodite V since it occupied 89.7 % on average in overall compositions in individual numbers. There were two size compositions of the copepodite V, say, 3.0∼3.2 mm and 3.5∼3.6 mm by the whaling areas, and they were supposed to be the difference due to isolation by breeding stock, and also the difference in generations.

11. The feeding ability in sei whale is a function of the mandible size which grows proportionaly with the body length. However, the filtering structure in feeding mechanism is the row of baleen plates which furnished on the upper jaw with the average density of 1.4 plates/cm near the rostrum and 0.93 plates/cm at the distance of 66.4∼69.5 % posterior from the rostrum where the baleen plates attain at their maximum length. The length of the bristles furnished on the inner margin of the baleen plates varied 3∼5 cm with the averaged density of 45.5 bristles/cm regardless to sex and body legth.

12. The total area of the filtering apparatus in sei whale was 2.37 m^2 in 11.0 m long animal, and 3.59 m^2 in 14.4 m animal. None of sexual variations were observed. The area of filtering apparatus against the body length showed comparatively larger figures in sei whale than the another balanopterid whales though it was still smaller than that in balaenid whales.

13. The calculated porosity of the filtering apparatus varied between 77.2 % and 88.6 %. Comparing with the figure of 46 % in GG54 bolting silk cloth (0.33 mm mesh apertures), the netting in sei whale was considerably coarsely structured but its relative filtering ability was 1/8 of the GG 54 and 1/5 of the fin whales.

14. The number of animals which vomited the stomach contents during chasing against the total animal observed were 6/642, 1/129, and 21/125 in the order of sei, fin, and sperm whales respectively. This fact makes us confirm that the amount of stomach contents found in carcasses shows an actual figures at the moment of animals being killed.

15. By examining the fulness of stomach contents, it was known that 25~30% of the stomach contents in volume reduces within the following 5~6 hours supposedly by digestion. This fact leads to a consideration that the stomach of sei whale would be repleted fully once in a day.

16. The amount of stomach contents which were actually found in carcasses was 150~200 kg, 500~600 kg, and 30 kg in the order of sei, fin, and minke whales respectively. These amount of food however, seems to be far insufficient as the daily rations of the whales. When *C. tonsus* was fed by sei whale its amount usually found in the stomach does not exceed more than 50~60 kg. This would be due to a poorer availability as biomass in *C. tonsus* even when they form the densely populated swarms than the case in larger sized prey organisms.

17. Feeding activity in sei whale as indicated by the feeding percentages was high in the morning, but in some case it was unchanged throughout the day. This suggests that many sei whales feed much once in a day, but they have to prey on continuously throughout the day to fill their daily rations particularly when they feed on copepod. The habits of the diel vertical migration in prey organisms also affect on the whale's feeding activity.

18. After the formulations by Sergeant (1969), the theoretical daily rations in 3 species of the baleen whales were calculated as 4.4%, 4.07%, and 3.84% of body weight in the order of sei, fin, and minke whales respectively.

19. The population density in *C. tonsus* patches was assessed being based on the filtering ability, feeding habits, and the amount to stomach contents; and found that *C. tonsus* swarms into patches with the population density of $10^3 \sim 10^4$ inds/m^3. In these calculation it was also indicated that the sei whale can collect the foodstuff more effectively by employing skimming type feeding than the case by swallowing type.

20. A total of 220 patches of *C. tonsus* was investigated, and the following evidences were found: 1) the patches showed spindle-, oval-, and stripe- or stream-shape, of which the former two occurred most frequently, 2) the size was usually somewhere between hundred and several hundreds meters in their longer axis though sometimes it was several miles long in stream-shaped patches, 3) the patch is maintained tightly for long period through rough weather, and each patches are so completely isolated as to keep the overall biological characters as aggregated populations, 4) the patches occurred most frequently along the Subtropical Convergence where the sea temperature was 13.0°~14.0°C, 5) copepodite V of *C. tonsus* population forms the main body of the patches with slight numbers of adult female, 6) the observed population density in collected samples varied between 330 inds./m^3 and 2.4×10^4 inds./m^3 ($=3\times10^4$ mg/m^3). These figures agreed with those assessed theoretically, 7) possible causations of swarming behavior would be the density effects which supposedly benefits to growing larger the population as a functions of stimulation by physical contact of one to another, and then, 8) the formation of patchiness would hardly be explained by the hydrodynamical forces because what makes the organisms swarm or aggregate so densely would be, after Cassie (1960), a internal behavior patterns between individuals of the

same species through a social habits, that is, the subject of organisms themselves.

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APPENDIX. AMOUNT OF FOOD FOUND IN THE FIRST STOMACH OF FIN, SEI AND MINKE WHALES CAUGHT IN THE SOUTHERN OCEAN.

No.	Species of whale	Sex	Body length (m)	Kind of stomach contents	Date of catch	Time of catch (SMT)	Net weight of food (kg)	Water (kg)	Total weight of stomach contents (kg)	Total volume (1)
1	sei	M	14.4	*Calanus*	28/XII/67	1115	54.0	14.0	68.0	66[1)]
2	sei	M	14.1	Amphipoda	6/I/68	0600	136.5	18.1	154.6	171[2)]
3	sei	M	14.2	Amphipoda	15/I/68	0800	73.5	14.5	88.0	109[3)]
4	sei	M	14.6	Amphipoda	30/XII/67	1105	98.0	30.0	128.0	156[1)]
5	sei	M	15.2	Amphipoda	7/I/68	0925	200.0	28.0	228.0	312
6	sei	M	15.1	Amphipoda	15/I/68	1455	57.6	13.8	71.4	93.6
7	sei	M	14.7	Eu-L	21/II/68	1050	142.0	0.0	142.0	200
8	sei	M	15.1	Eu-S	13/I/68	1345	149.6	28.6	178.2	220[4)]
9	sei	F	13.0	Eu-L	23/II/68	0830	149.0	33.0	182.0	200
10	sei	F	13.2	Eu-S	12/I/68	1940	135.6	24.4	160.0	204[4)]
11	sei	F	14.3	Eu-L	22/II/68	0925	128.7	12.6	141.3	180[5)]
12	sei	F	14.7	Eu-S	12/I/68	1745	79.1	15.4	94.5	119
13	sei	F	15.6	Eu-L	23/II/68	0540	148.0	4.0	152.0	200
14	sei	F	16.2	Eu-L,M,S	18/I/68	0855	159.0	37.5	196.5	255
15	fin	M	18.6	Eu-L	21/I/68	1015	273.7	27.6	301.3	391[5)]
16	fin	M	21.0	Eu-L	2/III/68	0820	785.0	100.0	885.0	1000
17	fin	F	20.2	Eu-L	21/II/68	0550	556.5	10.5	567.0	700
18	fin	M	21.1	Eu-L	20/II/68	0640	286.0	28.0	314.0	400[5)]
19	fin	F	22.1	Eu-L	21/I/68	1115	127.4	5.6	133.0	238
20	minke	F	8.0	Eu-L	21/I/68	1805	22.4	4.0	26.4	31.2

Calanus: *Calanus tonsus*, Amphipoda: *Parathemisto gaudichaudii*, Eu-L or -M: *Euphausia supera*, Eu-S: *Euphausia vallentini*.

1) Approximate values, 2) Estimated by the stomach volume averaged on 13 whales, 3) Calculated by the mean weight of a unit volume of amphipod food from four animals, 4) Calculated by the mean weight of a unit volume of small-sized euphausiids taken by #12 animal, and 5) Calculated by the mean weight of a unit volume of large-sized euphausiids taken by six fin whales and one minke whale.

EXPLANATION OF PLATES.

PLATE I

Fig. 1. Inside view of a row of baleen plates in sei whale, female, 14.3 m.

Fig. 2. Same as Fig. 1, but viewed from outside.

Fig. 3. Enlarged view of a row of baleen plates showing the intervals of the plates neibouring with each other.

Fig. 4. Bristles furnished along the inner margin of baleen plate.

PLATE II

Fig. 1. Bristles at the tip of baleen plate.

Fig. 2. Enlarged view of the filtering meshes formed by the baleen bristles.

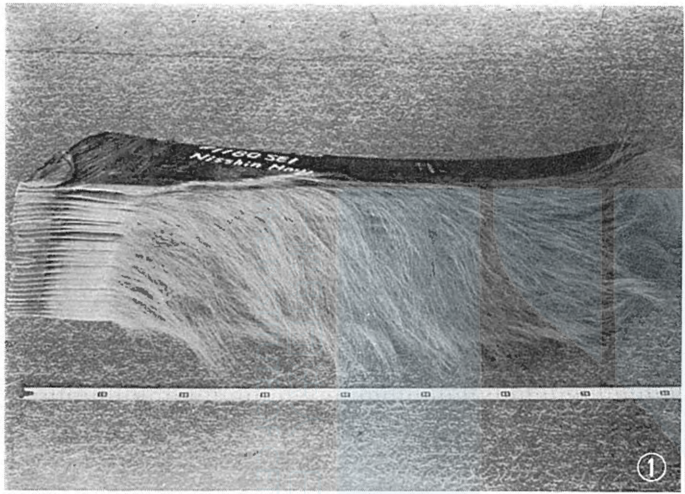
PLATE III

Fig. 1. An apparatus for measuring the filtering ability of a row of baleen plates of the sei whale shown in PLATE I.

Fig. 2. Same as Fig. 1, but small fraction of a row of baleen plates is attached on the apparatus.

Fig. 3. Frontal view of the apparatus. Bridles and a flow-meter mounted on the apparatus are shown.

Fig. 4. Flow-meter and the baleen plates attached on the bottom of the apparatus are shown.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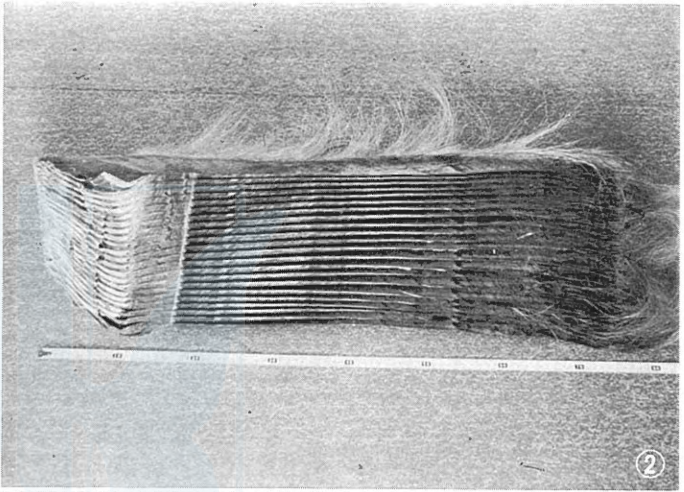
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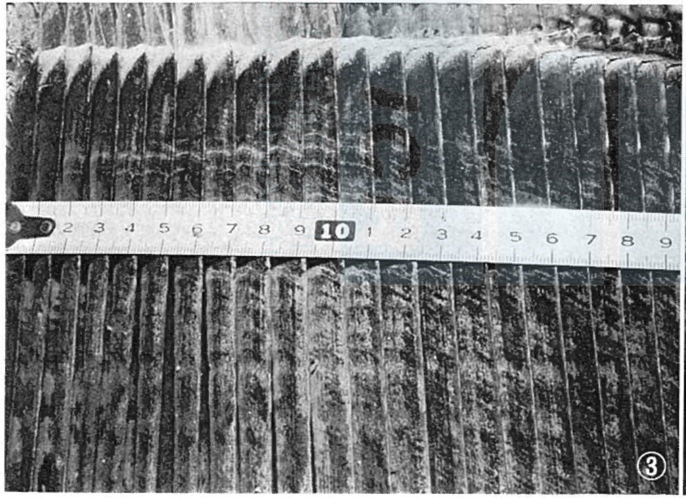
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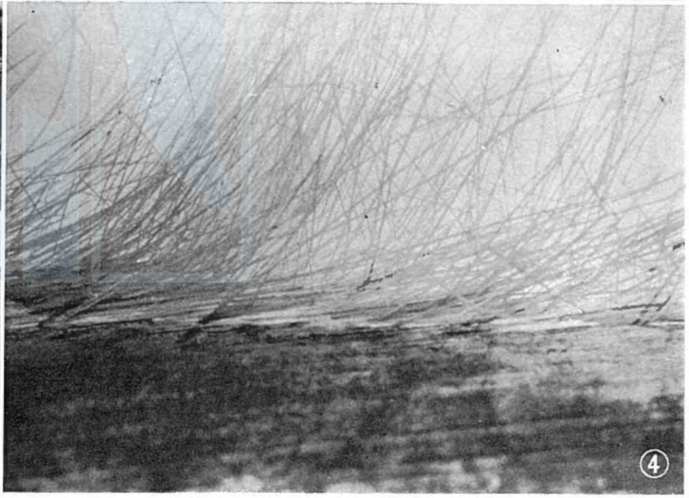
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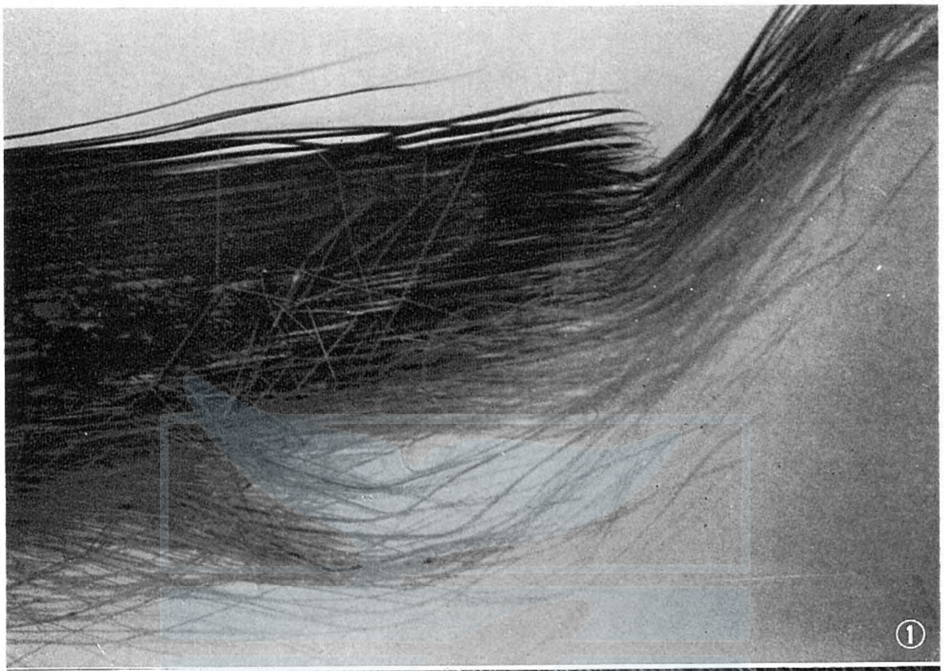
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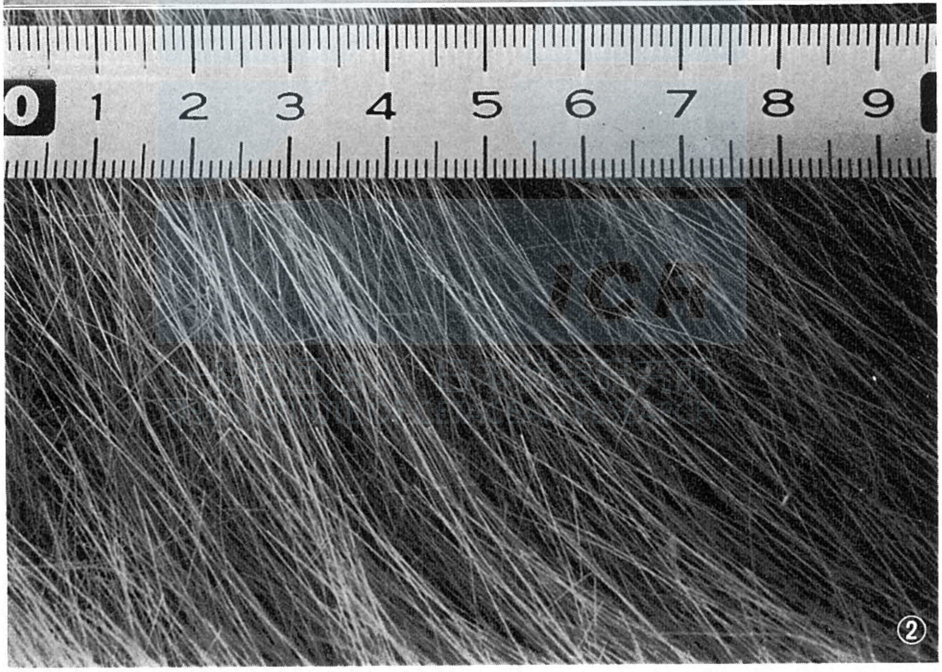

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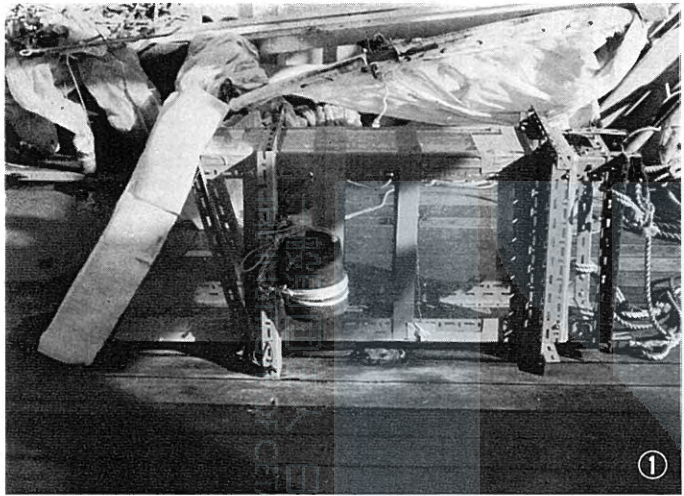
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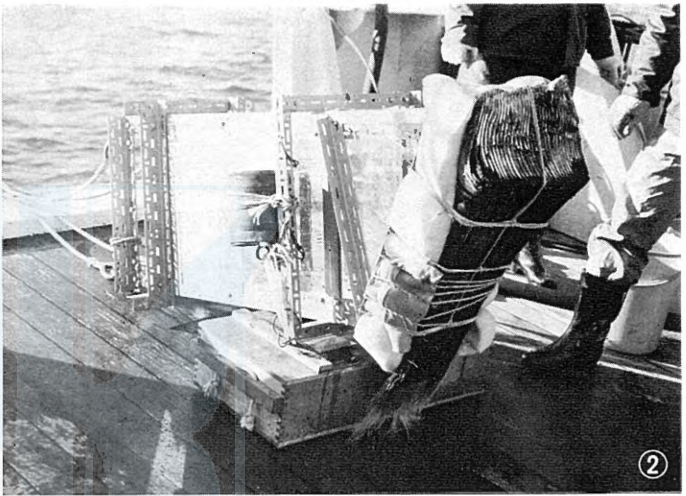
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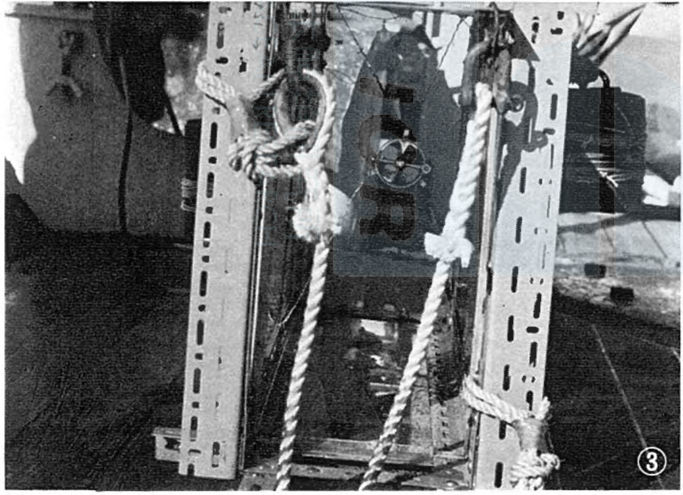
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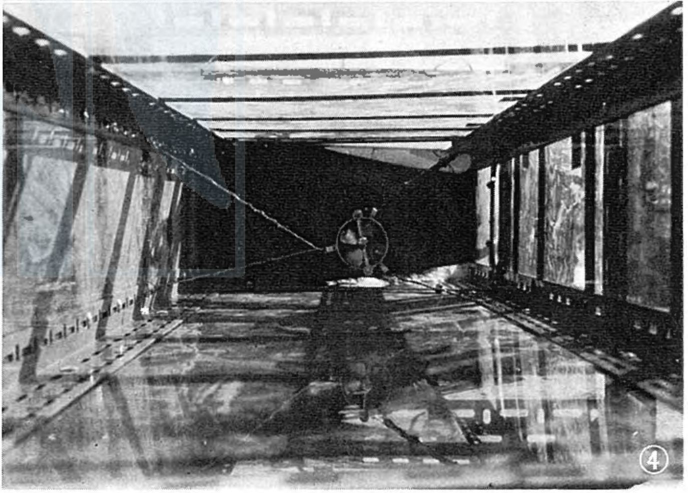
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BODY SCARRING ON CETACEA-ODONTOCETES

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ABSTRACT

An attempt is made to give some interpretation to the numerous and various scars found on the exterior of Odontocetes. Some of the scars are the result of male contests; firstly, in *play*, establishing superiority, *inter se*, between young males, and secondly, in the more serious combats to establish final *mastery* in anticipation of the breeding season for possession of an *harem*. Other causes of scarring are also discussed.

INTRODUCTION

Opinions vary in attempts to explain the cause or causes of scars frequently visible on the body of the various species of Odontocetes. The scars may be ascribed to multiple factors, such as: parasites, epizoans, predators (other cetaceans, sharks and perhaps seals) and most of all to play and combat *inter se*. Dealing with the last mentioned factors first, it is important to consider the behaviour pattern of each species and the differences between the sexes and the type of armament (teeth) in each species. A consideration of the play and battle scars is a good indication of the extent of pugnacity exerted by the males of the species.

Most of the Odontocetes live in small or large schools. The size of the school varies largely with the annual cycles of breeding, feeding, and migration. Similar patterns are observable among land animals, as, Bovidae and other gregarious mammals; even among the primates (monkeys).

Bulls (males) engage in much combat *inter se:* at first the young in *play*, without inflicting much serious bodily harm, but with advancing age and eventual sexual maturity, the play turns to greater violence and increase of scarring—it is no longer sparring. It is in the young male schools that the future master bulls establish their superiroity over all other bulls and finally become the prospective masters to challenge the ruling masters and fight to the finish or the vanquished breaks off the fight, perhaps, if not too badly wounded, to return to the fray at some distai [illegible] ture or perish on the waves. In the case of an old master, once he is defeated he may survive for a while and lead a solitary existance, or succumb to his wou

The form of the scars varies with the violence of the attacks and the extent of contact of the teeth made at the time of impact. Many of the scars appear to have been ugly wounds originally. Frequently, the wounds appear to be restricted to the depth of the blubber alone, but deeper wounds result in fractured ribs and damaged internal organs. Sometimes multiple fractures appear on the same rib

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when skeletonised. The fractures not being of the same age show the endurance of the animals.

In considering the various forms of scars it is essential to refer to the dental characters, food and enemy cycles. Few Odontocetes can open the mouth widely, hence the size of the food is restricted or of soft consistancy. This observation appears to have some bearing on the form of the battle scars, as we shall have occasion to note.

All illustrations showing body scarring were drawn by me.

PHYSETERIDAE: (Figs. 1 and 2)

Both the genera in the Physeteridae have markedly undershot jaws containing grasping teeth in the mandibles alone: when corresponding teeth are developed in the maxillae, they are invariably abortive and functionless. The food consists almost entirely of cephalopods—animals with a slimy gelatinous texture. The sharp teeth in the mandibles form a most efficient set of grasping teeth against the corresponding sockets in the maxillae left by the ‘ absent ’ teeth. The tongue is relatively short. Another remarkable feature of the family is the greatly enlarged head with its enormous ‘ sac ’ of *spermaceti*, particularly in the Sperm Whale, *Physeter catodon* Linn.

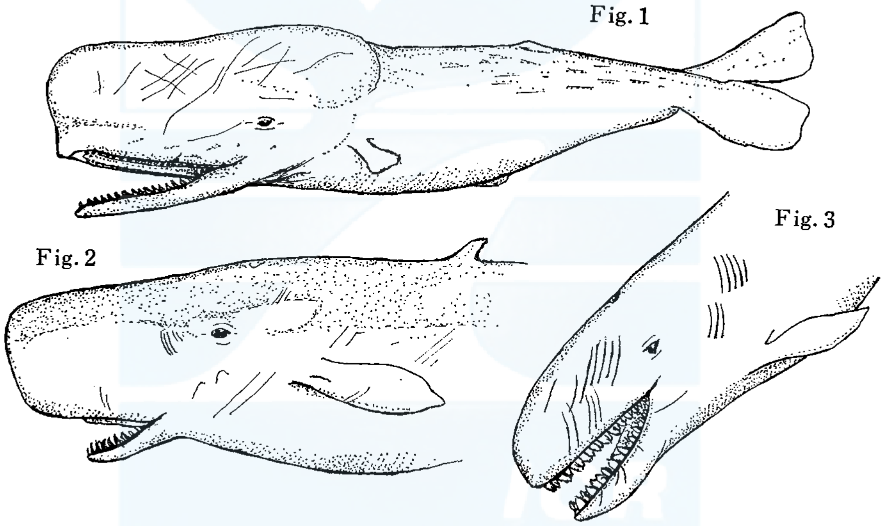

Fig. 1. *Physeter catodon* Linn. Fig. 2. *Kogia breviceps* Blainville. Fig. 3. *Pseudorca crassidens* Owen.

Physeter catodon Linn. (Fig. 1)

The enormous head of the Sperm Whale occupies almost one third of the total length of the animal. It is provided with the cushion of spermaceti, a waxy looking substance already referred to. To speculate, this ‘ cushion ’ functions as a shock-absorber when the animal uses its head as a battering ram in offence and defence. In addition, the array of large teeth serve as weapons of defence and offence, and their function as grasping organs in dealing with the large slithery cephalopods (particularly, the Giant Squid) which form a large proportion of the food of Sperm Whales.

In dealing with some of the larger cephalopods, there seems to be a suspicion that the Sperm uses its head to pummel the squids after grasping them with its jaws (the fleeing squid, going backwards as is its wont, would be grasped by its tentacles). Evidence of battles with large cephalopods is impressed on the facial region of the Sperms. The use of the head as a battering ram is well authenticated in literature.

The use of the teeth in sparring and more serious battles *inter se* is exhibited by the linear scars on the head and body of opponents.

Kogia breviceps Blainville (Fig. 2)

The Pigmy Sperm Whale is similar in some respects to the true Sperm Whale, but it lacks the greatly exaggerated head. However, it possesses a small sac of spermaceti which very likely serves a similar function to that met with in the larger Sperm Whale. Its food consists largely of cephalopods. The sharp teeth in the lower mandibles only play role of grasping organs and of weapons of offence and defence. Dental scars appear on both the head and body of the combatants. The jaws appear to be used ' pigwise ', the scaring depending on the number of teeth making contact at the time of impact.

DELPHINIDAE: (Figs. 3–10)

The Delphinidae are all provided with large or small teeth in both jaws, in both sexes: the number and size vary according to the species. In some species the anterior- and posterior-most 1–4 teeth are frequently unerupted. This peculiarity may lead to a variation in the field count. The form of teeth is a fair indication of the food—mainly fish and cephalopods; the larger species, such as the Killer and False Killer *Orcinus* (Pl. I) and *Pseudorca* supplimenting their diet with larger animals —seals, oceanic birds and chunks torn out of other whales.

Delphinids cannot open the mouth very widely hence true biting is limited when faced with large objects (*i.e.* biting dog-fashion). However, dental scars, of no great depth, are frequently visible, inflicted by an opponent's teeth in ' play ' or combat. These scars represent the dentition of one side of the lower jaw (mandible) only, they vary in number according to the number of teeth that made contact at the time of the impact. The movement of the jaw is somewhat like that of a pig when attacking an opponent. This form of scar is frequently seen on the head and body of stranded animals (males): *Tursiops, Grampus, Lagenorhynchus, Delphinus, Cephalorhynchus, Pseudorca, Globicephala,* and *Orcinus.*

It is well-known that the delphinids are far more gregareous and ' playful ' than most other cetaceans; also, that many of the species are capable of high speeds,

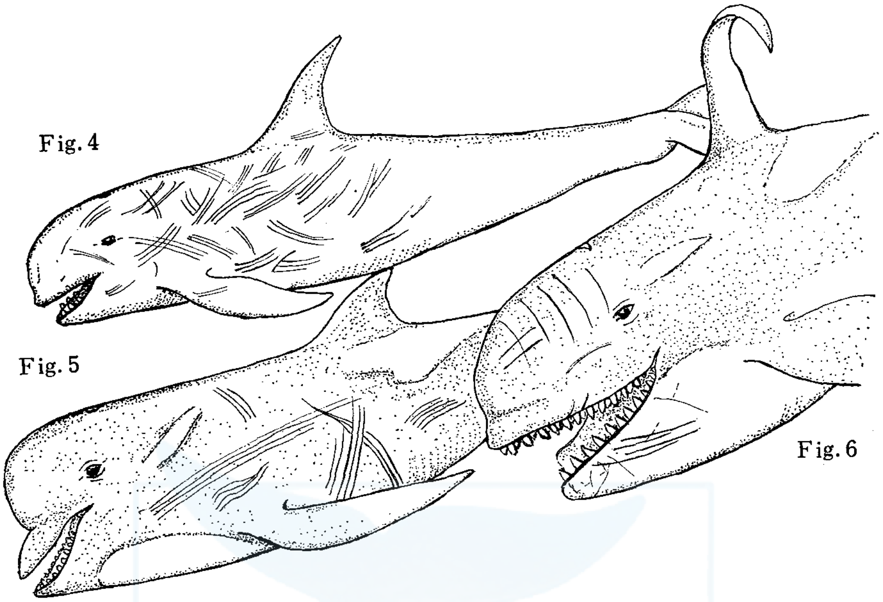

Fig. 4. *Grampus griseus* Cuvier. Fig. 5. *Globicephala melaena* (Smith). Fig. 6. *Orcinus orca* Linn.

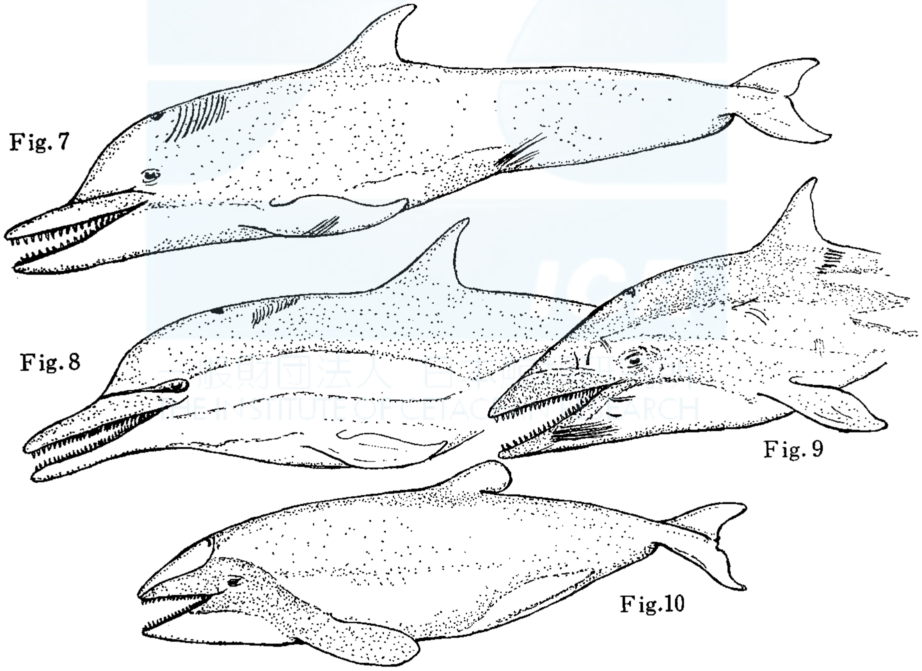

Fig. 7. *Tursiops truncatus* Montagu. Fig. 8. *Delphinus delphis* Linn. Fig. 9. *Lagenorhynchus obscurus* (Gray). Fig. 10. *Cephalorhynchus hectori* Breneden.

avoiding collision and attacks, but likewise capable of inflicting wounds on one another whether in ' play ' or sexual combat. Scars arising form other causes, such as epizoans and external parasites, are not frequent with delphinids, this may be ascribed to the high speed which enables the surface of the body to remain clean.

ZIPHIDAE: (Figs. 11–22)

Scarring is more prevalent and pronounced among the ziphioids than the delphinids. This marked difference between the two families may be explained by the peculiarity of the dentition; smaller schools and slower speed than delphinids. Smaller schools undoubtedly give rise to a greater competion for the mastery of the harem., particularly, during the breeding period. Ziphioid males alone erupt specialized teeth for defence and offence. Teeth are found in the corresponding positions in females as those of the male but they are small- and unerupted. However, there is one exception to this general rule, *Tasmacetus*, which, in addition to the enlarged paired teeth possesses a series of smaller teeth (delphinidwise) in both maxillae and mandibles. Occasionally, one might find rudimentary teeth in the maxillae which are not embedded in the bone: example *Mesoplodon*.

Fig.11

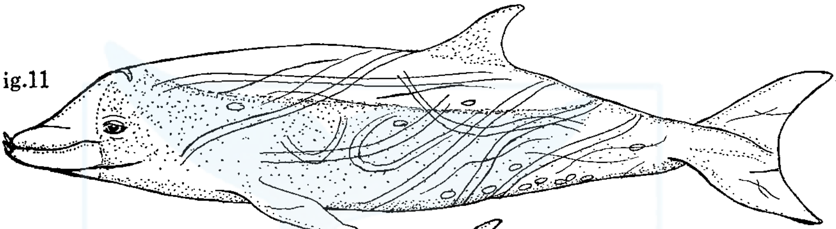

Fig.12

Fig.13

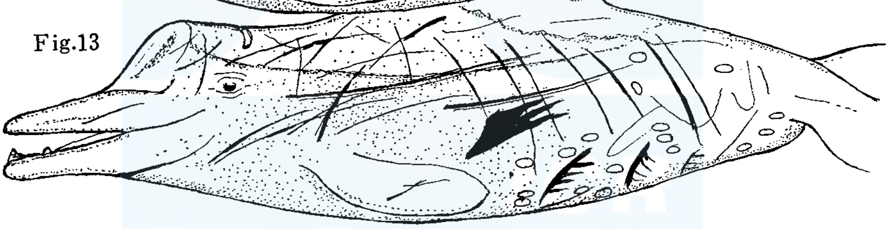

Fig. 11. *Ziphius cavirostris* Cuvier. Fig. 12. *Hyperodon planifrons* Flower. Fig. 13. *Berardius arnouxi* Duvernoy.

In addition to the forms of linear scarring on males of *Ziphidae* descirbed above, ziphioids carry other forms of scarring common to both sexes. The commonest forms of scarring being oval, elliptical or even circular. These white scars are to be seen on almost any part of the head or body, including the flukes and flippers, but they are most concentrated in the vicinity of the anal and genital regions. These scars appear to be inflicted by prolonged attachment of some stercophagous epizoans, such as, sucker-fish (*Remora*) or crustaceans. Some of the circular scars may be attributed to lampreys or hag-fish, however, the last mentioned I would regard as parasites. That the culprets which inflict the scars are seldom, if ever, (I have never come across them) taken still adhering to the carcases of stranded individuals is quite understandible. (Hag-fish will be attracted to a carcase during the process of cutting it up, if in a suitable depth of water.) The relatively slower speed of ziphioids evidentally permit of prolonged attachment of these creatures to the whales, sufficently long to scar the delicate texture of the whale ' skin '. I have examined many such scars and found that there was no evidence of them having penetrated to any great depth below the skin.

To the forms of scars described above attention must be drawn to scars inflicted by the jaws of large fish (sharks) marine mammals (seals?) and some of the larger Delphinidae, such as Killer Whales (*Orcinus*).

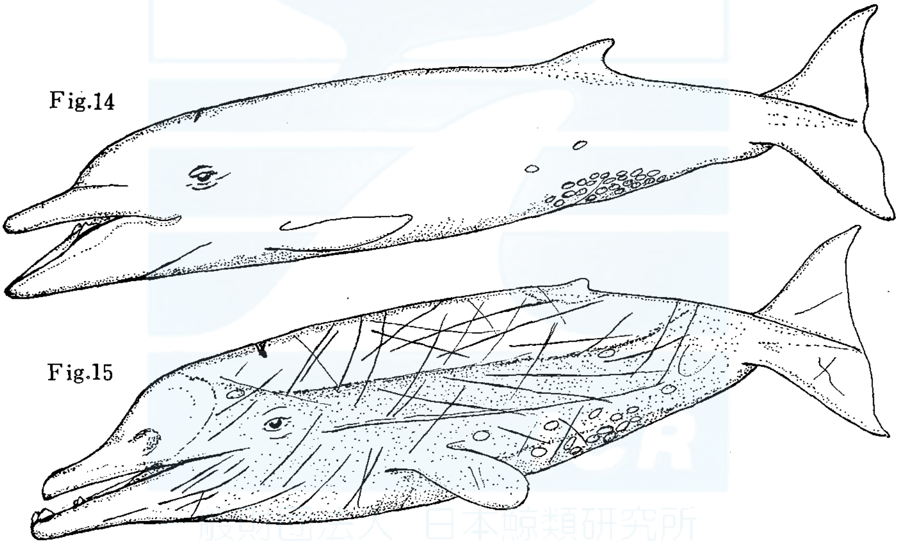

Fig.14

Fig.15

Fig. 14. *Mesoplodon ginkgodens* Nishiwaki & Kamiya (After Nishiwaki *et al.*, 1972). Fig. 15. *Berardius bairdi* Stejneger (After Omura *et al.*, 1955).

Ziphius cavirostris Cuvier

This almost cosmopolitan species, like so many males in the family Ziphidae, is virtually toothless except for a pair of defensive in the mandibles, erupted in the males alone used in sparring or battling with other males. The corresponding in the females are usually abortive and remain unerupted. The males appear to be very pugnacious *inter se* if one may draw conclusions from the numerous scars inflicted on each other by rival males. The scars appear as parallel wheals indicating, in the case of *Ziphius*, that both teeth make contact together normally. The wheals are often of considerable length Pl. VI, fig. 2 and Pl. VII, fig. 1.

The food consists largely of squids. The tongue and palate are sufficently roughened with small papillate projections to secure the soft, slithery textures, such as cephalopod's.

MESOPLODON: (Pl. VI, fig. 2 and Pl. VII, fig. 1)

Excepting *M. mirus*, which has its defensive teeth at the extremity of the mandibles, like *Ziphius*, all the other species have the defensive teeth at the side of the mandibles. Accordingly, I presume that *M. mirus* alone of the *Mesoplodon* would inflict parallel scars on its opponent. Unfortunately, the only good photograph I have does not show any scarring. The other member of the genus: *Mespolodon gervaisi*, *grayi*, *layardi*, *stejnegeri*, *densirostris* and *ginkgodens* inflict single linear scars at a time on their opponents.

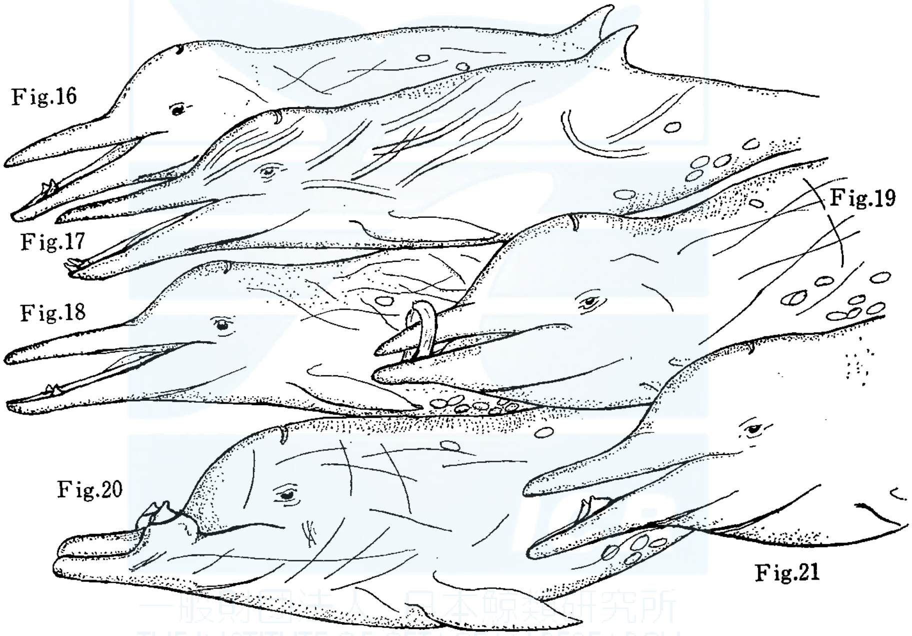

Fig. 16. *Mesoplodom gervaisi* (Deslongchamps). Fig. 17. *Mesoplodon mirus* True. Fig. 18. *Mesoplodon grayi* Haast. Fig. 19. *Mesoplodon layardi* Gray. Fig. 20. *Mesoplodon densirostris* Blainville. Fig. 21. *Mesoplodon stejnegeri* True.

HYPERODON:

There are two known species in the genus. The males of the species possess a single tooth at the extremity of the mandible, in some respects it resembles that of *Ziphius*, but may be distinguished from it by its larger size and somewhat different shape. Under the circumstances, I would expect similar parallel scarring but I have not seen either of the animal in the flesh nor have I seen suitable photographs showing the scars. However, I presume there would be a greater distance between the lines in *Hyperodon* than in *Ziphius*.

As the female ziphioids seldom carry ‘ battle scars ’ it may be concluded that the males alone do all the fighting and in the melée may, perhaps, scar a female accidently, which happened to be in the way.

The position of the ‘ battle-teeth ’ in the mandibles and their shape varies from species to species: the teeth may be at or near the extremity of the mandibles: between the extremity of the mandibles and the symphysis, or, yet again, nearer the angle of the gape. The wheals made by the ‘ battle-teeth ’ are almost characteristic of the species. The species with the ‘ battle-teeth ’ at the extremity of the mandibles produce long or short single or double parallel scars equel to the distance between the teeth, as in the case of *Ziphius cavirostris, Mesoplodon mirus* and *Hyperodon* spp. Species with single teeth in each mandible at, or posterior to the symphysis inflict deep snort or long linear scars; parallel scars may occasionly appear by accident—*Mesoplodon grayi, M. layardi* and others produce linear scars.

Then there is *Berardius* with two teeth in each mandible, one large anterior one and a smaller one a few centimeters behind. Close examination of the carcase of *B. arnouxi* and illustrations of the Japanese, *B. bairdi* resulted in the observation that parellel scars do not appear to be inflicted by the two anterior teeth as in the case of *Ziphius*, however, parallel scars appear which are made by both the teeth of the same mandible, with this difference: the anterior tooth makes a larger and deeper rip than the smaller: the parallel distnace between the scars being much less than the distace between the two anterior teeth alone. This indicates that *Berardius* fights in much the same manner as do the side-toothed *Mesoplodon*.

Finally, there is *Tasmacetus*. I have already drawn attention to its peculiar dention. It is a rare species and no suitable specimens nor photographs have come my way to make suitable observations on the scarring met with in this species.

BERARDIUS: (Fig. 15, Pls. IV and V)

There are two known species of *Berardius*. The males of *Berardius* unlike the males of other ziphoids possess two defensive teeth in each mandible: one large tooth followed by a smaller one, a short distance to the rear of the leading tooth. Reading the scars as they appear on the males of the individuals, three different patterns of scarring are made: a) parallel rips made by the two leading teeth alone, similar to those observed in the case of *Ziphius:* b) parallel scars, one more pronounced than the other, and closer together than those made by the leading teeth. This second form of parallel scarring is produced by the two teeth of the one mandible raking the body of the opponent at the same time, independently of the second mandible—“ pigwise ”. In addition to these parallel scars, single linear scars may be seen gouged out by the leading tooth of one mandible alone. Further, scars similar to the segment of a wheel with short spokes, appear above and below along the ventral and dorsal margins of the caudal region. These scars appear to be inflicted large sharks or Killer Whales.

TASMACETUS: (Fig. 22)

This curious ziphioid is rare and little is known of it. Unlike any other ziphioid *Tasmacetus* possesses functional teeth in both upper and lower jaws in addition to the defensive teeth usually present in the mandibles alone. Oliver (1937) records 19 teeth in each maxilla and 26 (27) teeth in each mandible plus one large defensive tooth bringing the total number of teeth up to 93. (*Mesoplodon grayi* has been known to produce rudimentry teeth in the maxillae occasionally. Such teeth have no sockets but are merely imbedded in the 'gums'.)

Fig.22

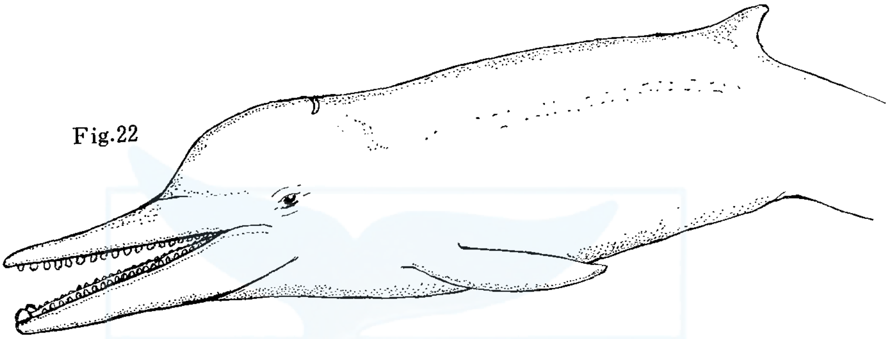

Fig. 22. *Tasmacetus shepherdi* Oliver.

Under the circumstances I would suspect that the defensive teeth at the extremity of the mandibles produce similar parallel scars as do other ziphioids with similarly positioned defensive teeth. In addition, I would suspect that following teeth would produce smaller scars, perhaps similar to some of those made by some delphinids. At the moment the subject must remain speculative.

PLATANISTIAE: (Fig. 23)

This small but curious family of cetaceans embraces three genera, the distribution of which is no less curious: *Inia* (Amazons), *Pantaporia* (River Plate) and *Platanista* (largest rivers of India, including Pakistan: Indus, Ganges and Bramaputra). In all cases the animals inhabit the muddy estuaries. In response to the opacity of the muddy environment, the members of the family have little or no vision. Many other adaptations have been evolved but their discussion here is beyond the scope of this paper. I will restrict my comments to the Indian species, because of the recent work done on the species by Japanese workers and my personal knowledge of some of the terrain of the species. However, I must confess that I have only seen skulls but not an animal in the flesh.

PLATANISTA:

A characteristic of *Platanista* is its prolonged maxillae and mandibles provided with numerous grasping teeth, like *Delphinus*. These sharp teeth, like those of *Delphinus* and *Lagenorhynchus*, leave scars similar to the series visible on the head and body of the two species mentioned above whether made in ‘ play ’ or more serious combat. Such scars are clearly visible in the illustrations by Kasuya (1972), Pl. III. In addition to the normal form of scars inflicted on one another, other scars and wounds appear on the snout and ‘ face ’, some as though they had been inflicted by true (dog-like) biting action, others, as scars inflicted during the process of capturing prey; such as fish armed with protective spines or teeth(?).

Fig.23

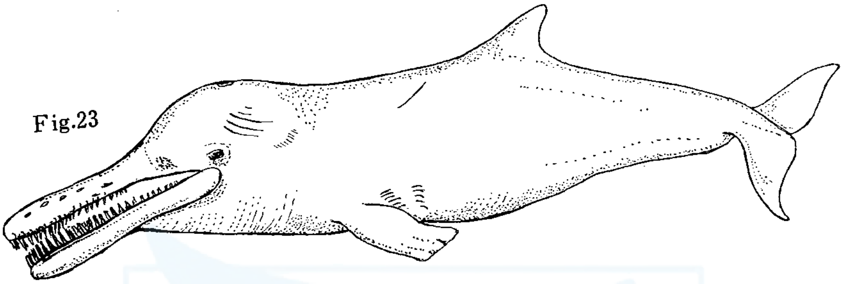

Fig. 23. *Platanista gangetica* (Lebeck).

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EXPLANATION OF PLATES

PLATE I

Orcinus orca Linn.
Fig. 1. Scars faintly seen on the dorsum.
Fig. 2. Scars more clearly visiible about the head and jaws.

PLATE II

Delphinus delphis Linn.
Series of teeth marks on the dark area of the dorsum.

PLATE III

Lagenorhpnchus obscurus (Gray)
Fig. 1. Scars clearly visible about the mandible and around the eyes.
Fig. 2. Scars seen about the region below the dorsal fin.

PLATE IV

Berardius arnouxi Duvernory
Fig. 1. Head on view showing dorsal and lateral scarring.
Fig. 2. Lateral view showing scars, old and new: at the lower edge, note scar possibly inflicted by 'Killer' Whale.

PLATE V

Berardius arnouxi Duvernory
Fig. 1. Caudal region, note the several attempts of 'Killers' or perhaps sharks.
Fig. 2. Note the various types of scarring below the dorsal fin.

PLATE VI

Ziphius cavirostris Cuvier
Fig. 1. Dorsal view.
Fig. 2. Closeup of dorsum showing dorsal fin and scars, single parallel and elliptical scars.

PLATE VII

Ziphius cavirostris Cuvier
Fig. 1. Ventral aspect showing vent and genital apertures together with the associated scars.
Mesoplodon grayi Haast.
Fig. 2. Ventral aspect showings vent and genital openings with the types of scarring.

PLATE VIII

Globicephala melaena (Smith)
Dorsal aspect showing the numerous series of scars inflicted by the teeth of the opponent.


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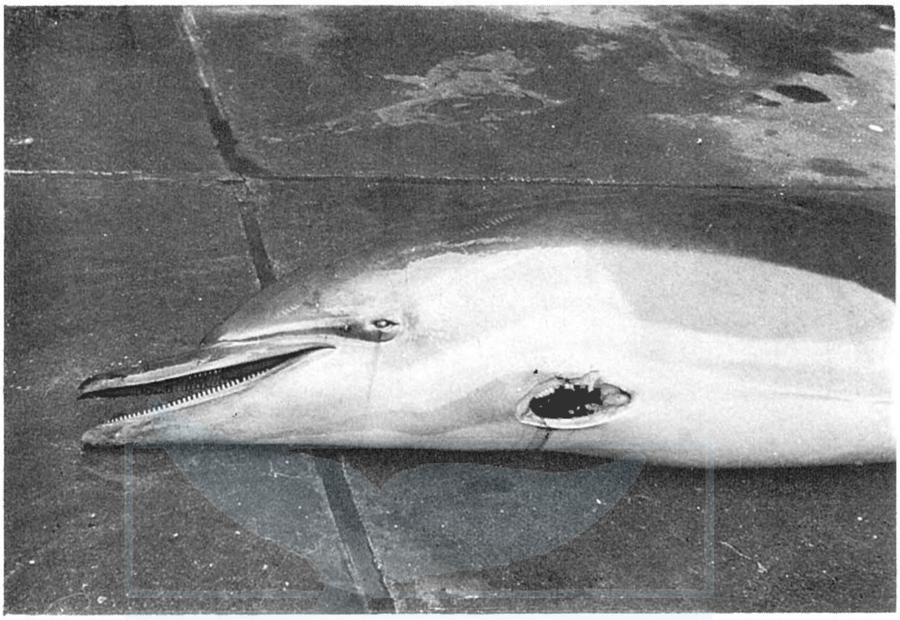
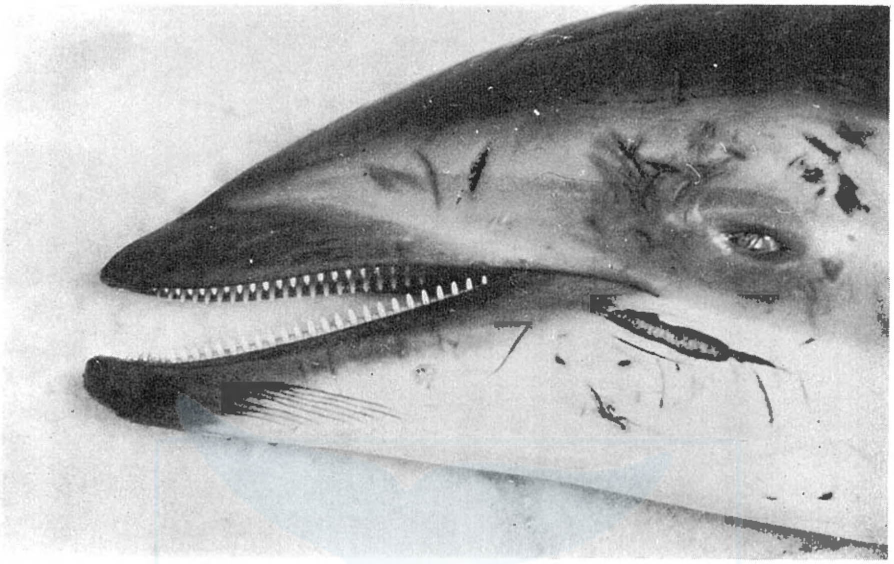
Fig. 1.

Fig. 2.





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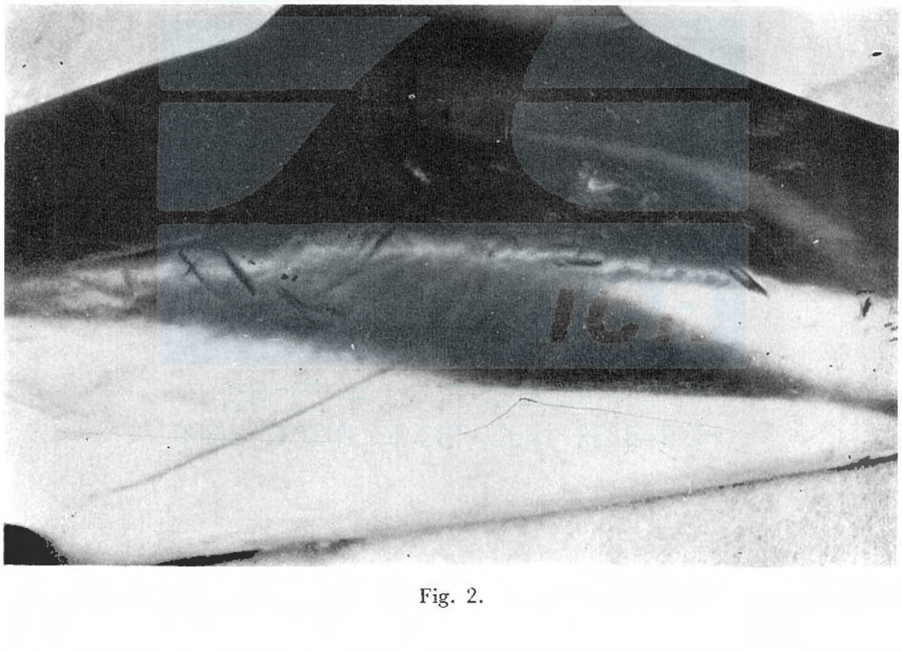

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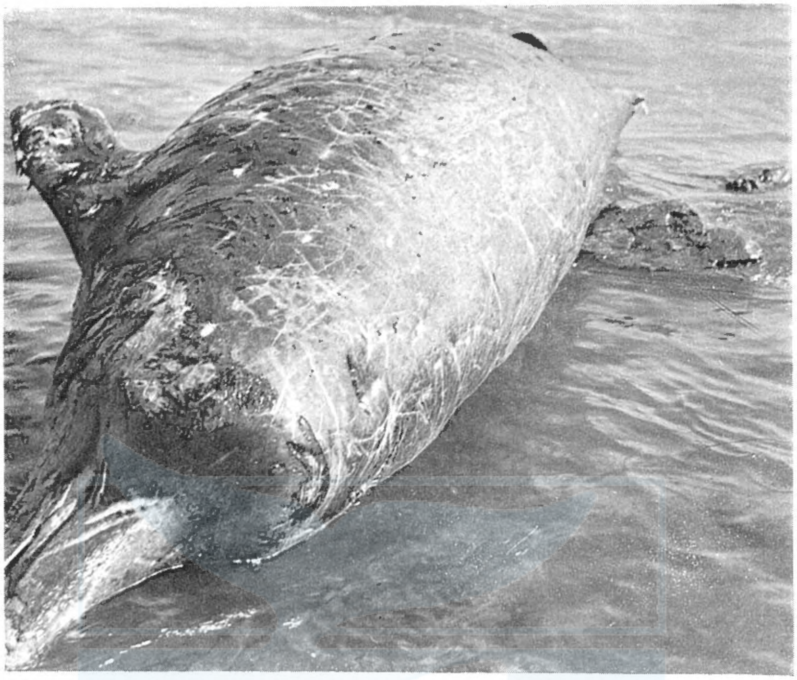

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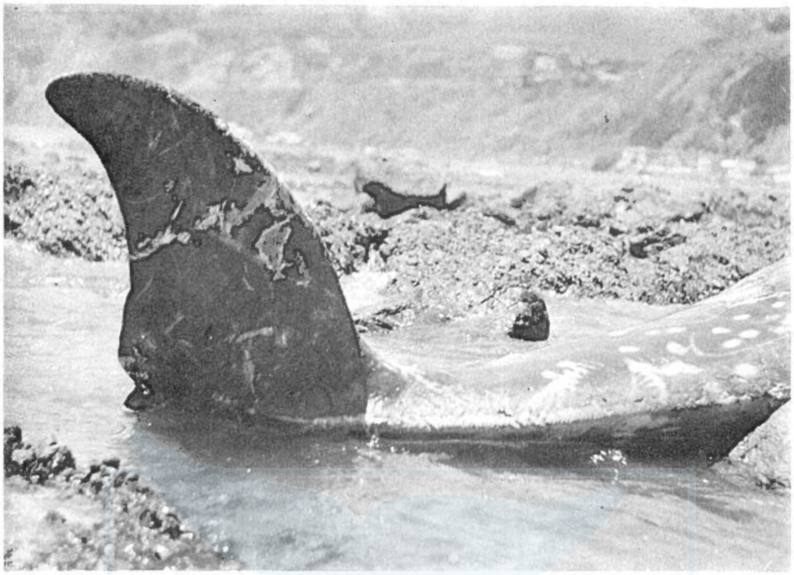

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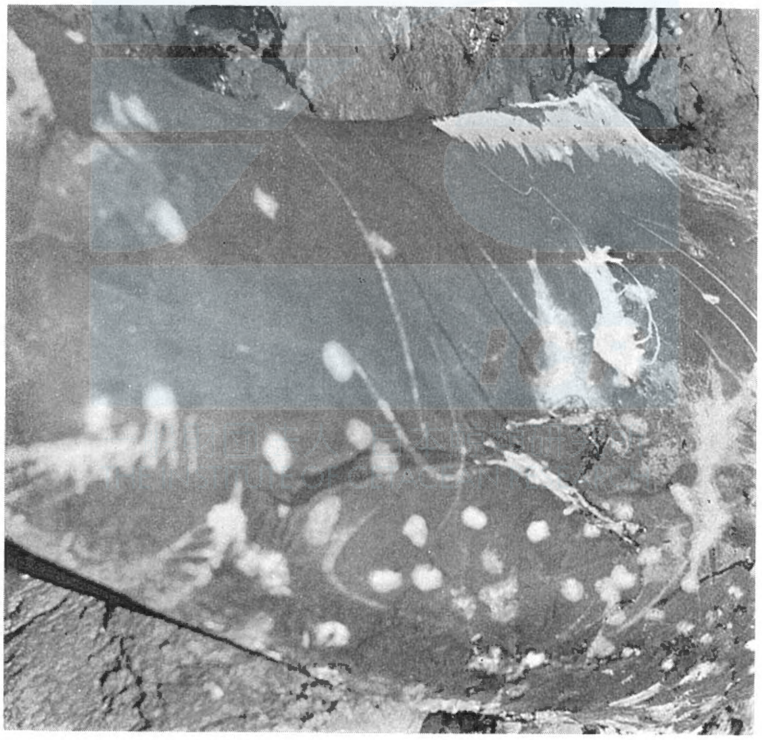

Fig. 2.

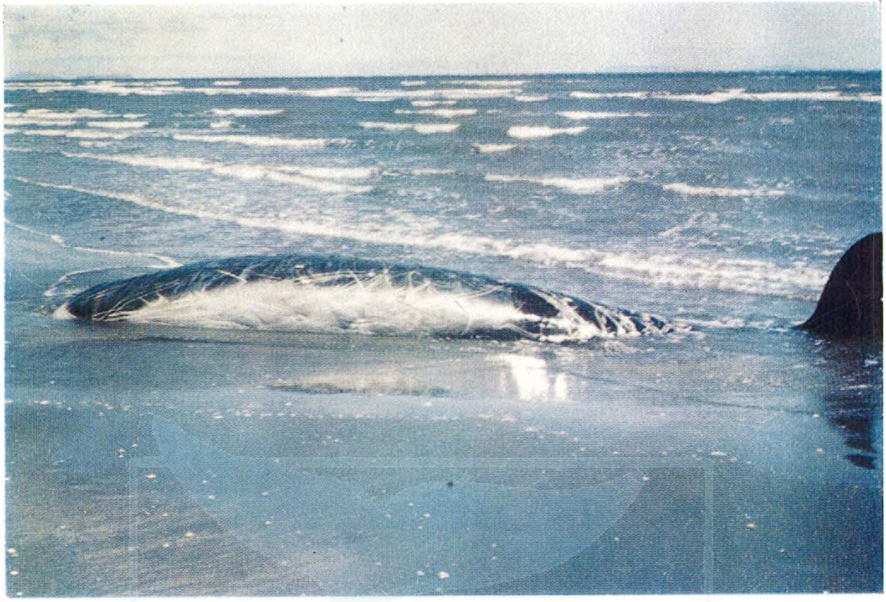

Fig. 1.

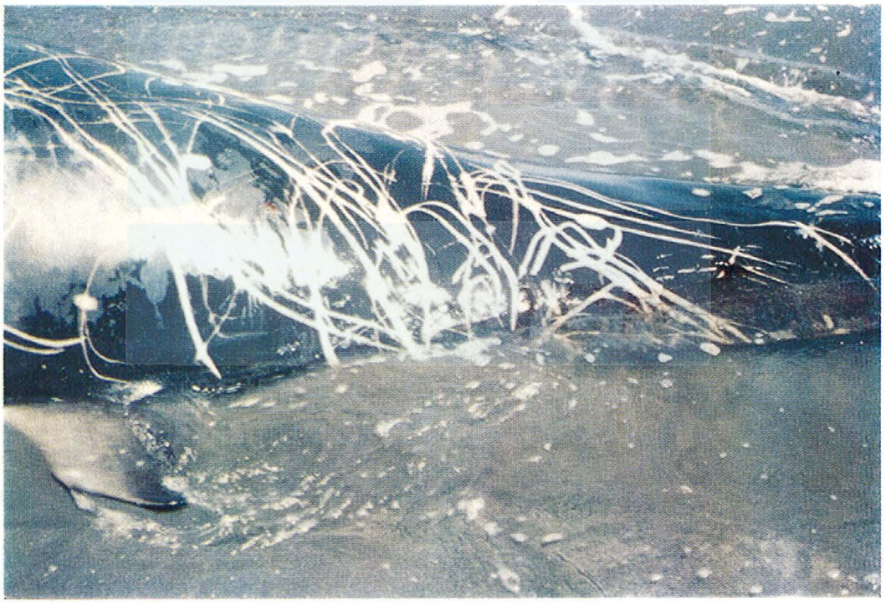

Fig. 2.

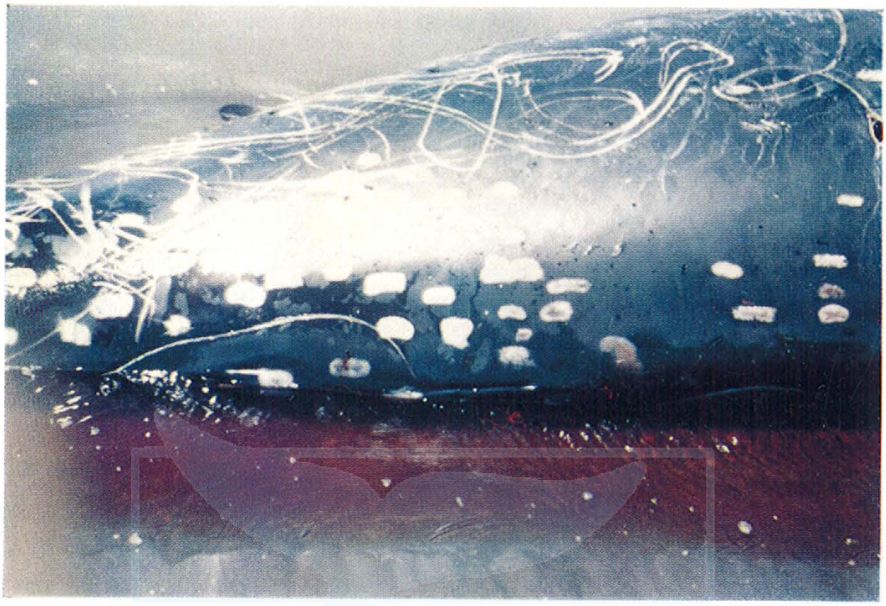

Fig. 1.

Fig. 2.

GROWTH AND REPRODUCTION OF *STENELLA ATTENUATA* IN THE PACIFIC COAST OF JAPAN

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ABSTRACT

Data collected from 7 schools of *S. attenuata* were analyzed. Body length at birth is 89 cm. Sexual maturity is attained at 8.2 years in females and 10.3 years in males. Physical maturity is attained soon after the attainment of sexual maturity at a length of 194.9 cm (females) and 203.3 cm (males). The pigmentation and size of the animals slightly differ from the corresponding species in the eastern North Pacific. Mating seasons are in February and March, July, and November. Gestation lasts for 11.2 months, and lactation for 29 months on average. The mean length of reproductive cycle is about 50 months, but changes with the age of the animal. The annual mortality rate is 0.074 in the mature female and about half of it in immature animals. Some females live for more than 40 years, and have an average of 8.3 calves. The mortality is higher in males than in females. Schooling behavior is discussed.

INTRODUCTION

Stenella attenuata (Gray, 1846) is distributed widely in tropical and subtropical waters of the Indo-Pacific Ocean. In the eastern tropical Pacific the probably conspecific separate population (Perrin, 1973) *S. graffmani* is often caught by tuna seine, and its biology is being studied (Perrin, 1969, Perrin and Roberts, 1972). In the southern Pacific some biological study is reported by Dawbin (1966) based on animals caught at Malaita (Solomon Islands). Though this species is also caught at Taiwan by hand harpoons for human consumption (Kasuya, unpublished), it has not been studied biologically.

In Japanese coastal waters this species is common along the southern coast from Kyushu (Mizue and Yoshida, 1962) to Onahama (36°56′N, 139°55′E) (Kasuya, 1971), and has been caught sporadically by fishermen with hand harpoons or the driving method. On the east coast of Izu Peninsula *S. attenuata* is usually caught in October and early November slightly before the peak of the season of *S. coeruleoalba* (Tobayama, 1969), and on the west coast of Izu Peninsula (Nishiwaki, 1965) slightly after the spring season of *S. coeruleoalba*. However, on the coast of Kii Peninsula a few animals have been captured with hand harpoons in all seasons of the year, and recently fishermen have started to catch this species by the driving method in both winter and summer seasons. This suggests that *S. attenuata* lives in warmer waters than *S. coeruleoalba*, and in early autumn they move to the south along the Pacific coast of Japan. As they are found in waters at more than 16.8°C (Miyazaki *et al.*, 1974), they surely migrate up to 40°N but the information on northbound migration is scarce (Kasuya, 1971, Miyazaki *et al.* 1974). The distribution of this species in the Japan Sea is also unknown.

The biology of *S. attenuata* was partially studied by Nishiwaki *et al.* (1965). The present study is intended to clarify differences between the life history of this species from that of a similar species, *S. coeruleoalba*, and to provide some information on relationships between ecology, environment, and certain species of delphinidae.

MATERIALS AND METHODS

All the materials used in this report were obtained, with a few ancillary materials, from 7 schools caught by the driving method at Kawana or Futo on the east coast of Izu Peninsula, or at Taiji on the coast of Kii Peninsula (Fig. 1, Table 1). One 48 cm fetus was collected in February from a female caught by hand harpoon at Taiji, and 2 of the 4 sets of data on stomach contents of calves were obtained separately at Kawana.

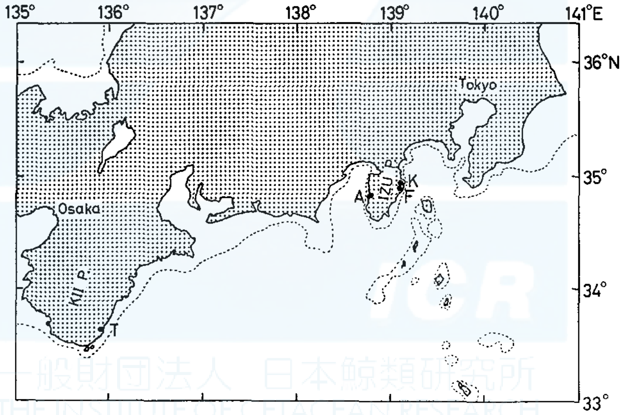

Fig. 1. Map showing the positions of sampling, A indicates Arari, K Kawana, F Futo, and T Taiji. Dotted lines indicate 200 m depth.

As shown in Fig. 2, school 1 was composed of adult males, females and newborn calves, but was lacking in calves of from 128 cm to 156 cm in body length. The pregnant females had small fetuses. The length frequencies of schools 2 to 5 are more or less similar with calves and adult dolphins of various length, but the fetuses were slightly bigger than those observed in school 1. School 6 was different from schools 2 to 5, in the larger size of fetuses. In school 7, full term fetuses and newborn calves were observed. It is difficult to know the exact composition of the larger individuals because of the limited material, but it may not be very different from that of school 3.

Body length was measured in 1 cm intervals in a straight line from the tip of the upper jaw to the bottom of the notch of the tail flukes. In some cases 4 length measurements shown by $4n \leqq L \leqq 4n+3$ were grouped, where n is an integer and L is body length in cm.

The mammary gland was observed in the field and classified into lactating and nonlactating. In some cases its thickness was measured in a longitudinal cut made by the fishermen, because they did not welcome transverse section of the mammary gland. These data were used for reference.

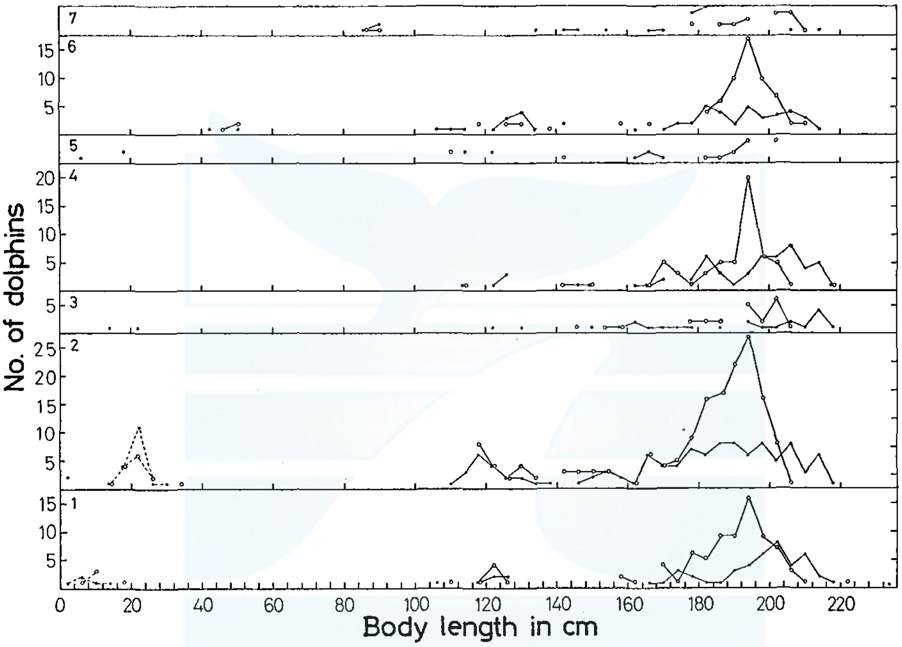

Fig. 2. Length frequencies of *S. attenuata* in the 7 schools studied. Numbers at the left indicate the school, open circles females, closed circles males, dotted lines fetuses, and solid lines postnatal animals. The full term fetuses and newborn calves in school 7 are not separated.

The ovaries were collected from most of the adult and immature females, and fixed with 10% formalin solution. The number of corpora albicantia and lutea was counted by Kasuya in the laboratory by slicing the ovary into about 1 to 2 mm thickness. The three diameters of all the corpora lutea and albicantia and those of the largest follicle were measured. The volume index of the corpora or follicle obtained by multiplying the three diameters was used in the analysis of ovarian activity. But in this report the mean diameter obtained as the cube root of the volume index has usually been used.

Both testes were collected from the males in schools 1 and 2, but only the left one in other schools. They were preserved in the same manner used for ovaries.

The weight was measured in the laboratory. As there is no significant difference expected in the weights of right and left testes, usually the left side was used for study and the right was used only when the left testis was not available.

Several maxillary teeth were collected from the center of the tooth row with a pair of gardening scissors. The tooth section for age determination was prepared after the method of Kasuya (1972) slightly modified to use a grinder. The growth layers in dentine were observed by Kasuya under transmitted light with a binocular microscope (×50).

TABLE 1. MATERIALS USED IN THIS REPORT.

School no.	Dates of		No. of dolphins*		Locality	Researcher
	catch	kill	caught	studied		
1	23, X, '70.	25, X.	264	131	Kawana	Kasuya and Miyazaki
2	10, XI, '70.	15, XI.	1381	273	„	„ „
3	4, XI, '72.	4, XI.	189	48	„	Miyazaki
4	13, XI, '72.	13, XI.	192	117	„	„
5	16, XI, '72.	18, XI.	67	23	Futo	„
6	12, II, '73.	12, II.	146	122	Taiji	„
7	2, VII, '73.	2, VII.	Ca. 60	36	„	Dawbin

*: Fetuses not included.

Some of the selected testes were studied histologically after staining with haematoxylin and eosin. In these cases samples were collected from the center of the cross section made at the midlength of a testis. In order to check the presence of spermatozoa in a wider range, smears were taken from most of the testes on the same cross section, and observed after staining with methylene blue. These testes observations were made by Miyazaki and Kasuya.

AGE DETERMINATION AND GROWTH

Age determination

The growth layers in dentine were used to determine the age characteristics as the cementum of *S. attenuata* is too thin to count the growth layers. The nature of the dentinal growth layers of this species does not differ much from that of *S. coeruleoalba* (Kasuya, 1972), but counting is slightly more difficult because of the irregularity of the layers. The poorly calcified secondary dentine is observed in teeth with about 12 or more layers. This may indicate that the growth of the dentine becomes slower in these ages, when physical maturity of the animal is attained.

To find the annual accumulation rate of dentinal growth layer, the condition of the last layer was checked on teeth which had 10 or less opaque bands and in which the thickness of the layer was not too thin to estimate the relative thickness. Though the relative thickness of the layer was estimated in comparison with the former layer taking into consideration the gradual decreasing size of the layer, this observation is less reliable than the identification of opaque or translucent layers. As shown in Fig. 3, most of the animals killed in July, October and November were forming opaque layers, but almost all the animals killed in February were accumulating translucent layers. In the present study it has been impossible to decide the date when the formation of the two kinds of layers alternate, but it seems probable that the alternations occur in December or January and in April or May, and that each opaque and translucent layer represent about 6 months respectively.

In this study the number of opaque layers in dentine, excluding the fetal layer, was counted together with observation of relative thickness and condition of the first and last layers. The layers were usually counted along the line set from the

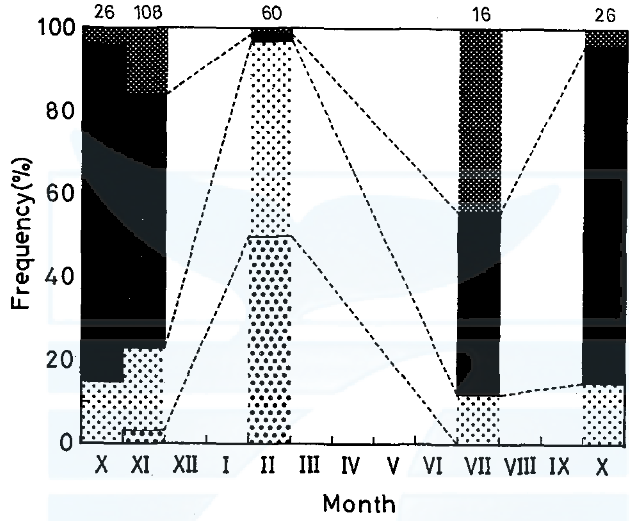

Fig. 3. Seasonal change of the formation of opaque and translucent dentine layers. Black with white spots indicates thin opaque layer, the black thick opaque layer, the white with small spots thin translucent layer, and the white with large spots thick translucent layer.

TABLE 2. CRITERION FOR CALCULATING THE AGE FROM THE NUMBER OF OPAQUE LAYERS (n).

First and last layers	Possible range of age	Approximate age (x)
tt-tt	$n+0.50 \geqq x > n$	$x \fallingdotseq n+0.25$
tt- t	$n+0.25 \geqq x > n-0.25$	$x \fallingdotseq n$
t- t oo-tt	$n \geqq x > n-0.50$	$x \fallingdotseq n-0.25$
oo- t o-tt	$n-0.25 \geqq x > n-0.75$	$x \fallingdotseq n-0.50$
oo-oo o- t	$n-0.50 \geqq x > n-1$	$x \fallingdotseq n-0.75$
oo- o	$n-0.75 \geqq x > n-1.25$	$x \fallingdotseq n-1$
o- o	$n-1 \geqq x > n-1.50$	$x \fallingdotseq n-1.25$

o: thin opaque, oo: thick opaque, t: thin translucent, tt: thick translucent middle of the neonatal line to the central portion of the pulp cavity, because the structure near the distal tip is sometimes discontinuous especially in the young layers. When the number of opaque bands (n) is counted the possible range of real age (x) is generally shown by the following formula.

$$n-1.5<x<n+0.5$$

In case of animals at 3.5 years or older, the approximate age was represented by the value at the center of both extremities, or

$$x \fallingdotseq n-0.5$$

However, in the case of the younger animals, it was calculated from the criterion shown in Table 2.

As indicated in the latter section the counting of the dentinal growth layers is not reliable after the accumulation of secondary dentine, but the age of animals obtained from dentinal growth layers by the above method has been used in this report without special comment.

Length frequencies

The length frequencies of fetuses and juveniles varies between schools. This reflects the special schooling behavior related to the maturity and reproductive cycle. These problems are dealt with separately. There is no significant difference observed between schools in the shape of the peaks for animals more than 184 cm in females or 196 cm in males. When all schools are combined, the highest frequency is found in the length group 192 cm to 195 cm in females, and 204 cm to 207 cm in males. The difference of the modal lengths is about 12 cm. Most females are shorter than 212 cm and males less than 220 cm, but exceptionally large records of a female and a male were 220 cm and 234 cm respectively.

The above modal lengths seem to be slightly bigger than that of *S. graffmani* reported by Perrin (1969).

Fetal growth and length of gestation

The mean body length at birth is estimated roughly from the 5 full term fetuses or newborn calves in school 7. In this school 85 cm female, 85 cm male, and 88 cm male were considered to be definitely prenatal because they were found with large umbilical cord attached, or taken out of the uterus by Dawbin. The 89.0 cm male was considered to be a newborn calf because it had no trace of umbilical cord, but the umbilicus was the shape of an oval hollow with thin epidermis and the size was larger than that of a fully healed umbilicus. Its stomach contained milk of about 13 g in weight. One 88 cm female animal was found in the pile of viscera with the thin fragment of the external layer of the umbilical cord. However, the size of the fragment was much smaller than that of the 3 specimens first mentioned. The dorsal fin was not bent completely to one side as in the case of the fetus, but stood obliquely. On the lateral side of the body of the animal there were observed several transverse shallow grooves which are often found on the fetus. It had no milk in the stomach. According to the observation of Nakajima *et al.* (1963) on a *Tursiops truncatus* born in an aquarium, it takes several hours for the dorsal fin to stand vertically. Our observation on a newborn *S. coeruleoalba*, 100 cm in body length, shows that it had plenty of milk in the stomach in spite of features quite similar to the above 88 cm *S. attenuata* in the umbilicus, dorsal fin, and grooves on the flank. This suggests that the 88 cm animal was postnatal. However, we have some query on the last specimen of *S. attenuata* as to whether it was delivered by the artificial action given to the mother in the period from the start of driving to the time of kill. However, the present best estimate of the mean body length of *S. attenuata* at birth comes between 88 cm and 89 cm. In this paper 89 cm has been used as the tentative mean length at birth. Even if it is 88 cm in reality, the length of gestation is changed by only 3 days, which is negligible in relation to our tentative estimate of the mean length of gestation obtained below.

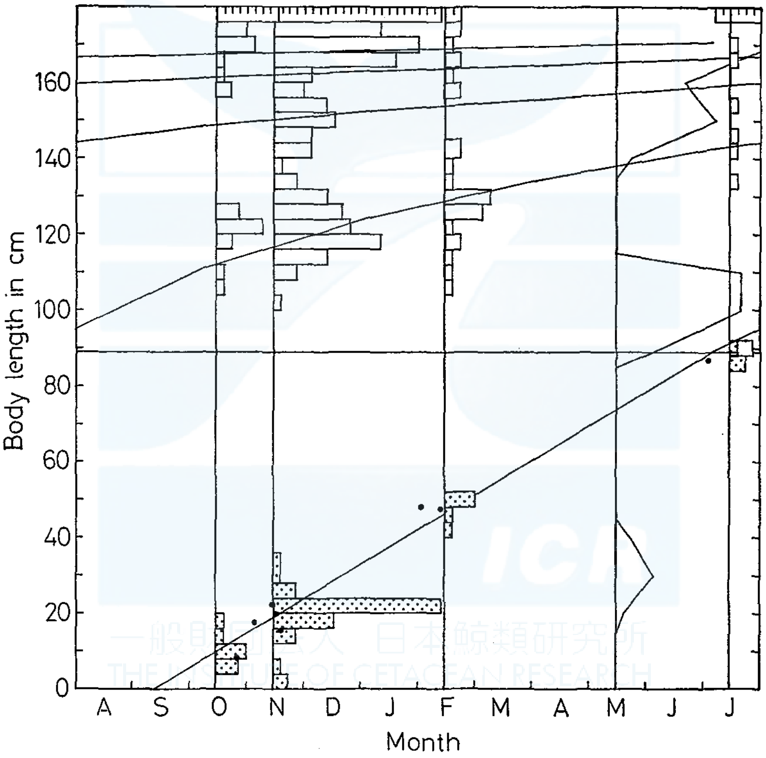

Fig. 4. Growth of fetus and juvenile calves. Length frequencies are grouped into months. The dotted area indicates fetuses, the white postnatal, and closed circles the mean body lengths of fetuses in each school. A school caught in May (Nishiwaki *et al*, 1965) is shown by solid line.

The length of gestation and fetal growth were calculated from the seasonal change of fetal length. In Fig. 4, the mean fetal length in each school was plotted against the date of kill. In school 2 the fetal length is bimodal, but it was not separated because the deviation from the main mode is not large. In other schools the fetal length is unimodal. In school 7 all the full term fetuses and newborn calves were combined in calculating the mean length. In addition to the 7 schools, one record of a fetus caught at Taiji in Feburary is also plotted in Fig. 4. All the above 8 points fall on a straight line, but the fetuses reported by Nishiwaki *et al.* (1965) come on quite a different position. The latter are considered to represent other mating seasons, and are dealt with separately. Laws (1959) showed in odontoceti that, except during the very early stage of growth, the relation between fetal length and the elapsed time after conception is shown by a single straight line. If a straight line is calculated by least squares for the above 8 points, the growth of the fetus is shown by the following formula,

$$y = 0.30094x - 76.74$$

where y is the length of the fetus in cm and x is the number of days counted from the last lst of January. This formula shows that the daily increment of length at the straight part of the growth is 3.0 mm. The extended growth line cut the axis of time at day 255.01 or 12th of September, and attains the mean length at birth, 89 cm, on day 550.73 or 5th of July. Accordingly the length from the date when the extended straight line crosses the axis of time to the date of birth is 295.72 days.

If 0.135 × gestation period is tentatively used here for Lto of Laws (1959), which is the time from the start of gestation to the date when the extended straight line of the fetal growth cuts the axis of time, the length of gestation (L) is shown by the following formula

$$L - Lto = 295.72 \text{ days}$$
$$Lto = 0.135L$$

Then L is 341.87 days or 11.24 months and Lto is 46.15 days or 1.52 months. The date of conception of the growth line in Fig. 4 comes on 28th of July. The fetal growth rate of this species at the straight part of growth is close to that of *Tursiops* and *Phocoena* reported by Fraser and Huggett (1973).

Postnatal growth

The relation between body length and age of 195 males and 239 females is shown in the scatter diagram of Figs. 5 and 6.

The growth during the first three years is rapid. The mean growth curve of this part was drawn by eye based on the mean lengths in each 1/4 year interval and considering the distribution of each point in Figs. 5 and 6. As no sex difference in these age classes is observed, both sexes were combined.

The growth of males between the age of 3 years and 12 years, and of females between the age of 3 years and 7 years seems to be almost straight. The growth line of this age range was calculated by least squares based on the mean body lengths, weighted by the sample size. As the sample is small and no significant sex difference is observed in the age groups between 3 and 6 years, the data for females were included. Then, the the following relation is obtained between the year after birth (x) and the body length (y) in cm.

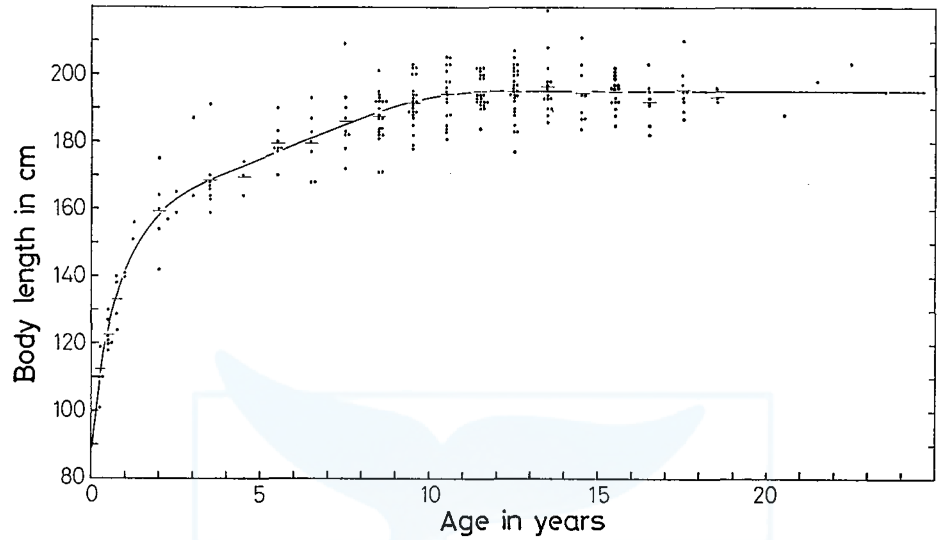

Fig. 5. Mean growth curve of female *S. attenuata*. Age was estimated from the dentine growth layers. Each spot indicates one animal and rod the mean body length.

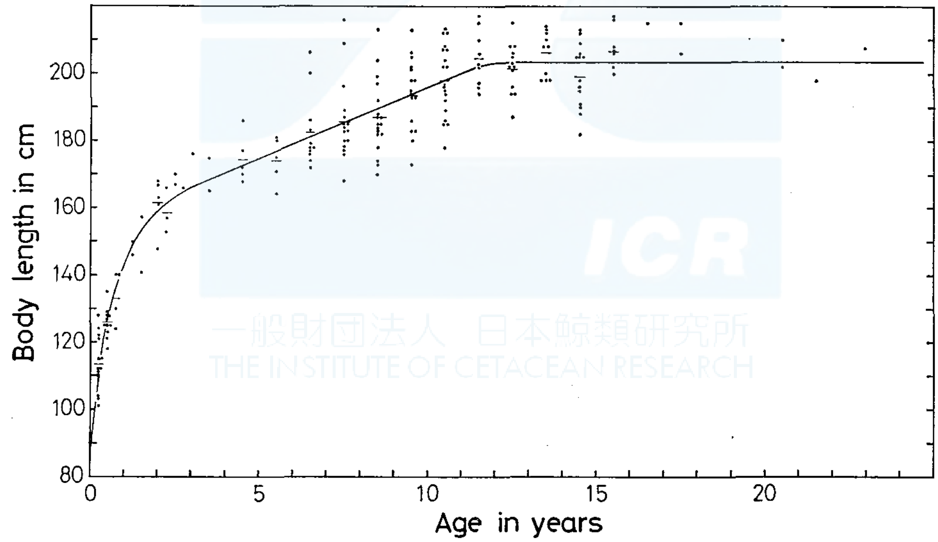

Fig. 6. Mean growth curve of male *S. attenuata*. For symbols see Fig. 5.

$$y = 4.20x + 153.8, \quad 3.5 \leqq x \leqq 11.5$$

This indicates that the mean annual increment of body length is 4.20 cm

The increase of the mean body length finishes in males at the age of 11.5 years. This is the age when most of the animals attain physical maturity. The asymptotic length of males at 203.3 cm is obtained as the mean of 49 males with ages of 12.5 years or more.

The mean growth of females becomes slower after 6.5 years of age and the differences of length between the sexes increases. The growth of females seems to stop at the 11th year. The mean asymptotic length of females obtained from 137 females which are at the age of 11.5 years or more, is 194.9 cm. This is 8.4 cm smaller than that of males. This difference results from the earlier slowing down of growth and the earlier attainment of physical maturity in females. Females seem to attain physical maturity soon after the attainment of sexual maturity as in the case of males. This is confirmed by the fact that the mean body length at the ovulation of 1, 2, 3, and 4 is 189.5, 191.4, 192.5, and 192.4 cm respectively, and attains at 5 ovulations 195.1 cm which is approximate to the asymptotic length 194.9 cm. Then the mean lengths do not show the increase but fluctuate in the range between 192 cm and 198 cm. The mean body length of the sample in each

TABLE 3. GROWTH OF *STENELLA ATTENUATA*.

<table>
<tr><th rowspan="3">Age (year)</th><th colspan="4">Body Length (cm)</th></tr>
<tr><th colspan="2">mean of sample (sample size)</th><th colspan="2">on growth curve</th></tr>
<tr><th>♂</th><th>♀</th><th>♂</th><th>♀</th></tr>
<tr><td>0</td><td colspan="2">89.0 (1)</td><td colspan="2">89.0</td></tr>
<tr><td>0.25</td><td colspan="2">113.4 (17)</td><td colspan="2">111.0</td></tr>
<tr><td>0.50</td><td colspan="2">124.6 (18)</td><td colspan="2">124.6</td></tr>
<tr><td>0.75</td><td colspan="2">133.1 (8)</td><td colspan="2">134.5</td></tr>
<tr><td>1.00</td><td colspan="2">140.5 (2)</td><td colspan="2">142.7</td></tr>
<tr><td>1.25</td><td colspan="2">150.8 (4)</td><td colspan="2">148.3</td></tr>
<tr><td>1.50</td><td colspan="2">149.0 (2)</td><td colspan="2">152.3</td></tr>
<tr><td>1.75</td><td colspan="2">—</td><td colspan="2">155.8</td></tr>
<tr><td>2.00</td><td colspan="2">160.2 (10)</td><td colspan="2">158.9</td></tr>
<tr><td>2.25</td><td colspan="2">158.3 (4)</td><td colspan="2">161.2</td></tr>
<tr><td>2.50</td><td colspan="2">165.3 (4)</td><td colspan="2">163.1</td></tr>
<tr><td>2.75</td><td colspan="2">166.0 (1)</td><td colspan="2">164.7</td></tr>
<tr><td>3.00</td><td colspan="2">175.7 (3)</td><td colspan="2">166.0</td></tr>
<tr><td>3.5</td><td colspan="2">168.8 (10)</td><td colspan="2">168.5</td></tr>
<tr><td>4.5</td><td colspan="2">172.6 (8)</td><td colspan="2">172.7</td></tr>
<tr><td>5.5</td><td colspan="2">177.3 (13)</td><td colspan="2">176.9</td></tr>
<tr><td>6.5</td><td>182.6 (11)</td><td>179.4 (7)</td><td>181.1</td><td>181.1</td></tr>
<tr><td>7.5</td><td>185.7 (16)</td><td>186.2 (9)</td><td>185.3</td><td>185.0</td></tr>
<tr><td>8.5</td><td>186.8 (18)</td><td>187.6 (20)</td><td>189.5</td><td>188.3</td></tr>
<tr><td>9.5</td><td>193.3 (16)</td><td>191.5 (22)</td><td>193.7</td><td>191.5</td></tr>
<tr><td>10.5</td><td>198.1 (19)</td><td>194.0 (18)</td><td>197.9</td><td>194.0</td></tr>
<tr><td>11.5</td><td>204.4 (9)</td><td>194.9 (22)</td><td>202.1</td><td>194.9</td></tr>
<tr><td>12.5≦</td><td>203.3 (49)</td><td>194.9 (115)</td><td>203.3</td><td>194.9</td></tr>
</table>

age group and the corresponding body length on the growth curve obtained in the above are shown in Table 3.

Kasuya (1972) tried to adopt exponential formulae for the mean growth curve of *S. coeruleoalba*, but the fit was never good. In the present study we could not find a suitable formula to express the mean growth of the present species. For comparison, the mean growth curve of *S. coeruleoalba* is shown in Fig. 7. This was based on the 881 animals obtained by the end of 1972 including the data used by Kasuya (1972), in which age determination was made by the same author. The straight part of the male growth curve was calculated by least squares, but that of the female was drawn by eye. The feature of this part is its strong resemblance

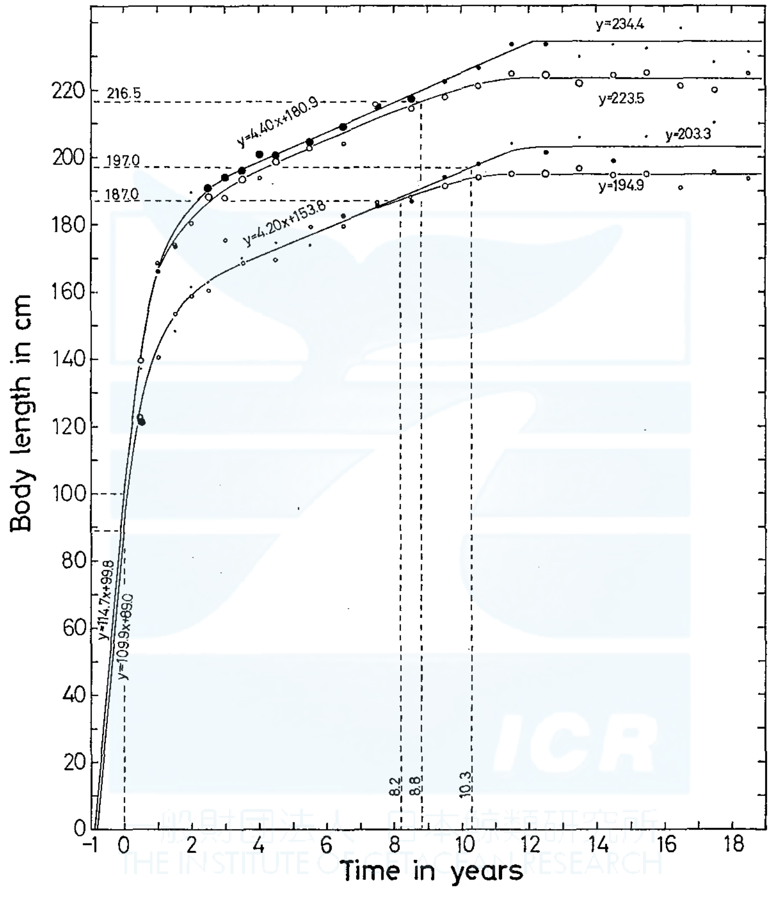

Fig. 7. Comparison of the mean growth curves of *Stenella coeruleoalba* (upper pair) and of *S. attenuata* (lower pair). The largest circles indicate the mean length represented by 25 or more animals, the intermediate from 11 to 24 animals, and the smallest 10 or less animals. In both species closed circles and the upper line indicate males and open circles and the lower line females. The age of female *S. coeruleoalba* at sexual maturity was cited from Kasuya (1972). The slow growth stage at early pregnancy is not shown.

to that of *S. attenuata,* except for the slight between sexes difference of length. If enough data is accumulated, a similar pattern of growth seems likely to be observed in *S. attenuata.* The age at physical maturity of *S. attenuata* seems to be about 1 year earlier than that of *S. coeruleoalba.* The difference of asymptotic lengths between two species is mainly affected by the difference of growth in young stage.

Weaning

Direct information on the start of the weaning is scanty (Table 4). Our data suggest that some animals start feeding on solid food at the length of 115 cm and the age of 1/4 year, but most of the animals start at about 130 cm, or about half a year after birth.

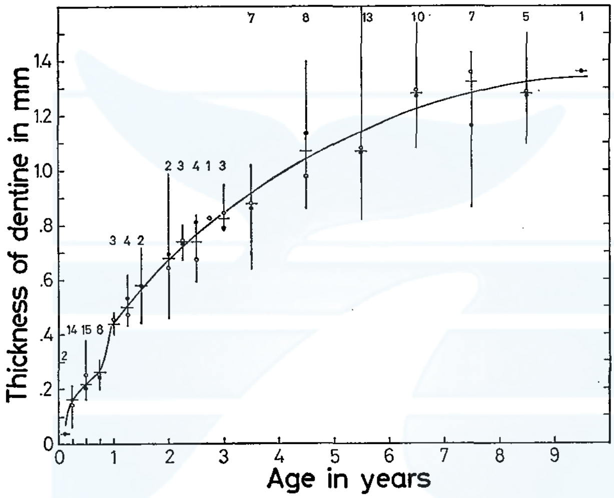

Fig. 8. Relation between age and the thickness of postnatal dentine of *S. attenuata.* Open circles indicate the mean of females, the closed males, and vertical and horizontal rods the range and mean for both sexes. Numbers at the top indicate sample size. The line was drawn by eye.

TABLE 4. STOMACH CONTENTS OF JUVENILE *STENELLA ATTENUATA.*

Body length	Age	Sex	Milk	Food remains	Nematoda
115 cm	—	♂		+	+
122 cm	1/4	♂		−	
128 cm	—	♂	+	−	−
129 cm	1/2	♂		+	
168 cm	—	♀		+	+

The thickness of postnatal dentine measured in cross section at the level of the proximal end of prenatal dentine was compared with the growth of the animal. As shown in Fig. 8, the increase of the thickness of dentine after 1 year of age shows a similar pattern to that of body length, but it shows a rapid increase at the age between 0.5 and 1.0 year. When it is compared with the body length (Fig. 9), the growth of dentine changes from a low rate to a higher rate at a body length of about 133 cm, which corresponds to the age of 0.7 year.

It is generally known that the baleen plates of mysticeti grow rapidly at the period of weaning. A similar feature is also expected in the growth of teeth, because teeth would start to have a mechanical function in catching food after the start of weaning. Probably the weaning of *S. attenuata* starts, in the average, at an age between 0.5 and 0.75 year or at the length of 130 cm. However, the weaning period seems to last long in the case of toothed whales, and the start of feeding on solid food does not necessarily mean the cessation of suckling. The duration of suckling is dealt with separately.

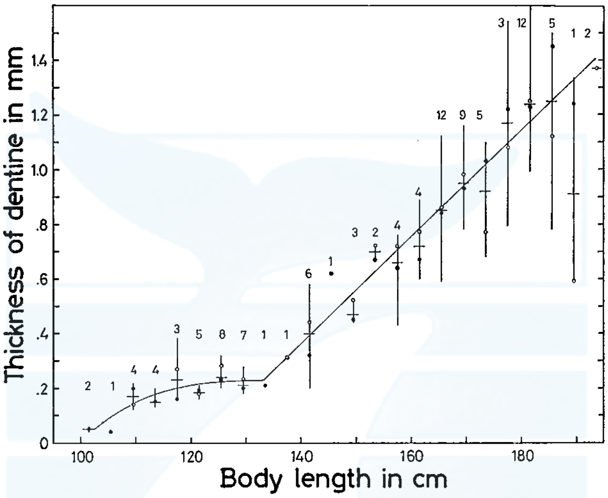

Fig. 9. Relation between the thickness of postnatal dentine and body length of *S. attenuata*. The line was drawn by eye. For other symbols see Fig. 8.

The calf of *Tursiops truncatus* starts to take solid food at an age of from 6.3 to 9 months, or 0.5 to 0.8 year (Tavolga and Essapian, 1957, Nakajima *et al*, 1963). This coincides well with the information obtained on *S. attenuata*.

Age at the attainment of sexual maturity of the female

As the left ovary of this species matures earlier than the right (Ohsumi, 1964), it is reasonable to expect earlier development of the left ovary even in immature animals.

Fig. 10 shows the difference of weight between the two ovaries of immature females of *S. attenuata*. In young animals the weight of the left ovary is nearly equal or slightly smaller than that of the right, but the growth of the left ovary starts to exceed that of the right at a body length of about 170 cm. The age corresponding to this length is about 4 years. This may indicate the approach of puberty even if development of the follicle has not started. This age is about one year later than the age of the male when the formation of spermatozoa in the testis starts.

Fig. 11 shows the relation between age and the diameter of the largest follicle of mature and immature females of *S. attenuata*. The observed largest diameter was between 10 and 11 mm. This size is considered to be close to the size at ovulation. The development of the follicle in immature females is observed only in animals at the ages of 6.5 years or more. This means that puberty of females starts at this age which is very close to the age at the attainment of sexual maturity, and that the growth of follicles is rapid to attain the size at ovulation.

The youngest mature female is found in the age class of 7.5 years and the oldest immature in that of 9.5 years. The percentage of newly mature females at

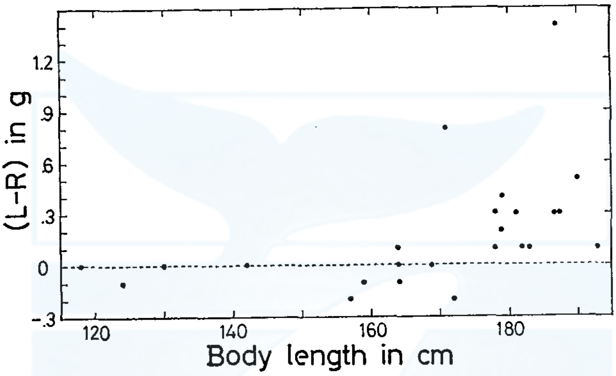

Fig. 10. Relation between the difference of the weights of both ovaries and body length in immature *S. attenuata*.

TABLE 5. MATURITY OF *S. ATTENUATA* BY AGE GROUPS.

Age	Male*				Female		
	immat.	pub.	mat.	mat. (%)	immat.	mat.	mat. (%)
<1	12	—	—	0	15	0	0
<2	2	—	—	0	4	0	0
≦3	2	3	—	0	10	0	0
3.5	—	1	—	0	8	0	0
4.5	—	2	—	0	3	0	0
5.5	—	3	—	0	7	0	0
6.5	—	9	1	10.0	7	0	0
7.5	—	12	—	0	6	2	25.0
8.5	—	13	2	13.3	7	12	63.2
9.5	—	9	3	25.0	2	18	90.0
10.5	—	7	11	61.2	0	18	100
11.5	—	2	6	75.0	0	21	100
12.5	—	3	8	72.8	0	27	100
13.5	—	1	8	88.9	0	15	100
14.5	—	—	10	100	0	11	100

*: Based on testis weight when other information was not available

the age of between 6.5 and 7.5 years, 7.5 and 8.5 years, 8.5 and 9.5 years, and 9.5 and 10.5 years are calculated from Table 5 as 25.0 %, 38.2 %, 26.8 % and 10.0 % respectively. This indicates that most of the animals attain maturity at an age between 7.5 and 8.5 years. But as there are observed some females which are considered to be in the second cycle of reproduction in the age classes of 7.5 and 8.5 years, a few females seem to attain sexual maturity at an age between 5.5 and 6.5 years (Table 19). The mean age of females at the attainment of sexual maturity was obtained after the method of Kasuya (1972) as the age where the cumulative frequency of immature animals in older age classes is equal to that of mature animals in younger age classes (Fig. 12). It gives the mean age of females at the

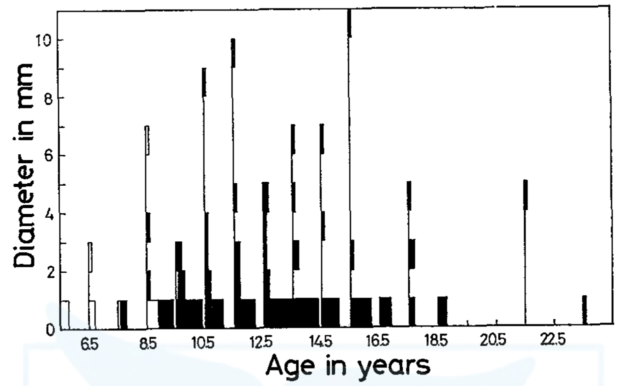

Fig. 11. Relation between the diameter of the largest follicle and age. White squares indicate immature females and black the mature.

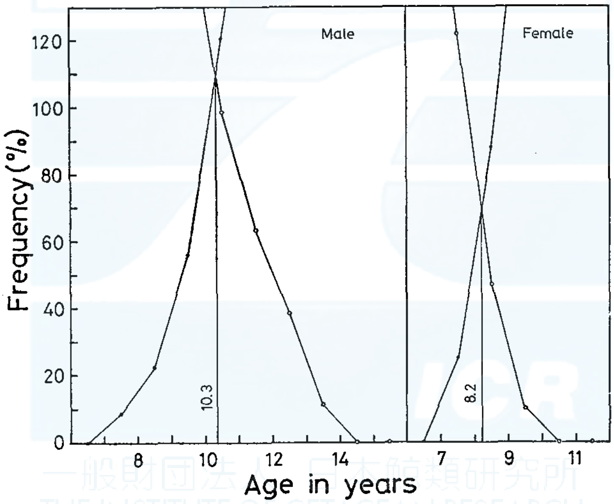

Fig. 12. Age at the attainment of sexual maturity in *S. attenuata*. Open circles indicate the cumulative frequency of immature animals, and closed circles that of mature animals. For explanation see text.

attainment of sexual maturity as 8.2 years. The body length at this age is 187 cm on the mean growth curve.

Age at the attainment of sexual maturity of males

The bilateral difference of testis weight was checked on 44 animals collected from schools 1 and 2.

If the mean of the left weight minus right weight is equal to zero it is concluded that there is no bilateral asymmetry. As shown in Table 6, the mean difference in mature animals is small enough to consider that there is no significant asymmetry of the testis weight. In testes with 68 g or less weight, the observed deviation of the mean from zero is large enough to be expected at the probability between 2 to5 %. But at present we consider that this does not prove asymmetry of testis weight, so the weight of the left testis was usually used in the following discussion.

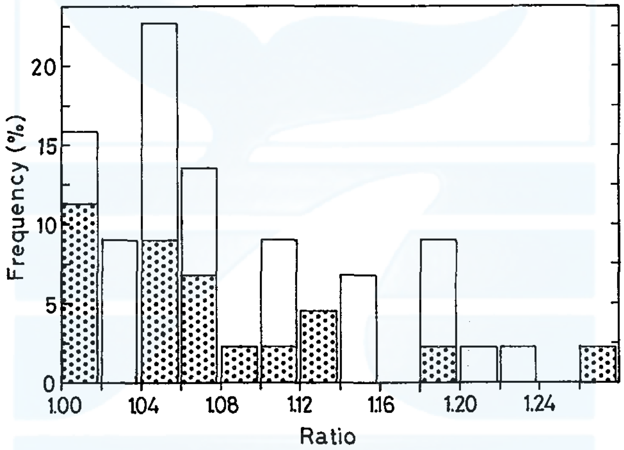

Fig. 13. Frequency distribution of the ratio of the weight of the heavier testis to the lighter. Dotted area indicates the pairs where the right testis is heavier or equal to the left.

TABLE 6. T-TEST OF THE SYMMETRY OF THE TESTES WEIGHT.

Weight (left, g)	Range (L.-R.)	Mean difference	Sample size	Standard error	Probability
68>	−10.9∼ 1.4	−1.2720	25	0.5808	0.05>p>0.02
68≦	−30.0∼30.0	+1.9053	19	3.6574	0.70>p>0.50
Total	−30.0∼30.0	+0.1000	44	1.6075	p>0.90

The ratio of the heavier testis to the lighter comes between 1.00 and 1.28 (Fig. 13). However, about 93 % of all the pairs observed show a ratio of less than 1.20. This means that if the left testis is weighed, the weight of the right side is expected with a probability of more than 90 % to be between 1.20 and 1/1.20 (0.83) times that of the left.

The maturity of the testis was checked by two methods. One is histological examination of testis tissue taken from the center of the cross section at the midlength of the testis. When spermatozoa were observed in this part, the testis was considered to be in full maturity. The smallest testis in this condition was 66 g, and the largest immature testis was 71 g. Accordingly the mean weight of testis at the attainment of full sexual maturity is considered to be about 68 g, and any testis of this weight or heavier was classified as mature.

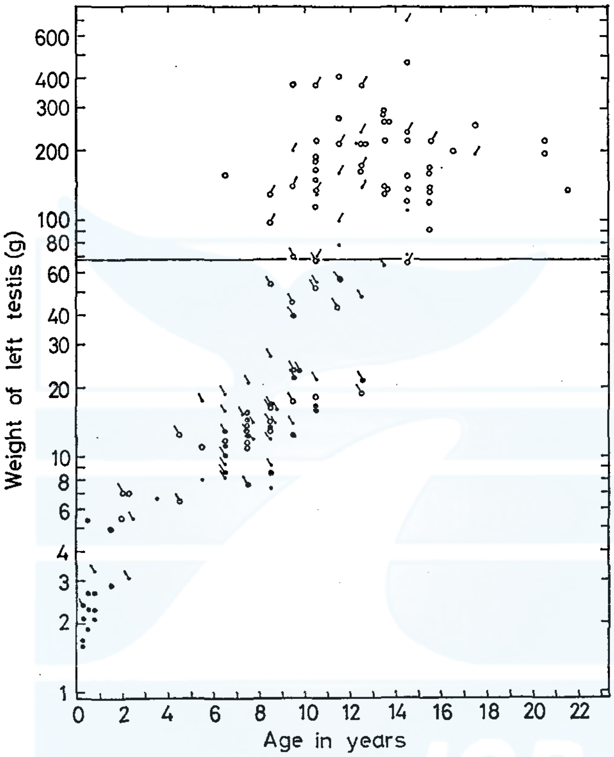

Fig. 14. Scatter diagram of the weight of testis and age. The weight of testis is plotted on logarithmic scale. Large closed circles indicate spermatozoa absent in the smear, open circles spermatozoa present in the smear, small closed circles no observation of the smear, rod at the upper left immaturity of the tissue at the center of testis, rod at the upper right the maturity, and solid line mean weight of testis at the attainment of sexual maturity.

Even if a testis is identified as immature by the above method, when the smear taken from the cross section at the midlength of the testis is observed some spermatozoa are usually found. This probably means that even when the core of the testis is not mature, some part, most likely the tissue at the periphery has already started the formation of spermatozoa. This phenomenon is the reverse of the observation on sperm whales reported by Best (1969), and will need further confirmation. An animal which has the testis at this stage is considered to be in puberty. This stage of testis was commonly found among those with weight between 6.0 g and 68 g, so any animal with a testis of between 6.0 g and 67.9 g was classified as puberal.

Among animals which have a testis weight corresponding to the criterion of puberty, there are some which have no spermatozoa in the smear. The ratio of these to all puberal animals varies between schools. This can be related to the reproductive season or the school structure and will be dealt with separately.

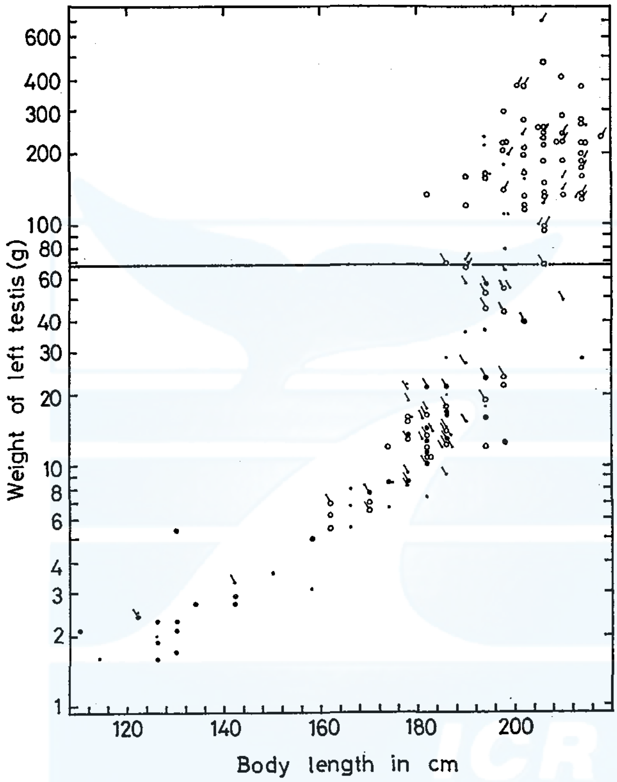

Fig. 15. Scatter diagram of the relation between weight of testis and body length. For symbols see Fig. 14.

As shown in Table 5 and Figs. 14 and 15, all males younger than 2.0 years or 160 cm in body length are immature. Puberal animals first appear in the age class 2.0 years and are observed until the age of 13.5 years. Most animals in age classes between 2 and 8 years or length between 160 cm and 187 cm belong to the puberal stage.

Fully mature animals start to appear at the age of 6.5 years and all animals attain sexual maturity by the age of 14 years. After this the weight of testis does not increase with age.

The mean age at the attainment of sexual maturity obtained by the same method used for females is 10.3 years. This is about one year higher than that of *S. coeruleoalba*, in spite of the larger weight of testis and smaller diameter of seminiferous tubules at sexual maturity of *S. attenuata*. The mean body length corresponding to this age, 197 cm, is obtained from the mean growth curve.

Fig. 16 shows the relation between mean diameter of seminiferous tubules and weight of testis. The histological samples were taken from the center of a section at midlength of the testis. The mean of the measurements of 15 tubules measured on a photograph was used as the mean diameter of tubules of the animal. The relationship between weight of testis and the mean diameter of tubules is shown by two lines as calculated below.

$$D=24.94\ W^{0.22528},\quad W<68$$

$$D=11.11\ W^{0.44692},\quad W\geqq 68$$

In the formulae, D is the mean diameter of tubules in μ, and W the weight of testis in g. The mean diameter of tubules at the attainment of sexual maturity is between 60 and 70 μ, which is smaller than that of *S. coeruleoalba* (Hirose and Nishiwak, 1971).

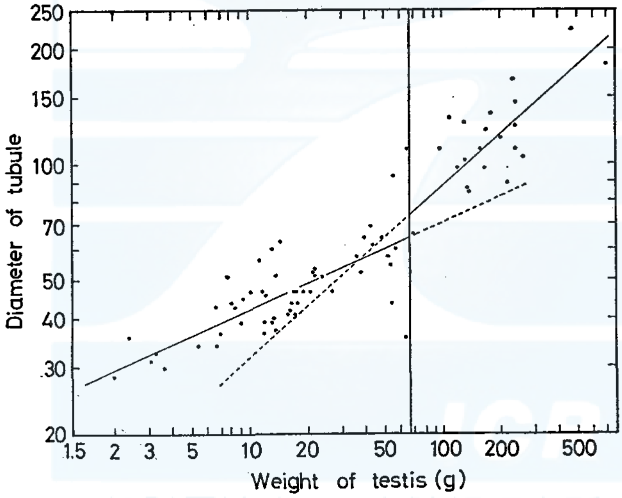

Fig. 16. Relation between the mean diameter of seminiferous tubules and the weight of testis, plotted on logarithmic scales. Lines are drawn by the least squares.

The weight is proportional to $D^{4.4}$ in immature animals but to $D^{2.2}$ in mature animals. This suggests that the fluctuation of the weight of testis of mature animals is affected by the change in diameter of seminiferous tubules.

The body length where half of the animals attain sexual maturity

This length is defined as that where the number of immature animals above this length is equal to that of mature animals below this length, and obtained by the same method used in the former section in calculating the mean age at the attainment of sexual maturity. It gives a length 181.9 cm for females and 194.3 cm for males (Fig. 17). These values are slightly shorter than the body lengths corresponding to the mean age at the attainment of sexual maturity. The difference is 5.1 cm in females and 2.7 cm in males. These discrepancies are reasonable, because the growth of the animal stops soon after the attainment of sexual maturity and the attainment of sexual maturity may be more dependent on age than on body length. However, the absolute values of the differences obtained here are not highly reliable. The body length where half of the animals are sexually mature is strongly affected by the age composition of the sample or of the population. If the ratio of sexually mature old animals decreases by the effect of exploitation, the value may become higher. This value is useful only when the maturity must be classified based on the body length frequency.

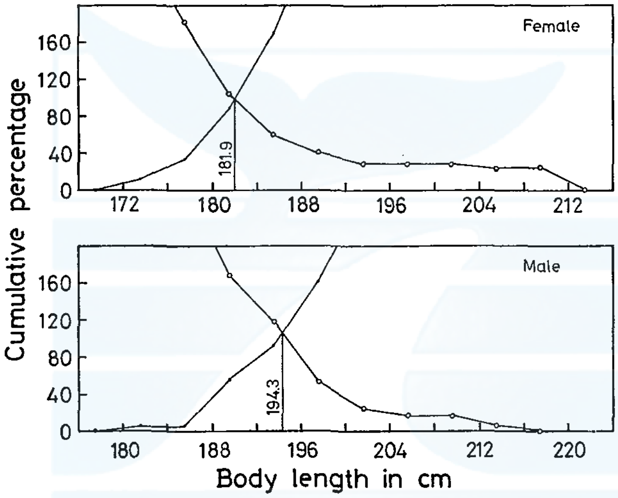

Fig. 17. Body length of *S. attenuata* where half of the animals attain sexual maturity. For explanation see text.

Body weight

Body weight of *S. atteuata* is known for 20 females and 14 males. These data are plotted on a logarithmic scale in Fig. 18. As the data are scarce a difference between the sexes was not demonstrated. The relation between body length (L, cm) and the weight (W, kg) seems to be expressed by two straight lines. If the formula $W=aL^b$ is calculated by least squares, the following constants are obtained. For the samples between 86 cm and 130 cm

$$a_1=0.0001901$$
$$b_1=2.3638$$

For the samples between 110 cm and 207 cm

$$a_2=0.00001876$$
$$b_2=2.8504$$

The two regression lines cross at the point L=116.6 cm. This means that the body weight of the newborn calf is heavier than the weight obtained by extrapolating the length-weight relationship of the older animals, and that after birth the calf grows more in length than in circumference and therefore becomes more slender. After the attainment of a length from 110 cm to 130 cm or an age of about 6 months, the circumference increases more closely in parallel with that of the body length than at the earlier stage. However, as b_2 is still less than 3, *S. attenuata* continues to become slender with increase of body length.

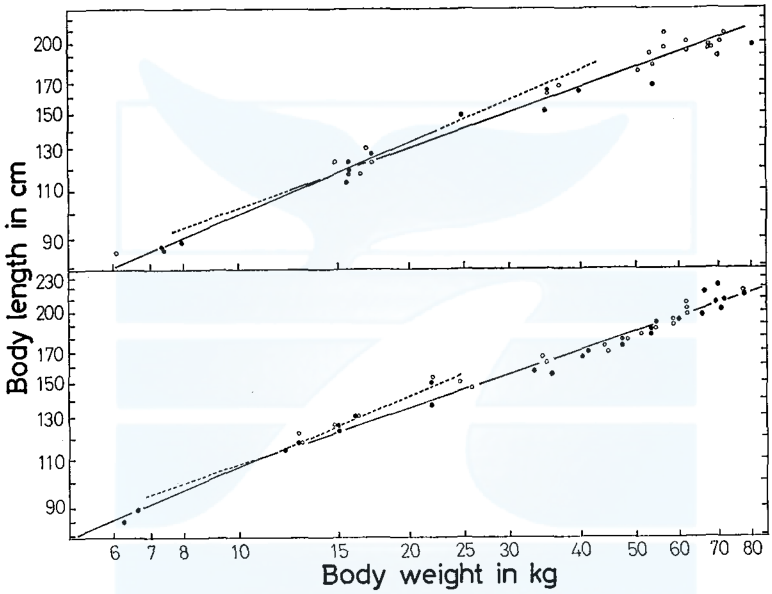

Fig. 18. Relation between body length and body weight (top), and weight without viscera (bottom). In the former each mark indicates one animal, and in the latter each mark the mean for each length group. Open circles indicate female and closed male. Weight and body length are plotted on logarithmic scale.

The weight of the animal without the viscera was measured by the fishermen. The mean weight in each length group calculated from 179 females and 148 males are shown in Fig. 18. The relation between body length and weight (w) without viscera in kg was obtained combining both sexes as follows:

For the data between 84 cm and 131 cm in body length

$$w=0.0001237L^{2.4217}$$

For the data between 112 cm and 220 cm in body length

$$w=0.000009887L^{2.9595}$$

These two lines cross at a body length of 109.8 cm

If the ratios of the visceral weight to the total weight is calculated from the data used in the top of Fig. 18, they are 17.5% (4 animals from 85 to 89 cm), 11.5% (10, 114–130 cm), 11.6% (9, 149–189 cm), and 9.9% (11, 190–207 cm). They seem to decrease with the growth of the animal, and the decrease is especially rapid at a body length between 89 cm and 114 cm. This feature is also presumed from the two sets of formulae in the above.

PIGMENTATION

The pigmentation of *S. attenuata* from the Pacific coast of Japan was studied on 100 animals in schools 1 and 2. The pigmentation was classified into 4 grades as explained below, and compared with the body length or with the age determination based on the dentinal growth layers. However, the latter was used only for reference, because age information is scanty. The body lengths were grouped into nearest 5 cm units.

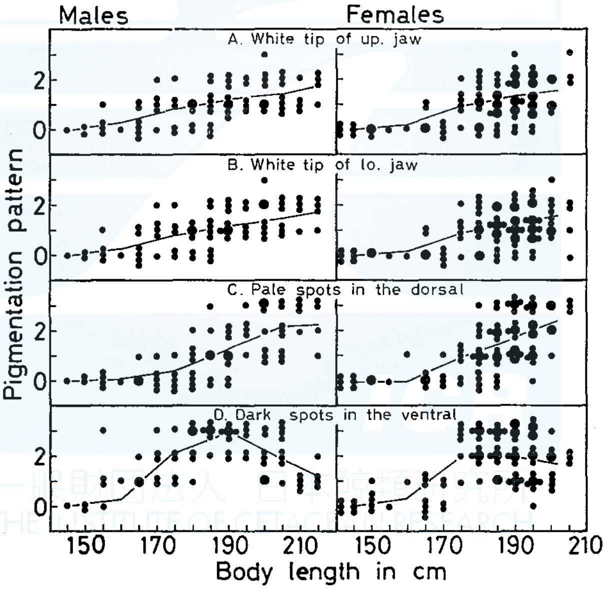

Fig. 19. Relation between body length and pigmentation of *S. attenuata*. Smaller circles represent one animal and the larger 5 animals. Body lengths are grouped into 5 cm intervals. Lines indicate the mathematical mean of the grades. For further explanation see text.

Pigmentation of newborn calf

The pigmentation of a newborn animal is pale and the pattern is quite different from that of an adult animal. The dorsal surface is bluish gray with a pale band extending postero-dorsally at the base of tail peduncle. Both jaws and the dorsal surface of the flipper is bluish gray. A dark band connects the eye and the base of the upper jaw, and a paler band connects the insertion of flipper and lower jaw. A very faint wide dark band extends from eye to the anal region. This band is covered, in the adult, by dark spots and becomes inconspicuous. Other parts of lateral and ventral regions are white. The border of the dorsal dark area and ventral white area is shaped like an arch at the part from the chest to the forehead. This pattern of pigmentation strongly resembles that of *Delphinus*.

White area at the tip of upper jaw

The white tip was classified into 4 patterns. Satage 0 represents no pure white area. In many animals classified into this stage, there is observed a small area of paler pigmentation at the tip of the jaw. Stage 1 is represented by the animal which has the white area but it does not extend posteriorly beyond the anterodorsal corner of the upper jaw, stage 2 by the animal of which the white area extends between the antero-dorsal corner and the midlength of the rostrum, and stage 3 by the animal of which the white area on the upper jaw extends beyond the midlength of the rostrum.

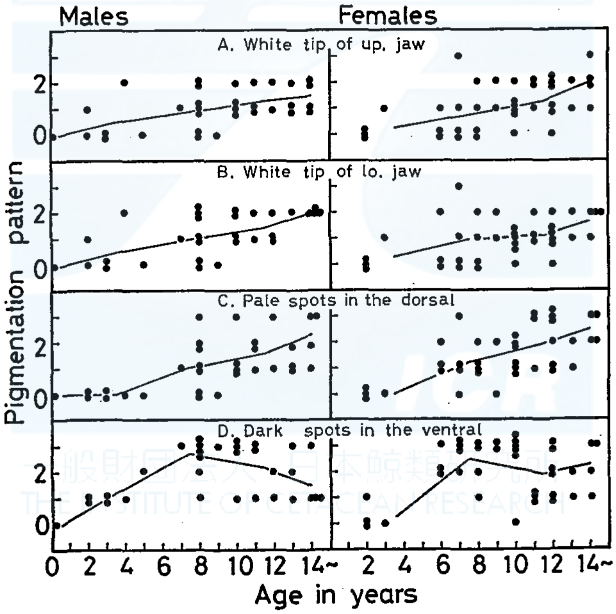

Fig. 20. Relation between the pigmentation of *S. attenuata* and the age of the animal. For symbols see Fig. 20.

The animal of stage 0, or the animal which has no white tip at the upper jaw is found only among animals smaller than 185 cm (male) or 195 cm (female) in body length. The white tip starts to develop at a body length of 155 cm and the ratio of animals with a white tip increases with age. The body length where half of the animals have a white tip is about 170 cm in both sexes. All animals have the white tip at a body length of 190 or 200 cm. The length 170 cm mentioned above corresponds to an age of about 3.5 years. According to age determination of a few animals, the white tip of the upper jaw is formed at an age between 2 and 12 years. As stage 2 is found in animals of slightly larger length, it is supposed that the extent of the white area increases in some degree with the growth of the animal.

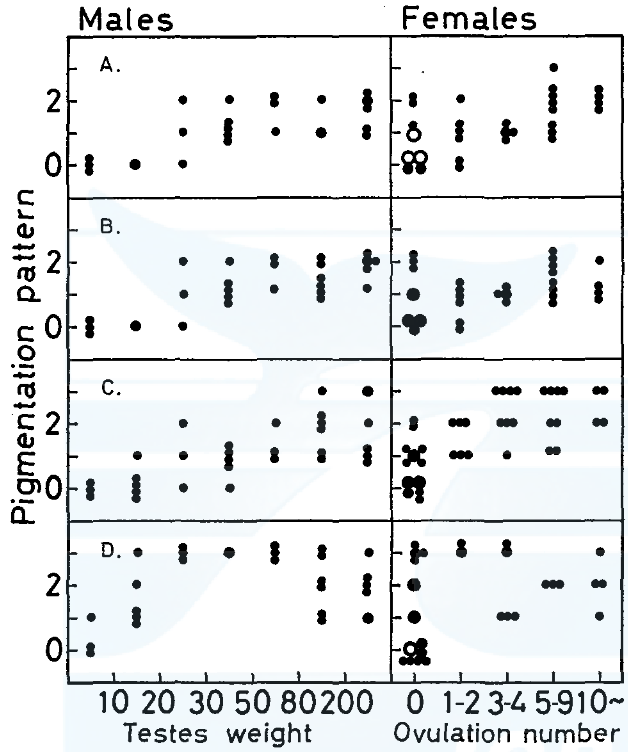

Fig. 21. Relation between the pigmentation of *S. attenuata* and gonadal condition. Open circles indicate 20 animals. For other symbols see Fig. 20.

White area at the tip of the lower jaw

The 4 stages of the development of the white area on the tip of the lower jaw were defined by the same method used above. The white areas on the tip of upper jaw and of lower jaw show good correlation, and both jaws showed the same stage in almost all the animals observed (Fig. 19). Accordingly, the mean body length where half of the animals have the white tip on the lower jaw is the same as the corresponding figure for that of the upper jaw.

White spots on the dorsal surface

The stage of this character was classified into 4 categories of stage 0 of no spot, of stage 3 of heaviest spot, and intermediate stages 1 and 2. The spot starts to appear in the earliest individuals at a length of 165 cm (male) or 170 cm (female), and all animals of more than 195 cm in body length have white spots on the dorsal surface. The body length where half of the animals have dorsal spots is about 180 cm in males and 170 cm in females. According to age determination all animals show the spots by the age of 9 years. The density of the spots increases with growth of the animal.

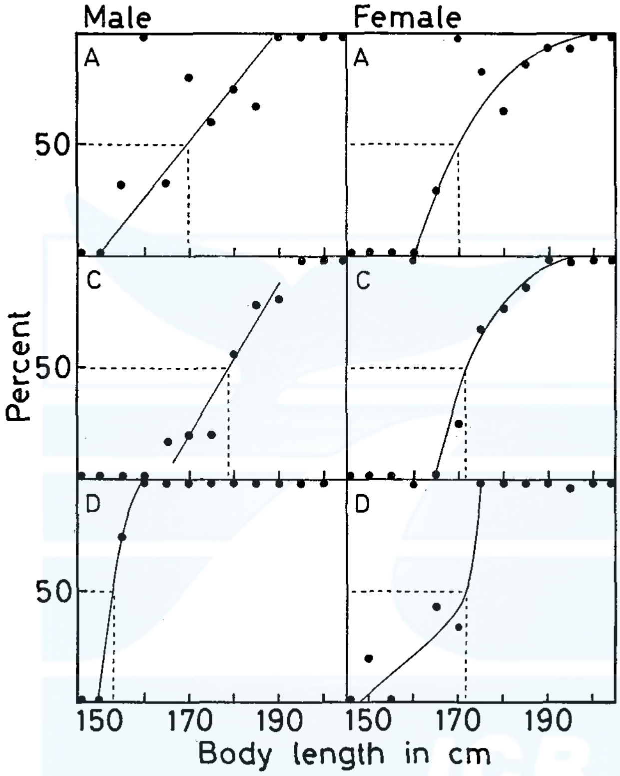

Fig. 22. Body lengths where half of the animals start to develop the pigmentation of the adult. Lines are drawn by eye.

Dark spots on the ventral surface.

The density of dark spots on the ventral surface was classified by the same method used for pale spots on the dorsal surface. The dark spots first appear on the lower jaw and on the band connecting the lower jaw and base of flipper, then on other parts of the ventral surface.

The age when dark spots start to develop shows a large sexual difference. In males it starts to develop between 150 cm and 160 cm in body length or between 1 $^1/_4$ and 2 years of age. However in females all the animals show the spots at 175 cm or 5 years of age. The body length where half of the animals have dark spots on the ventral surface is about 153 cm in males and about 170 cm in females. The former corresponds to an age of 1.5 years and the latter to an age of 3.5 years.

As shown in Fig. 19, the mathematical mean of the stages decreases after 190 cm in males and 180 cm in females. This does not mean the disappearance of the spots, but indicates that the spots are so numerous as to have contact with each other. In our method of classification this stage was not separated from the earlier stage because we checked mainly the density of independent spots. This stage seems to corresponds to the fused stage of Perrin (1969).

Discussion

The typical development of pigmentation is shown schematically in Fig. 23, and can be summarized as follows. The newborn male starts to develop dark spots in the ventral and throat region at the age of 1.5 years. The female does not have the spots at this age but show only slight darkening of the band connecting the base of flipper and lower jaw. At an age of about 3.5 years the white mark at the tip of both jaws of both sexes, and dorsal white spots and ventral dark spots of females start to develop. The white spots on the dorsal region start to develop in males at an age of about 6 years. Then both kinds of spots increase in density to fuse with each other, and attain the final adult form at the ages of 11 years in males and 9 years in females.

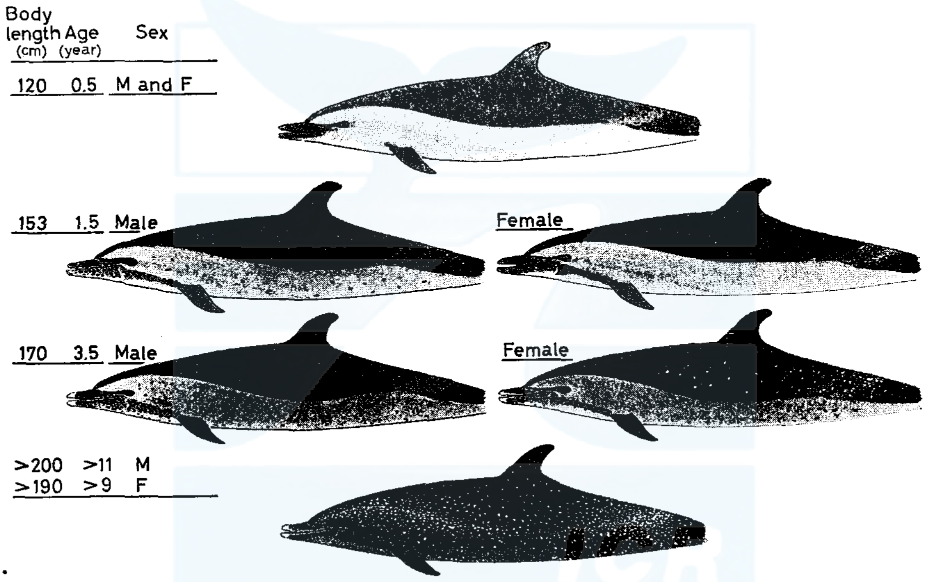

Fig. 23. Schematic figure of the pigmentation of *S. attenuata* at various growth stages.

The age when the animal attains the pigmentation of the adult coincides well with the age at the attainment of sexual maturity. The formation of the white tip on the jaws coincides with the age of the attainment of puberal stage, and with the time when the animals start to leave the breeding school and join the school of immature animals. This suggests that they may be formed by the influence of some kind of sex hormone. If there is any function in the white tips of jaws and in the mottled pattern, it seems to be a social and ecological function to help the visual identification of the species or of the growth stage of the same species as suggested by Yablokov (1963) and Evans and Bastian (1969). However, the probable effect as camouflage suggested for *S. plagiodon* (Caldwell and Caldwell, 1966) is not denied in *S. attenuata*.

The reasons for the delayed formation of dorsal white spots or of earlier formation of ventral dark spots observed in the male are not analyzed here. It may be related to the difference of endocrinological condition between the sexes.

Table 7 shows the frequency of the pigmentation patterns of females in various reproductive stages. Though other characteristics of pigmentation do not show any difference between the reproductive stages of mature females, the density of dark spots is slightly lower in lactating females. If these data really reflect the ratio in mature females, it is supposed that dark spots become less conspicuous in anoestrous females.

In the present data, 96.3 % of sexually mature females and 100 % of sexually mature males have the white part on the tip of the upper jaw. Animals with white tips are scarce in *S. attenuata* in the eastern Pacific (Perrin, 1969). This difference seems to indicate morphological differentiation between these two populations. In this respect the animals reported from Malaita (Dawbin, 1966) are closer to *S. attenuata* in the Pacific coast of Japan. If observations on pigmentation are

TABLE 7. PIGMENTATION OF FEMALE *S. ATTENUATA* BY REPRODUCTIVE CONDITION.

Character and stages[1]		Immature		Pregnant[2]		Lactating		Resting	
		no.	%	no.	%	no.	%	no.	%
A	0	22	57.9	0	0	3	6.5	0	0
	1	14	36.8	10	52.6	25	54.5	8	47.1
	2	2	5.3	9	47.4	18	39.0	8	47.1
	3	0	0	0	0	0	0	1	5.8
B	0	22	57.9	0	0	3	6.5	0	0
	1	13	34.2	13	68.4	30	65.2	10	58.8
	2	3	7.9	6	31.6	13	28.3	7	41.2
	3	0	0	0	0	0	0	0	0
C	0	20	60.6	1	5.3	1	2.2	5	31.3
	1	11	33.3	8	42.1	11	23.9	0	0
	2	2	6.1	5	26.3	18	39.1	5	31.3
	3	0	0	5	26.3	16	34.8	6	37.4
D	0	14	43.7	0	0	0	0	0	0
	1	3	9.4	3	15.8	19	41.3	3	17.6
	2	7	21.9	7	36.8	15	32.6	6	35.3
	3	8	25.0	9	47.4	12	26.1	8	47.1

[1] See Fig. 18. [2] Pregnant and simultaneously lactating females included.

made on many animals along the Malaita coast, it will give some information on the identification of populations.

The pigmentation of other spotted species *S. plagiodon* in the Atlantic (Caldwell and Caldwell, 1966) is distinguished from that of *S. attenuata* in the Pacific by the absence of the fusion of ventral dark spots and by the larger size of the spots.

FEMALE BREEDING CYCLE

Graafian follicle

The frequencies of the diameter of the follicle obtained as the cube root of the multiple of three dimensions are shown in Fig. 24. The ovaries of pregnant females are inactive having no large follicles in any school or in any season. The ovaries of all the lactating and the resting females in school 7, which was caught in July, show high activity. On the other hand in schools caught in November or in February, there were observed many lactating or resting females with inactive ovaries. As a result the mean diameter of the follicles of females in the two categories is smaller than that of the schooll killed in Juy. However, even in schools killed in February or in November the size of follicles of active females is not small. Accordingly it can not be concluded that all females in February and November are sexually inactive. It will need observations on more schools in various seasons to draw conclusions on the seasonal variation of the size of follicles.

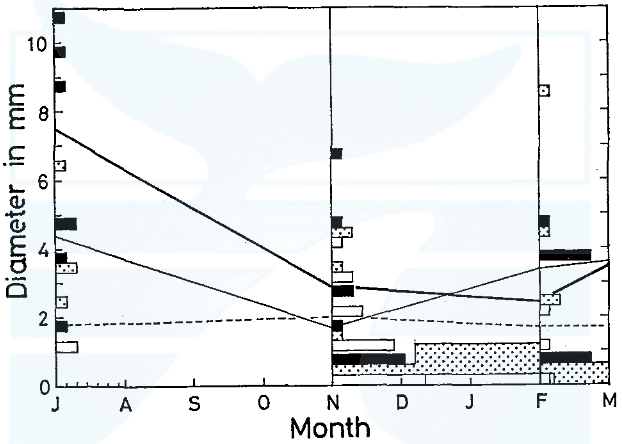

Fig. 24. Seasonal variation of the diameter of the largest follicle in mature females of *S. attenuata*. Black squares and thick solid lines indicate the resting females, dotted squares and thin solid lines the lactating, and white squres and dotted lines the pregnant or pregnant and simultaneously lactating.

Diameter of corpus luteum

Even when we got the ovaries of pregnant female it was not necessarily possible to obtain the fetus, because the fetus or fetus and part of uterus were sometimes removed by the fishermen and piled elsewhere. In these cases the pregnancy was checked by a fragment of uterus or by the condition of ovaries. Table 8 shows the relationship between the size of corpora lutea and the presence of a fetus. This table shows that if the corpus luteum is larger than 6000 mm^3 in volume index it may be correct to consider that the animal was pregnant. The scarcity of corpus luteum of the size between 4000 and 6000 mm^3 in volume index may indicate that when the ovulation is not successful even if the corupus luteum may grow to a size similar to that of corpus luteum of pregnancy, it may regress very rapidly. Accordingly, when other information is not available, we tentatively consisdered that a corpus luteum smaller than 4000 mm^3 in volume index or 15.87 mm in diameter as the corpus luteum of ovulation.

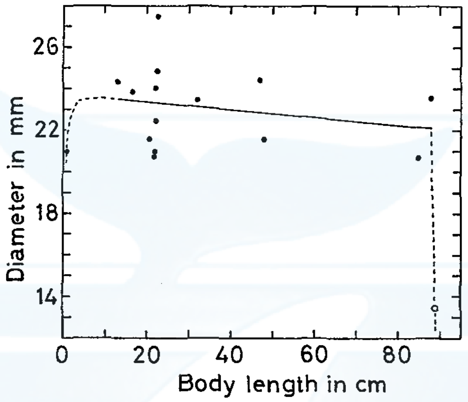

Fig. 25. Relation between the diameter of corpora lutea and body length of fetuses. Solid line is drawn by least squares, and dotted lines by eye. Open circle indicates a lactating female.

TABLE 8. SIZE OF LARGE CORPORA AND THE SEXUAL CONDITION OF FEMALE.

Range in volume index (mm^3)	Diameter (mm)	R	L	PL	P	PF	Total
1001– 2000	12.60	—	3	—	—	—	3
2001– 3000	14.42	1	1	—	—	—	2
3001– 4000	15.87	—	1	—	—	—	1
4001– 5000	17.10	—	—	—	—	—	—
5001– 6000	18.17	—	—	—	—	—	—
6001– 7000	19.13	1	—	1	1	—	3
7001– 8000	20.00	—	—	—	1	—	1
8001– 9000	20.80	—	—	—	1	1	2
9001–10000	21.54	—	—	—	2	4	6
10001–11000	22.24	—	—	—	—	2	2
11001–12000	22.89	—	—	—	1	1	2
12001–13000	23.51	—	—	—	1	—	1
13001–14000	24.10	—	—	—	—	2	2
15001–21000	30.00	—	—	—	—	5	6

R: resting. L: lactating. PL: pregnant and lactating, fetus not confirmed. P: pregnant, fetus not confirmed. PF: Pregnant, fetus confirmed.

The relation between diameter of corpus luteum of pregnancy and the body length of fetus is shown in Fig. 25. The diameter of a corpus luteum of a pregnant female with 1.0 cm fetus was so large as to be in the range of corpora with larger fetus. Though the diameter of corpus luteum does not show a large change related to the growth of the fetus, there seems to be a slight decreasing tendency. If the regression line is calculated by least squares for the 14 corpora corresponding to the medium and larger fetuses, it gives the relation $y=-0.01825x+23.700$, where y is the diameter in mm and x is the length of fetus in cm. The mean diameter at the time of parturition is 22.08 mm on the above formula.

Regression of corpus albicans

Fig. 26 shows the frequency of diameters of corpora albicantia in each age group. The modal diameter gradually decreases with the increase of the age of the animal until 14.5 years of age or the 7th year after the mean age at the attainment of sexual maturity. Then the highest peak of the mode stays between 2 and 3 mm in diameter, and the ratio of the corpora number constituting the mode increases with age. No corpora smaller than 1 mm in diameter were observed.

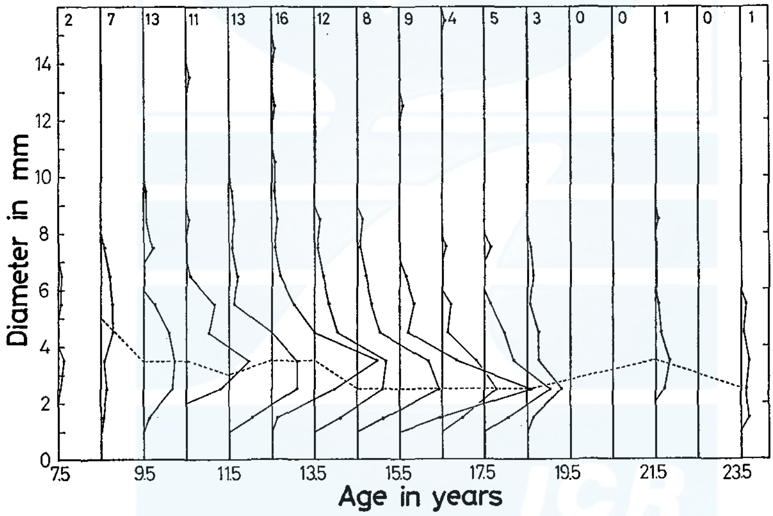

Fig. 26. Distribution of the diameter of corpora albicantia of *S. attenuata*. The numbers at the top indicate the number of animals, and the dotted line the position of the mode.

They indicates that the corpora albicantia attain a final size within several years after the start of regression and may stay in the ovary all the lifetime. The mean final diameter suggested by the shape of the mode is about 2.5 mm or slightly more.

It is easily supposed that the size of corpora albicantia decreases rapidly after the parturition. If the size of the largest corpora albicantia of lactating females in each school are arranged by size, some modes are observed. These modes may represent some parturition season. The mean growth curve and the mean modal length of calves caught in the same school give the time after parturiation. The length frequencies of juvenile calves and the size frequencies of the largest corpora albicantia of pregnancy of lactating female in corresponding schools are shown in Fig. 27. In this figure the few corpora albicantia of ovulation were omitted and

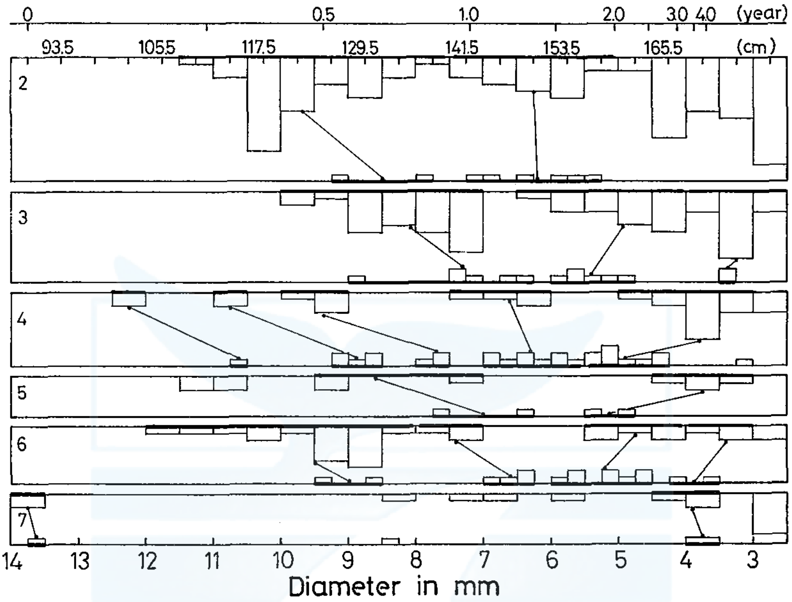

Fig. 27. Comparison of the frequency of the diameter of copora albicantia of the last parturiation of lactating females and the length frequency of juvenile calves. Scale in years was calculated from the growth curve. Numbers at the left indicate the school. The length frequency of school 3 was calculated from the weight data.

TABLE 9. LACTATING FEMALES WHICH OVULATED AFTER LAST PARTURITION.

Animal		Diameter of corpus (mm) of		No. of ovulation	
school	no.	largest	last parturition	postpartum	postlactum*
3	3	4.88	4.38	1	—
3	24	12.35	3.29	1	1
3	35	8.82	4.95	3	3
3	38	12.12	3.21	1	1
4	5	5.37	5.30	1	—
4	19	15.14	4.79	—	1
4	47	10.69	5.28	—	3
4	48	5.24	4.78	1	—
4	96	5.01	4.72	1	—
4	119	8.51	6.50	1	—
5	48	6.46	6.12	1	—
6	102	4.66	4.28	1	—

*: based on the criterion used in this study.

the probable corpus albicans of the last parturition was used. These exceptional individuals are shown in Table 9. The mean modal diameters of corpora albicantia of the last parturition of lactating females are plotted in Fig. 28 against the time after parturition. It shows that the regression of the size of corpora albicantia is so rapid that it regresses from the mean diameter of corpus luteum 22.08 mm to 13.6 mm within 0.2 months. Then the speed of regression gradually decreases, and after 16th month the diameter decrease is almost straight. If this line is extended, it reaches the mean final diameter of corpora albicantia at about 70 months. This coincides with the information described above.

The elapsed time after the start of regression of corpora lutea was calculated

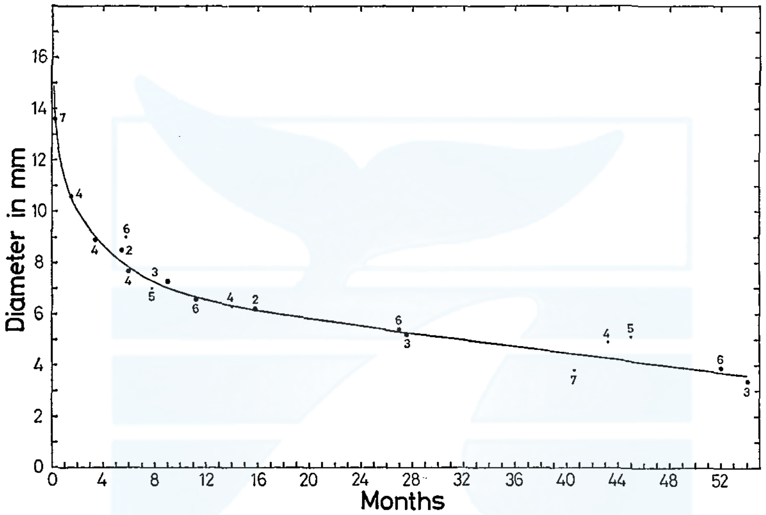

Fig. 28. Regression of the diameter of corpora albicantia obtained from the combinations in Fig. 27. Larger circles indicate reliable combinations, number by the each circle the school.

from the regression line of the corpora albicantia drawn for volume index and volume indices of the corpora, assuming that the size of corpus albicans of pregnancy and of ovulation is not significantly different. This assumption should not be unreasonable, because the corpus luteum of ovulation seems to attain a size near to that of pregnancy and the regression rate is rapid in the first month. The corpora albicantia of pregnancy were then identified based on the following assumptions and considering the reproductive conditions at the time of death.

1. During pregnancy the female does not ovulate.
2. There may be some postpartum ovulations or postlactum ovulations.
3. The time from a parturition to next conception is usually more than one year.

Thus the age of corpora albicantia which started the regression within recent 5 years were calculated and the corpora albicantia of pregnancy and those of ovulation were identified. The real date of ovulation of corpora albicantia of pregnancy is roughly estimated assuming that the length of gestation is 11.2 months. The date of ovulation of a corpus luteum of the pregenant female was calculated from the fetal growth curve and the fetal length. In a few cases where fetal length was not available the mean fetal length of the school was used.

Postpartum ovulations

The postpartum ovulations were analyzed in relation to the time from the preceding parturition based on the ovulation diagram prepared with regression curve of the corpora. The source of information was classified into two. The first (series A) is the ovarian activity after the last parturition ending at the death of the animal, which is more reliable because the time after the parturition is usually, but not necessarily, short and the reproductive condition of the female at the time of death was taken into consideration in assessing the corpora albicantia of the last pregnancy. The next (series B) is the ovarian activity from the parturition that occurred one cycle before the parturition used in series A and ends at the last conception. The date of parturition of series B is usually earlier than that of series A.

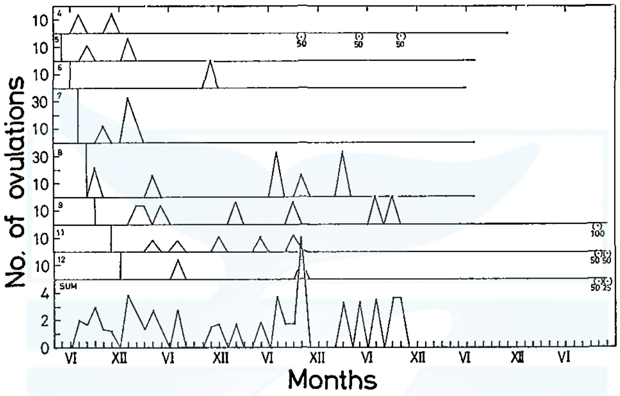

Fig. 29. Seasonal variation of ovulation shown in relation to the date of the last parturition. Females are grouped by the month of parturition (numerals at the left). The females that are grouped into Jan., Feb., March, and Oct., show no ovulation, but are included in the sum. Number of ovulations is shown per month per 100 animals. Based on series A.

TABLE 10. NUMBER OF POSTPARTUM AND POSTLACTUM OVULATIONS.

No.	Postpartum ovulations						Postlactum ov.		
	A		B		Total		No.	B	
0	60	82.2%	36	70.6%	96	77.4%	1	34	66.7%
1	10	13.7	6	11.8	16	12.9	2	14	27.5
2	2	2.7	9	17.6	11	8.9	3	2	3.9
3	1	1.4	0	0	1	0.8	4	1	2.0
Sum	73	100	51	100	124	100	Sum	51	100.1
Mean	0.234		0.471		0.331		mean	1.412	

At the first step the analysis was made on series A. The samples were grouped in accordance with the month of parturition, then the dates of ovulations were arranged chronologically and the frequency of ovulation per month per animal was calculated (Fig. 29). This only shows that the ovulations after the recent parturition had occured in various seasons of the year.

To know the range of the time when postpartum ovulations may occur, the relation between the time after the last parturition and the number of ovulations that occurred after the parturition was analyzed based on the materials of series A (Fig. 30). In some animals ovulation occurs soon after parturition and the number of ovulated females increases. As a result the percentage of unovulated females decreases untill the 12th month, then the percentage becomes rather stable during the next 12 months. After this the number of unovulated females again starts to decrease. We consider that the former period corresponds to the period of postpartum ovulations and the latter probably to postlactum ovulations.

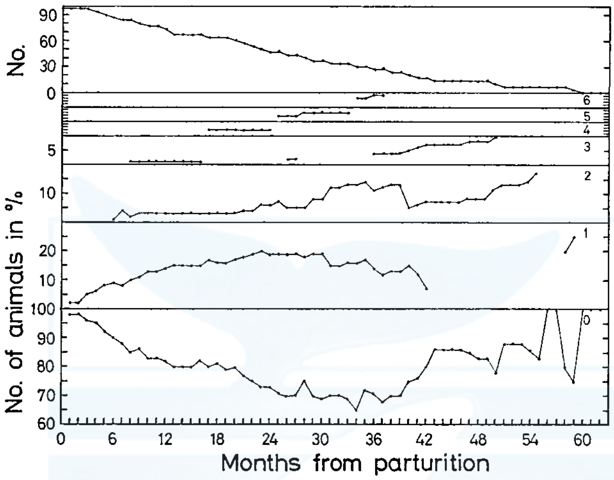

Fig. 30. Relation between the time from parturition and the number of ovulations undergone by each female (numbers at the right). Figure at the top indicates the number of females observed. Based on series A.

Thus defining postpartum ovulations, the time and frequency were obtained from series A and B (Tables 10 and 11). About 20% of the females have a post partum ovulation but they seems to be all infertile. The mean number of post partum ovulations is 0.331 per reproductive cycle.

As shown in Table 11 and Fig. 31 the time of the postpartum ovulation measured from the date of parturition shows some regularity. The first peak is in the 3rd month after parturition, then next peaks come with the interval of 4 months. These peaks may, as mentioned in a later section, correspond to the mating season of this species. But it must be noticed that some postpartum females do not ovulate in the first season but in the 2nd or 3rd seasons. The length of interval between two postpartum ovulations was studied on the few females which have experienced two or more postpartum ovulations. As shown in Fig. 31, if more than 1 ovulation are made in one breeding season the minimum of the interval is about 1 month. The longer intervals are approximately a multiple of 4 months.

Postlactum ovulation

The postlactum ovulation was tentatively defined as the ovulation occurring after 12 months or more from the last parturition, and analyzed only on the series B because series A does not end at conception. It was not confirmed here whether the animal has finished lactation by the first postlactum ovulation. However our data suggest that it is not necessarily so. As shown in Table 12 the interval between the last postpartum and the first postlactum ovulations, on animals where two or more postlactum ovulations exist, is usually 12 months or more. This means that the ovarian activity usually stops for a long period after the last postpartum ovulation. However only in 2 cases among 73 animals the interval was 4.0 or 8.8 months. In these cases the postpartum ovulation is almost continuous to postlactum ovulation. About 67 % of the females conceive by the first postlactum ovulation, and the remaining experience two or more postlactum ovulations. The mean number of postlactum ovulations is 1.412 per one reproductive cycle (Table 10).

The peak of postlactum ovulations is observed in the interval of 4 months (Table 11 and Fig. 31). There are some females which do not ovulate at the 4th month before conception but do it at the 8th or 12th. The information on postpartum and postlactum ovulations are shown in the diagram of Fig. 32.

The cycle of postlactum ovulation of females which have two or more postlac-

TABLE 11. TIME OF OVULATION MEASURED FROM THE DATE OF PARTURITION OR OF CONCEPTION.

Time in month (t)*	Postpartum ovulation				Postlactum ovulation			
	1st	2nd	3rd	Sum	2nd**	3rd	4th	Sum
n=1	3	—	—	3	3	—	—	3
2	4	1	—	5	—	—	—	—
3	5	1	—	6	—	—	—	—
4	2	1	—	3	4	—	—	4
5	2	1	—	3	3	—	—	3
6	4	2	—	6	—	1	—	1
7	4	3	—	7	1	—	—	1
8	2	2	1	5	2	—	—	2
9	1	1	—	2	1	—	—	1
10	—	—	—	—	—	—	—	—
11	—	—	—	—	—	—	—	—
12	—	—	—	—	—	1	1	2
13	—	—	—	—	3	—	—	3
14	—	—	—	—	—	—	—	—
18	—	—	—	—	—	1	—	1

* : Time range (t) : $n-1 \leqq t < n$,

** : Nearest to postlactum ovulation of pregnancy or the first.

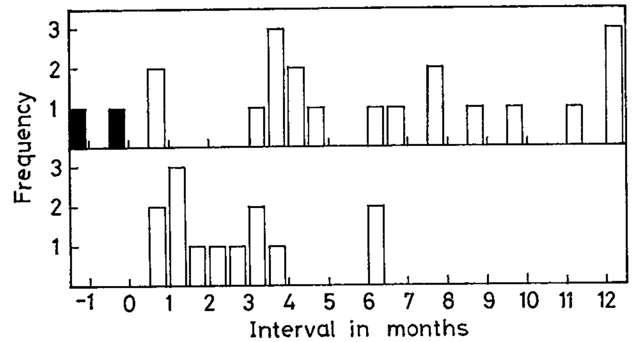

Fig. 31. Intervals of postlactum ovulations (top) and of postpartum ovulations (bottom), in the animals where several of them are observed. Black indicates unreasonable case, where the superficial date of ovulation comes after the date of conception.

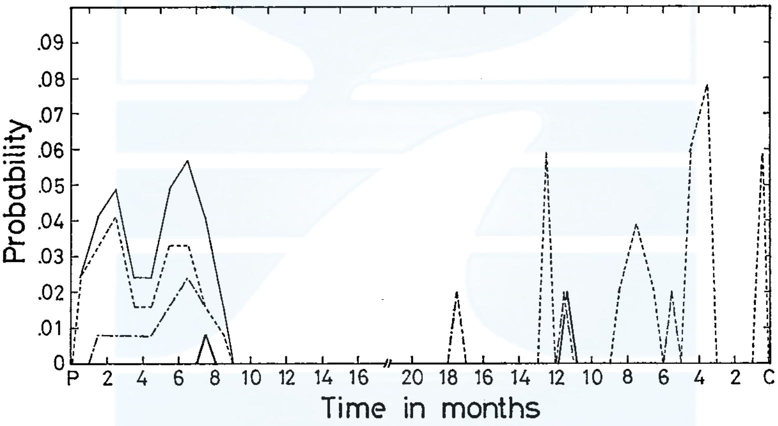

Fig. 32. Diagram of ovulation in one reproductive cycle. The postpartum ovulation is at the left and the postlactum ovulation at the right. P indicates parturition, C conception, dotted lines postpartum ovulation nearest to parturition or postlactum ovulation nearest to conception, chains the second, thick solid lines the third, and thin solid lines the total of postpartum ovulation. Probability of ovulation is shown by the number of ovulations per animal per cycle. The fertile postlactum ovulation, of which probability is 1, is not shown. The length of the reproductive cycle is set at 50.3 months, one of the estimate of mean reproductive cycle in *S. attenuata*.

TABLE 12. INTERVAL BETWEEN LAST POSTPARTUM OVULATION AND FIRST POSTLACTUM OVULATION.

Interval in month (n)*	4	9	11	12	13	17	20	24	29	31
Frequency	1	1	1	2	2	1	2	1	1	1

* : Interval is shown by month, $n-1<\text{month}\leqq n$

tum ovulations is classified into two types. One is the cycle of 4 months or a multiple of it. This may be the cycle related to the mating season. The other is short and is an ovulation cycle in one breeding season. This probable real oestrous cycle is of about 1 month. These features are quite similar to the cycle found in postpartum ovulations.

Accordingly it is concluded that *S. attenuata* is polyoestrous and the oestrous cycle is about 1 month, and this oestrous cycle occurs in some of the breeding seasons which have an interval of 4 months.

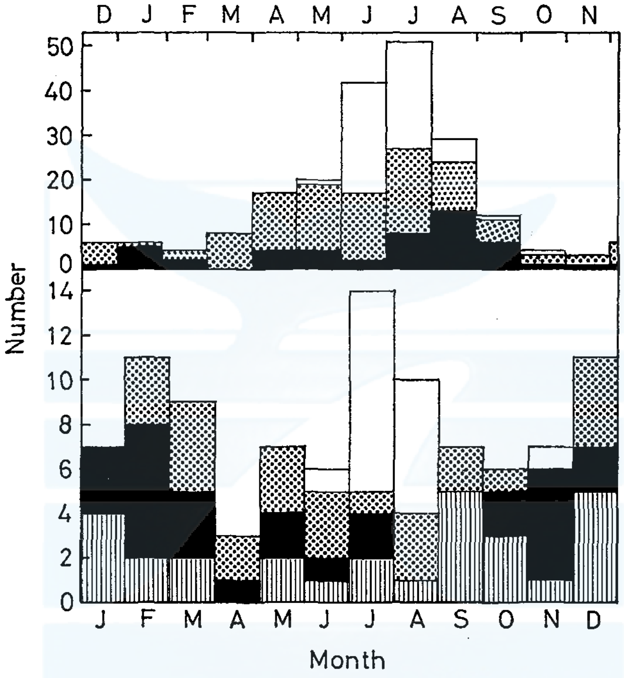

Fig. 33. Breeding season of *S. attenuata*. Top indicates the monthly frequency of parturition calculated from the length frequencies of fetuses and juvenile calves younger than 2 years of age. Bottom indicates the frequency of the date of conception calculated from the ovulation diagram. The scales of date of conception (bottom) and that of parturition (top) are moved apart for 11.2 months, the length of gestation. White areas indicate conception within 1 year before the death of the animal, the dotted that between 1 and 2 years, the black that between 2 and 3 years, and the shadowed that between 3 and 4 years.

Breeding season

The parturition seasons are calculated from the mean growth curve and length frequencies of juvenile calves and of fetuses (Fig. 33). As the apparent mating season differs between schools, it is necessary to observe many schools and a wide chronological range in obtaining the information on the mating season of the species.

However after the attainment of 2 years of age, it is impossible to estimate the date of birth because the growth of the calf becomes too slow compared with the range of individual variation of the body length. By this method the reproductive activity of the females in the most recent 3 years can be estimated. The date of conception was obtained by sliding the chronological scale of the parturition season for 11.2 months.

In all the 7 schools the peak of conception calculated from the fetal length is in July and August. This strongly suggests that one of the mating seasons of this species is in these months. The result calculated from animals born within one year is almost similar to that obtained from fetuses, but there appears another small peak of conception in January. Though the information obtained from the calves born between 1 and 2 years before death is inaccurate, there seems to be peaks of conception in February, in May and June, and in September. But when all are totaled there remain only two peaks of conception one in July and August, and the other in January and February.

The bottom of Fig. 33 indicates the frequency of conception in the past 4 years obtained from the size of the corpora albicantia of pregnancy. In this figure the date of conception corresponding with the corpora lutea of pregnancy was calculated from the length of fetus. There seems to be three peaks in the conception occurred between the past 1 and 4 years. However it is also possible to read in the total height two main peaks of mating between May and September, and between November and March, each of which having one accessory peak in it. This feature coincides with the seasonal change of the ratio of fertile ova to the total number of ovulations (Fig. 34). The ratio of fertile ova is higher in the two mating season. However the frequency of total ovulation shows another feature. As expected from the 4 months cycle of ovulation, there are observed three peaks in January to

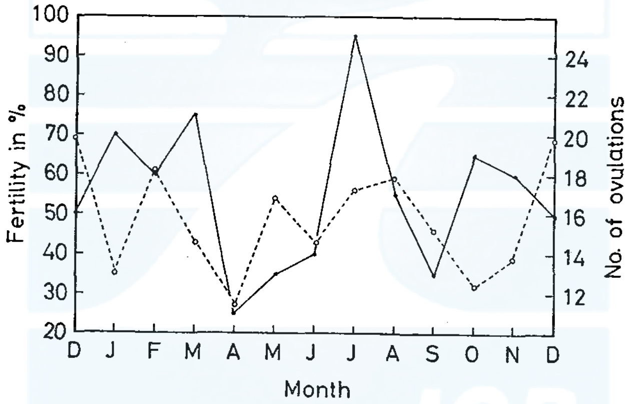

Fig. 34. Seasonal change of frequency of ovulations (solid line) and of the ratio of fertile ovulations (dotted line). Ovulations in the recent 4 years studied are combined.

March, July, and October and November.

The above three sets of data on mating seasons do not coincide well. Between the first two methods (Fig. 33), the peaks around February and that in July coincide. This first method is good in accuracy but covers too short period. On the other hand the second method covers a longer period and suggests the other peak in December, but the accuracy of dating is less reliable. The third method or the frequency of ovulation, which is similar to the second but includes all the ovulations, suggests a mating seasons of four months interval. To increase the accuracy of the second method, if the dates of the conception at each end of the series B or the selected reproductive cycles used in the former section is considered, there is observed three clear peaks of conception (Table. 13). Two of these mating seasons coincide well with those obtained from Fig. 33. The third peak in November coincides approximately with the corresponding peak in Fig. 33 (bottom) and frequency of ovulation in Fig. 34. Then the interval of the peaks are 4 months which is suggested by the postpartum and postlactum ovulations.

As a conclusion, though more confirmation is necessary, we are inclined to expect three mating seasons with the peaks in February and March, in July, and in November. The last two mating seasons coincide with the seasons of just after the north bound and south bound migrations, and the first just before the north bound migration. However it is probable that the migration is affected by the breeding cycle and there is a segregation of females in different reproductive conditions. The parturition seasons seems to be about one month ahead of the mating peak i.e. in Jannuary and February, in June, and in October.

TABLE 13. MONTHLY DISTRIBUTION OF DATE OF CONCEPTION OBTAINED FROM SERIES B.

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sept.	Oct.	Nov.	Dec.
Frequency	1	7	4	1	1	5	14	5	1	4	4	4

Reproductive cycle

The mean length of reproductive cycle can be obtained from the ratio of various reproductive conditions assuming the 11.2 months for the approximate length of gestation. When the data of all the schools are combined the number of pregnant females is 64 or 25.6 % of mature animals, including each half of the number of animals which are simultaneously lactating and pregnant into both categories (Table 27). The length of lactation $140 \div 64 \times 11.2 = 24.5$ months is calculated. By the same method the length of resting 8.1 months, and the length of one reproductive cycle of 43.8 months or 3.65 years are obtained.

If the samples are obtained evenly from various seasons in a year and covers schools of various reproductive stages, this method gives good information on the mean length of reproductive cycle. However, as can be seen in Table 27, the samples were collected mainly in October and November, and the frequency of mature females constituting the reproductive stages shows wide between school variation. In this condition we cannot expect the accuracy of the method. Another problem is the presence of females which are sexually mature but in which the reproductive stage was not identified. This kind of imperfect observation is usually made on animals whose reproductive organs have been removed by the fishermen and precise study was not made. On this case the identification of pregnant females is usually possible based on fragments of uterus. However it is very difficult to distinguish the resting animal from the very early stage of pregnancy. Accordingly the real ratio of resting animals, which represent the sexually mature females other

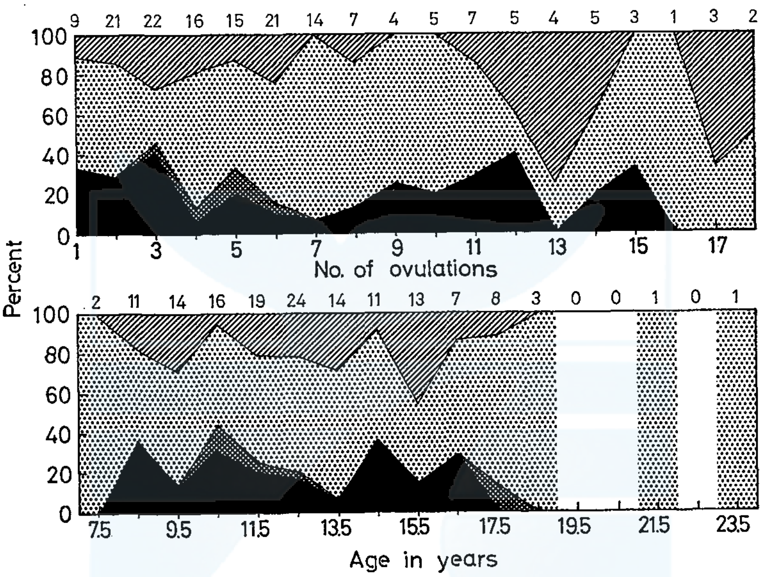

Fig. 35. Change of the ratio of sexual conditions by age in mature females of *S. attenuata*. Black indicates pregnant females, black with white spots those pregnant and simultaneously lactating, white with black spots those lactating, and lines those resting. The number at the top indicates sample size.

TABLE 14. RATIO OF REPRODUCTIVE CONDITIONS AT THE TIME OF DEATH AMONG MATURE FEMALES OF VARIOUS AGE GROUPS.

No. ovulations	Pregnant		Preg. & Lact.		Lactating		Resting		Total		Reproductive cycle (Months)
	no.	%	no.	%	no.	%	no.	%	no.	%	
1- 6	24	23.1	5	4.8	55	52.9	20	19.2	104	100	40.2
7-12	8	19.0	0	0	30	71.4	4	9.5	42	100	58.8
13-18	2	11.1	0	0	8	44.4	8	44.4	18	100	100.8
Total	34	20.7	5	3.1	93	56.7	32	19.5	164	100	50.3
Age (years)											
7.5-11.5	15	24.2	3	4.8	33	53.2	11	17.7	62	100	38.6
12.5-17.5	13	16.9	2	2.6	44	57.1	18	23.4	77	100	57.5
18.5-23.5	0	0	0	0	5	100	0	0	5	100	—
Total	28	19.4	5	3.5	82	56.9	29	20.1	144	100	52.9

than pregnant or lactating, may be higher than that observed. Accordingly the real mean reproductive cycle must be longer than 43.8 months.

Table 14 and Fig. 35 shows the change of the pregenant ratio accompanied with increase of age. They show that the ratio of pregnant females decreases and length of reproductive cycle increases in the older animals. The length of reproductive cycle calculated by adding all the ovulation classes or age classes are 50.3 and 52.9 months respectively. As these calculations are based on observation of reliable materials, the figures obtained are more reliable than the 43.8 months cycle obtained from Table 27. Furthermore as the ovulation data used in Table 14 represent 96.5 % of all the available ovulation data, the figures obtained from it seems to be the best estimate of the mean reproductive cycle of the present population of *Stenella attenuata* in Japanese coastal waters. It gives the length of gestation 11.2 months, lactation 29.3 months, resting 9.8 months, and total length of reproductive cycle 50.3 months or 4.19 years.

The mean length of reproductive cycle is obtained separately from the frequency of ovulations of conception. It is generally observed in the ovulation diagram that the presumed dates of ovulation are not very reliable in the case of 5 years or older corpora albicantia, and that it is almost impossible to distinguish the corpora of pregnancy and of ovulation on the diagram of that part. This is clearly shown in Table 15, where numbers of corpora albicanta of preganancy and of ovulation are shown together with the number of animals (no. × months). In this table the pregnant ratio and mean annual ovulation rate show smooth fluctuation until the 4th year from death, but they show higher fluctuation after the 5th years. The mean of the pregnant ratios in the recent 4 years in Table 15 is 0.2062, which gives the length of reproductive cycle as 54.3 months or 4.63 years. This figure is very close to the figure 50.3 or 52.9 months obtained from the ratio of various reproductive conditions of individuals of known age.

TABLE 15. REPRODUCTIVE PARAMETERS CALCULATED FROM OVULATION DIAGRAMS IN RELATION TO THE INTERVAL FROM THE DATE OF DEATH.

	Year	1st	2nd	3rd	4th	5th	6th
A.	Sample size (No.×Month)	1159	1464	1424	1312	1162	673
B.	Fertile ovulation	21	22	24	31	37	27
C.	Total ovulation	40	38	44	67	104	89
D.	Pregnant ratio (B×11.2÷A)	0.2029	0.1683	0.1888	0.2646	0.3566	0.4493
E.	Mean annual ovulation (C÷A×12)	0.4142	0.3115	0.3708	0.6128	1.0740	1.5869

The individual variation of the length of reproductive cycle is obtained, though it is unsatisfactory, from the ovulation diagram. Fig. 36 shows the relation between the time after the last partutition and reproductive stage at the time of death. It shows that some individuals finish lactation at about the 17th month after parturition but some animals continue lactation for about 60 months or 5 years after parturition. If the length of lactation means the length of the suckling period, the calf may continue to take both milk and solid food until the age of 17 months in the shortest case or of 60 months in the longest case after starting to feed on solid food at the age of about 9 months. It is highly probable that the lactation is finished in the usual shortly before the conception, and that the lactation lasts longer on an animal of which interval between conceptions is long.

The length of lactation can be presumed from a direct comparison of the number of juvenile calves and that of lactating females caught together (Kasuya 1972). This method does not give the mean length of lactation but the longest range. At first step, the body length where the cumulative length frequency of juvenile animals coincides with the number of lactating females (Table 27) was obtained as shown on Fig. 37. Schools 5 and 7 were excluded here because the number of investigated lactating female was too few. On Fig. 35 the results obtained from schools 2 and 6 give a very small length (correspond to 1.0 and 1.75 years respectively), so they will not give the real length of lactation but will show only that there were no large suckling calf in the school. Accordingly the informations obtained from schools 1, 3 and 4, or the length 169 cm, 178 cm and 175 cm respectively, were used here. Then the modal lengths of the peak which includes the above body lengths were obtained on Fig. 2. They are shown in parentheses in Fig. 35. The ages corresponding to these modal lengths read on the mean growth curve are 4.0, 5 1/4 and 4.0 years respectively. For the comparison, same method was applied for the age frequencies of the schools 3 and 6. In these schools the ages of all the

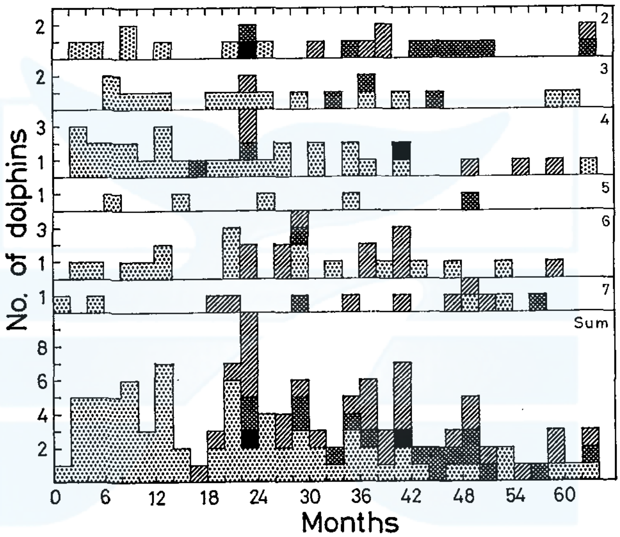

Fig. 36. Relation between the sexual condition at the time of death and the length of time after last parturition, obtained from the ovulation diagram series A. Black dots indicate lactating females, lines the resting, white dots the pregnant, and black the females lactating and simultaneously pregnant. Numbers at the right show the school.

young animals of known length were determined. The length of lactation obtained by it was 5.5 years (school 3) or 1.5 years (school 6), showing a good coincidence with that obtained from the body length frequencies. These result indicates that in some animals the lactation lasts for 4 or 5 years, even if there are many females which finish the lactation within a shorter period.

The date when the female starts the next pregnancy, or that enter into the next cycle after weaning the calf, is calculated by estimating the date of conception from the length of fetus. Fig. 38 indicates that some females enter into the next pregnancy at about 18 months after the last parturition. After this date, the number of females which enter into the next pregnancy increases rapidly. At 28th month after parturition there begins to appear the females which give birth to the next calf and complete one reproductive cycle. The time when all animals complete the reproductive cycle is about 68 months. This information on the length of reproductive cycle coincides approximately with that obtained by other methods. In this method, as the abundance of lactating female is underestimated compared with that of pregnant females, it is incorrect to presume the mean length of reproductive cycle as the time when 50% of females finish the cycle.

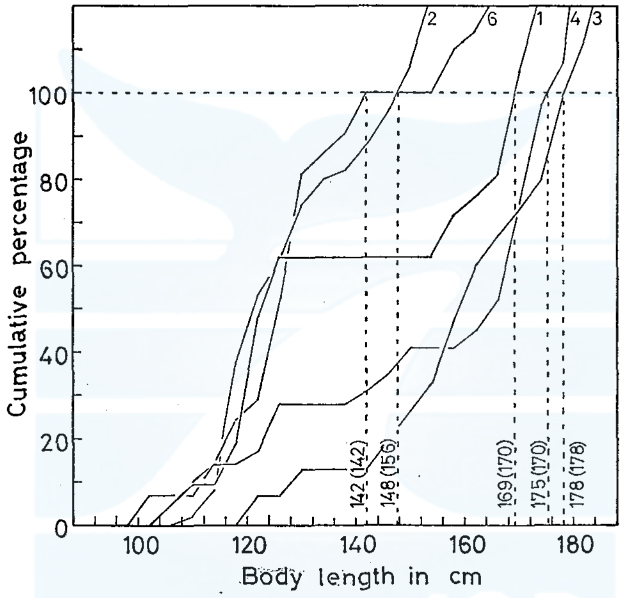

Fig. 37. To ascertain the maximum length of lactation, the cumulative frequency of calves is compared with the number of lactating females. Numbers at the top indicate schools. For further explanation see text.

Fig. 39 shows the length frequency of reproductive cycles based on 67 cycles of 64 animals obtained from the series B. As the ovulation diagram covers only about 65 months, the frequency of long reproductive cycles is underestimated and the cycles longer than 60 months are entirely neglected. However this can give a

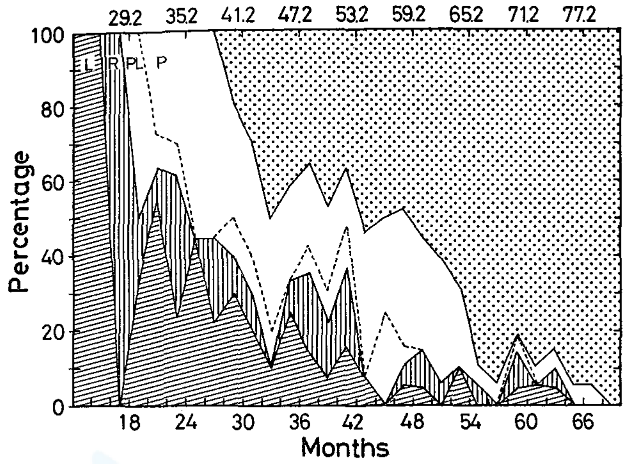

Fig. 38. Length of reproductive cycle calculated from the data in Fig. 36 and length of fetuses. The dotted area indicates the females which have finished the cycle after giving birth to the calf. Scale at the top indicates the number of months from last conception, and that at the bottom months from last parturition. L, lactating. R, resting. P, pregnant. PL, pregnant and lactating.

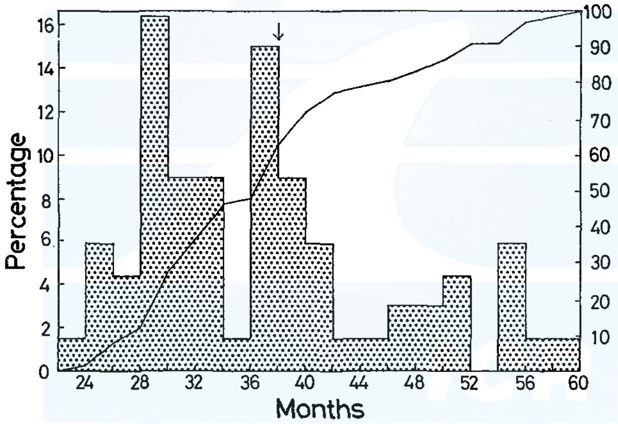

Fig. 39. Frequency of the length of reproductive cycle in months obtained as the interval between the dates of two ovulations of pregnancy (left scale), and its cumulative frequency (solid line and right scale). Arrow indicates the position of mean length of the cycle.

rough idea on the range of the length of reproductive cycle. An exceptionally short reproductive cycle is about 23 months, but most of the cycles are more than 29 months. This means some few females start the next pregnancy at the 12th month after the former parturition but more usually at the 18th or later months as indicated in Fig. 38.

As the length of reproductive cycle changes with age, the reproductive parameters must be obtained in relation to the age of the animal. At first step the number of animals, number of fertile ovulations, and total number of ovulations in the recent 4 years were calculated on the ovulation diagram for each group of females classified by the number of ovulations at the time of death. Then the mean values of various parameters in the past 4 years were calculated (Table 16). The constants of the regression lines calculated by least squares are shown in the same table, and by the lines in Fig. 40. It shows that the mean length of a reproductive cycle increases rapidly from 3.6 years of the young animal to 6.5 years for the old animal. This prolongation of reproductive cycle in old females is not produced by the cessation of ovulation, but by the increase of unsuccessful ovulations. The fertility ratio of ova decreases from 64 % of young animals to 32 % of old animals. On the other hand the number of annual ovulation shows a very slight increase with age. Anyway such a long mean reproductive cycle of old females suggests

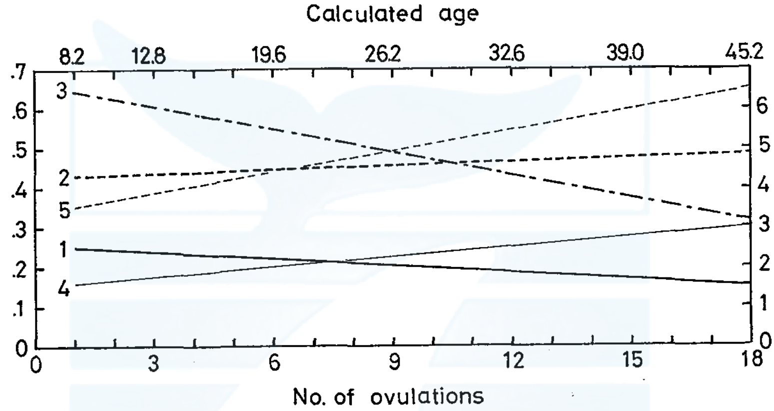

Fig. 40. Relation between age and reproductive parameters obtained from the ovulation diagram. 1 indicates pregnant ratio (left scale), 2 annual ovulation rate (left scale), 3 fertility ratio of ovum (left scale), 4 number of ovulations in a reproductive cycle (right scale), and 5 length of reproductive cycle in years (right scale).

TABLE 16. REPRODUCTIVE PARAMETERS CALCULATED FROM OVULATION DIAGRAMS OF THE PAST 48 MONTHS IN RELATION TO THE NUMBER OF OVULATIONS AT DEATH.

Number of ovulations at death	1–3	4–6	7–9	10–12	13–15	16–18	a*	b*
A. Sample size, No.×Month	1474	1606	959	733	565	288	—	—
B. Fertile ovulation	36	23	21	12	12	3	—	—
C. Total ovulation	50	67	33	26	28	10	—	—
D. Pregnant ratio	0.2735	0.1604	0.2453	0.1834	0.2379	0.1167	−0.00584	0.2584
E. Mean annual ovulation	0.4071	0.5006	0.4129	0.4256	0.5947	0.4167	0.00327	0.4286
F. Ovulation per reproductive cycle	1.389	2.913	1.571	2.167	2.333	0.333	0.0817	1.518
G. Length of reproductive cycle, Month	40.94	69.83	45.67	61.08	47.08	96.00	2.119	39.97
H. Fertility of ovum	0.7200	0.3433	0.6364	0.6415	0.4286	0.3000	−0.01923	0.6643

* $y=ax+b$. $D=B\times 11.2\div A$, $E=C\div A\times 12$, $F=C\div B$, $G=A\div B$, $H=B\div C$.

that their participation in reproduction is almost negligible.

Accumulation rate of corpora albicantia

The corpora albicantia with clear yellow or yellow brown colour and have no internal structure typical of usual corpora albicantia nor typical external scar were considered to have been derived from atretic lutealized follicles (Harrison and Ridgway, 1971), and were not included in the number or corpora albicantia. The number of corpora atretica was counted, if found, when the number of corpora albicantia and lutea was counted. The relation between number of ovulations and of corpora atretica is shown in Table 17. However if they had been searched for more intensively, the number might have been more than that shown here.

No corpora atretica are observed in immature animals. However, in the mature animals, corpora atretica ranging from 0 to 13 in number were observed. It does not seem to increase with the age of animals. This may be because the size of corpora atretica decreases rapidly and many of them have been overlooked. But at present the possibilities are not denied that corpora atretica are formed frequently in young animals or that very few corpora atretica are erroneously included as corpora albicantia.

Ohsumi (1964) showed on *S. attenuata* that the left ovary is precocious and the number of ovulations in the left ovary usually predominates that in the right. Among the present 171 pairs of mature ovaries, 162 pairs or 95.7 % of the total females had the higher number of corpora in the left ovary. This supports his result.

TABLE 17. RELATION BETWEEN NO. OF OVULATIONS AND NO. OF CORPORA ATRETICA OBSERVED.

No. of ovulations	0	1	2	3	4	5	6	7	8	9	10	13	mean
0	126	—	—	—	—	—	—	—	—	—	—	—	0
1	10	1	—	—	—	—	—	—	—	—	—	—	0.09
2	18	2	1	—	—	—	—	—	—	—	—	1	0.77
3	18	3	—	—	—	—	1	—	1	—	—	—	0.74
4	16	—	—	—	—	—	—	—	—	—	—	—	0
5	13	1	—	—	—	—	1	—	—	—	—	—	0.47
6	18	2	1	—	—	1	—	—	—	—	—	—	0.41
7	10	3	2	—	—	—	—	—	—	—	—	—	0.47
8	6	—	—	—	1	—	—	—	—	—	—	—	0.57
9	4	—	—	—	—	—	—	—	—	—	—	—	0
10	2	2	—	—	—	—	—	—	1	—	—	—	2.00
11	6	1	—	—	—	—	—	—	—	—	—	—	0.14
12	4	1	—	—	—	—	—	—	—	—	—	—	0.20
13	1	1	1	—	—	—	—	1	—	—	—	—	2.50
14	3	1	1	—	—	—	—	—	—	—	—	—	0.60
15	2	1	—	—	—	—	—	—	—	—	—	—	0.33
16	—	—	—	—	—	—	1	—	—	—	—	—	6.00
17	2	—	—	—	1	—	—	—	—	—	—	—	1.33
18	1	1	—	—	—	—	—	—	—	—	—	—	0.50
Total	260	20	6	0	2	1	3	1	2	0	0	1	0.33

However, the presence of 8 pairs (4.7 %) of ovaries, in which the number of corpora in right ovary exceeds that in the left, indicates that there may be few females which do not show the precocity of left ovary. The same number of corpora in each ovary was observed only in one (0.6 %) female. These few females should be dealt with separately in analyzing the ovulation activity of the females with precocious left ovary.

Fig. 41 shows the mean number of ovulations in one ovary plotted against the number of ovulations in both ovaries. It is considered from this figure that the right ovary of some of the females with a precocious left ovary starts to ovulate at the age of 6 to 10 ovulations. But most of the left ovaries cease the ovulation at 13 or 14 ovulations when the right ovary take the place of left ovary. The mean number of ovulations at this stage calculated from 13 females with 13 or more corpora is 13.5. The thick solid and dotted lines in Fig. 41 indicate the mean ovulation activity of the female with a precocious left ovary. On the other hand the bilateral asymmetry is not clear in females in which the corpora number in the left ovary does not exceed that in right ovary. This may mean that the right ovary of these individuals starts to ovulate at a younger age, or that both ovaries ovulate equally. Possibly both cases occur in these individuals.

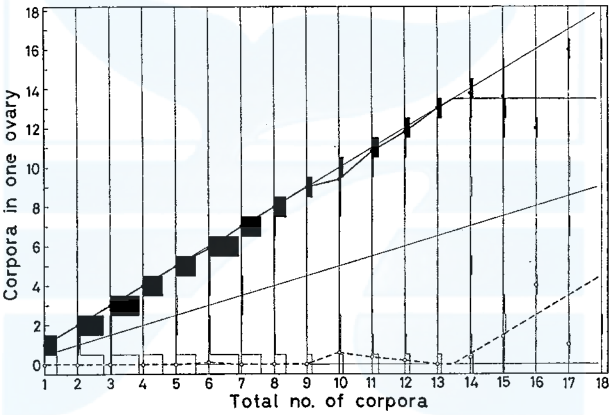

Fig. 41. The asymmetry of corpora number in the ovaries of *S. attenuata*. Black squares indicates the frequency of corpora in left ovary, the white that in right ovary, closed circles and thick solid line the mean number of corpora in the left ovary of the female with precocious left ovary, and open circles and dotted line that in right ovary in the same animal. Three thin solid lines indicate the case where all the corpora are in the left ovary or in the right ovary, and the cases where both ovaries have the same number of corpora.

The accumulation rate of corpora albicantia in one reproductive cycle was shown to change from 1.6 of youngest animals to 3.0 of oldest animals (Fig. 40). The mean accumulation rate of corpora in all the age groups is obtained by totalling the mean number of postpartum ovulations and that of postlactum ovulations (Table 10). This method gives the value 1.743 for the mean number of ovulations in one reproductive cycle. This value corresponds in Fig. 40 to the value at the age of 3 ovulations or 12.8 years of age calculated by the method mentioned in a later section.

The number of ovulations experienced before the first pregnancy is obtained by two methods. One is to use the ovulation diagram. In some recently matured females the number of ovulations undergone before the first pregnancy is directly counted on the ovulation diagram (Table 18). The mean of these ovulations is 1.784, which is fairly close to the number of ovulations per one reproductive cycle obtained as above and to the value obtained on *Globicephala melaena* (Sergeant, 1962). The second is the method of Sergenat (1962). If the female attains the sexual maturity at age between 5.5 and 10.5 years of age and minimum length of reproductive cycle is 2 years, most of the young pregnant or lactating females may be in the first cycle of reproduction (Table 19). In this table the animals shown by italics were excluded from the calculation because they are considered to be in the second cycle. Then the mean number of ovulation 2.08 was obtained from 13 animals, which is too high compared with the values obtained by the above two methods. This is possibly because some postpartum ovulations, or females in the second cycle are included.

Accordingly we conclude that, though it may change with the age of the animal, the mean number of ovulations in one reproductive cycle is between 1.7 and 1.8, and that it will not be very different from the number of ovulations undergone before the first pregnancy.

The relation between the number of ovulations and the age determined by the dentinal growth layers is shown in Fig. 42. The highest annual accumulation

TABLE 18. NUMBER OF OVULATIONS UNDERGONE BEFORE THE FIRST PREGNANCY (FROM OVULATION DIAGRAM).

No. of ovulations	Frequency	
	no.	%
1	19	51.4
2	9	24.3
3	7	18.9
4	2	5.4

TABLE 19. NUMBER OF OVULATIONS IN RECENTLY MATURED PREGNANT OR LACTATING FEMALES.

Age	No. of ovulations									
	1	2	3	4	5	6	7	8	9	10
7.5	1			*1*						
8.5		3	2			*1*				
9.5	3	2	1	1		*1*		*1*		*1*
Total	4	5	3	1+*1*		*2*		*1*		*1*

rate of the corpora is 3.0 on the figure and the lowest 0.50. The relation between the number of ovulations (y) and the age (x) of the mature females, $y=0.821x-3.967$, was obtained by least squares. If this annual accumulation rate 0.821 is applied to the mean length of the reproductive cycle 4.19 years, the number of ovulations in one reproductive cycle must be 3.44. Even if the shorter and less reasonable estimate of reproductive cycle 3.65 years is adopted the ovulation in one cycle is 3.00. These values are higher than any other values obtained in this section, and considered to be unreasonable.

The open circles and dotted line in Fig. 42 indicate the mean age corresponding to each number of ovulations. This dotted line is almost vertical after the attainment of 12.5 years of age. As the annual ovulation rate does not change much with the age of animal (see Fig. 40), this tendency must indicate that the age of the animals older than that point is underestimated. This age corresponds roughly to the time when the poorly calcified secondary dentine starts to be accumulated in the pulp cavity and age determination becomes difficult. As physical maturity of this species is attained by the age of 11.5 years, it will be concluded that after the attainment of physical maturity the secondary dentine is accumulated and reliable age determination becomes impossible by the present technique.

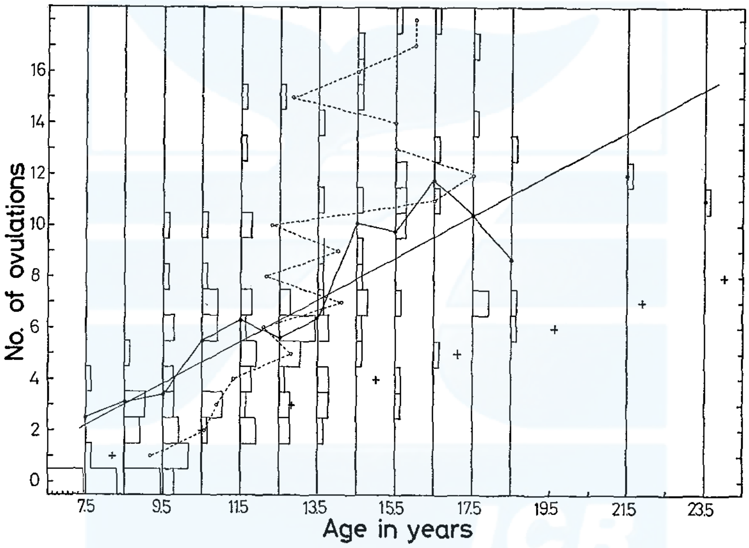

Fig. 42. Relation between number of ovulations and age of *S. attenuata* estimated from the dentinal layers. Open circles and the dotted line indicate the mean age in each ovulation number, closed circles and thick solid line the mean number of ovulations in each age class, thin solid line the relation between ovulation and age calculated by least squares, and cross marks the number of ovulations estimated from the ovulation diagram.

A similar feature is expected even in *Stenella coeruleoalba*. Though Kasuya (1972) obtained the number of ovulation-age relationship $y=0.69x-5.16$, the fitness is poor in younger animals. And the relationship between mean ages and number of ovulations is almost vertical after the age of 14 years. This is an indication of underestimation of the age. If 13 years of age or younger 15 females selected from his data (Kasuya 1972, Fig. 14), excuding one 10 years old female which shows too high count of the corpora, are used, 0.325 is obtained as the annual ovulation rate. This value is less than the half of the annual ovulation rate estimated by Kasuya (1972).

It is impossible to use a similar method to estimate the real ovulation rate of *S. attenuata*, because reliable age determination is possible only for a shorter period. The real annual ovulation rate of *S. attenuata* was calculated from the relation between the annual ovulation rate and the number of ovulations (Table 16).

$$Y_t = 0.00327x_t + 0.4286$$

where y_t is the mean annual ovulation rate between the age t and t−4 years and x_t is the number of ovulations at the age of t years. This formula means that the annual ovulation rate is approximately 0.432 at the first year after the attainment of sexual maturity and 0.487 at the age of 18 ovulations which is the oldest animal observed. These values are higher than the corresponding value obtained in *S. coeruleoalba*, but coincides with our observation that simultaneous ovulation is rare in *S. coeruleoalba*. A *Tursiops truncatus* matured and died in captivity had undergone 7 ovulations in 15 years (Sergeant *et al*, 1973) showing an ovulation rate, 0.465/year, similar to that of *S. attenuata*.

The number of corpora albicantia and lutea at age t is obtained from the above formula. If the constants of the above formula are shown by a and b, it is rewritten as follows.

$$x_{t+1} - x_t = ax_{t+1} + b$$

or

$$x_{t+1} = \frac{1}{1-a}x_t + \frac{b}{1-a}$$

Here, if the age at sexual maturity is shown by m, the number of ovulations at n years after sexual maturity is shown by the following equations,

$$x_m = 1$$

$$x_{m+n} = r^n + b\sum_{n=1}^{n} r^n$$

where n is interger and r is $(1-a)^{-1}$.

As a and b are obtained from Table 16, the number of ovulations at age m+n is calculated from this formula. The age corresponding to each ovulation number was obtained on the graph and shown in Table 24. The oldest animal observed had undergone 18 ovulations corresponds the age of 45.2 years. However as an animal with many corpora may have undergone an annual ovulation higher than the average, the observed real maximum age is considered to be less than 45 years.

LIFE TABLE

Litter size

Among 59 confirmed pregnancies, twins were observed only in two females in school 1., the other 57 pregnancies were single. Accordingly the ratio of twins in total pregnancy is 3.39 %, and the mean litter size is 1.034.

Sex ratio

The sex ratio is shown in this paper by the number of males per one female. It is shown in Tables 20 and 21, and Fig. 43 that the number of males exceeds that of females in the fetus and newborn animals. Then the ratio of male constantly decreases to attain the sex ratio of 0.579 in the age groups of more than 10 years of age where animals of both sexes have attained sexual maturity. As males attain sexual maturity 2 years later than females, the sex ratio of mature animals is very low. When calculated from length frequency it is 0.380, and when calculated from 10 years or older males and 8 years or older females it is 0.440. Probably the former figure is close to the truth because it is based on much more data. A similar ten-

TABLE 20. SEX RATIO OF *S. ATTENUATA* BY SCHOOLS AND LENGTH RANGES.

School	Sex	Fetus	Juvenile[1]	Puberal[2]	Mature[3]	Total
1	♀	5	10	13	58	86
	♂	3	7	14	29	53
		0.600	0.700	1.077	0.500	0.616
2	♀	14	38	22	105	179
	♂	19	33	44	31	127
		1.357	0.868	2.000	0.295	0.709
3	♀	0	3	2	18	23
	♂	2	7	5	11	25
			2.333	2.500	0.611	1.087
4	♀	0	3	11	45	59
	♂	2	10	16	32	60
			3.333	1.455	0.711	1.017
5	♀	0	3	1	11	15
	♂	3	4	4	0	11
			1.333	4.000	0	0.733
6	♀	3	12	1	59	75
	♂	2	14	21	15	52
		0.667	1.167	2.100	0.254	0.693
7	♀	2	0	2	17	21
	♂	2	5	11	1	19
		1.000		2.200	0.059	0.905
Total	♀	24	69	52	313	458
	♂	33	80	115	119	347
		1.357	1.159	2.212	0.380	0.758

[1] up to 165 cm, [2] 166 cm to 181 cm (♀), or 194 cm (♂), [3] more than 182 cm (♀), or 195 cm (♂).

dency of the ratio in relation to the age of animal is also found in *Globicephala melaena* (Sergeant, 1962).

There are three possible reasons for the fluctuation of sex ratio. One possibility is the segregation of adult males. Though it may exist in the puberal stage, there is observed no rapid change of sex ratio at the ages corresponding to the sexual maturity of the animal. Accordingly this possibility cannot explain all the phenomena. The other possibility is the difference of catchability between sexes. As males are always single, they might find more chances to escape from the chasing boats. However, the fact that the sex ratio continuously decreases with age even before the attainment of sexual maturity denies this hypothesis.

The only certain reason is the higher mortality of the male. As physical maturity is attained slightly earlier in females and age determination by the dentine

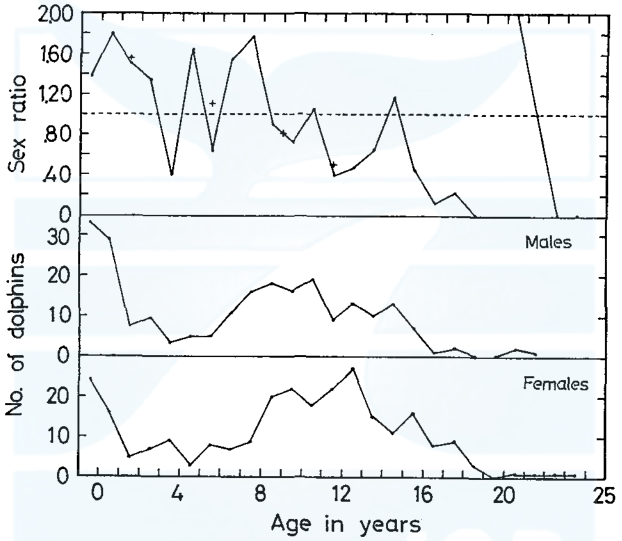

Fig. 43. Relation between sex ratio and age of the animal presumed from the dentine layers. Crosses indicate the mean sex ratio in Table 21.

TABLE 21. SEX RATIO OF *S. ATTENUATA* BY AGE DETERMINED BY DENTINE LAYERS.

Age		Female no.	Male no.	Sex ratio
range	mode			
0>	−0.5	24	33	1.375
3≧, > 0	1.5	29	45	1.552
8>, > 3	5.5	35	39	1.114
10>, > 8	9.0	42	34	0.810
13>, >10	11.5	60	31	0.517
>13		73	46	0.630
Total		239	195	0.816

layer becomes difficult, if the mortality rate of both sexes is equal there must be observed more old males than the females. However as shown in Fig. 43, the number of males of the age more than 16 years is only 6, whereas the corresponding number of females is 34. This indicates that the mortality of the male is much higher than that of the female.

If the mortality of the male can be higher than that of female in any stage of the life, it is reasonable to expect that the sex ratio may change even in the fetal stage. But this problem was not analysed in this paper. When the mortality coefficient of male is shown by m, that of female by μ, and the sex ratio at birth by a, the sex ratio at the age of t years can be shown by the formula in the below.

$$\text{Sex ratio} = a \cdot e^{-(m-\mu)t}$$

The a and $m-\mu$ are obtained from the 5 mean sex ratios in Table 21. The data on animals older than 12.5 years were not included because age determination by dentine growth layer is in some case unreliable. The a and $m-\mu$ calculated by the least squares are 1.568 and 0.08348 respectively. This indicates that 38.94% of total number of newborn calves is female. The age when the both sexes are equal in number is 5.4 years of age. In other species of mammals such a high sex ratio at birth is observed in red deer (Asdel, 1964).

Mortality and recruitment

Fig. 44 shows the age frequencies of the 239 females and 195 males based on the age determined by the dentine growth layers. The age is grouped into nearest n+0.5 years, where n is an integer. Each half of animals at the age of 1.0, 2.0, and 3.0 years were divided into age groups of younger or older animals.

The number of animals between 3 and 8 years of age is small. This category of animals may have left the breeding schools which we had the chance to study. The highest frequency of females is in the age group of 12.5 years and that of males 10.5. If the mortality is constant after this year and the age determination is correct, there is expected to be the following equation,

$$l_t = l_0 e^{-\mu t}$$

where t is the age of animal in years, l_t the number of animals at age t, and μ the mortality coefficient. The mortality coefficient of the animals of both sexes more than 12.5 years old were calculated by the least squares. It gives the mortality coefficient,

$$\mu = 0.3545$$

or the annual mortality rate,

$$M = 1 - e^{-\mu} = 0.2985$$

The mortality coefficient of mature females can be calculateed by another method, based on the annual ovulation rate. The age frequency calculated with the Number of ovulation-Age relationship is shown in Table 22 and Fig. 45. The mortality coefficient and mortality rate of mature female, μ and M, calculated for

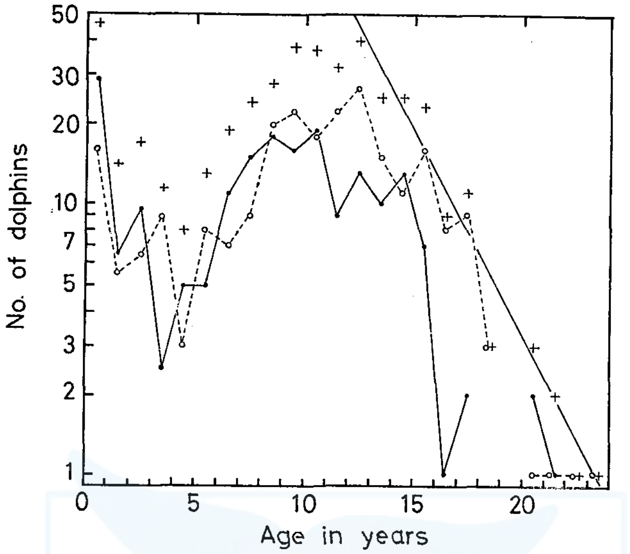

Fig. 44. Age frequency of *S. attenuata* based on the dentine layers. Open circles and dotted line indicate females, and closed circles and solid line males. Crosses show the total of both sexes including animals of unknown sex. Straight line was calculated by least squares for all animals of more than 12.5 years of age.

TABLE 22. FREQUENCIES OF NO. OF OVULATIONS AND OF AGE CALCULATED FROM NO. OF OVULATIONS.

No. of ovulations	Calculated age	School no.							Total
		1	2	3	4	5	6	7	
0	—	22	64	5	15	5	13	—	124
1	8.2	1	4	2	3	—	1	—	11
2	10.5	9	2	—	2	1	5	3	22
3	12.8	4	5	2	4	—	5	3	23
4	15.0	4	5	1	3	—	3	—	16
5	17.3	5	2	1	5	—	—	2	15
6	19.6	6	3	4	3	1	5	—	22
7	21.8	3	1	4	2	2	2	1	15
8	24.0	1	1	—	1	1	2	1	7
9	26.2	1	1	—	1	1	—	—	4
10	28.4	—	—	2	1	—	2	—	5
11	30.5	1	—	1	5	—	—	—	7
12	32.6	—	1	—	2	—	1	1	5
13	34.8	—	2	—	—	—	1	1	4
14	36.9	—	1	2	1	—	1	—	5
15	39.0	—	1	—	1	—	1	—	3
16	41.1	—	—	1	—	—	—	—	1
17	43.1	—	—	—	—	—	2	1	3
18	45.2	—	—	—	2	—	—	—	2
No. of the mature	—	35	29	20	36	6	31	13	170

the ages corresponding to 2 or more ovulations are shown below.

$$\mu = 0.07705$$
$$M = 0.07416$$

The catch of *S. attenuata* by means of the driving method is, on the coast of Izu Peninsula, sporadic and small in number (Table 23). The catch of school no. 7 at Taiji by the same method was the second case at least in recent several years. Though the tuna seine is operated in the western North Pacific, as schools of tuna are usually found by the floating wood or flocks of birds in these waters, the catch of *S. attenuata* by tuna boats seems to be negligible (Ohsumi, 1972, Dr. Suda, personal communication). Catch by means of hand harpoon is operated off Taiji on the coast of Kii peninsula. But the number caught is small.

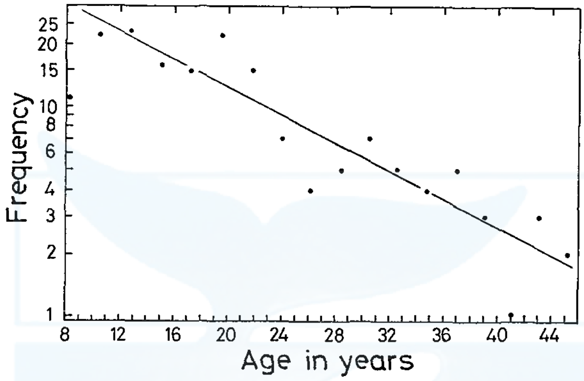

Fig. 45. Age frequency of female *S. attenuata* calculated from the number of ovulations and estimated accumulation rate of corpora. Line was calculated by least squares excluding a point of the youngest animal.

TABLE 23. NUMBERS OF *S. ATTENUATA* CAUGHT AT IZU AND KII PENINSULA.

Year Driving	1963	'64	'65	'66	'67	'68	'69	'70	'71	'72	'73[1]
no. of school	1	1	0	2	2	0	1	7	0	4	5+
no. of dolphin	37	470	0	322	373	0	437	2907	0	660	1366+
Harpoon[2]	—	—	—	—	—	—	—	14	37	12	17+

1963–1968: Tobayama (1969), [1]: Includes 206 animals in two schools caught at Taiji. [2]: Taiji.

Accordingly, the population of *S. attenuata* in the western North Pacific is considered to be close to virgin stock. In the stationary virgin stock, there must be an equation shown below.

$$S \cdot r^{-1} \cdot f \cdot l \cdot e^{-\mu' t} = S \cdot (1 - e^{-\mu})$$

where S is the number of sexually mature females, r length of reproductive cycle in year, f ratio of females at birth, l the mean litter size, t the age at the attainment of sexuall maturity, μ' the mean mortality coefficient before the attainment of sexual maturity, and μ the mean mortality coefficient of sexually mature females. Assuming $t=8$, $r=50.3$ months (=4.19 years), $1=1.034$, and $f=0.3894$, the following values are obtained.

$$\mu' = -0.14312, \text{ and } M' = -0.13335, \text{ when } \mu = 0.3545$$
$$\mu' = 0.03240, \text{ and } M' = 0.03188, \text{ when } \mu = 0.07705 .$$

The values at the top are unreasonalbe, indicating that the mortality coefficient, $\mu=0.3545$, obtained from the age frequency based on the dentine growth layer is too high. This is easily expected because the age of physically matured animal is often underestimated by this method. Accordingly, one of the estimates of the mean mortality coefficient of immature females is 0.03240 when that of mature females is 0.07705. The mean length of reproductive cycle 50.3 months used here is the best estimate. Even when the less reasonable under- or over- estimates 43.8 months or 54.3 months are applied, the mean mortality coefficients of immature females are 0.04964 or 0.02264 respectively and still certainly lower than that of mature females. Possibly the best estimate of the mean mortality coefficients of immature females seems to be between the above two estimates or 0.023 and 0.049. This is about half of the value for mature females.

The rough estimate of the morality of the male is calculated from the mortality of female and the sex ratio at the age t. As $m-\mu=0.08348$ was obtained in page 209, the mean mortality coefficient of the male at the age between 0 and 8 years is

$$m = 0.08348+0.03240 = 0.12588$$

and that at the age over 8 years is

$$m = 0.08348+0.07705 = 0.16053$$

The corresponding annual mortality rates are 0.118 and 0.148 respectivelty.

The present result shows that the mortality of immature animals is lower than that of sexually matured animals. Brodie (1969) suggested that the long lactation of toothed whales will be effective as the period of education. This seems to be true in *S. attenuata.* This species starts feeding on solid food at the age of about 3/4 years, but it continues to take both solid food and milk at least by the age of 1.5 years. This weaning period seems to work as the education or training period of the calf, and work to lower the mortality of the young calf. The immature animals of both sexes aggregate after weaning, to have probable cooperative life. Of course other than these special mode of life, the life of immature female free from the reproductive activity must keep the mortality lower than that of sexually mature females.

The probability of survival in Fig. 46 and Table 24 is drawn based on the lowest mortality coefficients in the above and assuming 8 years as the age at the attainment of sexual maturity. It indicates that the number of females at attainment of the maturity is 83.4% of that at the birth. The mean life expectancy of newborn females is 14.6 years, and that of sexually mature females is 17.0 years.

The probable number of gestations experienced by a female is obtained by integrating the relation between fertility rate of ova and number of ovulations (x) in Table 16.

$$\int_1^n (-0.01923x+0.6643)dx$$

The known highest number of ovulations, 18, suggests 8.3 gestations in the past. The number of gestations, corresponding to the mean number of ovulations of adult females, 6.16, is 3.2.

The number of female calves (R_t) produced annually by the mature females (S_t) of the age t is shown by the following formula, assuming the start of conception at the beginning of the year.

$$R_t = S_t \cdot r_t^{-1} \cdot l \cdot f \cdot \rho^{11.2/12}$$

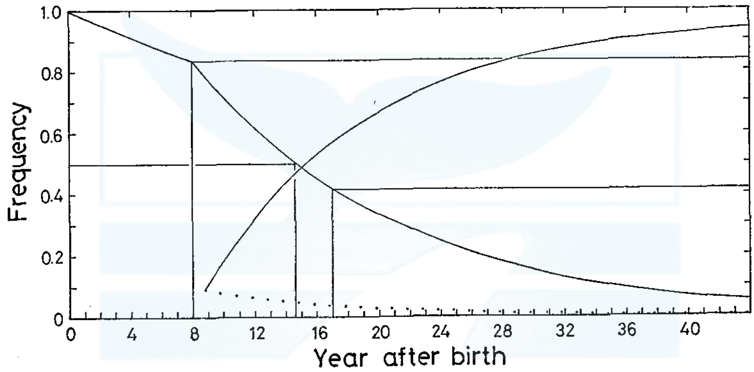

Fig. 46. Calculated survival and reproduction in the female of *S. attenuata*. Small dots at the bottom indicate the annual recruitment.

TABLE 24. LIFE TABLE OF FEMALE *S. ATTENUATA* AT SELECTED AGES.

Year after birth	Probability of survival[1]	Total ouvlation	Annual ovulation rate	Fertility ratio of ovum	Ratio of pregnant female	Reproductive cycle, year	Annual reproductive rate[2]	Total reproduction
0	1.0000	0	0	—	0	—	0	0
4	0.9134	0	0	—	0	—	0	0
8	0.8343	1	0.432	0.645	0.253	3.51	0.1068	0.089
12	0.6130	2.7	0.437	0.612	0.243	3.81	0.0984	0.370
16	0.4504	4.5	0.443	0.578	0.232	4.13	0.0908	0.560
17	0.4170	4.9	0.445	0.570	0.230	4.20	0.0893	0.597
20	0.3310	6.3	0.449	0.543	0.222	4.44	0.0843	0.690
24	0.2432	8.1	0.455	0.509	0.211	4.76	0.0787	0.778
28	0.1787	9.9	0.461	0.474	0.201	5.08	0.0738	0.839
32	0.1313	11.8	0.467	0.437	0.189	5.41	0.0692	0.881
36	0.0965	13.7	0.473	0.401	0.178	5.75	0.0652	0.910
40	0.0709	15.6	0.480	0.364	0.167	6.09	0.0616	0.930
44	0.0521	17.5	0.486	0.332	0.156	6.42	0.0584	0.944
48	0.0383	19.5	0.492	0.290	0.145	6.77	0.0553	0.954

[1] $lt=e^{-0.02264t}$, $1 \leqq t \leqq 8$. $lt=0.834335e^{-0.07705(t-8)}$, $t \geqq 8$. [2] R_t/S_t.

where ρ is the annual survival rate, r_t the length of reproductive cycle in year at age t, and 11.2/12 is the length of gestation in year. Other symbols are same with the formula in page 211. r_t is calculated from the relation between the number of ovulations and age (page 206), and that between length of reproductive cycle and number of ovulations (Table 16).

The annual recruitment thus calculated, and the total recruitment are shown in Fig. 46. Though the total recruitment must be 1 when the probability of survival is 0, l_t of the formula of survival, $l_t = l_0 e^{-\mu t}$, can be 0 only when t is infinite. In Fig. 46 the probability of survival at the age 48 is 3.83 %, but the probability of total recruitment is 95.40 %, and the recruitment seems to be slightly lower to keep the population stable. But as this model is based on several assumptions, the above defect is considered to be negligible at present.

If the population is depleted as the result of exploitation, the total reproductive rate $\Sigma R_t/\Sigma S_t$ will increase as the results of the increase of the ratio of young mature female with high reproductive potential, and of the shortening of reproductive cycle of each age classes. The increase of the ratio of the female in the newborn animals is also expected. This change of sex ratio works to increase the reproductive rate.

SCHOOLING BEHAVIOR

School size

The information of the number of dolphins constituting one school of *S. attenuata* was obtained from the records of the catch by the driving method in the fishermen's cooperative unions at Arari, Futo, Kawana, and Taiji. The records cover the years from 1963 to 1973. As fishermen hope to catch all the animals they find, they may sometimes drive to combine schools found at close distance. However, it is also probable for them to lose a part of the school. However these problems are not discussed here, because the information at the time of driving is insufficient and the definition of a school is also unsatisfactory.

Table 25 shows the frequency of the size of the school. The smallest school was composed of 37 animals, and the largest, 1,381 animals. The mean school size is 281.0 animals. There are 4 modes observed in the frequency, or from 37 to 98, from 120 to 437, from 509 to 617, and 1,381. The modal means are shown in the table and they suggest that the basic unit of the school is less than 100 animals, and that larger schools might be formed as the result of annexation of the smaller schools.

Immature animals

The age frequency of 7 shcools shows that the number of juvenile animals of the age between 2 and 7 years is few (Figs. 44 and 47). It is lowest at the age of 3.5 years (male) or 4.5 years (female). Though we had no chance to confirm it, it is suggested that the calves of the above age classes may have left the school of the mother as in the case of *S. coeruleoalba* (Kasuya, 1972). The age when they leave the

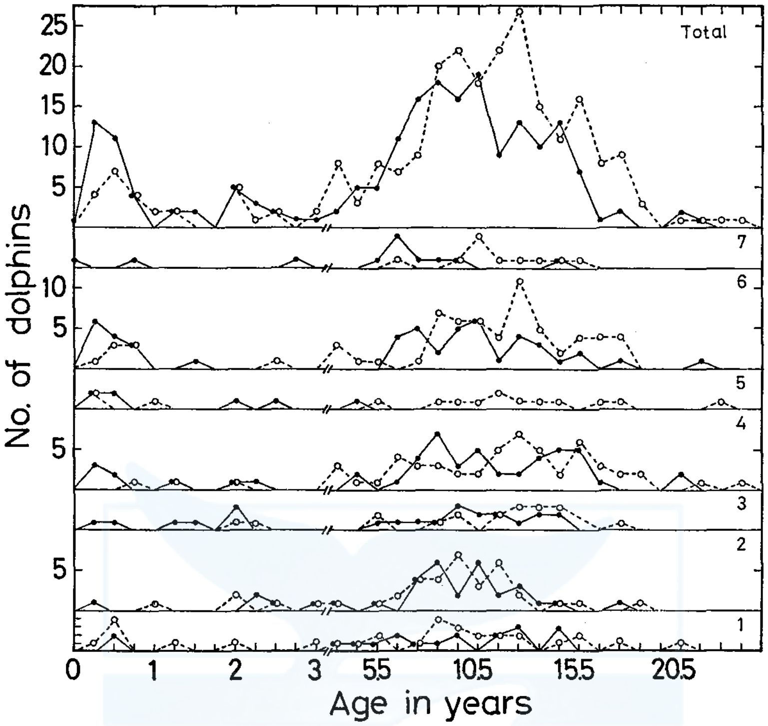

Fig. 47. Age frequency of *S. attenuata* by schools and sexes based on dentine growth layers. Open circles and dotted lines indicate females, and closed circles and solid lines males.

TABLE 25. SCHOOL SIZE FREQUENCY OF *S. ATTENUATA* CAUGHT BY DRIVING METHOD[1].

School size	No. of schools	Percent	Mean
1- 24	0	0	65.5
25- 49	1	4.8	
50- 74	2	9.5	
75- 99	1	4.8	
100- 124	1	4.8	235.9
125- 149	1	4.8	
150- 199	5	23.8	
200- 299	4	19.0	
300- 399	2	9.5	
400- 499	1	4.8	
500- 599	1	4.8	563.0
600- 699	1	4.8	
1300-1399	1	4.8	1381.0
Total	21	100	

[1] 4 schools reported by Tobayama (1969) and Nishiwaki (1965) included.

mother's school is not directly known, but it may be soon after the weaning. It was indicated from the length of lactation that calves of *S. attenuata* are weaned at the age between 17 and 60 months with an average of 29.3 months (2.44 years). As the latter age is slighly before the age of lowest frequency, the above supposition is supported. The age when the calf leaves the mother's school might be slightly earlier in males than the female.

After the age of 3 or 4 years, the number of immature animals in the breeding school increases. In females, the age of 4 years corresponds to the time when the weight of left ovary start to exceeds that of the right indicating the approach of the puberty. And in males the age of 3 years is the time when the production of spermatozoa, an indication of the arrival of puberty, is started in many animals. Accodingly it is highly probable that the calves of both sexes which have left the mother's school gradually return to the school of mature animals after reaching puberty, and all the animals will return by the attainment of sexual maturity. However some of the few calves which are accompanied by the lactating female for more than 4 years might attain puberty or sexual maturity in the same school.

The school of immature animals of *S. coeruleoalba* reported by Kasuya (1972) was composed of the males between 1.50 years and 12.5 years of age (228 samples), and of the females between 2.75 years and 7.75 years of age (62 samples). The modal age of that school was 4.5 years in males and 3.5 years in females. This feature strongly resembles the schooling behavior of juvenile animals of *S. attenuata* presumed here.

The school of mature females usually contains puberal animals in it. The only exception among 7 schools is school 5. In this school the animals of the age corresponding to the puberal stage are only 2 animals. As the age determination was made on only one third of the total number of the animals in the school, it is not

TABLE 26. PRESENCE OF SPERMATOZOA IN TESTIS SMEAR.

School no.	Spermatozoa	Testis weight (g) 0–5.9	 6–67.9	 68≦
3	none	3	1	—
	few	1	6	1
	medium	—	1	5
	many	—	—	3
	mean weight (g)	4.8	23.4	281.9
4	none	—	—	—
	few	—	8	2
	medium	—	7	9
	many	—	—	17
	mean weight (g)	—	17.3	195.6
6	none	10	17	—
	few	—	1	7
	medium	—	—	6
	many	—	—	2
	mean weight (g)	2.2	18.1	158.6

conclusive at present as to whether there is a school of mature females which does not contain puberal animals. However it is highly probable that the connection between puberal animals and mature females is less strong and the former form smaller groups when the school is dispersed or leave the latter school to join with a school of immature animals.

If the sexual activity of the puberal males, or males from 6 g to 67.9 g in testis weight, is shown by the density of spermatozoa in the testis smear, the activity is high in schools 2, 3 and 4 (Table 26). And a parallel relationship is observed between the sexual activity of puberal males and that of mature males indicated by smears or by the mean weight of testes. However it was not conclusive as to whether it is related with the reproductive cycle of the male or with the schooling behavior.

Mature female

The age frequency of mature females in each school does not show the predominance of a particular age class, but seems to be evenly distributed and affected only by the mortality (Fig. 47).

As shown in Table 27, the breeding school of *S. attenuata* always contains both pregnant females and lactating females. But the ratio of the latter to the former varies widely between schools. The lowest ratio about 1.0 is found in the schools 1 and 5, and the highest ratio 6.4 in the school 4. Most of the mature females in school 4 were in lactating or resting stage. The abundance of resting females is more variable from 0 in schools 1 and 5 to 3.5 times of the pregnant females in school 7.

The history of the reproductive activity of the females in each school is known from the length frequency of the juvenile calves and of fetuses (Fig. 48). The simplest example is in school 6, where the mating peaks in the past are in March, January, and August (from left to right in Fig. 48). The intervals between the peaks are 17 months and 12 months respectively. The feature of school 1 are very similar to that of school 6, except for a small peak in October. The intervals between the peaks in the school 1 are 16, 4.0, and 10.5 months.

School 2 shows complicated features. The peaks of conception are in February, late May, October, January, May, August, July, and October. The intervals are 3.5, 4.0, 3.5, 4.0, 3.0, 11.0, and 3.0 months. Possibly the schools 4 and 5 belong to a similar pattern with the approximate interval of the peaks of 4.0, 4.5, 4.0, and 9.0 months for school 4, and 4.5, 3.5, and 11.0 months for school 5. School 7 has no small fetus, but the arrangement of mating peaks in schools 3 and 7 is not largely different from that of school 2.

It is already suggested that *S. attenuata* in the Japanese coastal waters has 3 mating seasons. If all the mature females stay in the same school for their life time, there should be observed the peaks of 3 mating seasons in one school because the length of reproductive cycle is highly variable between animals and it is difficult for all the females to conceive synchronously in only one of the 3 mating seasons. No such case was observed in any of 8 schools studied by us or by Nishiwaki *et al*, (1965). This strongly suggests that the member of mature females in any shcool is

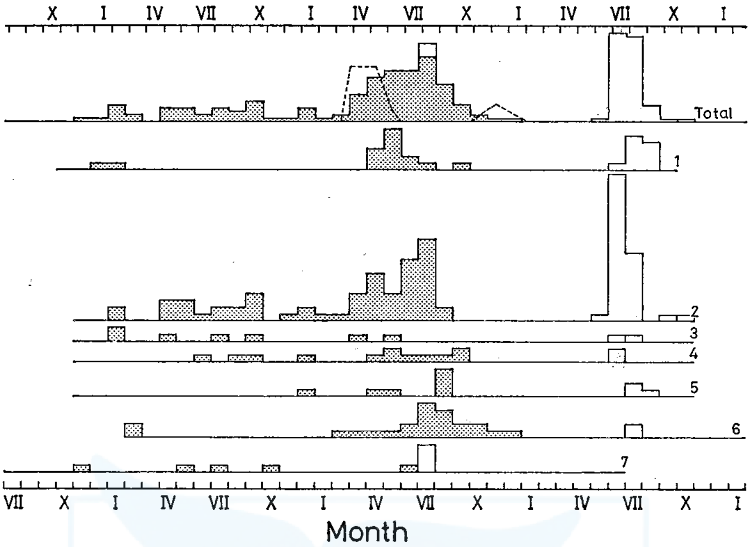

Fig. 48. Frequency of date of conception (scale at the top) and of parturition (scale at the bottom). Dotted areas indicate the frequency obtained from the body length of postnatal animals, white from that of fetuses, and dotted lines cited from Nishiwaki *et al* (1965). Numbers indicate the school.

TABLE 27. RATIO OF REPRODUCTIVE CONDITIONS OF FEMALE *S. ATTENUATA*.

School	Date killed	Immature**	Mature						Total***
			unknown	pregnant	p. & l.	lactating	resting	total*	
1	25, Oct.	24	12	15	3	18	0	36	72
		33.3%		41.7	8.3	50.0	0	100	
2	15, Nov.	67	4	19	2	47	18	86	157
		42.7%		22.1	2.3	54.7	20.9	100	
3	4, Nov.	5	0	4	0	15	1	20	25
		20.0%		20.0	0	75.0	5.0	100	
4	13, Nov.	15	3	3	1	28	7	39	57
		26.3%		7.7	2.6	71.8	17.9	100	
5	18, Nov.	5	2	4	0	4	0	8	15
		33.3%		50.0	0	50.0	0	100	
6	12, Feb.	13	8	14	0	21	13	48	69
		18.8	%	29.2	0	43.8	27.1	100.1	
7	2, Jul.	3	2	2	0	4	7	13	18
		16.7%		15.4	0	30.8	53.8	100	
Total		132	31	61	6	137	46	250	413
		32.0%		24.4	2.4	54.8	18.4	100	

* : Excluding the unknown.
** : Percentage of total.
*** : Excluding the maturity unknown.

not fixed but some of them can be exchanged between schools.

The interval between two recent mating peaks is usually long, but the intervals obtained from length frequencies of postnatal individual is often appears short. This seems to indicate that the oestrous females assemble together to conceive as suggested in *S. coeruleoalba* (Kasuya, 1972), and this connection is retained during the period of gestation. However after parturition the connection becomes weaker with the elapse of the time, and some of the lactating females may move to another school accompanying the calf in some case. Possibly the shift of the lactating females between schools is related to the cycle of postpartum or postlactum ovulations. The schooling behavior of resting females is probably similar to the late lactating females, but the ratio of the between school movement will be much higher.

The frequency of interval between the two mating peaks in the present 7 schools has 4 modes with the modal means of 3.8 month (13 examples), 8.1 months (4), 11.2 months (4), and 16.5 months (2). These modal means are a multiple of 4 months which is the interval of mating season of this species. If the combination of the peaks of conception observed in the present schools are formed through the random combination of each peaks, the frequency of each mode are expected to lie on the straight line shown in Fig. 49. However, the above data shows a higher frequency of the 4 months interval. This means that the neighbouring two mating peaks are not completely independent. Probably the females which failed to conceive in a mating season may often stay in the same school to conceive in the next mating season. This case is represented by a smaller peak next to the main peak

TABLE 28. MATURITY FREQUENCIES AND SEX RATIO OF MALE *S. ATTENUATA*.

School no.	Date killed	Testis weight in g						Total	Sex ratio of the mature
		imm.*	mat.*	5.9≧	6.0～67.9	68≦	un-known		
1	25, Oct.	16	21	0	2	8	3	50	0.605
		34.0%	44.7	0	4.3	17.0			
2	15, Nov.	49	17	4	20	11	7	108	0.311
		48.5%	16.8	4.0	19.8	10.9			
3	4, Nov.	1	0	4	9	9	0	23	0.450
		4.3%	0	17.4	39.1	39.1			
4	13, Nov.	11	2	0	15	30	0	58	0.762
		19.0%	3.4	0	25.9	51.7			
5	18, Nov.	8	0	0	0	0	0	8	0
		100 %	0	0	0	0			
6	12, Feb.	2	1	12	20	15	0	50	0.286
		4.0%	2.0	24.0	40.0	30.0			
7	2, Jul.	7	0	1	8	1	0	17	0.067
		41.2%	0	5.9	47.1	5.9			
Total		94	41	21	74	74	10	314	0.409
		30.9%	13.5	6.9	24.3	24.3			

* : Maturity of testis was identified by eye on the beach.

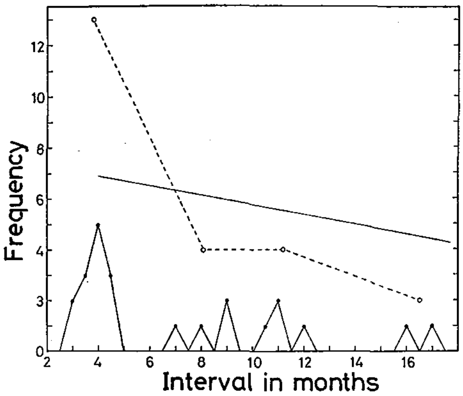

Fig. 49. Frequency of the interval of mating peaks in the 7 schools. Open circles and dotted line indicate the total frequency in each mode plotted against the modal mean of the interval. Straight solid line shows the frequency expected when mating peaks are independent.

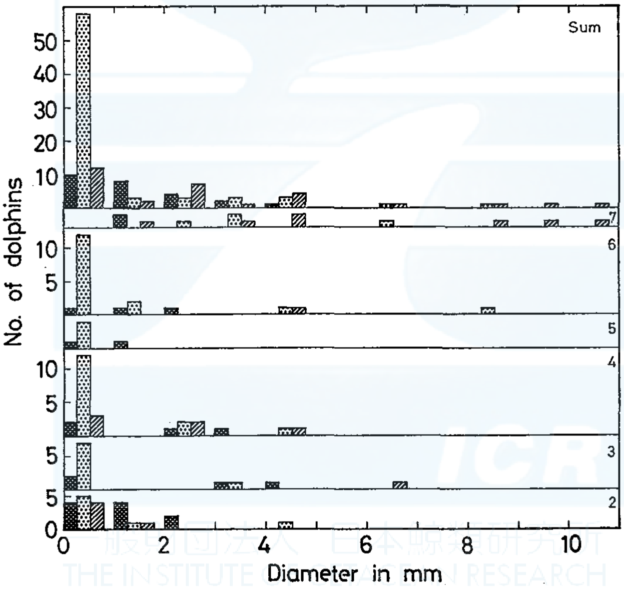

Fig. 50. Diameter of the largest Graafian follicle. White spots indicate pregnant females, black spots the lactating, and lines the resting. Schools are shown by the number at right.

observed in schools 2 and 1. In some cases, oestrous females from other schools exceeding in number the oestrous females in the original school, may join to this school. This is suggested by the 6th peak (from the left) of school 2, where the preceeding 5th peak is smaller. Of course there can be the case where all females which should have constituted the subsidiary peak shift to another school as suggested by the long intervals of peaks.

The origin of other peaks of short interval or of peaks of long interval might be the result of the annexation of schools or random exchange of members between two or more schools. The relative abundance of the 8, 12, and 16 months interval of peaks of conception decreases at the rate expected in random combination.

Mature males

As the diameter of seminiferous tubules and the weight of testis show a linear relationship, the weight of testis of mature male can be used as an indicator of reproductive activity. The mean weight of testis of mature male was compared with the mean diameter of the largest follicle of the mature females caught in the same

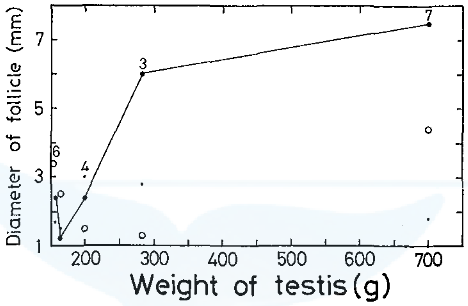

Fig. 51. Relation between the mean weight of testis of mature animal and mean diameter of Graafian follicle of the female in a same school. Large closed circle indicates the follicle diameter of resting female, open circle that of lactating female, and small closed circle that of pregnant female. Schools are shown by the numbers.

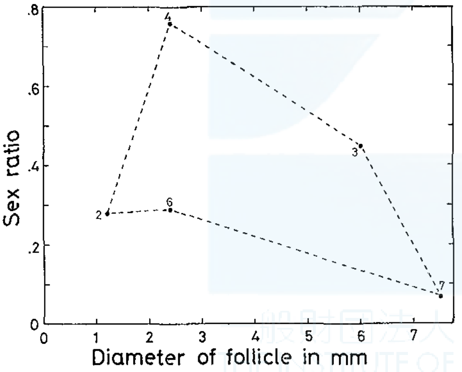

Fig. 52. Relation between the mean diameter of Graafian follicles of resting females and the sex ratio of mature individuals in the same school. Schools are shown by the number. The dotted line indicates the highest and lowest range.

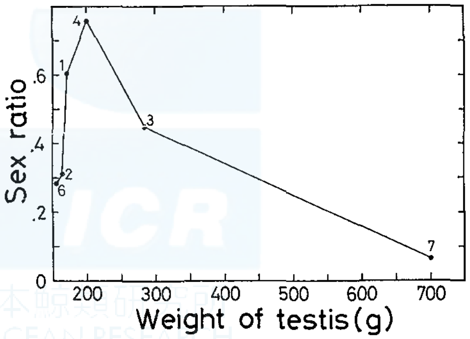

Fig. 53. Relation between sex ratio of mature animals and mean weight of testis of mature males in the corresponding school. Schools are shown by the number.

school (Fig. 51). The mean weight of testis shows a positive correlation with the diameter of the follicle of resting females. As resting females with large follicles are ready to ovulate, it is reasonable to expect males of high activity in the same school.

The sex ratio of mature individuals is small in schools containing resting females with large follicles (Fig. 52). A similar but clearer tendency is observed when it is compared with the mean weight of testis of mature males (Fig. 53). Though it is not shown in Figs. 51, 52 and 53, school 5, which does not contain resting females nor lactating females with follicles larger than 1.0 mm in diameter and is considered to be in low mating activity, it has no sexually mature male.

These results suggest that in schools at the beginning of the approach of heat many mature males may assemble in the same school, but at the peak of the heat most of them except a few males of high activity leave the school. It is highly possible that there is intrasexual aggression between the males of *S. attenuata* as in the case of another delphinidae species *Globicephala melaena* suggested by Sergeant (1962).

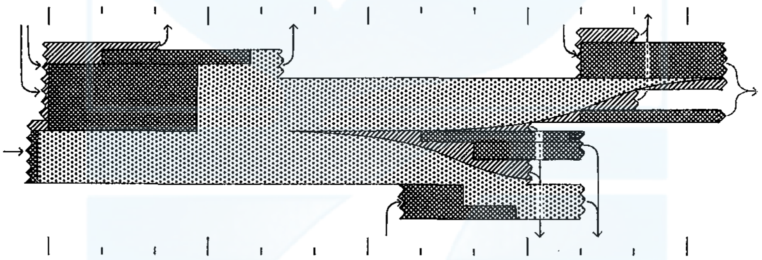

Fig. 54. Schematic figure showing one of the possible between school exchange of mature females. Arrows indicate the annexation or the split of the school. White spots indicate pregnant females, black spots the lactating, lines the resting. Mating seasons in each 4 months inteval are shown by vertical rods.

Discussion

It is well reported in several species of delphinidae that their school is compact in some cases, but in other cases it is composed of many smaller schools dispersed in a wide area. Sergeant (1962) and Saayman and Tayler (1973) suggested that it will be related to feeding or sexual behavior of the animal. Our observation on a large school of *S. coeruleoalba*, found in the evening of 24, Oct. 1972 at 34°52′ N, 141°05′ E, showed that it covered a wide area of about 21 km in one diameter and composed of numerous small groups of dolphins. This smaller groups had a distance of about 3 km to 15 km from each other, and were composed of 10 to 200 individuals. Some of them contained calves accompanied by the mother and several were composed mostly of smaller animals. This suggests that the larger schools of *S. coeruleoalba* contains smaller units.

It is probable that several small units leave the main larger school after which a larger dispersed school again forms a compact school, or that the smaller units move to an other school when the two groups come to a close distance. Fig. 54 was drawn on the assumption that the exchange or shift of the members between schools can occur through the procedure mentioned in the above. In this figure, though the composition of the reproductive condition at both ends of the diagram is similar, the members are largely different. The immature animals are not shown because their behavior is simple, the mature male was also excluded as its behavior is not well understood.

ACKNOWLEDGMENTS

The collection of data and samples were made through the cooperation of the fishermen's cooperative unions at Kawana, Futo, and Taiji. We had the help of Dr. T. Kajihara of the Ocean Research Institute and of Mr. J. H. Perano in collecting smaples. Dr. W. F. Perrin of the National Marine Fisheries Service kindly read the draft. Dr. K. Tatsukawa of the Ocean Research Institute, and Dr. A. Ohsumi and Dr. A. Suda of the Far Seas Fisheries Research Laboratory gave us valuable suggestions. This study was technically assisted by Miss. S. Wada and Miss. K. Nagayama and Mr. K. Kureha. These persons are deeply acknowledged.

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EXPLANATION OF PLATES

PLATE I

Fig. 1. *S. attenuata*, female, 118 cm in body length. Pigmentation of newborn stage.

Fig. 2. *S. attenuata*, female, 178 cm in body length. Dark spots have started to appear only on the lower jaw, and the white area on the tip of jaws is also started. The both characters are classified into stage 1.

Fig. 3. *S. attenuata*, data unknown. The white tips of jaws are classified into stage 2, and the dark and white spots into stage 3.

Fig. 4. *S. attenuata*, male, 209 cm in body length, same animal with Fig. 4 in Plate II. The white tip of jaws are classified into stage 2, white dorsal spots into stage 2, and dark ventral spots into stage 3.

Fig. 5. *S. attenuata*, adult male. The white tip of upper jaw is classified into stage 3, that of lower jaw into stage 2, white dorsal spots into stage 2, and ventral dark spots into stage 3.

Fig. 6. *S. attenuata*, dorsal view of left flipper of juvenile animal, showing the dark spots on the surface.

PLATE II

Fig. 1. *S. attenuata*, female, 117 cm in body length. Showing the pigmentation of newborn animal. An animal in the other side is also newborn calf.

Fig. 2. *S. attenuata*, female, 189 cm in body length (center). The conditions of two kinds of spots are classified into stage 3, and the white areas at the tip of jaws into stage 1. An animal at this side is a juvenile male.

Fig. 3. *S. attenuata*, male, 181 cm in body length. Ventral white spots are classified into stage 3, and other characters into stage 1.

Fig. 4. *S. attenuata*, male, 209 cm in body length, ventral view. Same animal with Fig. 4 in Plate I.

Fig. 5. *S. attenuata*, ventral wiew of an adult male.

PLATE III

Fig. 1(top). Underwater photograph of a group of adult or subadult *S. attenuata* in the school 5 enclosed in the harbor, showing the conspicuous white tip of beak. (Photographed by N. Miyazaki)

Fig. 2(bottom). Mother and suckling calf in the same school, showing the difference of the pigmentation of ventral region. (Photographed by N. Miyazaki)

PLATE IV

Tooth section of *S. attenuata*. photographed under transmitted light.

Fig. 1. 104 cm, male, killed on 12th, Feb. A thin translucent layer is accumulated. Less than 1/4 year.

Fig. 2. 112 cm, male, killed on 18th, Nov. A thick opaque layer is accumulated. About 1/4 year old.

Fig. 3. 135 cm, male, killed on 12th, Feb. A thin opaque layer and a thick translucent layer of full thickness are accumulated. About 3/4 year old.

Fig. 4. 175 cm, female, killed on 13th, Nov. A thin opaque layer and 2 opaque layers of full thickness are accumulated. About 2 1/4 years old.

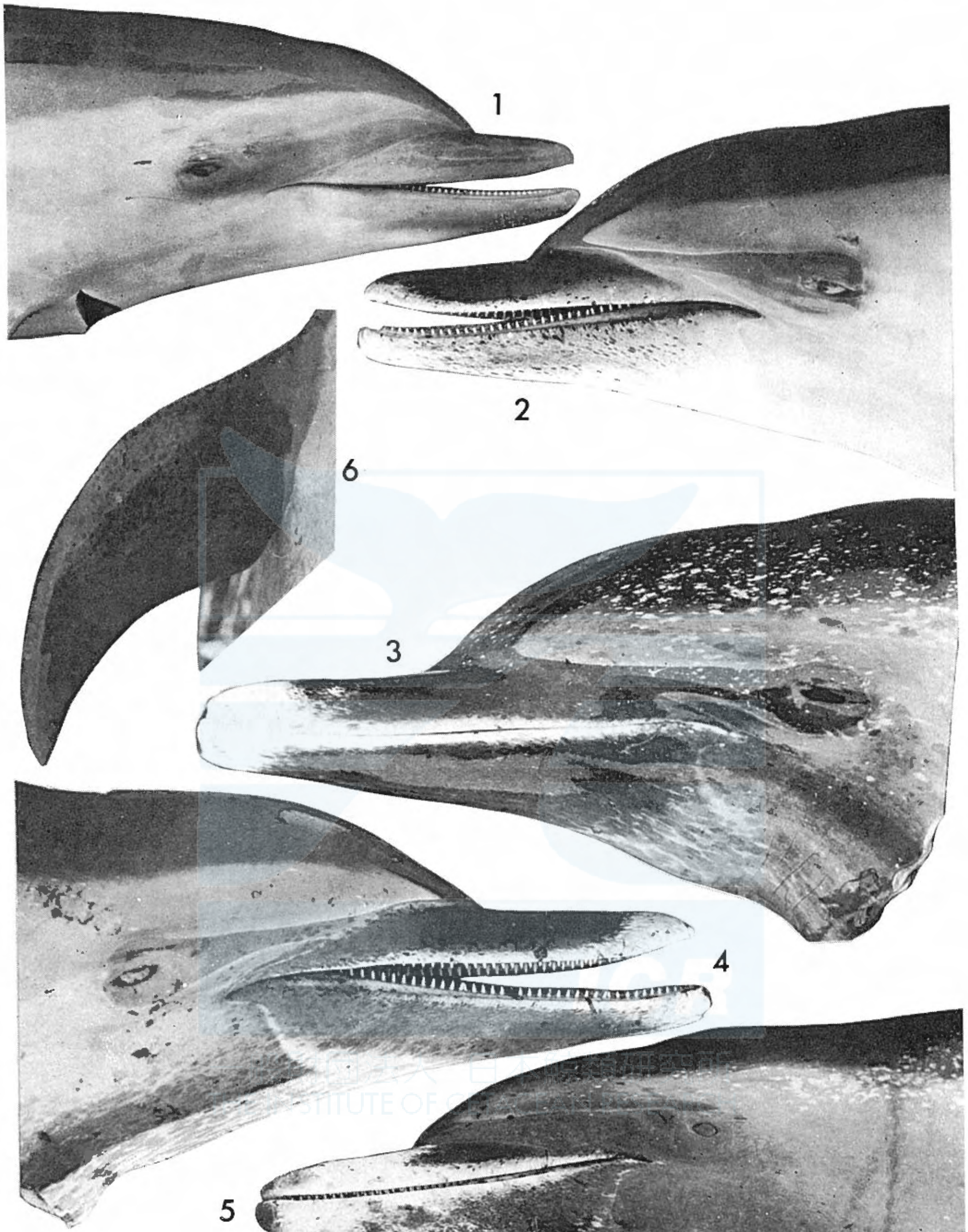
PLATE V

Fig. 1. 166 cm, male, killed on 2nd July. 3 opaque layers are accumulated. The both first and last layers are thin translucent layer. About 2 3/4 years old.

Fig. 2. 177 cm, female, immature, killed on 2nd, July. 6 opaque layers are accumulated. The first and the last layers are the thick opaque layer. About 5.5 years old.

Fig. 3. 205 cm, female, two corpora in the ovaries, killed on 2nd, July. 11 opaque layers are accumulated and the pulp cavity is still wide. About 10.5 years old.

Fig. 4. 195 cm, female, 11 corpora in the ovaries, killed on 13th Nov. 24 opaque layers are observed, and pulp cavity is filled with secondary dentine. Real age will be more than the number of the opaque layers.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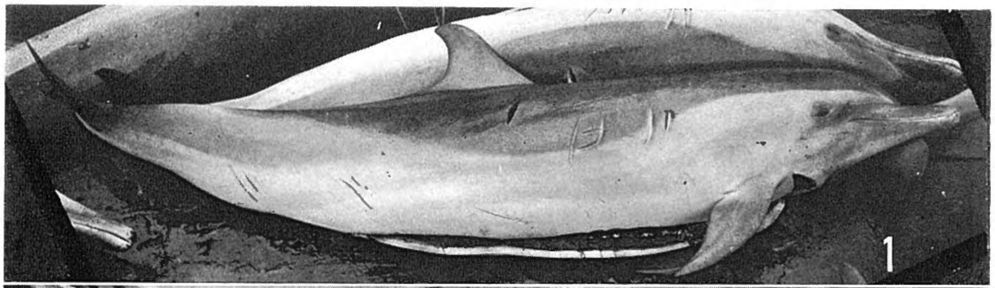
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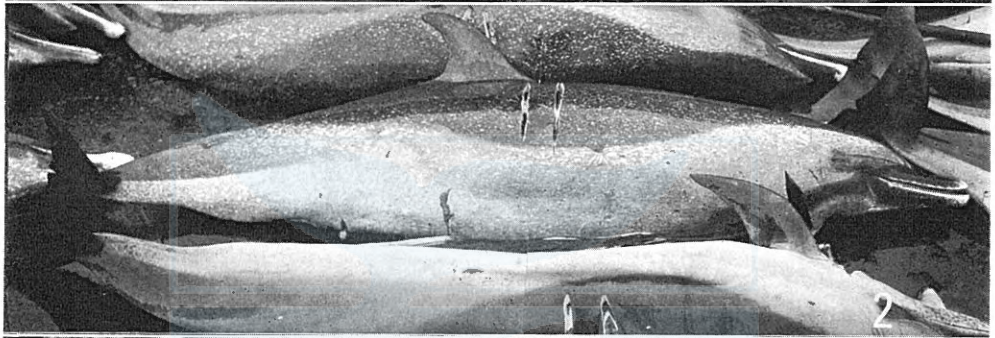
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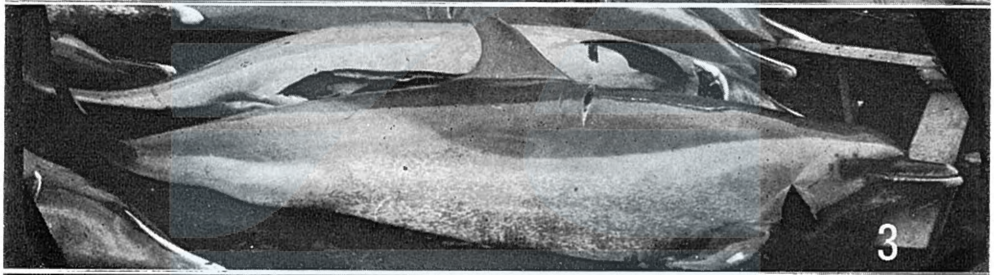
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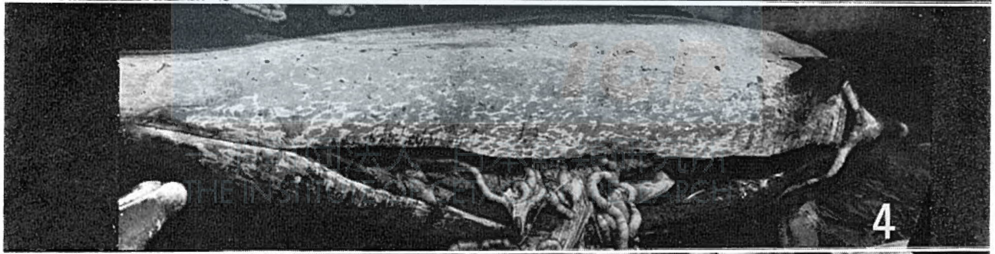
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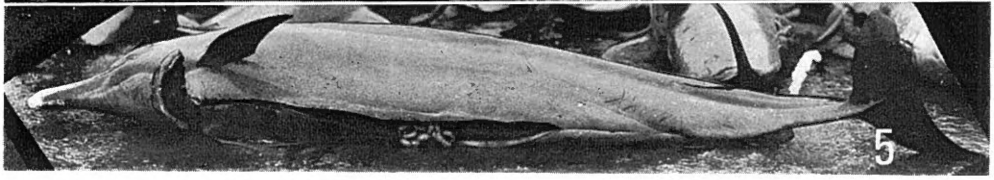
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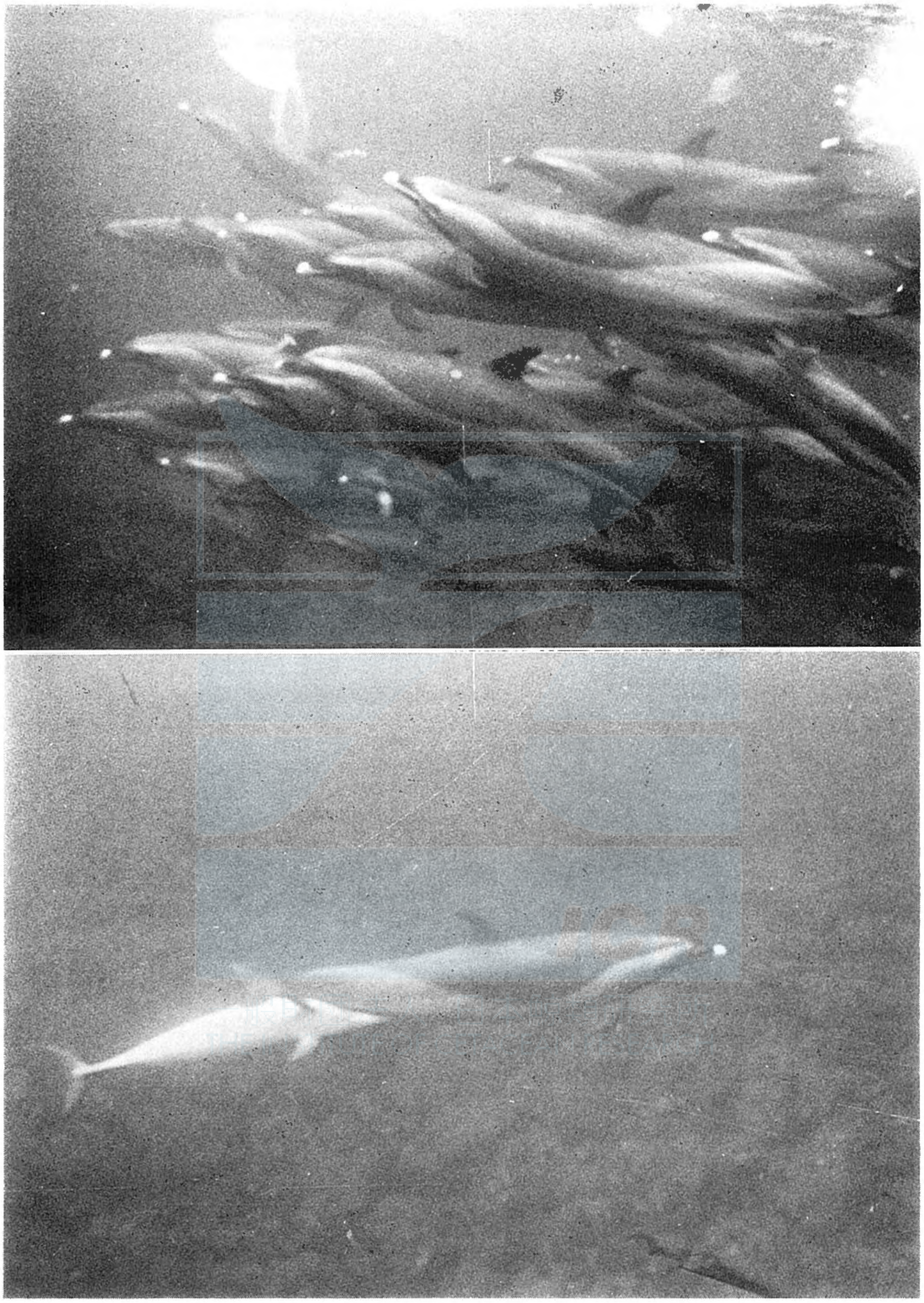

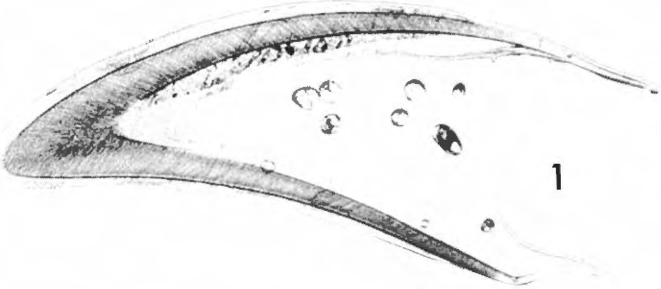

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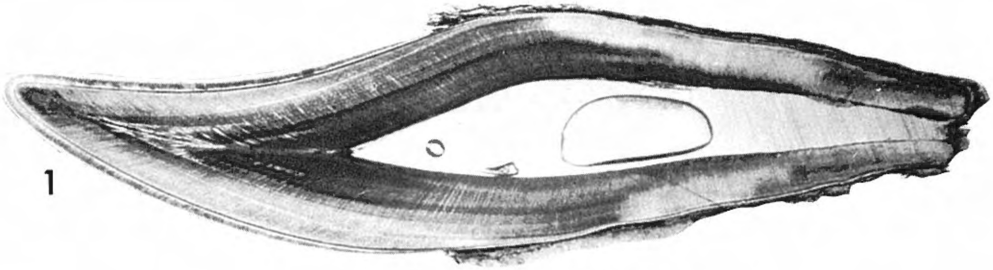

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DISTRIBUTION AND MIGRATION OF TWO SPECIES OF *STENELLA* IN THE PACIFIC COAST OF JAPAN

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ABSTRACT

Distribution and migration of *Stenella coeruleoalba* and *Stenella attenuata* in the Pacific coast of Japan were studied basing on the fishing data and the sighting data, and the relationship between them and the marine environment was discussed. *S. coeruleoalba* and *S. attenuata* are distributed in the pelagic and coastal waters influenced by the warm Kuroshio current. *S. attenuata* is distributed in slightly warmer waters than *S. coeruleoalba* is. Their range of distribution seems to extend up to 46°N in summer season and retreats to 33°N in winter. The concentration of these species in the northern boundary of the Kuroshio current is suggested.

INTRODUCTION

At least three species of *Stenella* are known from Japanese coastal waters. They are the spinner dolphin *S.* cf. *longirostris* (Mizue *et al.*, 1964), the spotted dolphin (Mizue *et al.*, 1962, Nishiwaki *et al.*, 1965) and the blue white dolphin (Okada, 1936, Ogawa, 1936). The first is rare and only known from the southern part of Japan, and the color pattern of these are very similiar to *S.* cf. *longirostris* described by Perrin (1972) from Hawaiian waters. The other two species are fairly common and have been the object of the commercial hunting at several places on the Pacific coast of Japan. These two species are caught at Taiji (33° 36′ N, 135° 56′ E) on the coast of Kii Peninsula, at Arari (34° 48′ N, 138° 46′ E) on the west coast of Izu Peninsula, and at Kawana (34° 57′ N, 139° 08′ E) and Futo (34° 52′ N, 139° 06′ E) on the east coast of Izu Peninsula. The fishermen at Taiji hunt the dolphin with hand harpoon, or with hand harpoon and shot gun off the coast of Kii Peninsula, but they have introduced the driving method since 1973. The people at Arari had captured the various species of dolphins in Suruga Bay with driving method, but the operation has almost ceased since 1962. The two villages on the east coast of Izu Peninsula operate the dolphin hunting with driving method in Sagami Bay and the waters around Oshima Island (Tobayama, 1969, Kasuya, 1972). Details of dolphin fishing is described by Ohsumi (1972).

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Tobayama (1969) analyzed the catch statistics of the two fishermen's cooperative unions at Kawana and Futo, and suggested the influence of the marine topography in the formation of the fishing ground. Howeven, Kasuya (1972) suggested another factor the inflow of warm water into Sagami Bay. Ohsumi (1972) analyzed the official statistics of dolphin fishing prepared by the Ministry of Agriculture and Forestry, and showed an estimated migration route of blue white dolphin.

This study intends to analyze the distribution and migration of *Stenella coeruleoalba* and of *Stenella attenuata*. This analysis is based on the catch records of the fishermen's cooperative unions and sighting records of these species collected by us or reported by various authors.

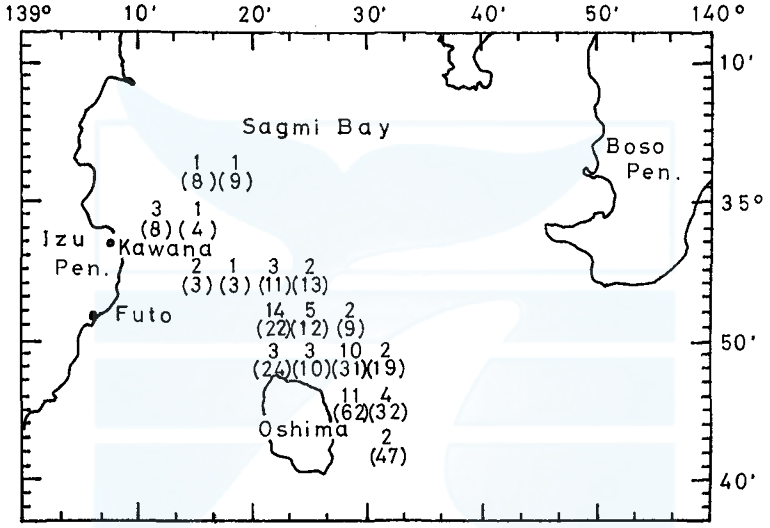

Fig. 1. The number of schools of *Stenella* spp. sighted by the scouting boats in 3.3′ (6.1 km) squares during 8 seasons from 1964–'65 to 1973–'74. Numerals in parenthesis indicate the number of schools per 10^7 nautical miles of scouting. (For Sagmi Bay read Sagami Bay)

MATERIALS

The statistics were collected by Miyazaki from four fishermen's cooperative unions.

The data collected at Taiji covers ten years from 1963 to 1972. Some of the statistics were provided by Dr. Kajihara. The distinction of the two species of *Stenella* is made only in recent three years. In this district " Mairuka " and " Haukasu " indicate *S. coeruleoalba* and *S. attenuata* respectively. All of that catch were made with hand harpoon, or hand harpoon and shot gun.

The data collected at Arari covers the catch of fourteen seasons from 1950 to 1970, but there are only sporadic catches after 1962. *S. coeruleoalba* and *S. attenuata* are recorded by the name " Mairuka " and " Hasunaga or Arari-iruka " respectively.

The various informations on the dolphin fishing in Sagami Bay were collected from the fishermen's cooperative unions at Kawana and Futo. They comprise the number of dolphins and schools, position of sighting, and the hours and the number of scouting boats engaged. The number of dolphins is known for the twenty seasons from 1949–'50 season to 1973–'74 season. But the statistics are fragmental before the 1961–'62 season, and do not give the total number of dolphins of the genus *Stenella* caught in Sagami Bay. The two species of *Stenella* are recorded separately since 1969–'70 season. The main fishing area in Sagami Bay is shown in Fig. 1. The total scouting hours of the four high speed, 20 knot at maximum, scouting boats were available for eight seasons from 1964–'65 to 1973–'74 season. This was used as the indicator of the fishing effort. These scouting boats leave the harbor, if the weather is good, at 5 o'clock in the morning. And if they find a suitable school, they drive it into the harbor with the help of other slower boats. They usually find the school before the noon, but they sometimes continue the scouting until 3 o'clock in the afternoon. The fishing season in Sagami Bay starts in the autumn season (October) and ends in the winter of the next year (January).

The sighting records of *Stenella coeruleoalba* and *Stenella attenuata* were obtained by Kasuya and Miyazaki through five cruises of the research vessel the Tanseimaru. They are used together with the many sighting records and sporadic catches of these species reported by various authors (Tables 1, 2).

Oceanographical data obtained through two cruises of the Tanseimaru in 1971 and 1972, and that reported by Japanese Meteorological Agency, Japanese Maritime Safety Agency, Tokyo Metropolitan Fisheries Experiment Station, and Shizuoka Prefectural Fisheries Experiment Station were used in analyzing the relation between the distribution of the dolphins and the environment.

ANALYSIS OF THE STATISTICS

Annual fluctuation of catch

Fig. 2 shows the annual fluctuation of the catch of *Stenella* spp. in each fishing area.

Though the statistics are imperfect before 1961–'62 season, it is suggested that the number of the dolphins caught in Sagami Bay shows rapid increase after that season. This seems to be related with the introduction of the high speed scouting boats. After this year the amount of the catch increases to record the maximum catch of 15,649 dolphins in 1965–'66 season. As the two fishermen's unions started the cooperative operation in 1967–'68 season to control the market price, the number of dolphins caught decreased to about one third of the maximum catch. But the change of the mode of operation cannot explain all the annual fluctuation of the catch. Because the number of dolphins caught per one scouting hour shows the fluctuation parallel with that of total number of catch (Fig. 3). It is suggested that the annual fluctuation of the catch will indicate that of the abundance of the dolphins migrating into the fishing ground. Fig. 4 shows the relation between the annual catch of *Stenella* spp. in Sagami Bay and the distance from Oshima Island to

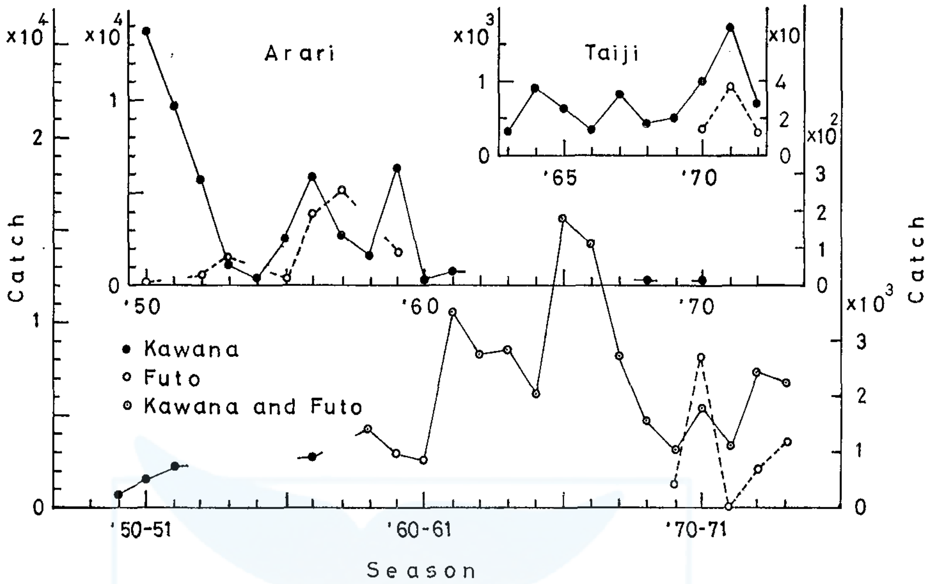

Fig. 2. The number of catch of *Stenella coeruleoalba* (left scale) and of *Stenella attenuata* (right scale) at each fishing ground. Solid line indicate *S. coeruleoalba*, and broken line *S. attenuata*.

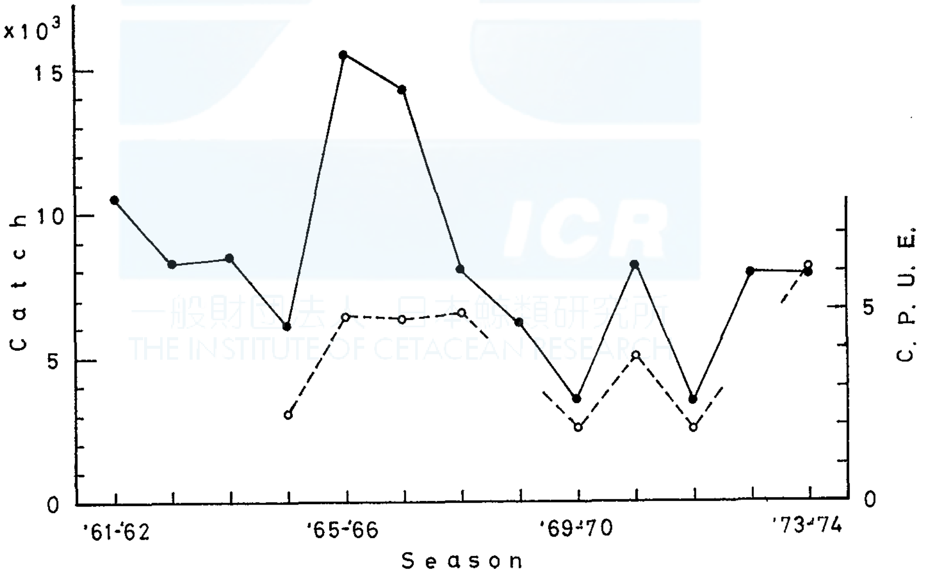

Fig. 3. The number of catch and the catch per one scouting hour (C. P. U. E.) of *Stenella* spp. in Sagami Bay. Closed circle and solid line indicate the catch, and open circle and broken line catch per one scouting hour.

the nearest border of the Kuroshio current from October to December (Japanese Maritime Safety Agency, 1961–'71). As the surface water temperature is highly variable by the effect of the meteorology or of the tide, the position of the 15°C isothermal at the depth of 200 m was used as the indicator of the position of the Kuroshio current. It is clear in Fig. 4 that the catch of *Stenella* spp. in Sagami Bay has the negative correlation with the distance of the Kuroshio current from the main fishing area. This means that in the years when the Kuroshio current situates close to Sagami Bay, there migrates many dolphins of the genus *Stenella*. The catch or catch per unit effort changes affected by the abundance of the migrating dolphins. Though the two species of *Stenella* are recorded separately in the statistics only in the seasons from 1969–'70 to 1973–'74 season, as the catch of *S. attenuata* comprises 4,956 individuals or 16.1 % of the total catch of *Stenella* spp. in Sagami Bay in these season, it is reasonable to expect the catch of *S. attenuata* even in the preceding years.

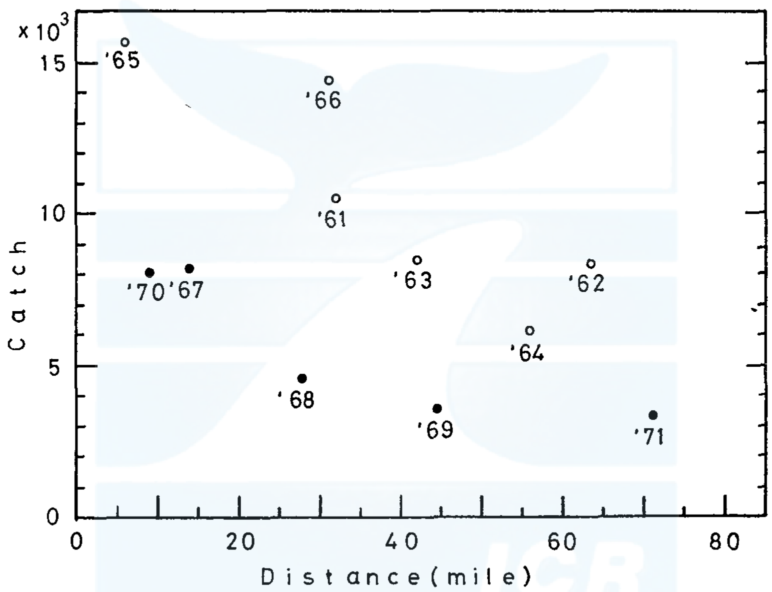

Fig. 4. Relationship between the number of catch of *Stenella* spp. in Sagami Bay, and the distance (nautical mile, 1.85 km) from Oshima Island to the 15°C isothermal line at the depth of 200 m. Closed circle indicates cooperative operation and open circle competitional operation. The numerals indicate the starting year of the season.

The catch of *Stenella* spp. in Suruga Bay was high until the early 1950's (see Arari in Fig. 2). But they had almost finished the operation since 1962. This age coincides with the time when the catch in Sagami Bay increased rapidly. The other shorter cycle of annual fluctuation of the catch is expected to be affected by the oceanographical conditions as in the case of Sagami Bay. Though Nishiwaki *et al.* (1965) reported the information from the fishermen's telling that the catch of *S. attenuata* in 1959 or in 1964 was the first case for them to catch this species. It is difficult to trust their telling at the following two aspects. At first, after that year the capture of several schools of *S. attenuata* within short period were reported from the village (Nishiwaki *et al.*, 1965), and secondly the catch of *S. coeruleoalba* and *S. attenuata* in the village seems to have been recorded by the different vernacular names mentioned before.

The catch statistics off Kii Peninsula shown in Fig. 2 do not include the catch by driving method as it was started in 1973. The general trend of the catch of *Stenella* is gradually increasing in recent years. The statistics of two kinds of *Stenella* were recorded separately only in the recent three seasons. As the result of the difference of the price between two species in this local district, the fishermen prefer *S. coeruleoalba.* So, the catch of *S. attenuata* in the recent three years was only 63 animals or 1.8 % of the total number of the catch of the two species. This ratio is lower than that of the catch in Sagami Bay.

Seasonal fluctuation of catch

In Sagami Bay the fishing season starts in late September, and ended in the former years in January or in early February but in recent years it ends in late December (Figs. 5 and 6). Fig. 6 shows the difference of the fishing season of the two species. Though the season of *S. attenuata* seems to start almost at the same season with that of *S. coeruleoalba,* the peak of the catch comes in early November and the season ends by late November. On the other hand the peak of the catch of

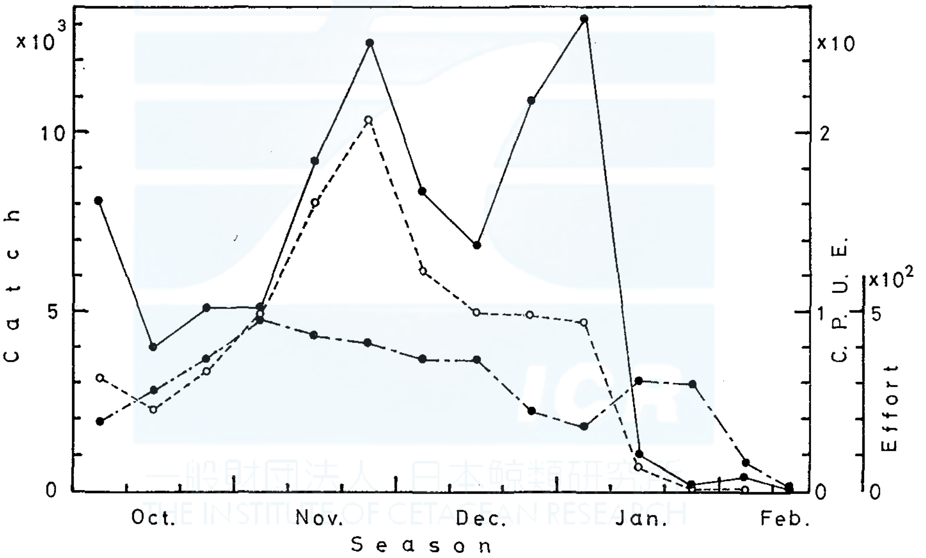

Fig. 5. The seasonal changes of the catch of *Stenella* spp., of the catch per one scouting hour (C.P.U.E.), and of the scouting hours (effort) in Sagami Bay. 8 seasons from 1964–'65 to 1973–'74 season are combined. Closed circle and solid line indicate C.P.U.E., closed circle and chain line the total amount of effort, and open circle and broken line the catch.

S. coeruleoalba is in late November about one month later than that of *S. attenuata*. The decrease of the catch of *S. coeruleoalba* in late October and early November will be the effect of the catch of *S. attenuata*.

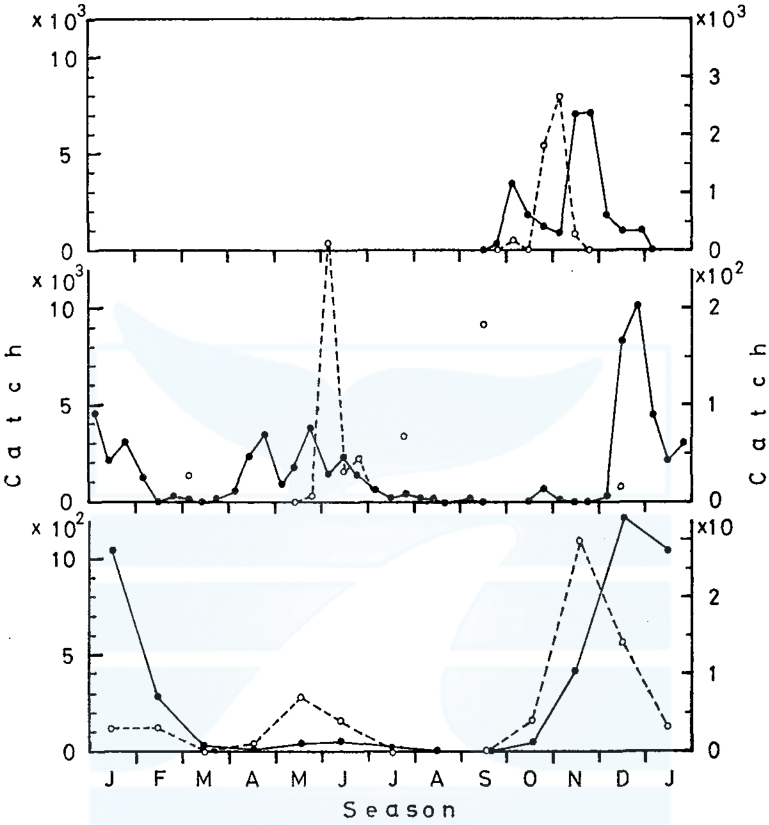

Fig. 6. The seasonal fluctuations of the catch of *Stenella coeruleoalba* and *Stenella attenuata* at each fishing ground. Closed circle, solid line and left scale indicate *S. coeruleoalba*, and open circle, broken line and right scale *S. attenuata*. Top: Sagami Bay, Middle: Suruga Bay, Bottom: Off Kii Peninsula.

The seasonal fluctuation of the catch per scouting one hour in Sagami Bay is shown in Fig. 5. The fluctuation shows three peaks, the first in early October, second in late November, and the third in late December or in early January. At the beginning of the season, they often start the catch after obtaining the information of sighting by other fishing vessels. And in the late December and early January the scouting effort decreases, because the fishermen spend the time for the new year festival or for its preparation. These two factors affect the catch per one scouting hour and keep it high. Accordingly, the first and the last peaks are supposed not to reflect the real abundance of the dolphins. The real peak of the migration of *S. coeruleoalba* in Sagami Bay is considered to be in the late November, and that of *S. attenuata* is in late October.

In Suruga Bay the catch of *Stenella* spp. was made in any season of the year, but the peaks of *S. coeruleoalba* caught are in the seasons from April to July and from December to January. The former peak is not observed in Sagami Bay, and the latter is about one month later than the corresponding peak in Sagami Bay. The spring peak of *S. attenuata* in Suruga Bay seems to arrive later than that of *S. coeruleoalba.*

Fig. 6 shows the seasonal fluctuation of catch of two species of *Stenella* off Kii Penisula. Though the catch of *Stenella* spp. in this area is made in any season of the year, the peak of *S. coeruleoalba* are in the seasons from April to July and from October to March. The former will correspond to that of Suruga Bay, and the latter to the winter fishing seasons in other grounds. The winter peak of *S. coeruleoalba* arrives slightly later in the southern area than the northern. Similar feature is observed also in *S. attenuata.* The catch representing the spring peak of *S. attenuata* is too small to discuss the difference of the season. The fishermen say that the fishing ground in March becomes too far from the coast to operate the dolphin fishing. This will be one of the reason of the smaller catch in spring season.

GEOGRAPHICAL DISTRIBUTION

All the available records of sighting or of sporadic catch of *S. coeruleoalba* and *S. attenuata* in the Pacific coast of Japan are plotted in Fig. 7. The origin of these records are shown in Tables 1 and 2. The 17°C isothermal line shows the surface water temperature in the warmest and coldest months of 1970. This figure shows that the distribution of these species is not restricted in the coastal waters, but extends into the offshore waters. The northernmost records in the summer season are be-

TABLE 1. LIST OF RECORDS OF SPORADIC CATCH OF *STENELLA* SPP. IN THE WESTERN NORTH PACIFIC.

No.	Date			Position	Author	Comments
S. coeruleoalba						
1	—	IX	'34	Off Choshi (35°44′N, 140°52′E)	Ogawa, 1936	Purchased at the market
2		—		Off Onahama (36°53′N, 140°52′E)	Okada, 1936	Purchased at the market
3	21	I	'35	Shimizu fish market (35°00′N, 130°30′E)	Okada, 1936	Possibly caught on Izu coast
4	27	II	—	Off Choshi	Okada, 1936	Purchased at the market
5	4	II	'35	Shimizu fish market	Okada, 1936	Possibly caught on Izu coast
6	26	I	'64	Kokufu (34°20′N, 136°52′E)	Higashikawa *et al.*, 1966	Stranded
S. attenuata						
7	12	VIII	'35	Nagasaki fish market (32°40′N, 129°50′E)	Ogawa, 1936	Purchased at the market
8	20	X	'61	Arikawa (33°00′N, 129°06′E)	Mizue *et al.*, 1962	Driven in
9	—	VIII	—	Onahama	Kasuya, 1972	—

tween 44°N and 46°N. This range approximately coincides to the 17°C isothermal line in the summer season. Though the northern range of the two species in winter season is not clearly indicated, it is suggested that they are distributed south of 17°C isothermal line.

TABLE. 2. LIST OF SIGHTING RECORDS OF *STENELLA* SPP. IN THE WESTERN NORTH PACIFIC.

No.	Date			Position	Time	Surface temperature (°C)	School size	Author
S. coeruleoalba								
1	11	VIII	'51	Nemuro Bay	—	—	150	Sleptsov, 1961
2	31	VIII	'51	Ekacherina Bay	—	—	50	"
3	9	IX	'51	Laperyza Bay	—	—	20–30	"
4	8	VIII	'54	38°18′N, 148°50′E	—	—	2,000	"
5	18	VIII	'54	39°04′N, 153°30′E	—	—	400	"
6	13	IX	'54	41°28′N, 153°03′E	—	—	150–200	"
7	15	IX	'54	44°34′N, 149°51′E	—	—	—	"
8	22	IX	'70	34°31′N, 139°35′E	13:45	22.7	10	Present data
9	22	XI	'70	34°35′N, 139°38′E	14:20	22.7	1,000	"
10	21	XI	'71	34°48′N, 141°07′E	11:10	20.6	60–70	"
11	21	XI	'71	34°52′N, 141°05′E	10:36	—	—	"
12	19	I	'72	29°36′N, 140°38′E	08:05	19.8	50	Masaki, 1972
13	19	I	'72	29°32′N, 140°42′E	09:26	19.8	30	"
14	19	I	'72	29°07′N, 141°11′E	12:18	21.4	100	"
15	21	I	'72	26°39′N, 142°28′E	07:55	21.7	10	"
16	5	II	'72	20°17′N, 152°12′E	11:46	25.5	30	"
17	24	X	'72	34°52′N, 141°05′E	15:34	20.5	200	Present data
18	8	X	'73	34°48′N, 139°54′E	10:00	24.7	50	"
19	8	X	'73	34°44′N, 139°47′E	11:25	25.4	500–1,000	"
20	11	X	'73	35°02′N, 139°18′E	08:00	23.1	20–30	"
21	10	II	'74	32°05′N, 132°12′E	07:00	—	50–60	"
22	10	II	'74	32°52′N, 133°08′E	12:00	—	100	"
23	10	II	'74	31°28′N, 134°09′E	16:40	—	20	"
S. attenuata								
24	10	XII	'67	26°40′N, 124°50′E	—	—	—	"
25	22	I	'72	25°55′N, 143°38′E	06:40	22.2	50	Masaki, 1972
26	22	I	'72	25°32′N, 142°00′E	09:41	21.9	50	"
27	22	I	'72	25°22′N, 142°43′E	11:22	21.4	50	"
28	7	II	'72	23°30′N, 151°42′E	12:23	24.3	20–30	"
29	7	II	'72	23°35′N, 151°35′E	16:10	24.5	20–30	"
30	8	II	'72	24°05′N, 149°09′E	16:00	24.8	20–30	"
31	23	V	'73	31°28′N, 134°36′E	06:40	19.0	30	Present data
32	23	V	'73	32°03′N, 135°01′E	11:00	19.0	—	"
33	24	V	'73	33°19′N, 137°52′E	05:05	16.8	5	"

The similar feature is also observed in the water temperature at the positions of sighting collected by us or reported by various authors (Table 2). The 32 records of water temperature at the sighting position of *S. coeruleoalba* and the 9 records at the sighting position of *S. attenuata* are in the range between 16.8°C and 26.0°C.

These informations suggest that the two kinds of the dolphins are distributed, in the western North Pacific, in the waters influenced by the Kuroshio current. Fig. 8 shows the oceanographical structure and the positions of sighting of *S. coeruleoalba.* The schools of this species seems to be concentrated near the area where the warm water intrudes into the colder water at the periphery of the Kuroshio current. Similar oceanographical structure is observed at the southeast entrance of Sagami Bay in the winter season (Kasuya, 1972; Miyazaki *et al.*, 1973), and at the southeast

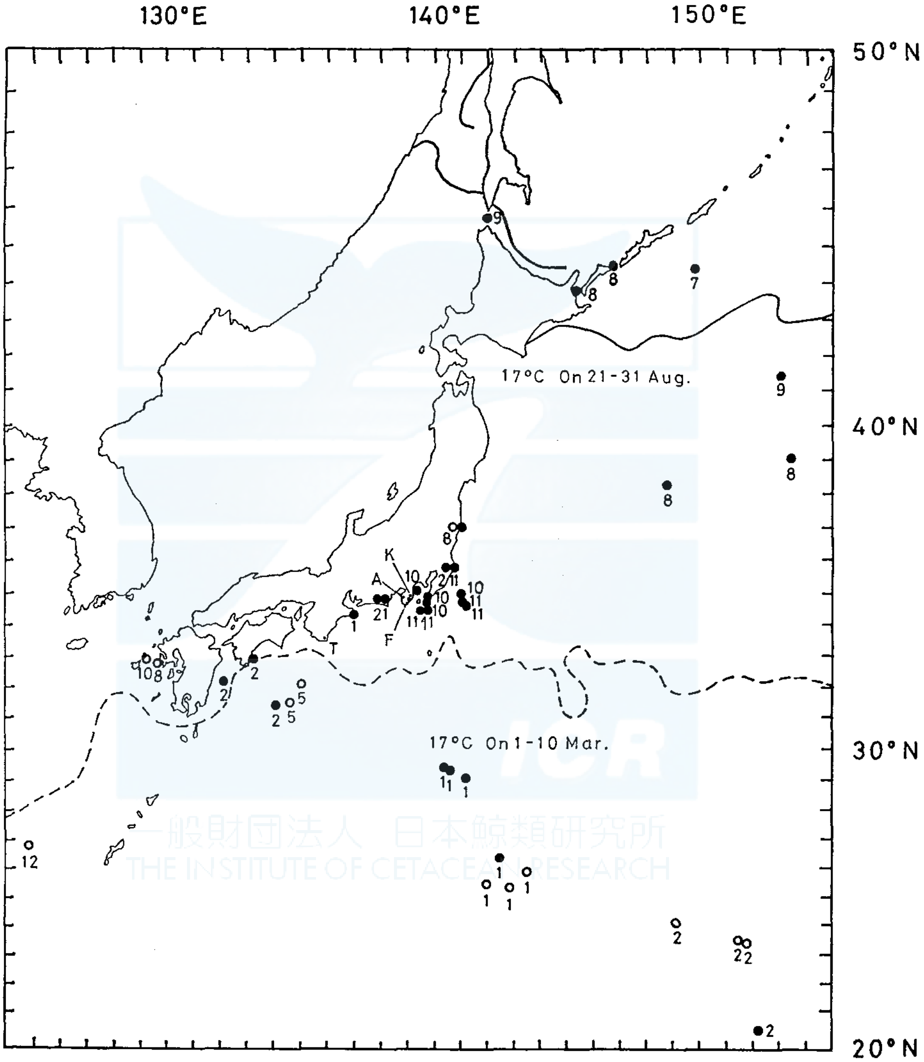

Fig. 7. Map showing the geographical distribution of *Stenella coeruleoalba* and *Stenella attenuata*. The numerals by the symbol indicate the month of sighting or collecting. A; Arari, F; Futo, K; Kawana, T; Taiji. The 17°C isothermal lines are for 1970 (Japanese Meteorological Agency).

area of Suruga Bay in winter and spring dolphin fishing season (Fig. 9). These places coincide with the important fishing ground of the dolphins. Though the species was not identified, there is observed in October and December a peak of landing of dolphins at the Choshi fish market (35°44′ N, 140°52′ E). This peak will

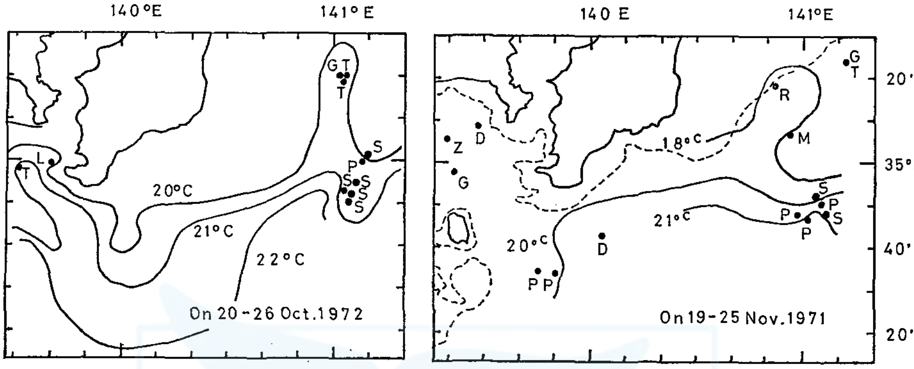

Fig. 8. The oceanographical condition and the sighting position of the dolphin obtained through 2 cruises of the Tanseimaru. S; *Stenella coeruleoalba*, L; *Lagenorhynchus*, T; *Tursiops*, D; Delphinidae, P; sperm whale, G; *Globicephala*, R; *Grampus*, M; minke whale, Z; Zyphiidae. Solid line indicate surface water isothermal line, and broken line the 200 m depth.

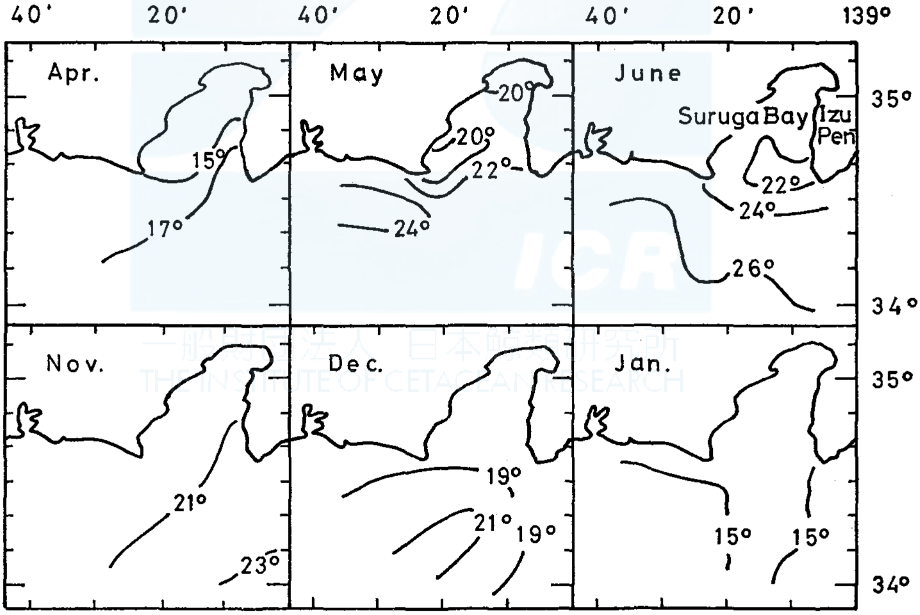

Fig. 9. The oceanographical condition in Suruga Bay in 1967. Solid line indicates surface water temperature. (Shizuoka Fisheries Experiment Station, 1967).

probably represent the catch of *Stenella* spp. in the waters off Choshi, where the similar intrusion of warm water is observed (Fig. 8). It is interesting to note that there occurs no intrusion of warm warter in the spring at the southeast entrance of Sagami Bay, and that this area has no spring dolphin fishing season.

DISCUSSION

Hubbs *et al.*, (1973) summarized all known records of *S. coeruleoalba* in the North Pacific, and showed that this species is distributed continuously from the west coast of North America to the central tropical Pacific. The sighting records reported by Masaki (1972) now suggest that the continuity of the distribution can be extended to the Japanese coastal waters. But this does not necessarily mean that *S. coeruleoalba* in the both sides of the North Pacific belongs to one population. It will be more reasonable to expect several separate populations in the North Pacific.

Stenella spp. and probably other tropical or subtropical dolphins seem to concentrate at the area where the warm water at the periphery of the Kuroshio current intrudes into the colder water as suggested by Kasuya (1972) and shown on large cetaceans by Uda (1954). This assumption can explain the mechanism concerning the formation of the several fishing grounds and fishing season. We don't deny all the possibility where the concentration of dolphins occurs on the steep slope along the continental shelf (Tobayama 1969). But this hypothesis can not explain the presence of the fishing ground near Choshi, because the sea floor off Choshi is flat and shallow.

The winter peaks for *S. coeruleoalba* and *S. attenuata* are observed in the earlier season in Sagami Bay at the north, and off Kii Peninsula at the south they delay for about one month. The time lag between Sagami Bay and Suruga Bay in closer distance is larger than that between Suruga Bay and Kii Peninsula in larger distance. This suggests that the time lag is related to the speed of the seasonal change of the oceanographical conditions or the seasonal movement of the area where the northern boundary of the Kuroshio current crosses the coastal waters. The spring peak observed in the catch at Taiji (Kii Peninsula) and Arari (Suruga Bay) will correspond to the northbound movement of the northern boundary of the Kuroshio current and that of dolphins induced by it. These features of the seasonal migration of the dolphins are close to that suggested by Ohsumi (1972). But it must be noted that the migration of these dolphins seems to be the shift of the area of the higher density of dolphins resulting in the expansion or retreat of the range of the distribution. Compared with the peaks of *S. coeruleoalba*, the winter peak of *S. attenuata* arrives earlier and the spring peak later. This indicates that *S. attenuata* lives in the warmer waters and possibly in the lower latitudes than *S. coeruleoalba* does.

As the catch of the two species of the dolphins are strongly affected by the annual fluctuation of the Kuroshio current, it was impossible to analyze the fluctuation of the population based on the fishing statistics covering only a short period.

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APPENDIX I. THE NUMBER OF CATCH OF *STENELLA COERULEOALBA* AND *STENELLA ATTENUATA* (IN PARENTHESES) IN ARARI.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
1950	60		10	4,794	3,293	1,231 (1)	47					4,236	13,671 (1)
1951	2,194	125	93	1,321	1,990	826	646					2,469	9,664
1952	245		(25)			1,321	11					4,050	5,627 (25)
1953			88	19	759 (6)	62	153 (65)						1,081 (71)
1954	53					245							298
1955						69						2,483 (15)	2,552 (15)
1956	1,390			69		611	48		(188)			3,634	5,752 (188)
1957	261			102	274	68 (257)	275					1,771	2,751 (257)
1958	1,274			79	151				63				1,567
1959	4,117	1,440			76	671 (83)							6,304 (83)
1960								67					67
1961	151									613	11		775
1968			90										90
1970					41								41
Total	9,745	1,565	281 (25)	6,384	6,584 (6)	5,104 (341)	1,180 (65)	67	63 (188)	613	11	18,643 (15)	50,240 (640)

APPENDIX II. THE NUMBER OF CATCH OF *STENELLA COERULEOALBA* AND *STENELLA ATTENUATA* (IN PARENTHESES) IN TAIJI.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
1963	16	30	34	18	46	4					63	120	331
1964	252	247	162	25	11	1		1	2	9	93	131	934
1965	207	138	29	17		14	3	4	1	30	78	121	642
1966	129	177	15	12	5						7	77	422
1967	336	206	29	29		1				16	97	105	819
1968	175	112	4	42	33					1	6	27	400
1969	77	3		3	90	12				3	74	237	499
1970	331	81		3	7	8	4			5 (1)	114 (8)	444 (5)	997 (14)
1971	423 (1)	178	11	(1)	5 (4)	8				35 (3)	327 (19)	730 (19)	1,717 (37)
1972	288 (2)	28 (3)	2	1	30 (3)	39 (4)				5	68	239	700 (12)
Total	2,234 (3)	1,200 (3)	286	150 (11)	227 (7)	87 (4)	7	5	3	104 (4)	927 (27)	2,231 (14)	7,461 (63)

APPENDIX III. THE NUMBER OF CATCH OF *STENELLA COERULEOALBA*

	Sep.			Oct.			Nov.		
	E	M	L	E	M	L	E	M	L
1949–'50		408							
1950–'51									
1951–'52									
1952–'53									
1953–'54									
1954–'55									
1955–'56									
1056–'57						1,035	374	71	
1957–'58									
1958–'59						862			279
1959–'60						717	275	510	310
1960–'61				470	364	237	283		210
1961–'62							268	162	1,903
1962–'63					99	158	183	952	1,187
1963–'64					820	453	686	160	389
1964–'65					50	351	116	173	1,445
1965–'66				29	101	248	1,634	1,229	2,768
1966–'67					1,324	191	404	251	1,203
1967–'68								162	2,325
1968–'69					169	510	11	1,643	1,345
1969–'70						401	145 (435)	1,840	355
1970–'71			131	1,310 (159)	293	603 (881)	0 (1,657)	314	2,197
1971–'72				517			25	776	
1972–'73				503	1,117	102 (213)	631 (189)	815 (260)	4,067
1973–'74				1,140	512	143 (786)	116 (376)	3,277	488
Total		408	131	3,969 (159)	4,849	6,011 (1,880)	5,151 (2,657)	12,335 (260)	20,471

*: The total catch at Futo and Kawana, but only the catch at Futo is given by month.

AND *STENELLA ATTENUATA* (IN PARENTHESES) IN KAWANA AND FUTO.

Dec.			Jan.			Feb.			Total
E	M	L	E	M	L	E	M	L	
327									735
1,515									1,515
		2,235							2,235
1,127	148								2,755
		973	1,805	100	129				4,148
		452			612				2,876
168	146	160	378	47	106				2,569
605	6,257	68	870	420	36				10,589
3,248	1,401	0	738	229	74				8,269
1,477	637	2,846	892	119	56				8,535
467	1,084	1,675	107	533	33	69			6,103
135	843	1,967	62	109	24				15,649*
3,253	1,500	50							14,351*
504	542	131	4,534						8,198
948									4,626
389									3,130 (435)
459									5,307 (2,697)
	903	1,094							3,315 (0)
									7,235 (662)
975	148								6,799 (1,162)
15,597	13,609	11,651	9,386	1,557	1,070	69			118,939 (4,956)

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BRAIN MORPHOGENESIS IN *STENELLA COERULEOALBA*

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ABSTRACT

Based on a series of 15 embryos and two new-born spcimens of *Stenella coeruleoalba*, a description of the changes in shape of the brain as size increases is given. Such changes involve strong brachycephalization and proliferation of transverse gyri. A temporary fetal pattern of the cortex in this species reminds one of a permanent adult condition in more primitive dolphins. The prominent development of vestibulocochlear nerve and the temporal region is also emphasized.

INTRODUCTION

One of the fundamental problems involved in any attempt at understanding the biology of animals is that of the relations between structures and functions, that is between morphology and physiology. Part of the treatment of that problem is an investigation of the ontogeny of brain structures, which is necessarily related to the emergence of brain functions. This points to the value of studying ontogenetic series i.e. embryonic and young animals.

The present paper is concerned with the gradual growth and differentiation of the brain in a dolphin, that is with its morphogenesis. The complexity of that problem is well known. The study of the vertebrate brain raises particular and intricate question concerning the relation between size and shape in the course of specific ontogenesis (see a review by Gould, 1966). We would like to contribute to the discussion with observations on a good series of brains from fetal dolphins. Both the size and the structural complexity of the brain in these animals make it a particularly favourable material; further, the well known high encephalization and corticalization of dolphins, as well as the sophistication of their sensory system (sonar) render such a study especially interesting. Kamiya (1962) and Hosokawa *et al.* (1969) have studied the embryonic development of the acoustic system with the myelinization method in *Stenella coeruleoalba*.

MATERIAL AND METHOD

The dolphin species dealt with here is *Stenella coeruleoalba*. Fifteen embryos ranging in size from 3.6 to 74.0 cm in body-length and two postnatal young (115.5 and 135.0 cm long respectively) were used. This selection of specimens was made from

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a series of 67 individuals (48 prenatal and 19 postnatal) which is being used for another growth study (Pirlot and Kamiya, in preparation). All that material was collected by Kamiya from Kawana and Futo, Shizuoka Prefecture (Table 1).

The principle of this study is to compare the prenatal brains with the postnatal ones and also to compare the prenatal brains with each other. The brains were examined from four distinct aspects: in lateral view (norma lateralis), in sagittal section (norma media), in dorsal view (norma verticalis) and in ventral view (norma basalis). A series of photographs were taken for each aspect and will be commented upon below. In order to make the visual study as easy as possible, we used the full area of the photograph in each case. Thus the brains are not shown to scale. The real size, however, can be estimated readily from the small scale provided with each picture. The dissecting work was done by Kamiya and the photographs also taken by him on 35 mm film with a 55 mm Takuma 1: 2 lens or a 100 mm Takuma 1: 4 lens mounted on a bellow attachment with Asahi body.

TABLE 1. MATERIAL.

Body length (cm)	Sex	Body weight (g)	Brain weight (g)
3.6		3.4	0.2
6.0		7.0	0.4
7.5		11.0	0.8
10.4		26.8	1.6
19.0		115.0	5.6
24.0	F	300.0	15.0
26.0	F	362.0	18.0
31.0	M	460.0	21.0
32.0	M	500.0	25.0
35.0	F	640.0	32.0
38.4	M	870.0	37.0
42.0	F	930.0	51.0
42.5	M	1220.0	58.0
51.0	F	1780.0	110.0
74.0	F	4020.0	228.0
115.5	F	19450.0	680.0
135.0	M	—	740.0

RESULTS

The description follows the order of the four distinct aspects as defined above, with a preliminary note on the postnatal brain.

Postnatal brain. It is convenient to start with a rapid examination of the postnatal brain of the 135.0 cm specimen (Plate I, 1). The caudad expansion of the hemisphere is striking; in fact, the cerebellum is almost invisible from above because it is covered by the telencephalon. Another impressive characteristic is the relative cephalo-caudal shortness or the relative great transverse width of the entire brain (brachycephaly). The complex cortical folding resulting in numerous gyri can be appreciated. It will be noted that no major sulci, either in a longitudinal or transverse direction, exist. In norma basalis (Plate I, 2), the bulging of the temporal cortex is especially noticeable as well as the large size of the cerebellum. One must also note the enormous vestibulocochlear nerve as well as the large trigeminal and optic nerves. In norma lateralis (Plate I, 3), the multiplicity of the gyri is also quite striking and the presence of a Sylvian fissure can be pointed to. This must be compared with *Platanista gangetica* (Plate IV, 3) and also with the pictures in Pilleri and Gihr (1970, Plate 7) for *Tursiops truncatus*, and also in Gruenberger, (1970, Fig. 5) for *Inia geoffrensis* as well as in Pilleri (1972, Plate 4) for *Platanista* again. One important feature that we shall have to comment upon later is the absence in *Stenella* of the cephalo-caudally oriented and longitudinal sulci that are typical for *Platanista* (Pilleri, 1972, Plate 1). The suprasylvian and ectosylvian fissures are but slightly visible in our specimen; they seem to be somewhat clearer in *Inia* (Gruenberger, 1970, Fig. 6) and in *Pontoporia blainvillei* (Pilleri, 1972, Plate 15, 3). On the other hand, the fan-shaped arrangement of the gyri, frontward and upward from the Sylvian fissure, is striking in *Stenella*, much more so than in *Inia* (Gruenberger, 1970, Fig. 6). In norma media, the relatively strong antero-ventral development of the hemisphere is noticeable. The genu of the corpus callosum accordingly reaches fairly far forward and downward. Well marked are the mesencephalon roof (corpora quadrigemina) and the pontine transverse formation. The colliculi inferiores, however, appear to be relatively smaller than in *Tursiops* (Pilleri and Gihr, 1970, Plate 3) and *Platanista* (Pilleri, 1972, Fig. 10), if, as it seems, all those sections are really comparable (sagittal). A great difference between those species is the relatively poor distinctness of the gyrus cinguli in *Stenella*, whereas this is so clear in *Platanista* and in *Pontoporia* (Pilleri, 1972, Fig. 5 and Plate 5, 10) as well as in *Inia* (Gruenberger, 1970, Fig. 7).

All those features, briefly described for *Stenella* in comparison with other dolphins, especially Platanistidae, will be reconsidered hereafter in the ontogenetic sequence of prenatal and young postnatal specimens.

Norma lateralis in ontogeny (Plates II, III, IV). The first three figures of Plate II refer to the same specimen. They firstly show the embryo before dissection (Fig. 1), with the two humps made by the bulging telencephalon and mesencephalon. In Fig. 2, one sees the dissection in progress, with the above named parts of the brain still *in situ*. The mesencephalic and cervical flexures are quite clear, and the pontine flexure on the dorsal side as well. For the sake of comparison, it may be mentioned that these three flexures are already present in a 6.7 mm human embryo (about 34 days) according to Hamilton, Boyd and Mossman (Fig. 153). Figure 3 presents the same brain after dissection. A comparison of Figs. 3, 4 and 6 reveals immediately the attenuation of the coiled, elongate and almost tubular aspect of the total brain as well as the relative increase of the telencephalon. The overall shape becomes bulkier, the parts (telencephalon, mesencephalon, rhombencephalon) begin to telescope into each other. On Plate III, Fig. 1, the apparent dilatation of the hemisphere increases. Between stages of Figs. 1 and 2 of Plate III, the morphogenesis progresses considerably from a qualitative viewpoint in particular: this is remarkable since the total size increase between the two stages is about 37% whereas it was over 80% between the two preceeding stages (Plate II, Fig. 6 and Plate III, Fig. 1) with less morphological differentiation. In this important step (Figs. 1 and 2 of Plate III), the surfaces of the hemispheres and of the cerebellum begin to differentiate while their size increases. The mesencephalic roof sinks and disappears beneath the overhanging cortex in lateral view. A Sylvian fissure begins to appear. Figuers 4 to 6 show the formation of the gyri. From 3 through 6, their fan-shaped arrangement above the Sylvian fissure becomes more marked. The coiled aspect of the gyri is predominent from stage 5 of this plate. A certain longitudinal orientation of the first groves may be seen temporarily in Figures 3 and 4 but this is temporary. On Plate IV, Fig. 1, we have a view of the brain shortly before birth while Figure 2 represents the brain shortly after birth. The question of size set apart, the general aspect is very much similar in both specimens. The gyri, however, are more tightly packed in the postnatal specimen than in the other one. Contrasting with our postnatal example, one can notice the longitudinal (cephalo-caudal) orientation of the gyri in the brain of *Platanista*, Plate IV, 3. The radial arrangement as seen in *Stenella* practicially does not exist in the platanistids.

Norma media in ontogeny (Plate V). We present on Plate V six sagittal sections of fetal brains of *Stenella*, from 24 to 51 cm, that is through stages corresponding roughly to those of Plate III. The gradual formation of the corpus callosum can be observed as well as the begining and complexification of the gyri on the medial surface. One can appreciate the relative morphic stability of the brain-stem portion: there is little change of shape in it. The relative size of the mesencephalic bulge (colliculi) decreases from section 1 to section 6. The fissura splenialis is well marked but the fissura genui much less so and the fissura suprasplenialis also is quite faint. In the early postnatal (Plate I, 4), the same fissurae are also difficult to trace, except for the caudal half of the splenial fissure, contrarily to what can be observed in the platanistids brains shown by Pilleri (1972).

Norma verticalis in ontogeny (Plates VI, VII). Both the change in relative size of parts and the change in shape can be fully appreciated from the fetal series seen in dorsal view. This sequence (12 specimens) is particularly striking.

It starts with the predominence of the mesencephalon, which makes, with the medulla oblongata, the main mass of the very early Mammalian brain, as shown quantitatively by Pirlot and Bernier (in press). The lateral hemispheric lobes are still quite small in Fig. 1 while the cerebellum is no more than an annular thickening. Stages in Figs. 2 to 5 are characterized by the relative decrease of the caudal half of the brain and the rapid increase of the hemispheres. The colliculi begin to shape up clearly in Fig. 2. It will be noticed that, for a time, the cerebellum remains almost unchanged in outline, a fact observed in bats by Pirlot and Bernier (in press). The rapid and profound modification of the brain surface between sizes 19 and 26 cm, already observed in the norma lateralis aspect, is also very striking in dorsal view. It is important to note the longitudinal (cephalo-caudal) orientation of the sulci that appears in Figs. 6 and 7 of Plate VI. The first one seems to be the fissura lateralis (fissura marginalis) (Fig. 6) while the fissura endolateralis begins to be visible on Fig. 7. Both are better marked at the 35 cm stage (Plate VII, 1) but they become somewhat less distinct soon after (38 and 51 cm, Plate VII, 2 and 3). In fact, that is due to the rapid complexification of the gyri system in all directions: among those gyri, the first fissures become less conspicuous. The foliation of the cerebellum is well under way from 26 cm (Plate VI, 6). The sequence 26 to 74 cm corresponds to a marked and rapid increase in both mass and suprficial area. That period must be one of very active histological proliferation all over the surface of the brain. In Plate VII, 5, the anterior cerebral artery is visible in the fissure lateralis (left side of the picture with arachnoid membrane). Finally, another striking feature that can be observed in the photographs (although these are not to scale) is the fast change in the width/length ratio. This ratio passes roughly from 58% at 3.6 cm to 82% at 10.4 cm, practically 100% at 19 cm, 114% at 31 cm, 133% at 74 cm i.e. shortly before birth and also soon after (115.5 cm). This of course simply reflects the change from an elongate outline to a rather telescoped shape which occurs in all developing Mammals but the modification is particularly strong in this dolphin.

Norma basalis in ontogeny (Plates VIII, IX). As seen from the ventral aspect, the morphogenesis of the brain is mainly characterized by a gradual differentiation of distinct regions and thus a general structural complexification. In the first four stages shown here (Plate VIII, 1 to 4), the main masses, that is prosencephalic and rhombencephalic, are visible, at first deeply then later shallowly separated by the mesencephalic flexure. The lateral lobes and the cerebellum, however, begin to shape up in Fig. 4 (10.4 cm). Thereafter, the differentiation is fast: the modelling of the whole undersurface progresses rapidly while the hypothalamic and pontine regions begin to show theire spective specific structures (Plate VIII, 5 to 7; Plate IX, 1 and 2). The hypophyseal mass is early visible in this series. The cranial nerves posterior to the optic appear as early as stage 19.0 cm (Plate VIII, 5). The trigeminal is first visible but the facial-acoustic-vestibular complex takes shape as a large double root a little afterward and is clearly visible at 35.0 cm (Plate IX, 1). Nervus vagus (X), nervus accessorius (XI) and nervus hypoglossus (XII) intermingled and nervus abducens (VI) are also formed in the 51 cm fetus. Nervus oculomotorius (III) is visible at 115.5 cm but was probably lost in the dissection of smaller embryos. The inferior olive starts bulging from the 19.0 cm stage and is quite distinctly individualized at stage 42.0 cm or even before.

CONCLUSION

From the above study of a series of prenatal and early postnatal brains of *Stenella coeruleoalba*, we can draw the following conclusions.

a) **General morphogenesis.** The changes in shape, as size increases, are very striking, in the sequence under consideration. The brain of this species starts its development with elongate outlines as is the case in all Mammals. But the modification is much more pronounced than in most other Mammals, in the sense that the final stage of embryonic life shows an exceptionally broad and short brain. A detailed quantitative analysis of the components' growth could give a satisfactory account of what really occurs from that viewpoint during that remarkable ontogeny; we have such an analysis in preparation.

b) **Cortical morphogenesis** Gross anatomical observations of the cerebral lobes reveal interesting features. Dolphins are probably amont the most strongly gyrencephalic Mammals outside the Primates. But, in this respect, they are not uniform. In the adult stage, the genus *Stenella* differs markedly from some Platanistid genera with which we were able to compare it on the basis of other material as well as of published reports and pictures. Indeed, *Stenella* is characterized by the predominence of transverse (in the broadest sense) or at least not longitunidally oriented gyri and sulci. Its superficial cortical pattern is extremely complicated with a large number of oblique sulci. But, in young embryos, longitudinal groves are the first ones to appear, as we have shown. They become more or less blurred or obliterated later as the adult pattern gradually sets in. This raises the recurrent question of repetitive processes in ontogeny. The platanistids show an obviously longitudinal orientation of the gyri and, further, platanistids are considered, on various grounds, a primitive group among dolphins. Our observations thus raise a fundamental problem in ontogeny with respect to phylogeny and evolution in general: are the temporary longitudinal sulci in *Stenella* a case of ontogenetic repetition? Only a new investigation along this line on the morphogenesis of dolphin brain can throw some light on that problem.

c) **Morphogenesis in relation to sensory functions.** The relationships between the rate of development of the sensory control centers in fetal life and the start of sensory activities are a very intricate problem. We will not venture into discussing its implications in the case of *Stenella*, but we must nevertheless insist upon the importance of the two following observed facts. Firstly, we have stressed the enormous size of the vestibulocochlear nerve (VIII) and, at the same time, the relatively great development of the temporal region in *Stenella*, both becoming obvious as growth proceeds. The possible correlation between an extensive use of hearing abilities, including sonar, and the development of the temporal cortical area remains mysterious, as far as we know. But whatever the results of researches on that point may be, our observations are of interest. Secondly, we would like to point to the total absence of an olfactory bulb in the rostro-ventral region of the brain in *Stenella* as seen in gross morphological aspects.

APPENDIX

Embryos smaller than 3.6 cm were too small to permit dissection and photography of the brain in gross morphological view. Approximately sagittal sections, however, could be prepared for some of them as shown on Plate X. It is probably easier to look at them in a decreasing size order.

In all embryos, the neurocoele is still quite large as can be expected. In Fig. 4, the spinal cord is visible over most of its length and the cervical flexure at the fourth ventricle level is strongly marked. The ventral portion of the neural tube is thick, especially in the pons-oblongata region, while its roof remains thin except where the cerebellum is forming. A thalamic mass has been cut parasagitally and the mesencephalic flexure is well marked. The third ventricle is still wide and the parasagittal section also cuts a large lateral ventricle. The blow-hole is visible dorsally to the snout and mouth.

Figure 3 presents a much younger stage (about 2/3 of the former in length). It is not quite so well centered but it shows about the same features as figure 4 in a less advanced state. The blow-hole can be seen again and the flexures are marked. Figures 2 and 1 are definitely different in aspect. While the membranous roof of the fourth ventricle is showing the concavity that will correspond to the pontine and cervical flexures, the more rostral structures do not show yet the various parts very distinctly. The common neurocoele just begins to divide into distinct cavities. In Fig. 1, the general tube-like appearance can be noted, the forming brain overhanging indistinct notochordal tissue.

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EXPLANATION OF PLATES

PLATE I

External form of the brain with arachinoid. Male, 135 cm long.

Fig. 1. Dorsal view.
Fig. 2. Ventral view.
Fig. 3. Laterial view of the left half.
Fig. 4. Medial surface of the right half.
II: Optic nerve V: Trigeminal nerve VIII: Vestibulocochlear nerve

PLATE II

External form of the embryo and brain.

Fig. 1. Photograph of the left side of 3.6 cm long embryo.
Fig. 2. Same embryo with cranial bone removed and brain shown *in situ*.
Fig. 3. External form, left half of the brain of 3.6 cm long embryo.
Fig. 4. Embryo, 6.0 cm long.
Fig. 5. Embryo, 7.5 cm long.
Fig. 6. Embryo, 10.4 cm long.

PLATE III

External form of the left half of the brain.

Fig. 1. Embryo, 19.0 cm long.
Fig. 2. Embryo, 26.0 cm long.
Fig. 3. Embryo, 32.0 cm long.
Fig. 4. Embryo, 35.0 cm long.
Fig. 5. Embryo, 38.4 cm long.
Fig. 6. Embryo, 51.0 cm long.

PLATE IV

External form of the left half of the brain.

Fig. 1. Embryo, 74.0 cm long, with arachnoid.
Fig. 2. Female, 115.5 cm long.
Fig. 3. *Platanista gangetica*, male, 117 cm long.

PLATE V

Median section of the right half of the brain.

Fig. 1. Embryo, 24.0 cm long.
Fig. 2. Embryo, 26.0 cm long.
Fig. 3. Embryo, 32.0 cm long.
Fig. 4. Embryo, 35.0 cm long.
Fig. 5. Embryo, 42.5 cm long.
Fig. 6. Embryo, 51.0 cm long.
Figs. 2, 4 and 5 with midbrain removed and showing gyrus.

PLATE VI

External form of the brain in dorsal view.
Fig. 1. Embryo, 3.6 cm long.
Fig. 2. Embryo, 6.0 cm long.
Fig. 3. Embryo, 7.5 cm long.
Fig. 4. Embryo, 10.4 cm long.
Fig. 5. Embryo, 19.0 cm long.
Fig. 6. Embryo, 26.0 cm long.
Fig. 7. Embryo, 31.0 cm long.

PLATE VII

External form of the brain in dorsal view.
Fig. 1. Embryo, 35.0 cm long.
Fig. 2. Embryo, 38.4 cm long, left hemisphere with arachnoid.
Fig. 3. Embryo, 51.0 cm long.
Fig. 4. Embryo, 74.0 cm long, with arachnoid.
Fig. 5. Female, 115.5 cm long, left hemisphere with arachnoid and arrow show anterior cerebral artery.

PLATE VIII

External form of the brain in ventral view.
Fig. 1. Embryo, 3.6 cm long.
Fig. 2. Embryo, 6.0 cm long.
Fig. 3. Embryo, 7.5 cm long.
Fig. 4. Embryo, 10.4 cm long.
Fig. 5. Embryo, 19.0 cm long.
Fig. 6. Embryo, 24.0 cm long.
Fig. 7. Embryo, 26.0 cm long, right hemisphere with arachnoid.

PLATE IX

External form of the brain in ventral view.
Fig. 1. Embryo, 35.0 cm long.
Fig. 2. Embryo, 42.0 cm long, right hemisphere with arachinoid.
Fig. 3. Embryo, 51.0 cm long.
Fig. 4. Embryo, 74.0 cm long, hemisphere with arachinoid.
Fig. 5. Female, 115.5 cm long, right hemisphere with arachinoid.
P: Pons O: Olive C: Crus cerebrum VII: Facial nerve.
VIII: Vestibulocochlear nerve.

PLATE X

Longitudinal median sections of embryos.
Fig. 1. Embryo, 1.1 cm long.
Fig. 2. Embryo, 1.7 cm long.
Fig. 3. Embryo, 2.4 cm long.
Fig. 4. Embryo, 3.5 cm long.

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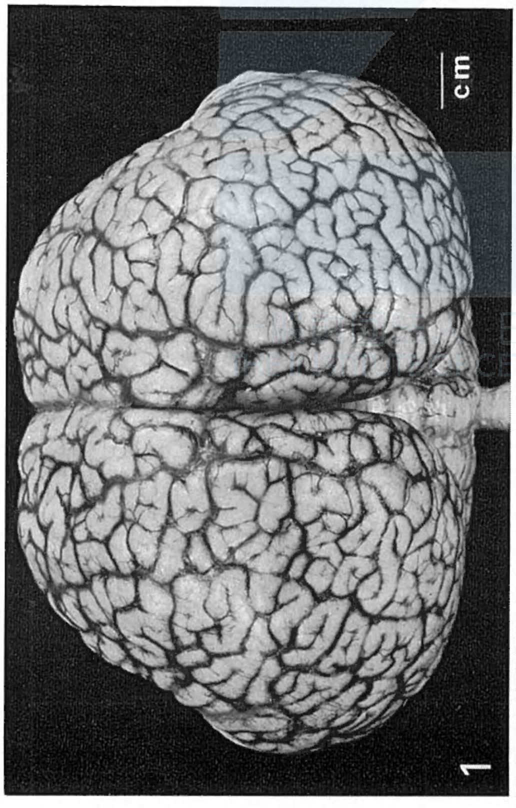

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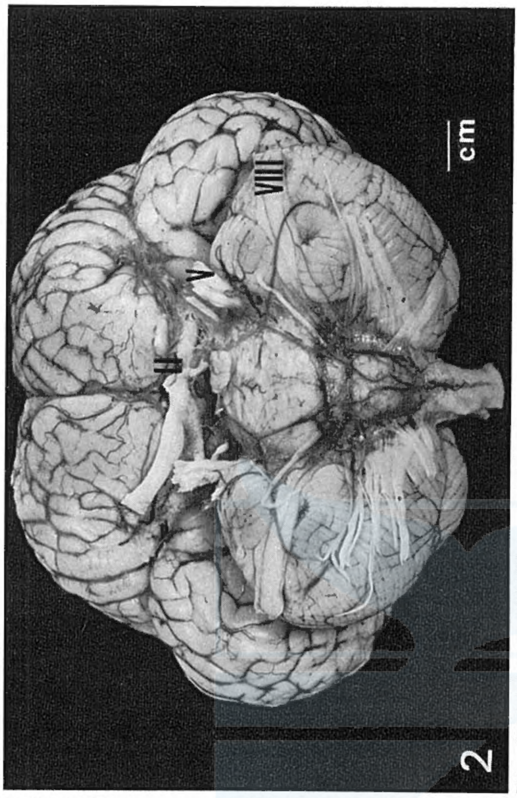

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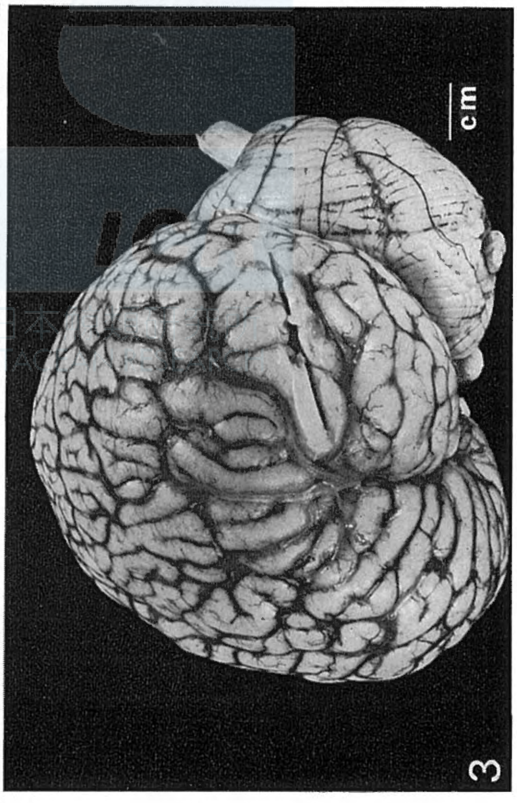

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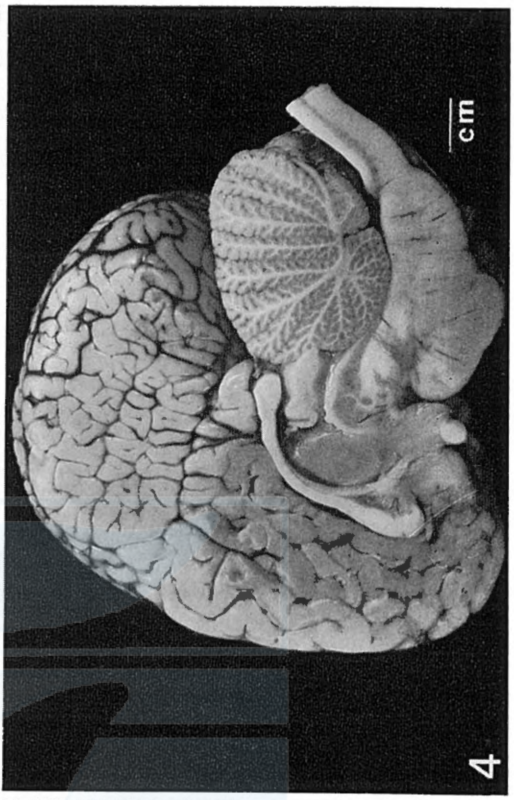

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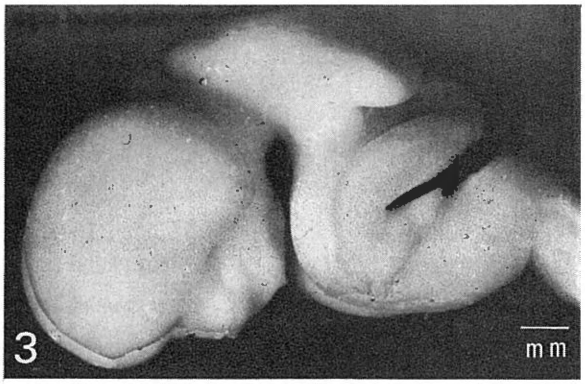
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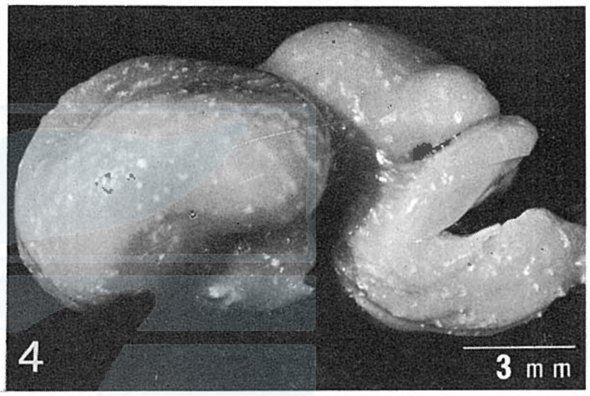
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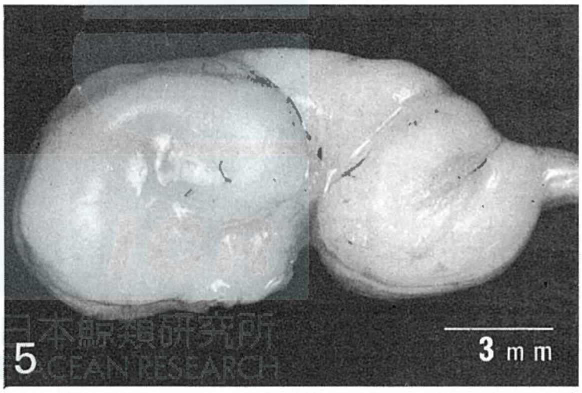
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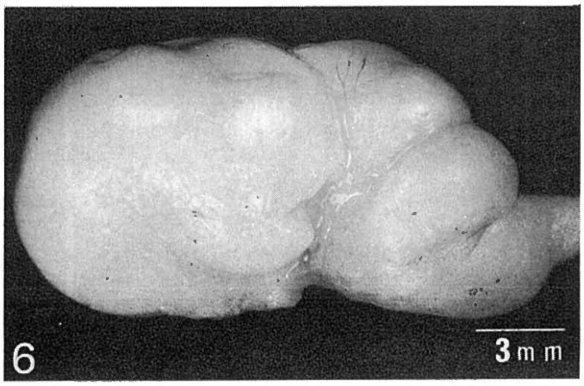
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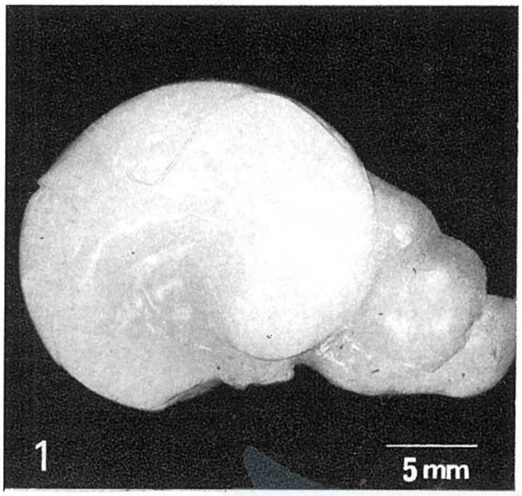
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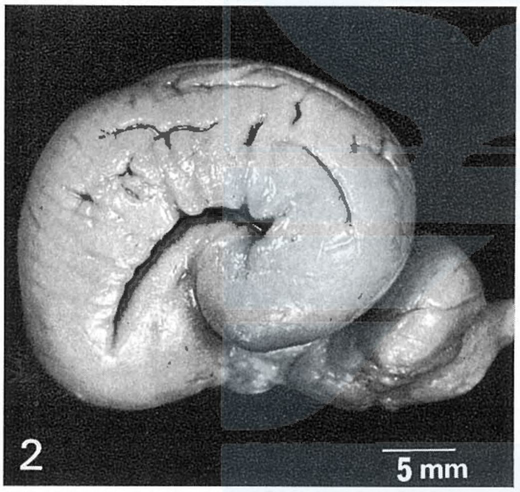
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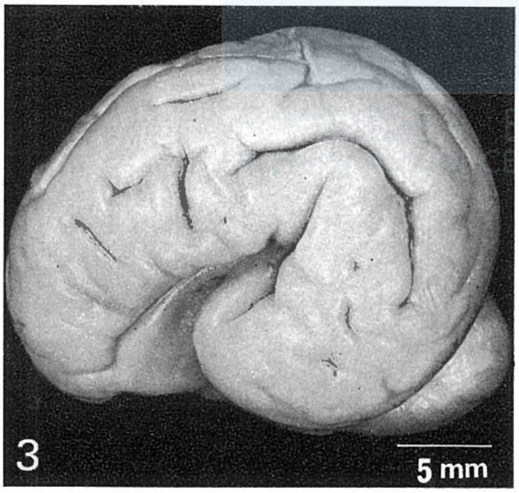
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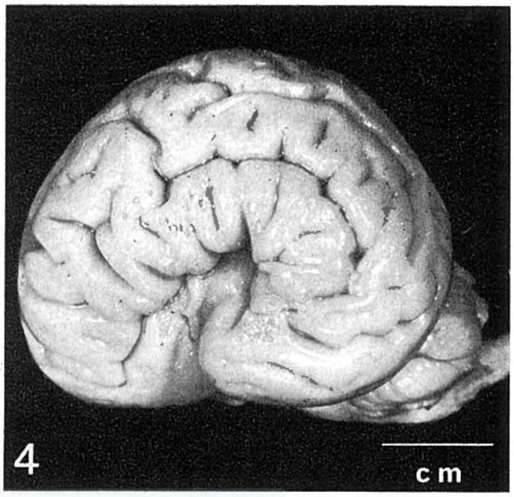
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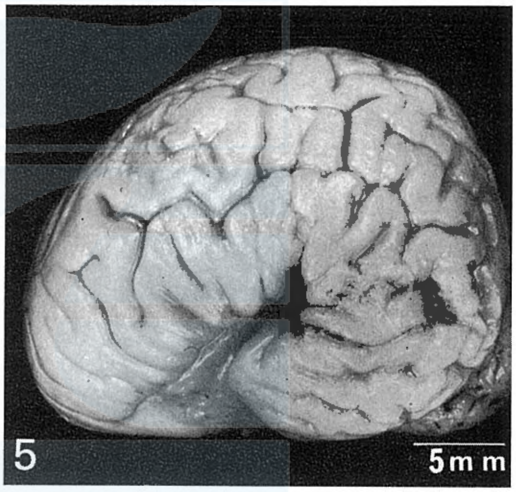
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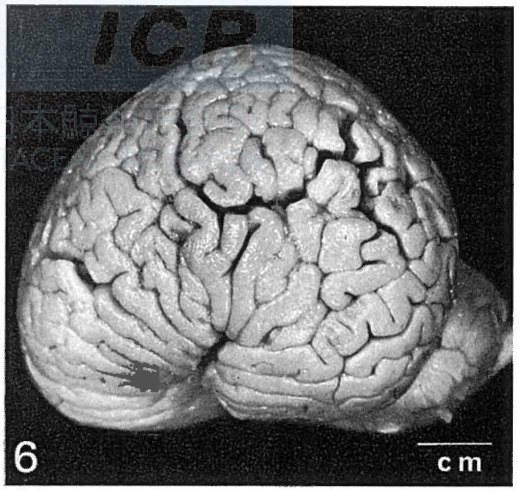
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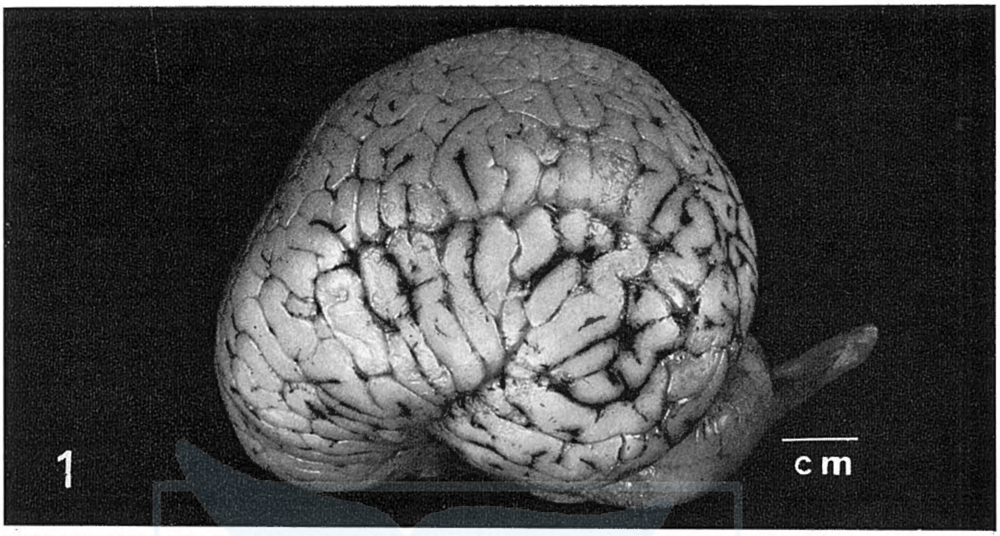
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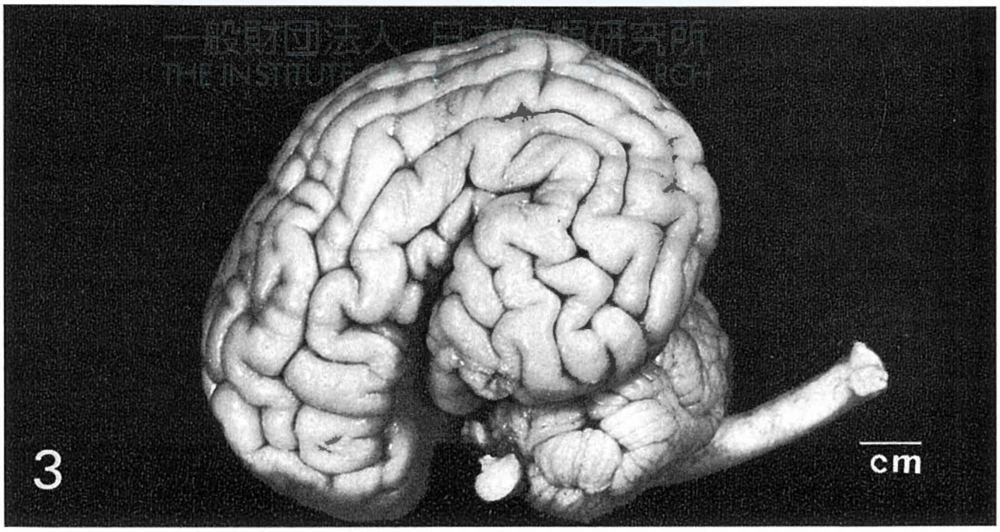
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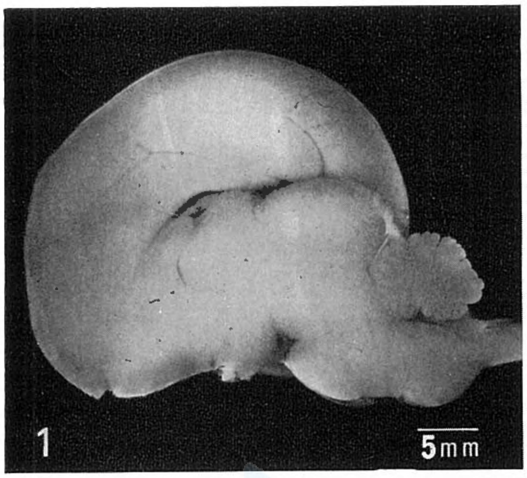
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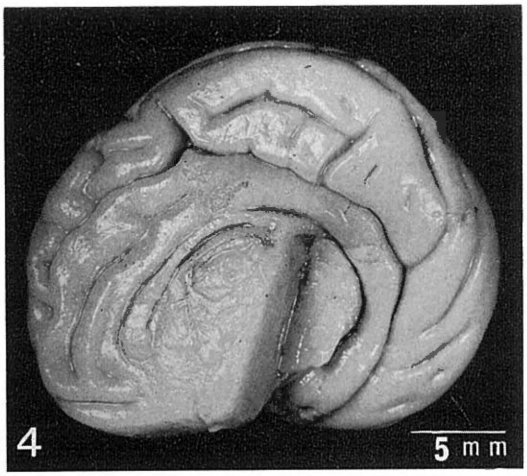
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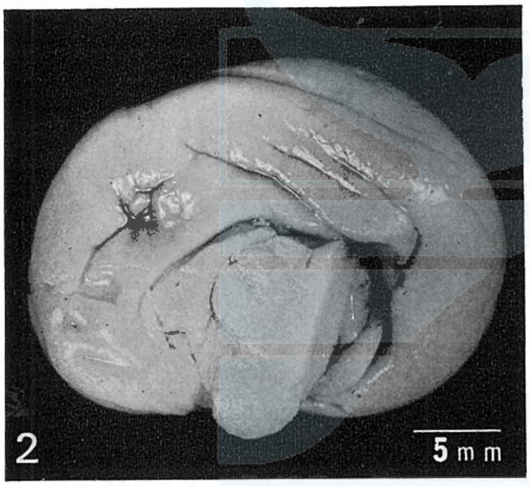
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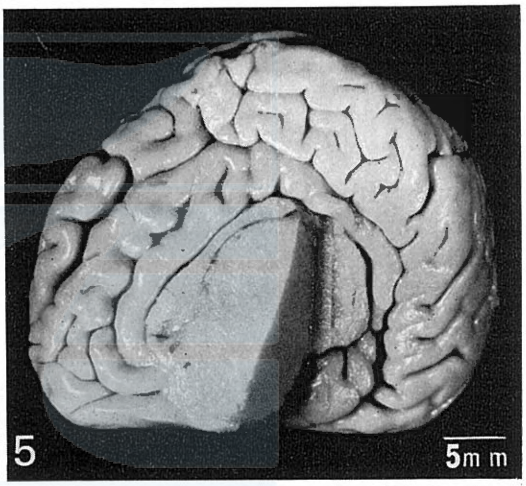
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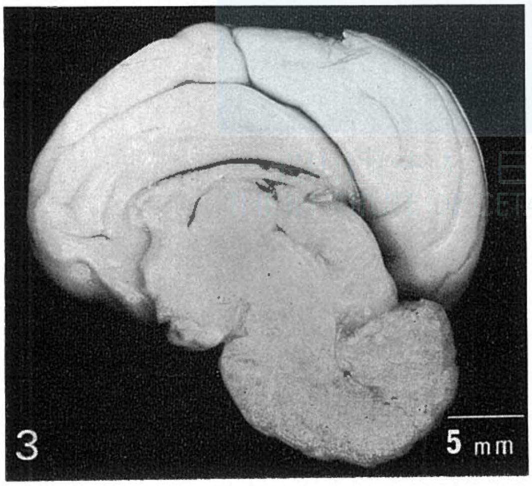
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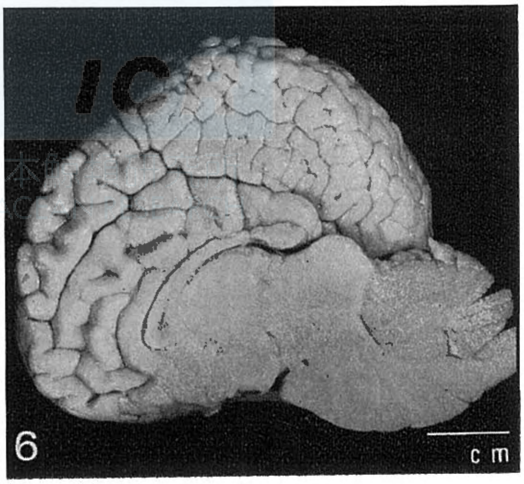
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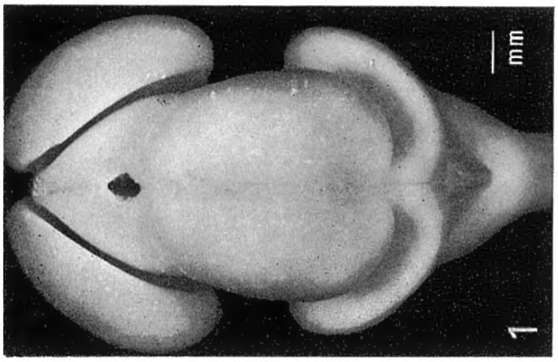
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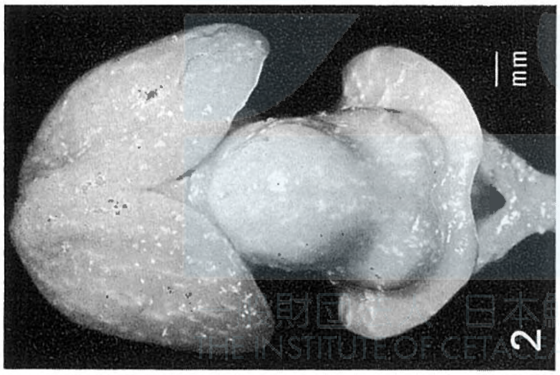
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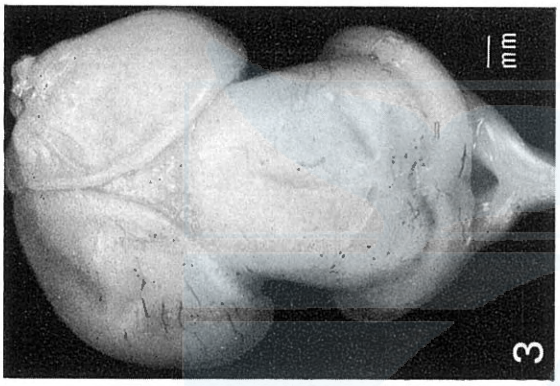
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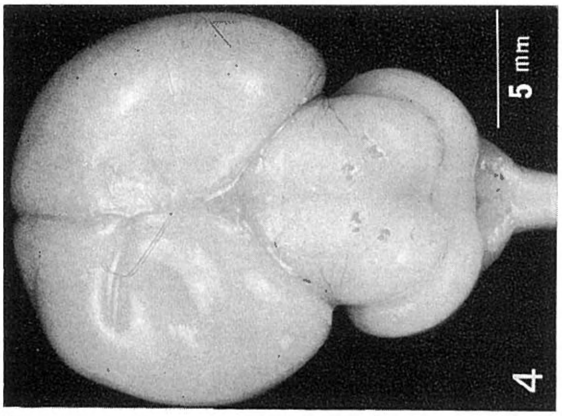
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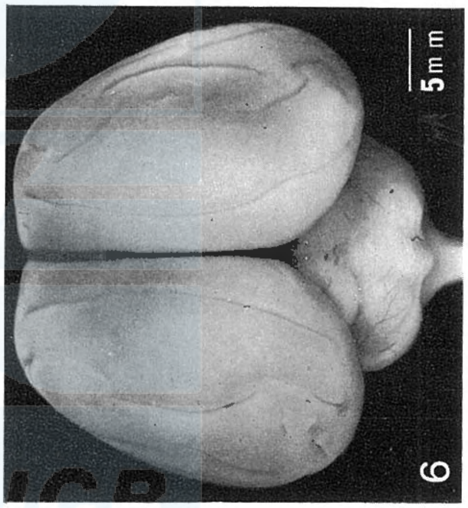
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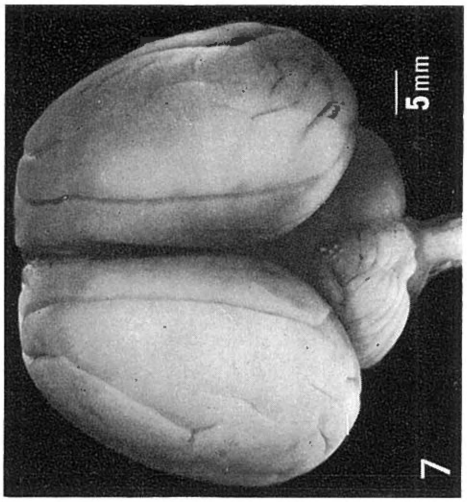
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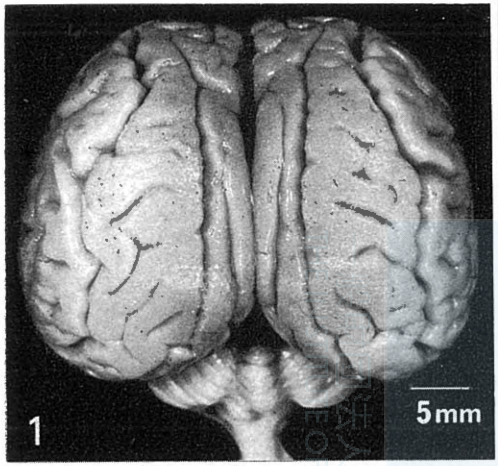

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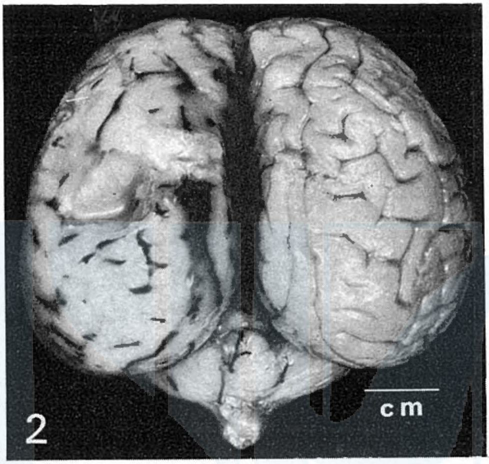

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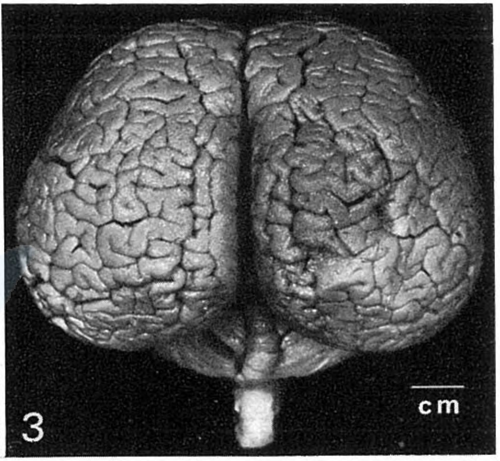

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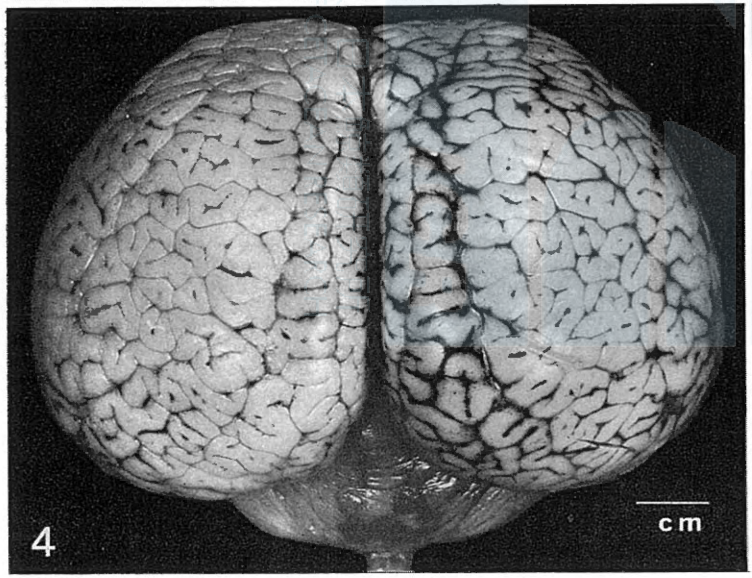

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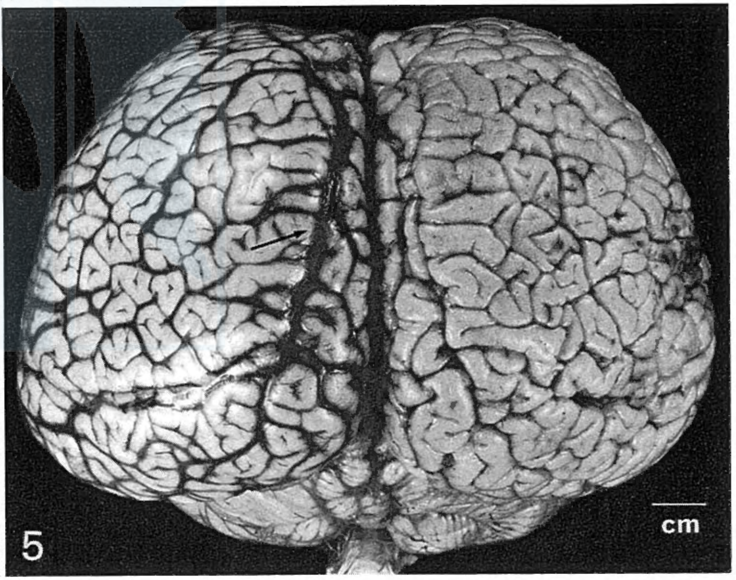

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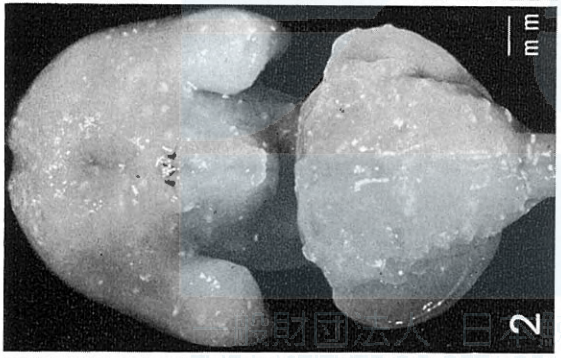
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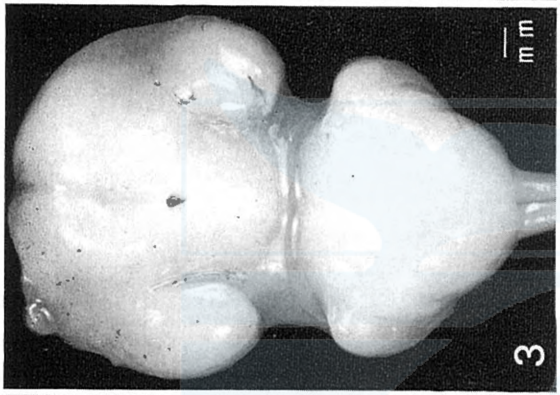
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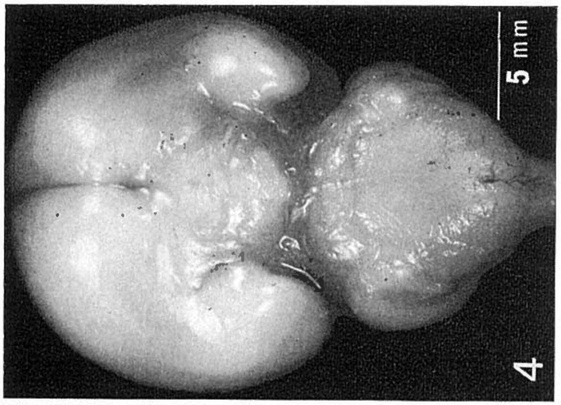
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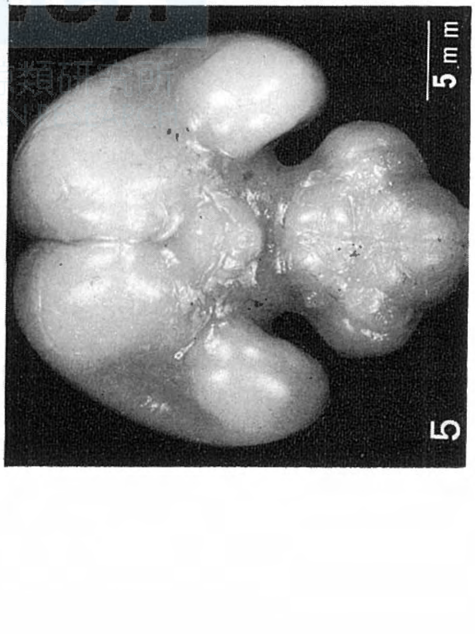
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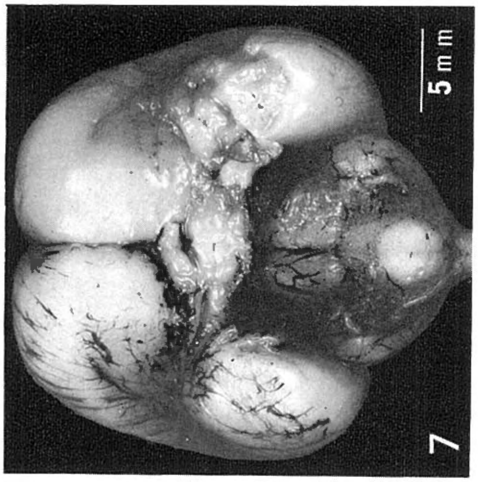
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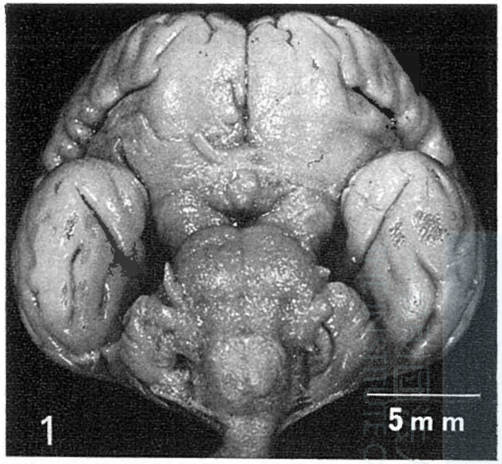
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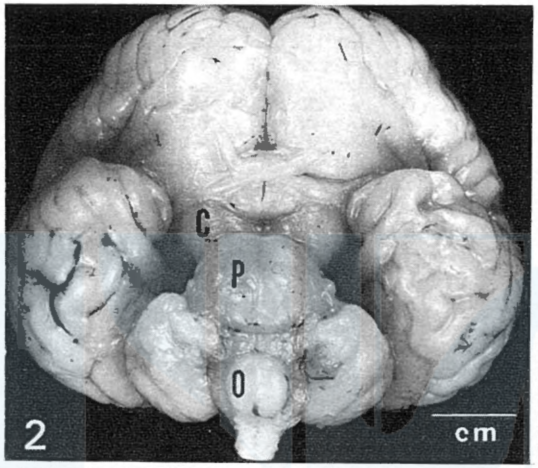
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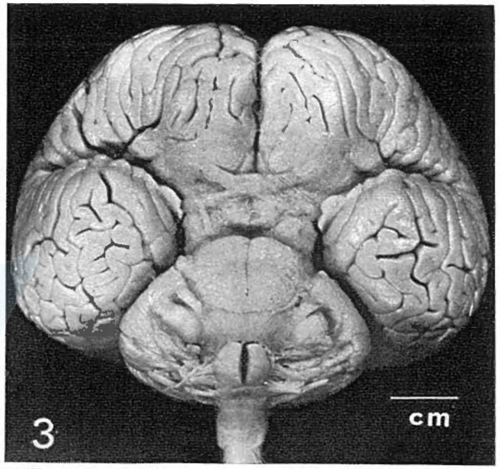
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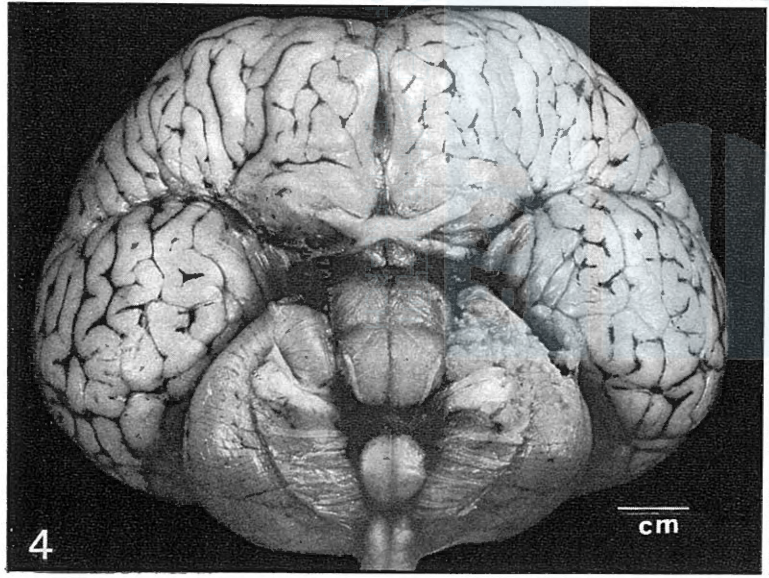
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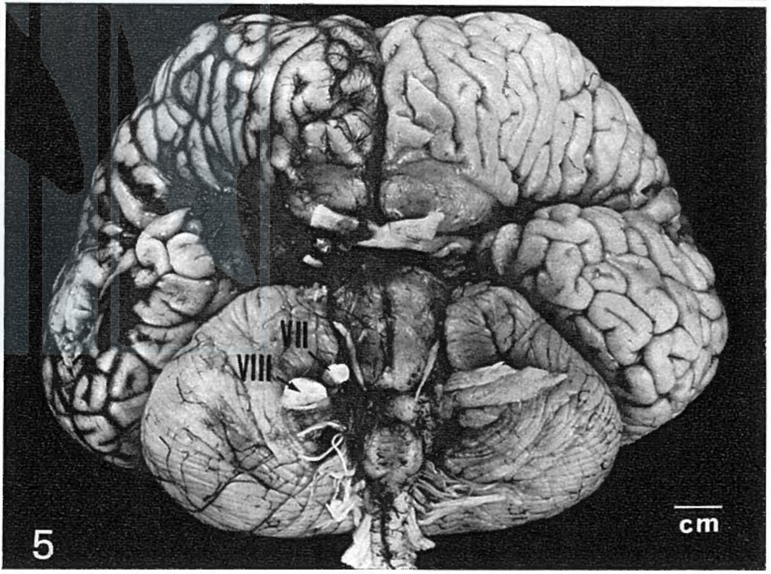
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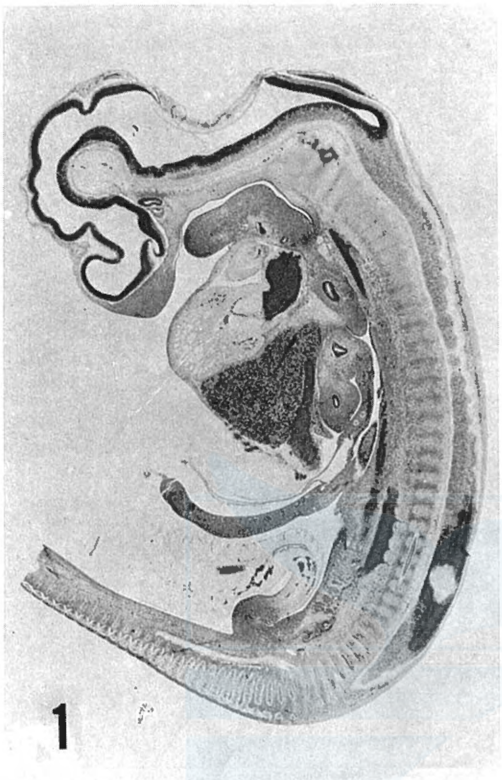

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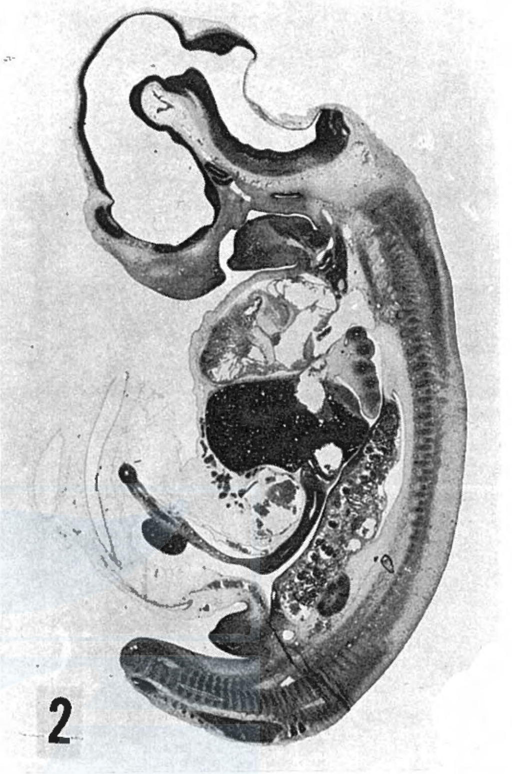

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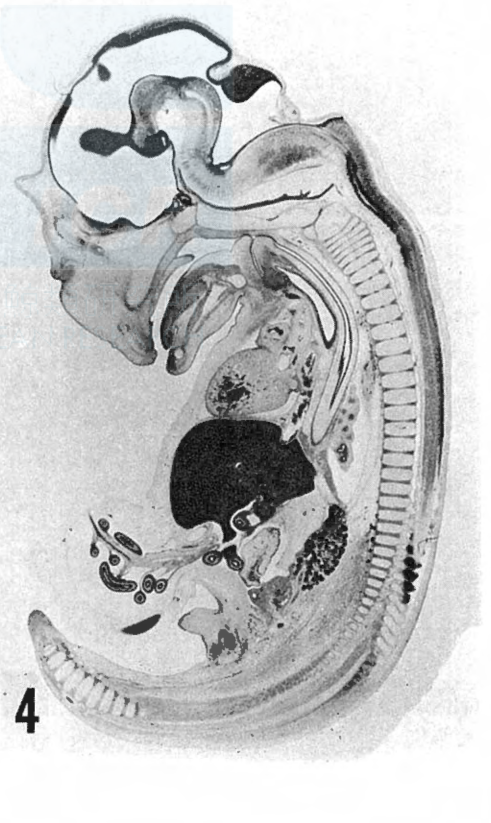

4

FIRST ANTARCTIC RECORD OF A KILLER WHALE STRANDING

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On the afternoon (6 P.M.) of 16 January 1973, during a " Zodiac " out motor rubber boat collecting trip from Palmer Station (64° 45′ S, 64° 58′ W), Antarctica, to Cormorant Island, looking for the blue-eyed shag (*Phalacrocorax atriceps*) we needed for neurophysiological research (Tomo, Panizza and Castello, 1973) arriving to the shore of Cormorant Island through a short channel carved in the rocks, we were surprised to find, during low-tide, a stranded killer whale (*Orcinus orca*), 5.2 meters long and approximately 1.5 metric ton in weight (Fig. 1). We took color photographs immediately and also some notes. The stranded " orca " was of female sex; time since death was estimated on two weeks or more. Black and white colors of the tegument had been partially removed by floating ice debris abrasion, some of the 25 powerfull teeth were broken, possibly by crashing floating ice against the open mouth (Fig. 2). It was possible to observe, also, " tooth wear " as it has been previously described (Caldwell and Brown, 1964) and some blood clots on a rock just under the tongue. Even though 0°C water temperatures are common during austral summer, air temperatures, specially during sunny days, may reach 10°C or more, thus the sun had heated the body and visceral putrefaction had greatly progressed when we met the carcass.

Some gas bubbles sporadically escaped from a 3 cm wide circular hole on the tegument of the middle back. No other wound was seen in the carcass. The body was full of gas and increased in width, so it probably floated.

Floating and drifting dead whales like the *Balaenoptera aff. borealis* (Fig. 3) are not common in the Antarctic. Scientific reports on stranded cetacea or bones collected in those latitudes are few, only one skull of the " cruciger dolphin " (*Lagenorhynchus cruciger*) has been found and recently described from Livingston Island (Islas Shetland del Sur) (Fraser and Noble, 1968) and one *Phocoena dioptrica* collected at South Georgia (Fraser, 1968).

When five days latter we returned to Cormorant Island for obtaining measureents and to examine it's stomach content we could not find the " orca " carcass along the coast of the tiny island. We realized then what had happened: in the same way as it probably reached the shore it went away, floating and drifting like

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Fig. 1. Female *Orcinus orca*, stranded at Cormorant Island (64°47'S, 64°59'W) on a rocky shore (16 January, 1973).

Fig. 2. Some teeth were broken, others showed certain wear related to feeding behaviour.

a buoy, carried away by local water currents, wind action and tidal displacements. *Orcinus orca* is world wide distributed, its range extending from the Greenland Sea in the North to the Ross Sea in the South (Fraser, 1964) chiefly in coastal waters and cooler regions (Rice and Scheffer, 1968). On the base of our observations one can found "killer whales" simultaneously during February at Valdés Peninsula (42° 05′ S, 63° 30′ W) feeding on adults and pups of fur seal, "lobo de un pelo", (*Otaria flavescens*) from the nearby shore rockeries and in the Gerlache Strait (Bellingshausen Sea) in Antarctica, chasing "Adelie penguins" (*Pigoscelis adeliae*), that try to escape with fast swimming and "porpoising" swimming movements.

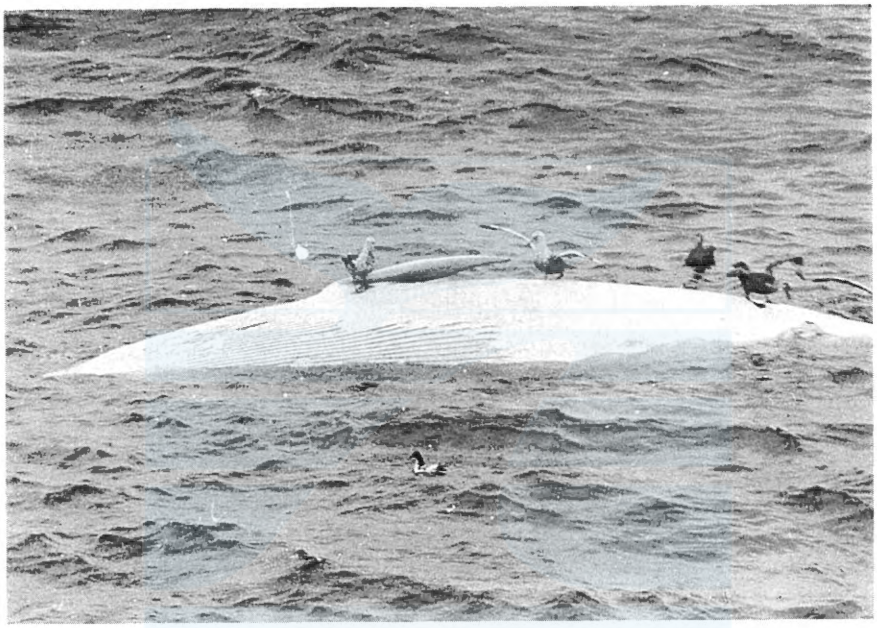

Fig. 3. Floating and drifting naturally dead, *Balaenoptera aff. borealis*, photographed at Mar de la Flota, near Base Esperanza, February 1970, by A. Tomo, from the Icebreaker A.R.A. "Gral. San Martín".

Although killer whale is the best known and the most popular cetacean in the Antarctic Ocean and rather common along the Antarctic Peninsula, there is no published report on its behaviour and biology, except an excellent paper on the habits of 60 killer whales, 120 minke whales (*Balaenoptera acutorostrata*) and 1 *Berardius arnouxi* being restricted to pools in the sea ice of (Hope Bay) Bahia Esperanza (63° S, 57° W) (Taylor, 1957), and an old report with some description on habits, young and adult color patterns, shape and variation in lengtht of the male dorsal fin, and remarks on their possible diet. During the period from middle September to middle of March, were observed in the area of Mc Murdo Sound (Ross Sea) (Wilson, 1907).

There is still much to be known about the killer whale, detailed information about its distribution is not available or whether it migrates or if stocks in the north are separate from those in the south.

The second of us spent 1967 at Estación Científica "Almirante Brown" (64° 50′ S, 62° 50′ W) and carried among other works, a record of cetacean sightings. Three different species were observed in 19 occasions with a total of 34 specimens observed in front of the main building of the Station in the period March-July. Only once, the 6 of April (08.50 A.M.), 5 killer whales were observed at Bahía Paraíso. As something unusual a whale (*Balaenoptera* spp.) was observed the 23 of July swimming between broken ice, while the last two were recorded the 15 of May.

It is almost sure that during the austral winter, before thick ice covers coastal areas of the Antarctic Peninsula, killer whales move to open waters, probably swimming to subantarctic areas. This hypothesis has to be proved and we must remark what has been previously stated: "research in the Antarctic so far has contributed but little to what is known of this creature" (Fraser, 1964).

Hershkovitz (1966) gives 80 bibliographic mentions on *Orcinus orca* only 5 are referred to sightings in antarctic waters at different places (Hope Bay; between Powell and South Shetland Islands; 70° 23′ S, 85° 57′ W; 78° S, 170° E; 77° 46′ S, 166° E).

In the period December 1972–February 1973, killer whales were observed in eight occasions in the Gerlache Strait (Castello and Duguy, in press) and in our opinion this strait must be selected as an area for studying the behaviour and biology of this important and largely neglected species.

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A MALFORMED EMBRYO OF *STENELLA COERULEOALBA*

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At the present time, the dolphin drive fishery, mainly *Stenella coeruleoalba* on the east coast of Izu Peninsula is cooperatively operated at Kawana and Futo villages. At these two villages, the fishing season starts in early October and closes in January. The mean annual catch of *S. coeruleoalba* for both villages has been 5,157 individuals during the past 5 seasons (1969–'70 to 1973–'74).

In 1972, 21 schools of *S. coeruleoalba* were driven ashore at these two villages and 7,235 individuals were killed. In that season, we examined 2,299 individuals and 467 foetuses taken from 20 schools. On October 17 a school of 187 individuals was driven into the Futo Port. This was killed between the 17th and 19th of October. The composition of 115 individuals of the school is shown in Table 1. This table indicates that 60.5 percent of the females and 33.3 percent of the males in this school had attained sexual maturity, and the socionomic ratio was 0.28. In the course of field examination of those 115 individuals at Futo village, we collected 17 foetuses. One was a small malformed embryo. The mother of this embryo was 220 cm in body length and was estimated to be 8.5 years old. The age was determined by the number of opaque dentinal layers. The condition of the ovaries was not observed. Kasuya (1972) stated that females of *S. coeruleoalba* attain sexual maturity at 9 years at the length 212 cm, so that it seems that this mother was in her first or second pregnancy.

TABLE 1. SCHOOL COMPOSITION OF *STENELLA COERULEOALBA* CAUGHT ON OCTOBER 17, 1972.

Sex	Pregnant	Lactating	Resting	Mature	Immature	Total
Female	17 (22.4)	27 (35.5)	0	2 (2.6)	30 (39.5)	76
Male				13 (33.3)	26 (66.7)	39
Total						115

Figures in parenthesis indicate percentages.

The external characters observed in this embryo were the following: Body length (cranio-caudal): 9 mm; greatest breadth: 7 mm; body weight: 2.0 gr. In ventral view, the cephalic region appears to be almost normal (Fig. 1). The eye is easily identifiable and so is the maxillary area. In the dorsal half of the head there is a groove or depression that cannot be identified with certainty. The man-

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dibular region is not clearly defined. The mandible is probably not developing. The upper limb bud is nearly normal on the left side (Fig. 2). On the right side, it is either not developing or in a state of abnormal formation (Fig. 4).

The abdominal region is not normal looking and, in particular, there is a string-like fold that can be the umbilical cord but it is not typical. The tail, as compared to that of a normal embryo, is too wide and placed with its tip in the oral region (Fig. 1).

In back view (Fig. 3), one can see the almost normal developing vertebrae and the segmentation. The curvature, from this aspect, is abnormally sideward. Comparing the two lateral views, one sees that, on the left side (Fig. 2), the appearance is almost normal (see above remark on mandible) but on the right side (Fig. 4), there is a mass of unidentifiable lumps of tissues.

Internal structures were observed in this embryo which was embedded in paraffin, sectioned longitudinally and serially 10 μ thick, and stained with hematoxylin and eosin for microscopical study. Also, we used an 11 mm long normal embryo of the same species for longitudinal serial sections to compare with the malformed embryo.

Fig. 5 shows an approximately sagittal section of the 11 mm normal embryo *S. coeruleoalba*. In this embryo, one clearly sees that the brain and spinal cord and all of the primordia of the cranial nerves are already present. Also, each visceral organ is quite well formed: primordial thymus, thyroid gland, lung, heart and liver with much blood, splenic primordium, gonad, primitive pancreas, mesonephros and metanephros respectively *etc.* are present.

One the contrary, in the malformed embryo which is covered with simple epithelium and the inner structure of which is mainly composed of mesenchyme cells, organ formation is extremely abnormal in comparison with the normal embryo. In the cephalic region, one cannot recognize any brain structure: there is only a non-differentiated nervous cell mass. In figure 6, the optic vesicle is cut near its center with the optic cup and the lens vesicle can be seen. The optic cup has inner and outer layers. The outer layer already presents the pigmented epithelium but the layer formation is irregular. In the thoracic and abdominal regions, we can mainly distinguish four kinds of tissue masses. Heart muscles, liver cells, neural tissue and segmental structures (Figs. 7, 8, 9). Bundle-like heart muscles with intercalated disks can be seen. The usual blood-cells accummulations were not observed. Nervous tissue is degenerated but spinal ganglion-like masses were identified and glia cells are abundant.

This case is one of the malformed embryos at an early developmental stage. A malformed embryo of *S. coeruleoalba* has been observed by Kawamura and Kashita (1971). That case was a double monster with body length of 16.8 and 17.2 mm respectively along a transverse axis. Rudimentary hind limbs in a mature individual were also reported by Ohsumi (1969) and the external development of normal embryos was described by Ogawa (1953). The normal cross-section of a 12 mm long embryo has been observed by Hosokawa (1955). Each of the above three embryos was from the same species.

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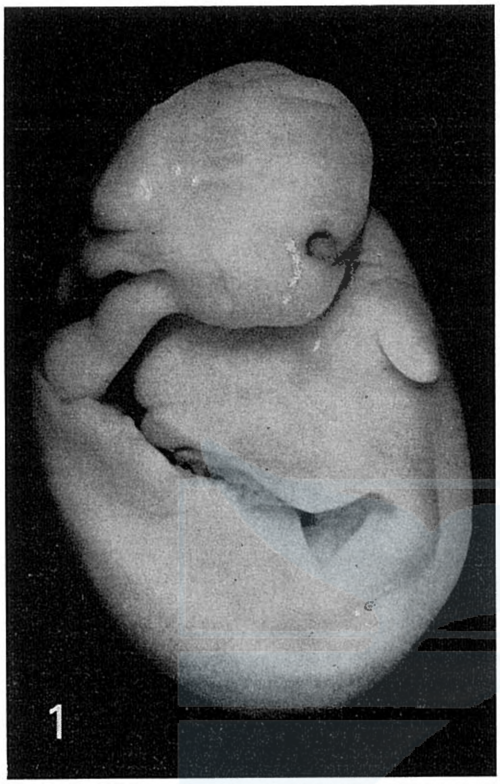
EXPLANATION OF FIGURES

Figs. 1–4. External form of malformed embryo of *S. coeruleoalba.* (ca. ×10.5).
1: Ventral view 2: Lateral view of the left side 3: Dorsal view
4: Lateral view of the right side

Fig. 5. Longitudinal median section of the 11 mm normal embryo of *S. coeruleoalba* (ca. ×10).

Figs. 6–9. Histological structure of malformed embryo of *S. coeruleoalba.*
6: Optic vesicle, L=lens (ca. ×300) 7: Heart muscles (ca. ×500)
8: Liver (ca. ×500) 9: Segmental structure (ca. ×120)



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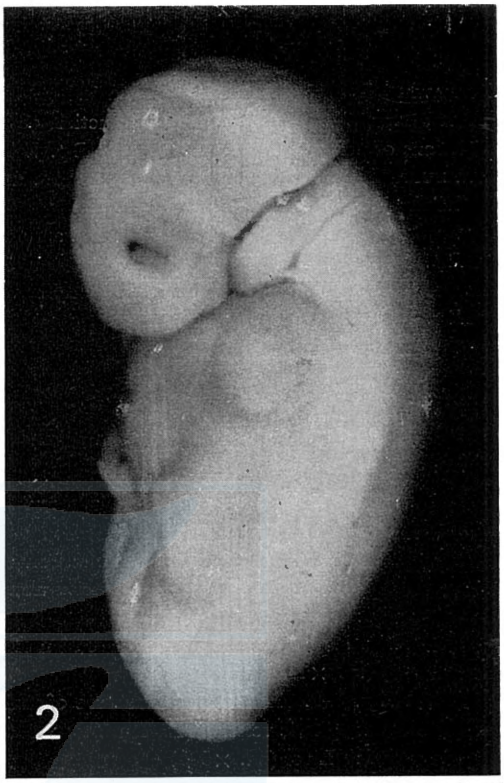

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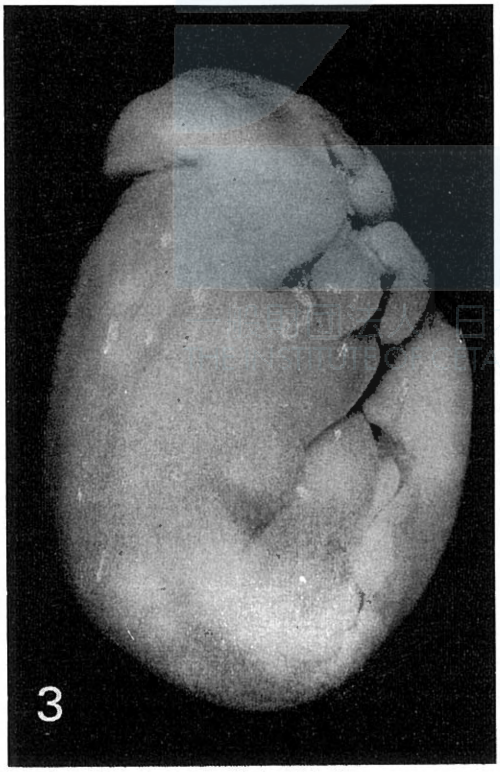

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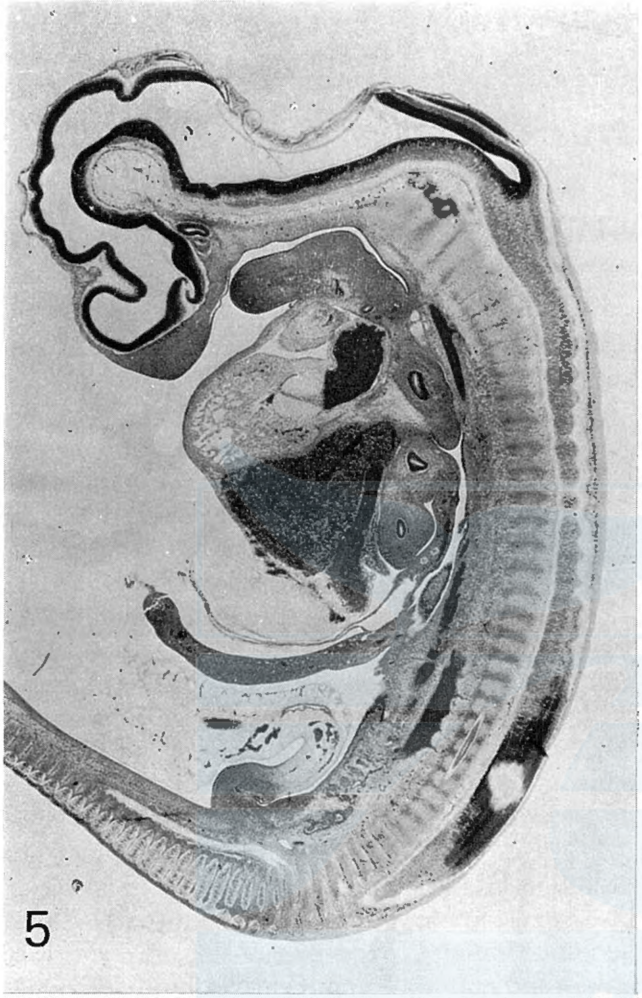
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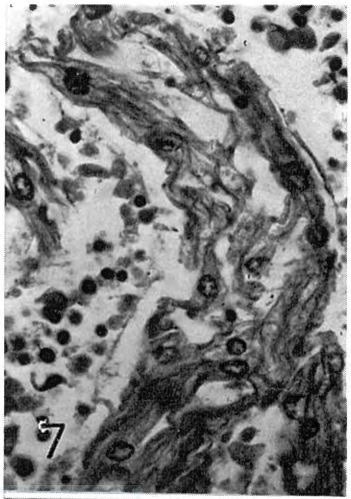
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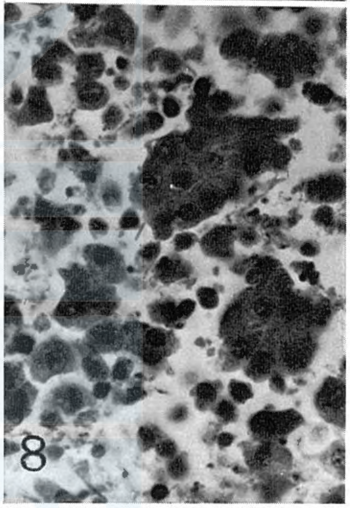
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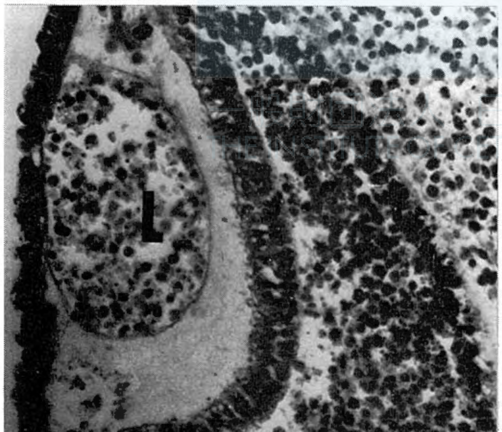
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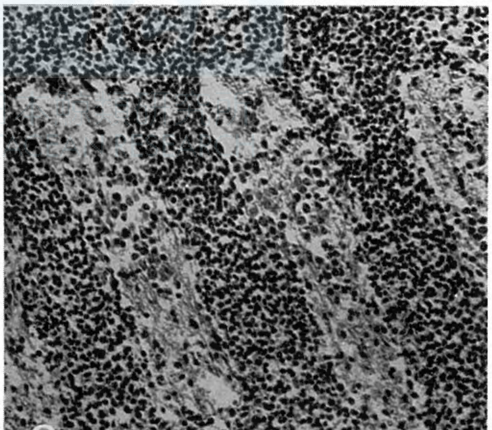
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ORGAN WEIGHTS OF *PONTOPORIA BLAINVILLEI* AND *PLATANISTA GANGETICA* (PLATANISTIDAE)

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Ninety-five specimens of the Franciscana *Pontoporia blainvillei* were collected by the University of Tokyo Cetacean Research Expedition at Punta del Diablo, Uruguay, from December 1972 to February 1973. Various measurements were taken on the visceral organs of 14 of those animals; they are shown in Table 1. Most of the organs were weighed fresh at Punta del Diablo, but some of them were weighed after fixation in 10% formalin solution.

The same organization collected 15 Susu, *Platanista gangetica* in the Brahmaputra River (Bangladesh) in 1969–'70 and similar quantitative data were obtained from 4 individuals (Table 2).

We wish to compare the figures obtained from the heart, the pancreas and the kidney of both species (*Pontoporia* and *Platanista*), limiting this paper to short notes on the raw data and percentages.

Heart. The relative weight of the heart varies from 0.42 to 0.69% in *Pontoporia* and from 0.22 to 0.28% in *Platanista.* The difference is notable. This may be because it is related to the difference of habitats, *Pontoporia* living in open coastal water and *Platanista* in quiet inland fresh water.

Pancreas. These figures also are higher in *Pontoporia* than in *Platanista.* The relative weight of the former ranges from 0.12 to 0.35% whereas that of the latter varies only from 0.04 to 0.09%. We should point out that, in *Platanista,* the pancreas occupies the usual retroperitoneal position but that, in *Pontoporia,* the greater part of the pancreas is enclosed in a mesentery, hanging more or less freely in the abdominal cavity. Also it is worth noticing that the organ is a bulky suboval mass in *Platanista* whereas that of the *Pontoporia* is flat and enclosed throughout most of the dorsal layer of the omentum majus.

Kidney. A similar difference is observed between the kidney of *Pontoporia* (0.30 to 0.43%) and that of *Platanista* (0.12 to 0.27%). Two specimens of *Platanista,* 117 and 199 cm long, had right kidneys weighing* 45 and 83 g respectively, but two specimens of *Pontoporia* approximately of similar size (113 and 171 cm) had right kidneys weighing 60 and 170 g, respectively. In the case of one *Inia geoffrensis* specimen with a body length of 204 cm, the kidney weight was 150 g. We get the impression again that the sea-living *Pontoporia* possesses a relatively larger organ

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* weight of renculi without interrencular connective tissue.

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than the fresh water inhabiting *Platanista* and *Inia*. This fact is reinforced by the figures obtained from three more sea-dolphins i.e., *Neophocaena phocaenoides* (body length 150 cm) with a kidney weighing 210 g, *Delphinus delphis* (177 cm) with a 154 g kidney and *Stenella coeruleoalba* (207 cm) with one of 186 g.

Observation of the lobulation of the kidneys also showed differences between the sea and river dolphins. We found 46 and 57 renculi in *Platanista*, 75 and 90 in *Pontoporia*, but 138 in *Neophocaena*, 269 in *Delphinus* and 270 in *Stenella*. However, notwithstanding that *Inia* lives in fresh water, it has a richly lobulated kidney with 215 renculi.

We plan to present more data in a forthcoming paper on other organs of the same species and to discuss more thoroughly the possible significance of the sea-habitat vs. the river-habitat concerning the relative size of those organs.

ACKNOWLEDGEMENTS

We are greatly indebted to Mr. R. L. Brownell, Jr., Department of Vertebrate Zoology, National Museum of Natural History, Smithsonian Institution, Washington, D. C., who arranged for us to collect materials and to the staff of the National Museum of Natural History, Montevideo, who helped make this project possible.

TABLE 1. BODY LENGTH, BODY WEIGHT AND ORGAN WEIGHTS OF 14 SPECIMENS OF *PONTOPORIA BLAINVILLEI*.

Specimen field number		RLB. 838	RLB. 836	RLB. 812	RLB. 805	RLB. 801
Body length		84.5 cm	90.5 cm	98.5 cm	105.0 cm	120.0 cm
Sex		M	M	F	M	F
Body weight		10.9 kg	11.8 kg	14.5 kg	14.5 kg	20.4 kg
Brain		160.0g (1.468%)	165.0 (1.398)		180.0 (1.241)	
Heart		73.5 (0.674)	50.0 (0.424)	100.0* (0.690)	68.5 (0.472)	130.0 (0.637)
Spleen			4.3 (0.0364)	1.7* (0.0117)	1.0 (0.00690)	
Lung	l	68.5 (0.628)	75.0 (0.636)	95.0* (0.655)	81.5 (0.562)	90.0 (0.441)
	r	80.0 (0.734)	80.0 (0.678)	120.0* (0.828)	83.5 (0.576)	105.0 (0.515)
Stomach		75.0 (0.688)	145.0 (1.229)	100.0* (0.690)	230.0 (1.586)	300.0 (1.471)
Intestine			770.0 (6.525)	360.0* (2.483)	800.0 (5.517)	1250.0 (6.127)
Liver		237.0 (2.174)	355.0 (3.008)	280.0* (1.931)	380.0 (2.621)	570.0 (2.794)
Pancreas		20.5 (0.188)	41.0 (0.347)	18.0* (0.124)	32.1 (0.221)	62.0 (0.304)
Kidney	l	43.0 (0.394)	41.0 (0.347)	62.0* (0.428)	56.0 (0.386)	72.3 (0.354)
	r	42.0 (0.385)	43.5 (0.369)	53.0* (0.366)	58.5 (0.403)	72.0 (0.353)
Adrenal	l	0.9 (0.00826)	0.4 (0.00339)	1.2* (0.00828)	0.7 (0.00483)	1.0 (0.00490)
	r	0.7 (0.00642)	0.6 (0.00508)	1.2* (0.00828)	0.7 (0.00483)	1.1 (0.00539)
Thyroid		2.4 (0.0220)	2.6 (0.0220)		2.0 (0.0138)	
Thymus		20.5 (0.188)	18.5 (0.157)	30.0* (0.207)		
Pituitary		0.15 (0.00138)				
Testis	l		0.9 (0.00763)		0.2 (0.00138)	
	r		0.8 (0.00678)		0.2 (0.00138)	
Epididymis	l		0.5 (0.00424)			
	r		0.5 (0.00424)			
Ovary	l			0.15* (0.00103)		0.2 (0.000980)
	r			0.15* (0.00103)		0.2 (0.000980)
Mammary gland	l					
	r					
Blubber		3900.0 (35.780)	4000.0 (33.898)		4450.0 (30.690)	5600.0 (27.451)
Skeletal muscle		3115.0 (28.578)	2605.0 (22.076)		5000.0 (34.483)	

* calculated from the value after preservation in 10% formalin solution.

Figures in parenthesis indicate percentages of body weight.

Continued . . .

TABLE 1. Continued.

Specimen field number		RLB. 807	RLB. 818	RLB. 808	RLB. 802	RLB. 870
Body length		123.0 cm	130.0 cm	131.5 cm	132.0 cm	136.0 cm
Sex		M	F	M	F	F
Body weight		23.1 kg	25.4 kg	29.5 kg	28.6 kg	29.0 kg
Brain			215.0 (0.846)			230.0 (0.793)
Heart		150.0g (0.649)	130.0 (0.512)	145.0 (0.492)	140.0 (0.490)	150.0 (0.517)
Spleen		5.4 (0.0234)	4.2 (0.0165)	5.3 (0.0180)	4.3 (0.0150)	2.8 (0.00966)
Lung	l	150.0 (0.649)	145.0 (0.571)	173.0 (0.586)	110.0 (0.385)	125.0 (0.431)
	r	160.0 (0.693)	175.0 (0.689)	235.0 (0.797)	140.0 (0.490)	175.0 (0.603)
Stomach			350.0 (1.378)	500.0 (1.695)	450.0 (1.573)	410.0 (1.414)
Intestine		1250.0 (5.411)	1600.0 (6.299)	1400.0 (4.746)	2150.0 (7.517)	1700.0 (5.862)
Liver		650.0 (2.814)	620.0 (2.441)	850.0 (2.881)	700.0 (2.448)	800.0 (2.759)
Pancreas		58.0 (0.251)	75.0 (0.295)	62.0 (0.210)	63.5 (0.222)	91.0 (0.314)
Kidney	l	72.0 (0.312)	90.0 (0.354)	120.0 (0.407)	95.5 (0.334)	100.0 (0.345)
	r	73.0 (0.316)	88.0 (0.346)	115.0 (0.390)	91.0 (0.318)	87.0 (0.300)
Adrenal	l	0.6 (0.00260)	1.1 (0.00433)		1.3 (0.00455)	1.1 (0.00379)
	r	0.7 (0.00303)	1.1 (0.00433)		1.3 (0.00455)	1.0 (0.00345)
Thyroid		3.0 (0.0130)	3.7 (0.0146)	3.2 (0.0108)	6.0 (0.0210)	3.0 (0.0103)
Thymus		13.5 (0.0584)	21.5 (0.0846)	8.5 (0.0288)	48.5 (0.170)	37.0 (0.128)
Pituitary			0.2 (0.000787)			0.15 (0.000517)
Testis	l	0.5 (0.00216)		3.2 (0.0108)		
	r	0.4 (0.00173)		3.2 (0.0108)		
Epididymis	l	0.6 (0.00260)		3.8 (0.0129)		
	r	0.5 (0.00216)		3.2 (0.0108)		
Ovary	l		0.25 (0.000984)		0.15 (0.000524)	0.2 (0.000690)
	r		0.2 (0.000787)		0.20 (0.000699)	0.25 (0.000862)
Mammary gland	l					
	r					
Blubber		7250.0 (31.385)	8610.0 (33.898)	9130.0 (30.949)	8350.0 (29.196)	8530.0 (29.414)
Skeletal muscle		8630.0 (37.359)	8700.0 (34.252)	10300.0 (34.915)	10400.0 (36.364)	10140.0 (34.966)

* calculated from the value after preservation in 10% formalin solution.
Figures in parenthesis indicate percentages of body weight.

Continued . . .

TABLE 1. Continued.

Specimen field number		RLB. 822	RLB. 835	RLB. 837	RLB. 803
Boday length		143.5 cm	144.5 cm	160.0 cm	171.0 cm
Sex		F	M	F	F
Body weight		33.1 kg	35.4 kg	45.4 kg	52.2 kg
Brain		235.0g (0.710)	240.0 (0.678)	205.0 (0.452)	250.0 (0.479)
Heart		170.0 (0.514)	170.0 (0.480)	235.0 (0.518)	260.0 (0.498)
Spleen		4.5 (0.0136)	3.5 (0.00989)	7.0 (0.0154)	3.4*(0.00651)
Lung	l	160.0 (0.483)	235.0 (0.664)	315.0 (0.694)	300.0 (0.575)
	r	165.0 (0.498)	260.0 (0.734)	255.0 (0.562)	350.0 (0.670)
Stomach		500.0 (1.511)	500.0 (1.412)	750.0 (1.652)	800.0 (1.533)
Intestine		2000.0 (6.042)	2050.0 (5.791)	2400.0 (5.286)	2600.0 (4.981)
Liver		950.0 (2.870)	900.0 (2.542)	1150.0 (2.533)	1350.0*(2.586)
Pancreas		100.0 (0.302)	95.0 (0.268)	135.0 (0.297)	110.0*(0.211)
Kidney	l	137.0 (0.414)	120.0 (0.339)	150.0 (0.330)	
	r	125.0 (0.378)	115.0 (0.325)	145.0 (0.319)	
Adrenal	l		1.6 (0.00452)	1.3 (0.00286)	
	r	1.4 (0.00423)	1.2 (0.00339)	1.3 (0.00286)	
Thyroid		6.1 (0.0184)	5.0 (0.0141)	5.6 (0.0123)	5.3 (0.0102)
Thymus		50.0 (0.151)	36.0 (0.102)	37.2 (0.0819)	
Pituitary			0.3 (0.000847)	0.6 (0.00132)	0.4 (0.000766)
Testis	l		4.1 (0.0116)		
	r		3.5 (0.00989)		
Epididymis	l		1.2 (0.00339)		
	r		1.4 (0.00395)		
Ovary	l	2.0 (0.00604)		4.8 (0.0106)	6.3 (0.0121)
	r	0.3 (0.000906)		1.6 (0.00352)	0.8 (0.00153)
Mammary gland	l	14.6 (0.0441)		220.0 (0.485)	270.0 (0.517)
	r	17.9 (0.0541)		220.0 (0.485)	300.0 (0.575)
Blubber		8650.0 (26.133)	10170.0 (28.729)	12250.0 (26.982)	13320.0 (25.52)
Skeletal muscle		12700.0 (38.369)	17200.0 (48.588)	18400.0 (40.529)	22070.0 (42.28)

* calculated from the value after preservation in 10% formalin solution.
Figures in prenthesis indicate percentages of body weight.

TABLE 2. BODY LENGTH, BODY WEIGHT AND ORGAN WEIGHTS OF 4 SPECIMENS OF *PLATANISTA GANGETICA*.

Specimen field number		No. 16	No. 18	No. 19	No. 20
Body length		120.5 cm	126.0 cm	122.0 cm	199.0 cm
Sex		F	F	M	M
Body weight		17.0 kg	17.0 kg	22.5 kg	84.0 kg
Brain		236.0 g (1.388%)			
Heart		40.0* (0.235)	47.6 (0.280)	49.6 (0.220)	210.9 (0.251)
Spleen		3.0* (0.0176)		1.7 (0.00756)	8.4 (0.010)
Lung	l	170.0* (1.000)	101.8 (0.599)	114.0 (0.507)	700.0 (0.833)
	r	154.0* (0.906)	100.8 (0.593)	131.0 (0.582)	610.0 (0.726)
Stomach		308.0* (1.812)			
Intestine					
Liver		460.0* (2.706)	420.0 (2.471)	300.0 (1.333)	1120.0 (1.333)
Pancreas		15.0* (0.0882)		10.2 (0.0453)	34.3 (0.0408)
Kidney	l	45.0* (0.265)	30.7 (0.181)	26.2 (0.116)	109.0 (0.130)
	r	42.0* (0.247)	36.2 (0.213)	27.8 (0.124)	101.5 (0.121)
Adrenal	l		0.3 (0.00176)		3.6 (0.00429)
	r		0.6 (0.00352)	0.5 (0.00222)	3.2 (0.00381)
Thyroid			1.0 (0.00588)	3.0 (0.0133)	
Thymus					
Pituitary					
Testis	l				520.0 (0.619)
	r				590.0 (0.702)
Epididymis	l				
	r				
Ovary	l	0.4* (0.00235)	0.8 (0.00471)		
	r	0.4* (0.00235)	0.8 (0.00471)		
Mammary gland	l				
	r				

* calculated from the value after preservation in 10% formalin solution.
Figures in parenthesis indicate percentages of body weight.

SURFACE TEMPERATURE FIELD IN THE CROZET AND KERGUELEN WHALING GROUNDS

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ABSTRACT

Some oceanographic conditions in the summer season at the surface in the Crozet and Kerguelen Ridge regions, where the good whaling grounds of baleen whales occur, are discussed on the basis of the distribution of the surface temperature observed by the Japanese whaling fleets in the 1965/66 to 1972/73 Antarctic seasons.

The surface isotherms bend northwards over the submarine rising around the Prince Edward, Crozet and Kerguelen Islands. These bends of the isotherms suggest to reflect the bending of the surface current, and that it is presumably influenced by the bottom topography. They may be also suggested that the convergence efficiency of the current is comparatively intense north and east of these submarine risings.

INTRODUCTION

It is well known that the good whaling grounds of baleen whales occur in the Crozet and Kerguelen Ridge regions. In these two regions right whales were taken by the old American whalers mainly in the 19th century and pigmy blue whales were also taken there in the early 1960's. Recently the Japanese whaling fleets have been often searching for the favorite haunts of the sei and fin whales in the regions.

We have little knowledge of the general oceangoraphic conditions in the Crozet and Kerguelen whaling grounds, though the oceanographic conditions are the close living evnvironment to the whales. A knowledge of oceanographic conditions is fundamentally necessary to think systematic study on the environment of the habits of various marine organisms. From this point of view, therefore, the purpose of the present study is to discuss the oceanographic conditions at the surface in the Crozet and Kerguelen Ridge regions on the basis of the surface temperature distribution, which was observed by the Japanese whaling fleets.

MATERIAL AND METHOD

The whaling fleets have been supplying us with the data of the oceanographic conditions in the different whaling grounds. They are temperatures observed by an electric thermometer, of which sensor is fixed to the bottom of a factory ship (ca. 10 m depth) and a scouting boat (ca. 5 m depth). As the surface layer down to a few

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ten meters in the Antarctic Ocean is roughly homogeneous in temperature, it seems to be reasonable to consider that there is no difference in the temperatures between 5 and 10 m depth. Therefore, they are taken as same and defined here as the surface temperature.

The surface temperatures were derived from " The survey report of the whaling grounds by a scouting boat " in the 1965/66 to 1972/73 Antarctic seasons and " The weather and oceanographic conditions at the noon position of a factory ship " in the 1957/58 to 1972/73 Antarctic seasons. A one degree square grid was adopted in making a monthly chart of the mean surface temperature, and isotherms were drawn by interpolation.

The Far Seas Fisheries Research Laboratry, Fisheries Agency of Japan kindly supplied me with the materials for this study.

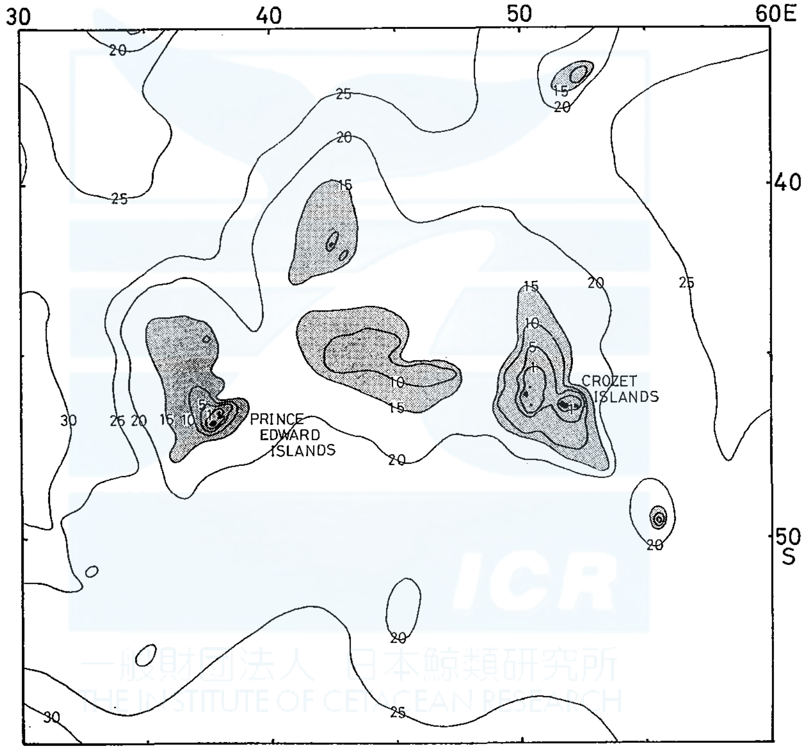

Fig. 1. Chart of the Crozet Ridge region showing general bathymetry. Depths in the 100 fathoms. (After U.S. Chart H.O. Misc. 15, 254–12).

The Crozet and Kerguelen Ridge regions are shown with bathymetric contours in Figs. 1 and 2. Although the submarine rising around the Prince Edward and Crozet Islands is not generally termed the Crozet Ridge (Herdman, Eiseman and Overy, 1965), the Crozet Ridge is named in this study after "Atlas zur Ozeanographie " by Dietrich and Ulrich (1968).

Fig. 2. Chart of the Kerguelen Ridge region showing general bathymetry. Depths in the 100 fathoms. (After U.S. Chart H.O. Misc. 15, 254–12).

LOCATION OF WHALING GROUNDS

Before discussing the features of the temperature distribution at the surface in the Crozet and Kerguelen Ridge regions, the features of the catch distribution of the sei and fin whales, which are the most important baleen whales as well as the minke whale for the recent whaling industry, is summarized.

In these two regions right whales were abundantly caught by the old American whalers mainly in the 19th century, and pigmy blue whales also were bulkly caught there in the early 1960's. The chart of the catch distribution of the right whale by Townsend (1935) and one of the pigmy blue whale by Ichihara (1966) are very usefull. According to them, the good whaling grounds of the right whale were located in the waters adjacent to the Crozet and Kerguelen Islands and ones for the pigmy blue whale were rather distributed over the Kerguelen and Crozet Ridges. Sei whales have been abundantly caught in these regions since the 1964/65 Antarctic season and fin whales have been frequently caught in the north of 60°S since the 1957/58 Antarctic season. The catch distribution of the sei and fin whales are shown in Figs. 3, 4, 5 and 6.

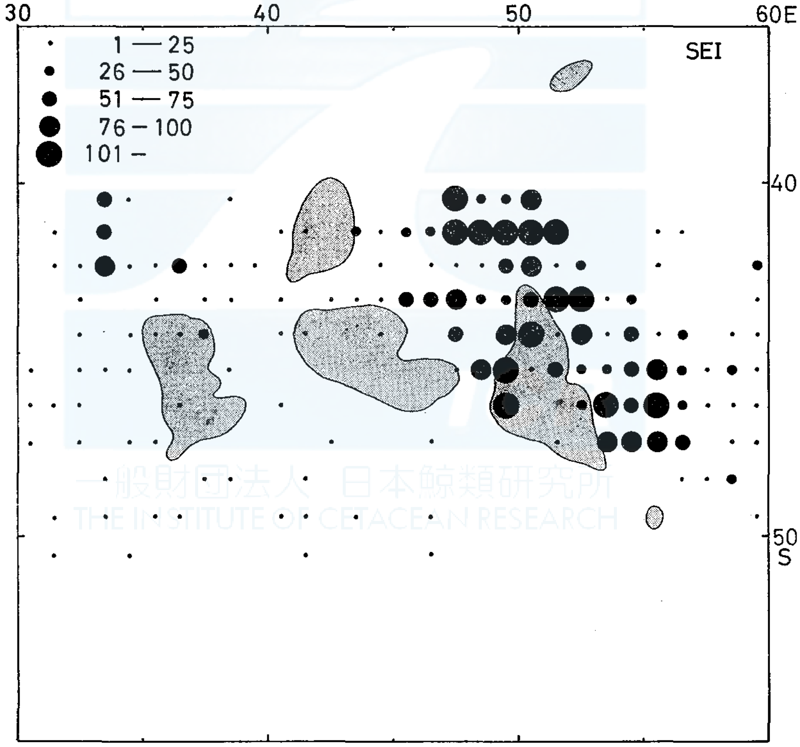

Fig. 3. Distribution of sei whales caught by Japanese Antarctic whaling fleets in the Crozet Ridge region from the 1965/66 to the 1972/73 seasons. Light shading: depths less than 1,500 fathoms (about 3,000 m).

The Crozet Ridge Region

Sei whales were caught abundantly in the submarine rising around the Crozet Islands, though their few catches are distributed widely on the Crozet Ridge. The good whaling grounds of the sei whale are located in the adjacent waters to the Crozet Islands. Although in the shallow waters around the Prince Edward Islands it is somewhat similar in appearance to the Crozet Islands region, catches of sei whales have been a little less than the former. The fin whale, on the other hand, also distributed widely on the ridge, and a great number of their catches is located on the far south-west waters to the Prince Edward Islands.

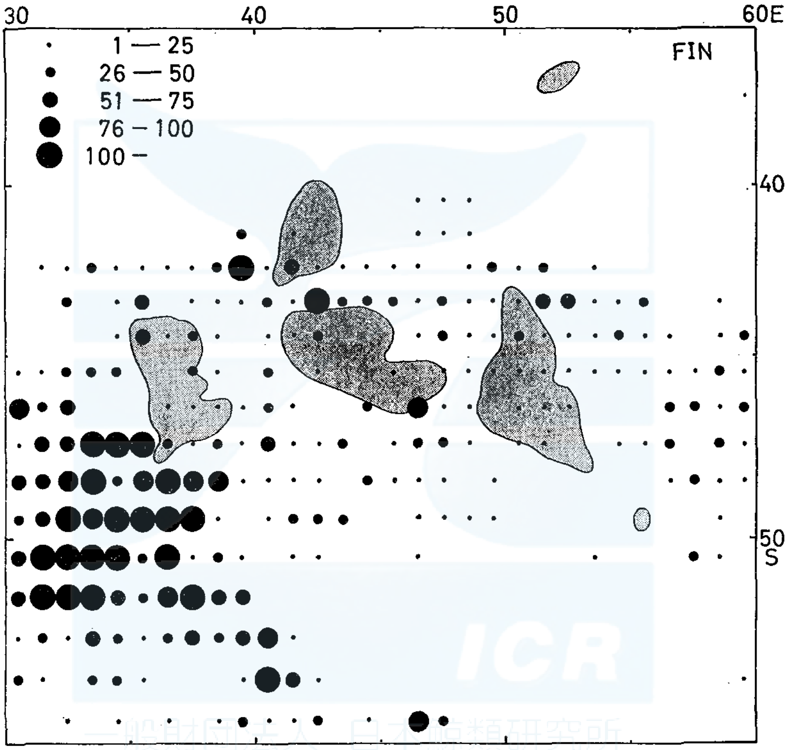

Fig. 4. Distribution of fin whales caught by Japanese Antarctic whaling fleets in the Crozet Ridge region from the 1957/58 to the 1972/73 seasons.

The Kerguelen Ridge Region

The catches of sei and fin whales are widely distributed on the ridge, though the features of their catch distribution is to some extent different from one on the southern part of the ridge. There are two heavy catches areas of sei whales over the ridge. It appears that the whaling grounds of the sei and fin whales between 40° and 45° S are related to the Subtropical Convergence. The fin whales seem to be distributed dominantly south of about 53° S. These two species of whales have a

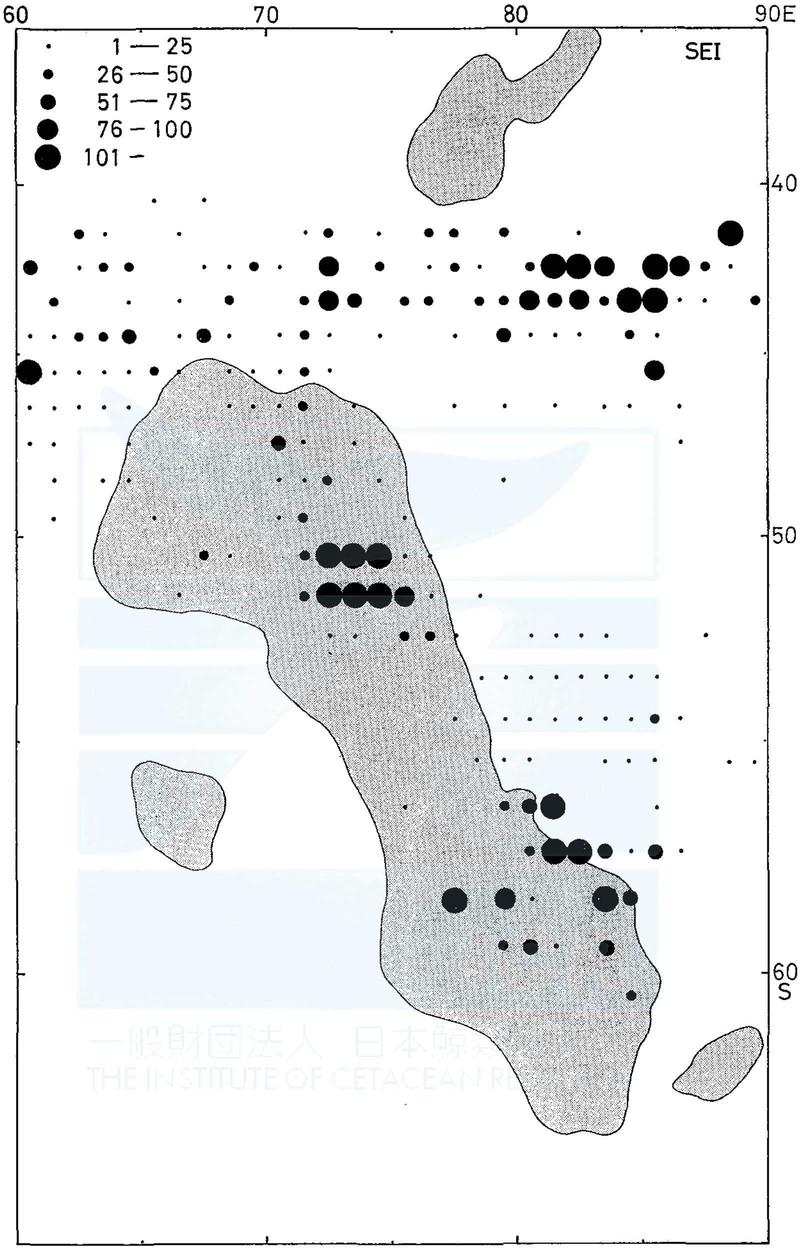

Fig. 5. Distribution of sei whales caught by Japanese Antarctic whaling fleets in the Kerguelen Ridge region from the 1965/66 to the 1972/73 seasons. Light shading: depths less than 1,500 fathoms (about 3,000 m).

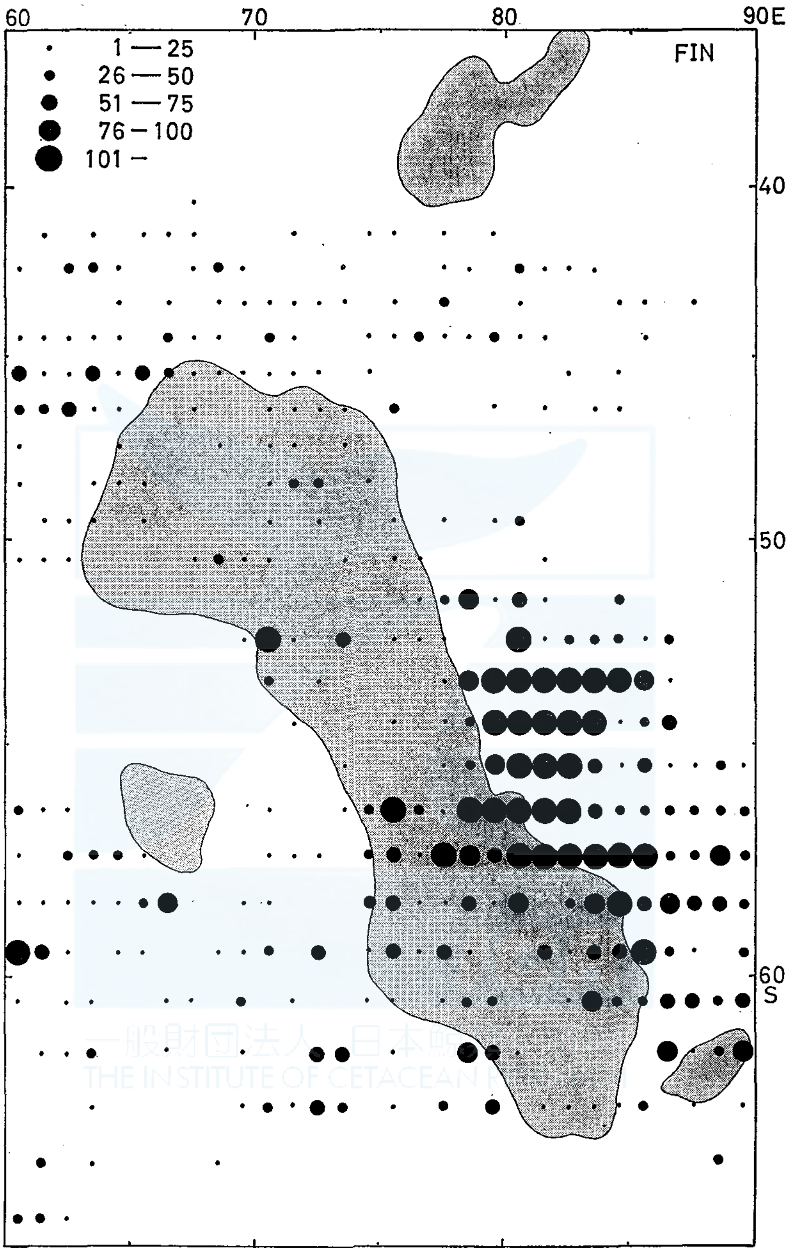

Fig. 6. Distribution of fin whales caught by Japanese Antarctic whaling fleets in the Kerguelen Ridge region from the 1957/58 to the 1972/73 seasons.

strong tendency to be distributed on to the eastern slope of the ridge and a few ones have been caught on to the western slope of it, except in the higher latitudes south of about 56° S, where the fin whales are widely distributed from west to east of the ridge.

The different features of the catch distribution of the sei and fin whales as mentioned above may be partly caused by the difference of their foods and habitat segregation. In the Subantarctic regions of these two whaling grounds, the quantitatively important food organisms of the sei whale is *Parathemisto gandichaudii*, and *Euphausia vallentini* is important as a favorite food of the fin whale (Nemoto, 1959, 1962, 1970; Nasu, 1966; Kawamura, 1970). I do not intend to mention further a pattern of their catch distribution, because it is not the main purpose of the present study.

SURFACE OCEANOGRAPHIC CONDITIONS

Figs. 7–21 show the distribution of the surface temperature in the 1957/58 to 1972/73 Antarctic whaling seasons. Some oceanographic conditions in the Crozet and Kerguelen Ridge regions are discussed on the basis of these distribution of the surface isotherms.

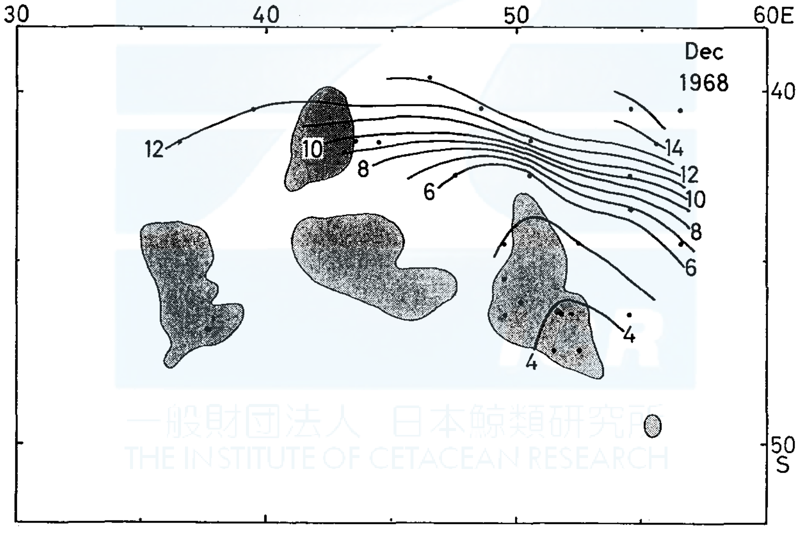

Fig. 7. Surface temperature (°C) in December 1968.

The Crozet Ridge Region

The distibution of th emonthly mean surface temperature in this region are shown in Figs. 7–14. The isotherms are remarkably bending, which is conspicuous in the submarine rising region around the Crozet Islands and less conspicuous in the Prince Edward Islands than the former, namely northward on the rising and

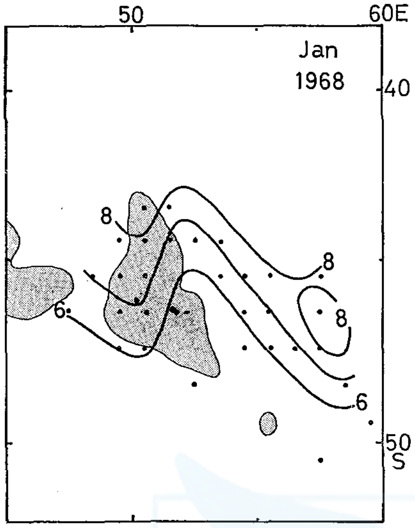

Fig. 8. Surface temperature (°C) in January 1968.

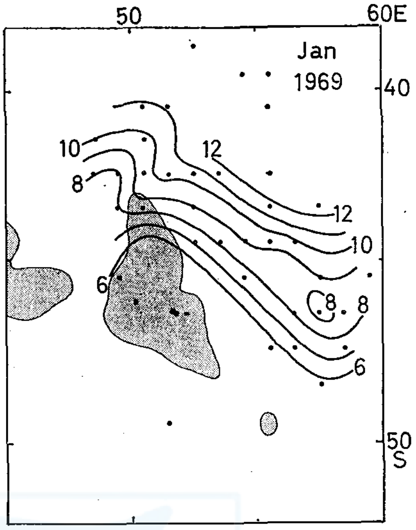

Fig. 9. Surface temperature (°C) in January 1969.

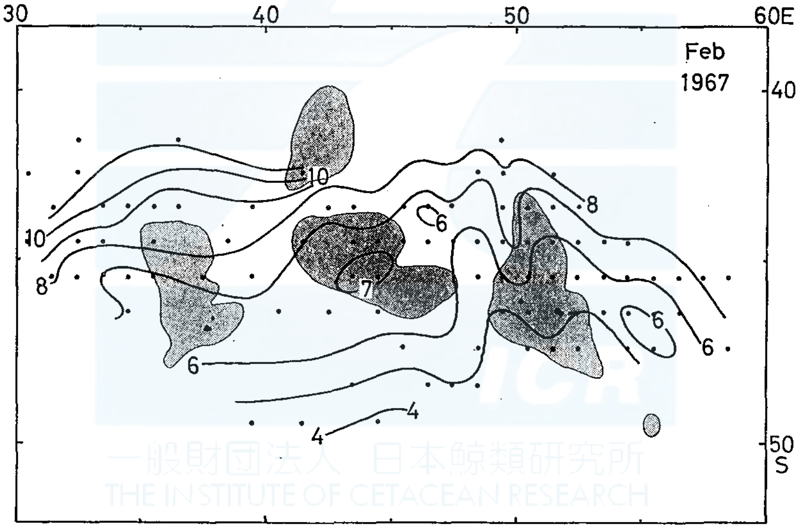

Fig. 10. Surface temperature (°C) in February 1967.

southward on the west and the east sides of it, with some irregularities. Such tendency of the isothermal pattern is especially distinct in the Crozet Islands region, where data are more abundant than in elsewhere. In the Prince Edward Islands region, however, the similar bend are not so clear as in that region in a certain months, perhaps owing to the lack of data.

The bend of isotherms in the adjacent waters to the Crozet Islands in winter

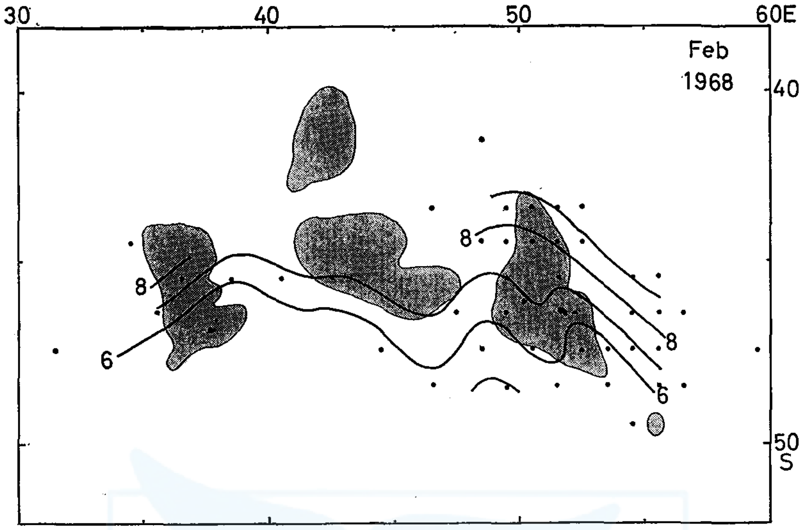

Fig. 11. Surface temperature (°C) in February 1968.

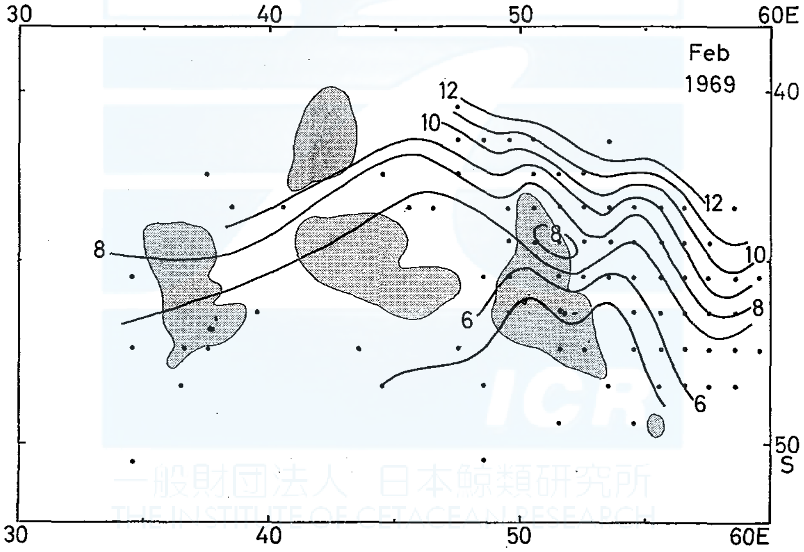

Fig. 12. Surface temperature (°C) in February 1969.

have been already shown by Darbyshire (1964), Visser and Niekerk (1965), Orren (1966) and Nel (1968). By these charts, therefore, it appears that such feature of the surface isotherms to be a permanent one. A steep temperature gradient still occurs in the adjacent waters to south of the Subtropical Convergence. Its oceanographic conditions seem to intencify an effect of the convergent movement in accompany with the Subtropical Convergence, lying about 42° S in the South West

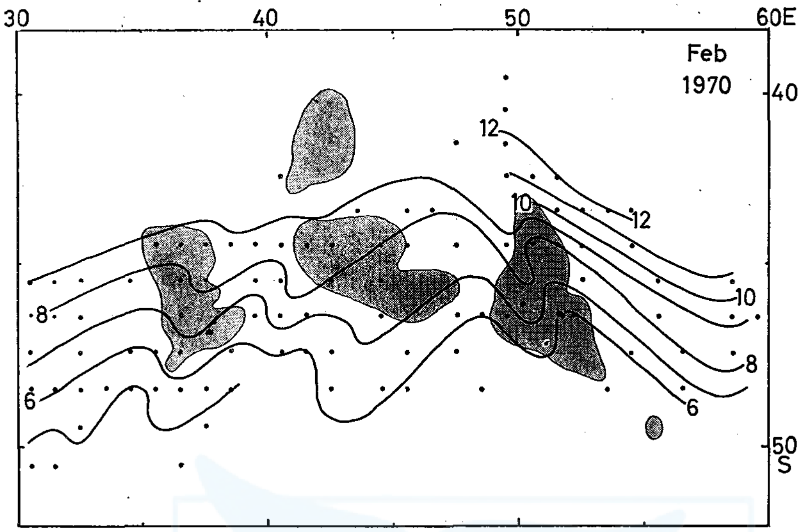

Fig. 13. Surface temperature (°C) in February 1970.

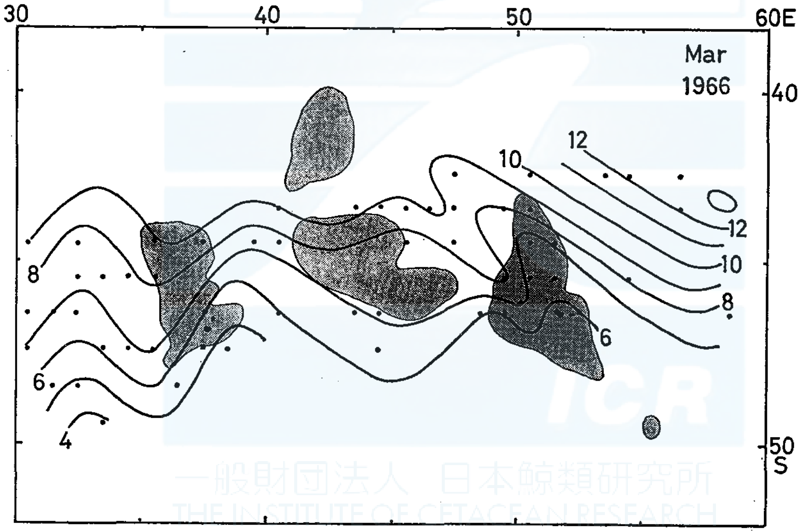

Fig. 14. Surface temperature (°C) in March 1966.

Indian Ocean (Deacon, 1937a; Orren, 1966). It also seems that the Subtropical Convergence bends soutwards on the eastern side of the Crozet Islands, presumably in approximately 60° E. The Subtropical Convergence by Deacon (1937a) also meanders southwards in approximately 60° E.

The Antarctic Convergence, which is one of the major features in the Antarctic Ocean, seems to run across the submarine rising around the Crozet Islands in December 1968, considering the location of the 4°C isotherm at the surface, which is one of the valid indication of the Antarctc Convergence (Deacon, 1937a; Mackintosh, 1946; Houtman, 1968). The 4°C isotherm, however, does not lie on the Crozet Ridge in January, February and March. The greater parts of the Crozet Ridge region, therefore, seems to be usually between the Subtropical and Antarctic Convergences, and so this region is occupied by the major Subantarctic Surface Water.

It is well known that the temperature distribution well reflects the feature of the current. If we accept this general view, the current deflects to the left (north) on approaching a submarine rising around the Prince Edward and the Crozet Islands, and after having passed the rising it deflects to the right (south). Such current deflection over the submarine rising seems to be variable probably under the influence of the bottom topography.

These findings support the view by Darbyshire (1964) and by Visser and Niekerk (1965), who described the current deflection to the left over the submarine rising around the Crozet Islands and the influence of the bottom topography on the ocean current. Orren (1966) also indicated a northward flow of the cold Subantarctic Surface Water in the Crozet Islands region, probably occasioned by a northward movement of the Antarctic Convergence south of that islands.

The Kerguelen Ridge Region

Figs. 15–21 show the distribution of the monthly mean surface temperature in this region. It is clear that the isotherms are bending in a similar way as in the Crozet Ridge region, namely with a northward bend over the ridge and a southward one on the east side of it. The 4°C isotherm lies near the 50° S parallel across the ridge with bending from the west to the east. Furthermore after passing the ridge the Antarctic Convergence bends down to about 55°S in approximately 90°E. Its position roughly coincides with the convergence by Deacon (1937a) or by Mackintosh (1946). In addtion to this convergence, a sharp gradient in the surface temperature occurs on the north slope of the ridge.

The distriburion of the montly mean surface temperature suggests that the current deflects to the left (north) on approaching the Kerguelen Ridge and after having passed the ridge it bends to right (south). These deflection of the surface current in the ridge region seems to be probably influenced by the bottom topography and to be variable as well as in the Crozet Ridge region.

Deacon (1973a, b) and Sverdrup (1942) described the current bends to the north and to the south on passing over the Kerguelen Ridge, and that the current deflection is probably under the influence of the bottom topography.

The deflection for a current on passing over the rising in the bottom topography may be anticipated on the theoritical grounds—in the southern hemisphere a current will deflect to the left as the sounding decreases and to the right as it increase (Deacon, 1937a, b; Sverdrup, 1941; Neuman, 1960), and in the case of eastern flowing is the West Wind Drift a northward movement is expected. These features are actually observed in many ridge regions, besides these two, in the Antarctic

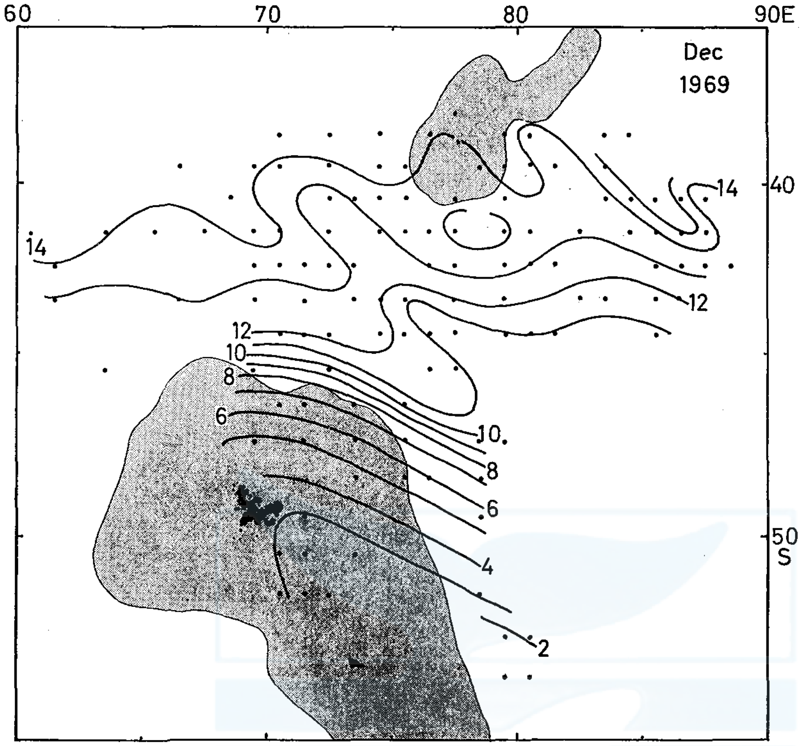

Fig. 15. Surface temperature (°C) in December 1969.

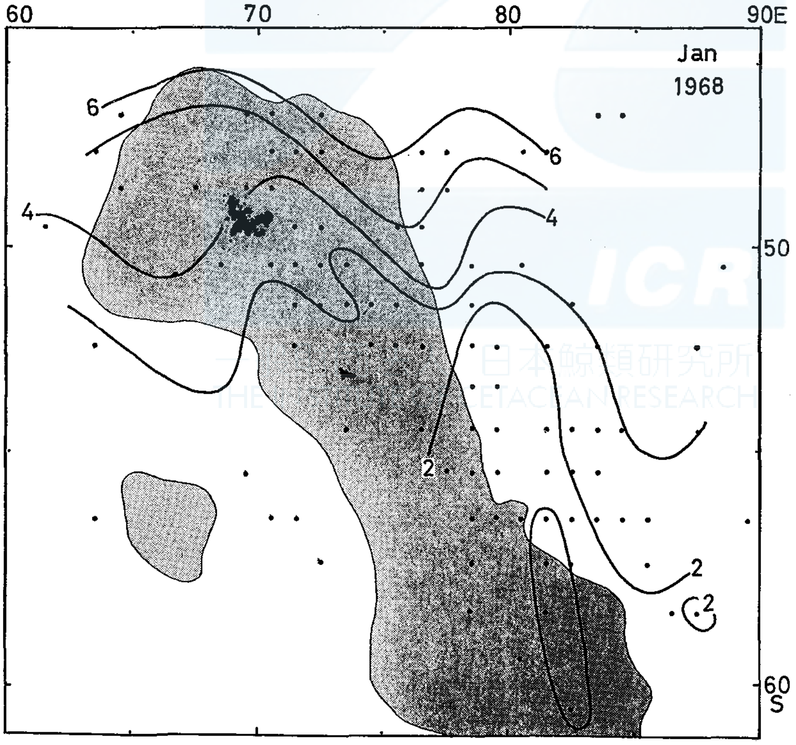

Fig. 16. Surface temperature (°C) in January 1968.

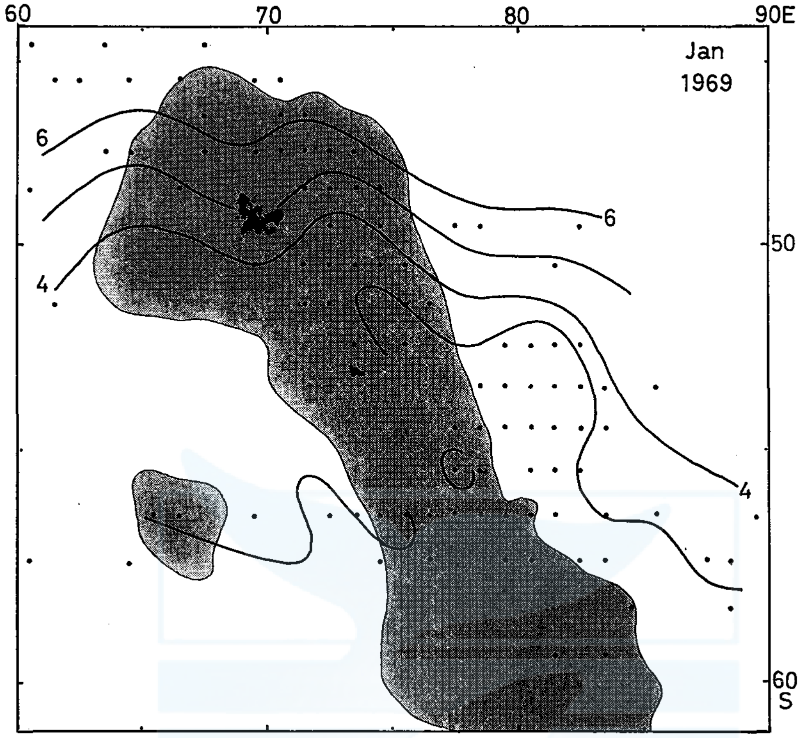

Fig. 17. Surface temperature (°C) in January 1969.

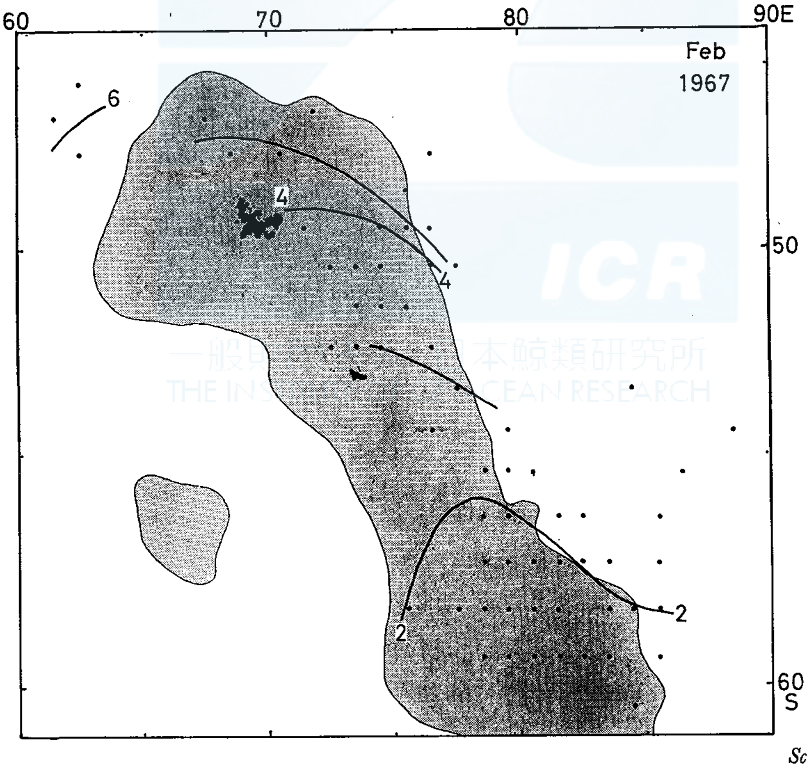

Fig. 18. Surface temperature (°C) in February 1967.

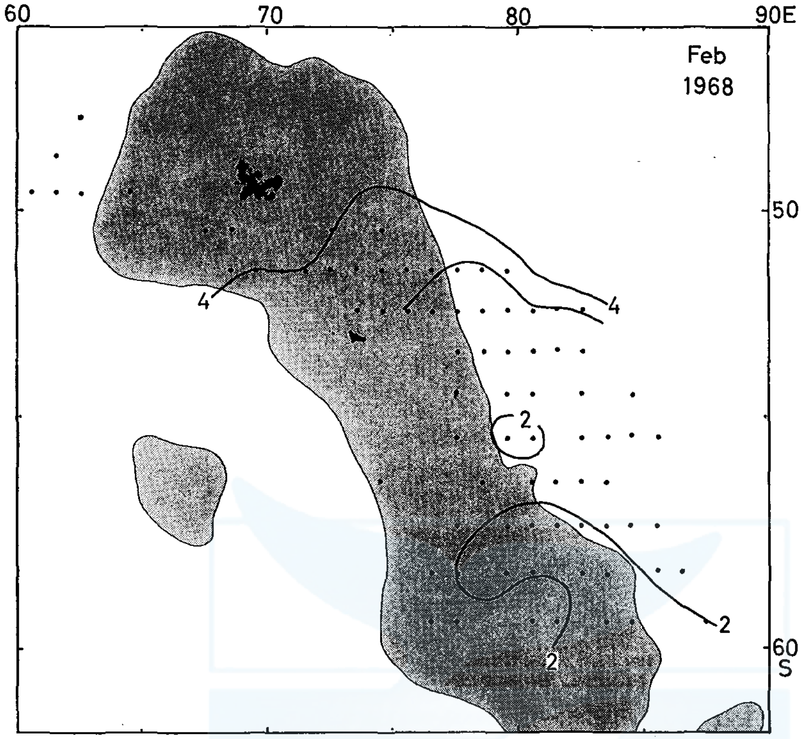

Fig. 19. Surface temperature (°C) in February 1968.

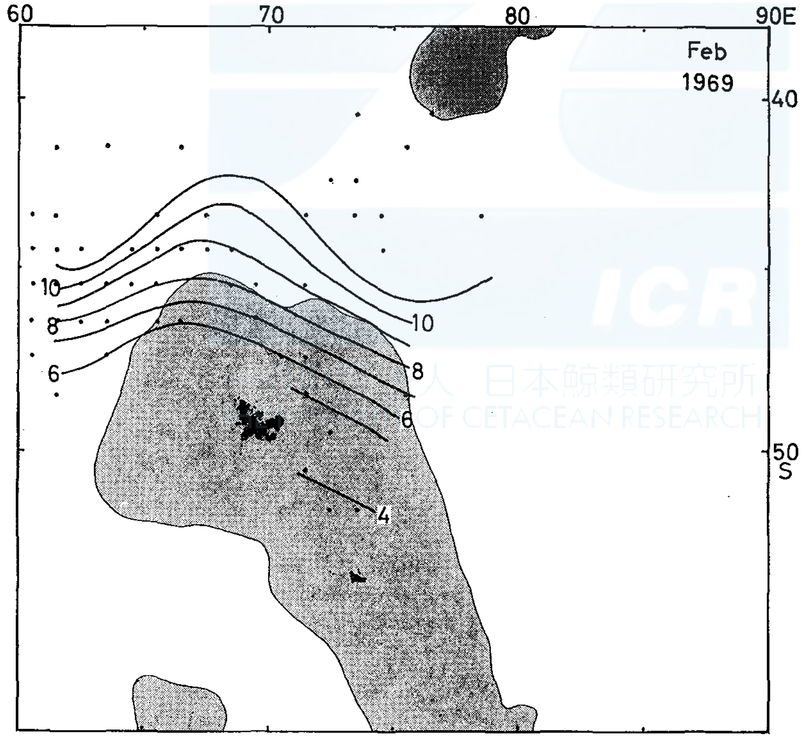

Fig. 20. Surface temperature (°C) in February 1969.

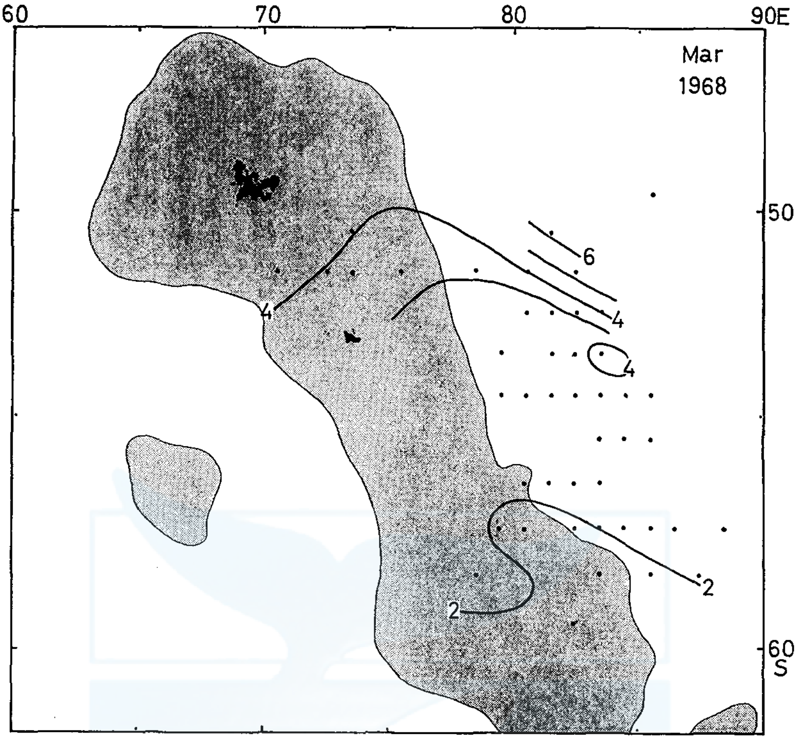

Fig. 21. Surface temperature (°C) in March 1968.

Ocean (Deacon, 1937a, b; Sverdrup *et al.*, 1942; Midttun and Natvig, 1957; Burling, 1961; Harris, 1970) and they support the theory.

ACKNOWLEDGEMENTS

I wish to express my thanks to Dr. Keiji Nasu of the Far Seas Fisheries Laboratory, Fisheries Agency of Japan and Professor Michitaka Uda of the Department of Marine Science and Technology, Tokai University for suggesting this study. Thanks are also due to Dr. Ichiro Yamanaka of the Far Seas Fisheries Laboratory, Fisheries Agency of Japan for some valuable suggestions and for reading this manuscript.

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ICR

THE VOYAGE OF THE KONAN MARU NO. 16 TO THE ANTARCTIC WHALING GROUNDS

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Whales Research Institute, Tokyo

ABSTRACT

Three major Japanese whaling companies, the Kyokuyo, the Nippon Suisan and the Taiyo Gyogyo Co. Ltds., made the joint observation on the distribution and abundance of whales by the whale catcher Konan Maru No. 16 in the Australian and New Zealand sector of the Antarctic Ocean from January 10 to March 8, 1973.

The number of whales sighted in about eight weeks and on the passage of 9,377 nautical miles was not great. We saw only 20 fin, 16 sei and 7 humpback whales. The blue and right whales was not encountered at all. The minke and sperm whales sighted are rather great; the former is 251 and the latter 108. 5 fin, 2 sei, 2 humpback and 8 sperm whales were effectively marked.

Oceanic observations at the surface were also worked during the voyage. The locations of the Subtropical and Antarctic Convergences and the Australasian Subantarctic Front on four traverse courses across the Antarctic Ocean are determined by the steep meridional gradient in the surface temperature and salinity. The distibution of the pack-ice, icebergs and patch of the krill at the surface are also shown.

INTRODUCTION

In order to contribute to the stock assessment of whales in the Antarctic Ocean, the major whaling companies, the Kyokuyo, the Nippon Suisan and the Taiyo Gyogyo Co. Ltds., made the joint observation on the distribution and abundance of whales by the whale catcher Konan Maru No. 16 in the Australian and New Zealand sector of the Antarctic Ocean from January 10 to March 8, 1973. The principal purpose of the voyage was: 1) to obtain the latest information on the distribution and abundance of whales in that area; 2) to mark as many whales as possible; 3) to observe some oceanic conditions at the surface. In those days Japanese whaling fleets were not operating in high latitudes south of Australia and New Zealand. We, therefore, have little information on the distribution and abundance of whales and on some oceanic conditions at the surface in the region, in which a great number of the blue, humpaback and fin whales had been taken in the early Antarctic whaling age.

The Konan Maru No. 16, belonging to the Nippon Suisan Co. Ltd., has a gross tonnage of 739.82, a disel engine of 3,280 HP, a cruising speed of 13.75 knots.

The watcher for whales on the whale cathcer consited of T., Yamada, Captain

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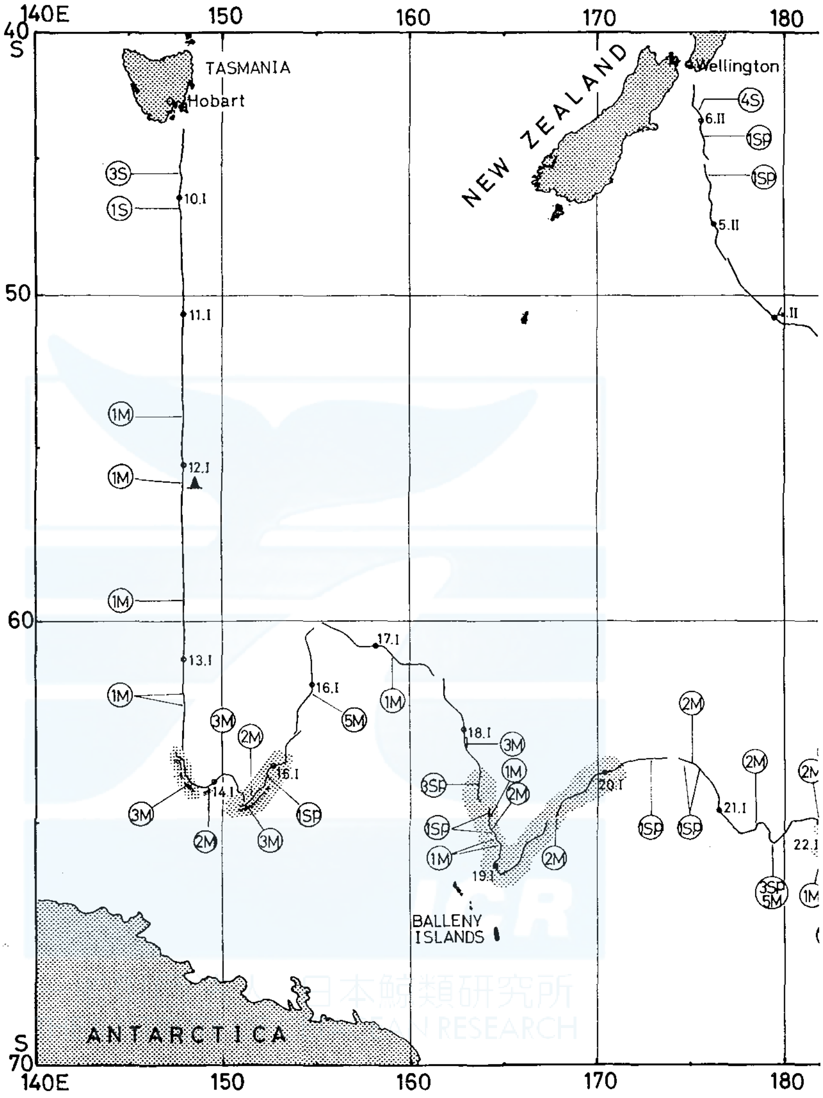
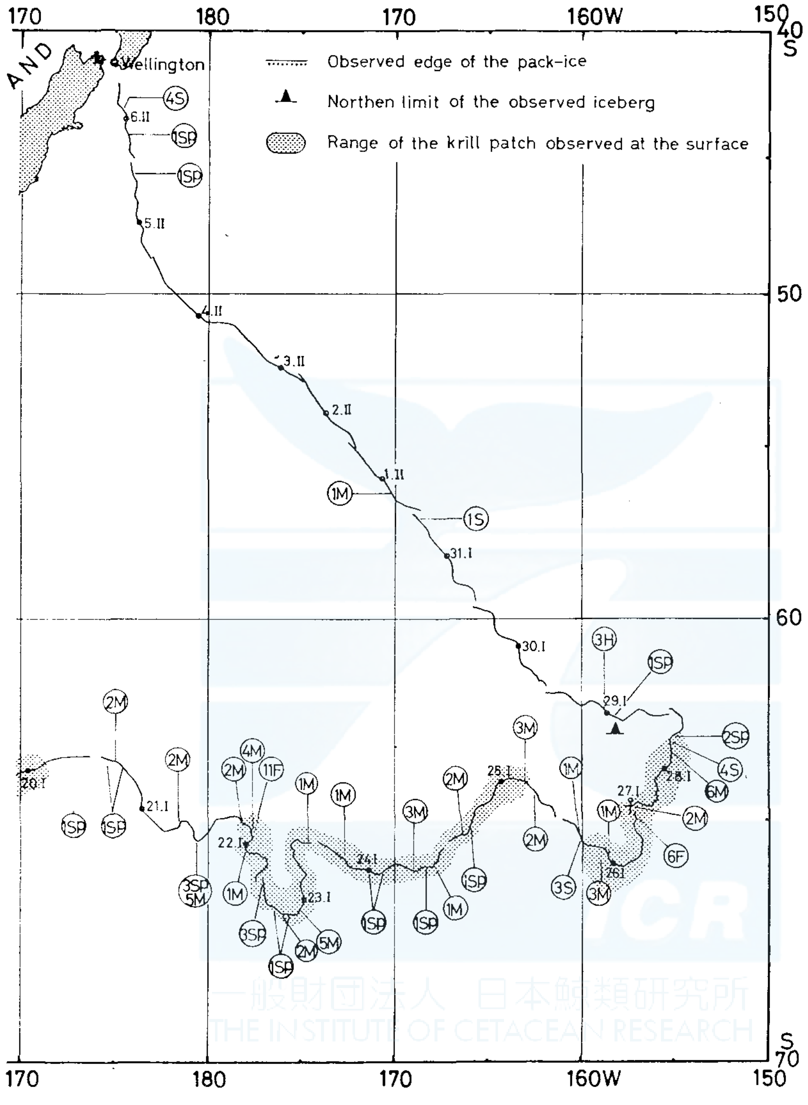


Fig. 1. Voyage of the Konan Maru No. 16
the first period from January 10 to Feb-
major species sighted, observed edge of
encountered on the traverse courses,



in the Antarctic whaling grounds during ruary 6, 1973. Ship's track, whales of the pack-ice, northern limit of icebergs and range of the krill patch observed.

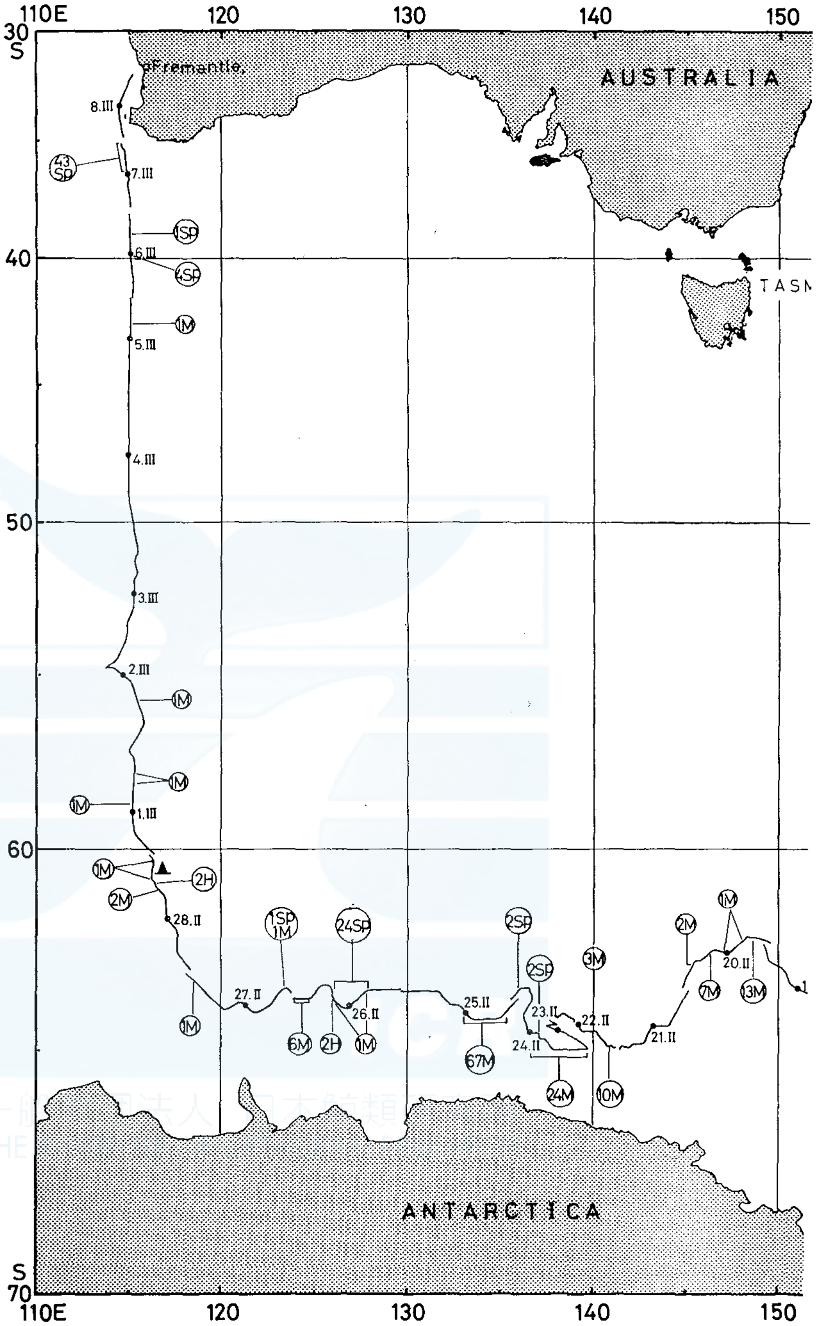
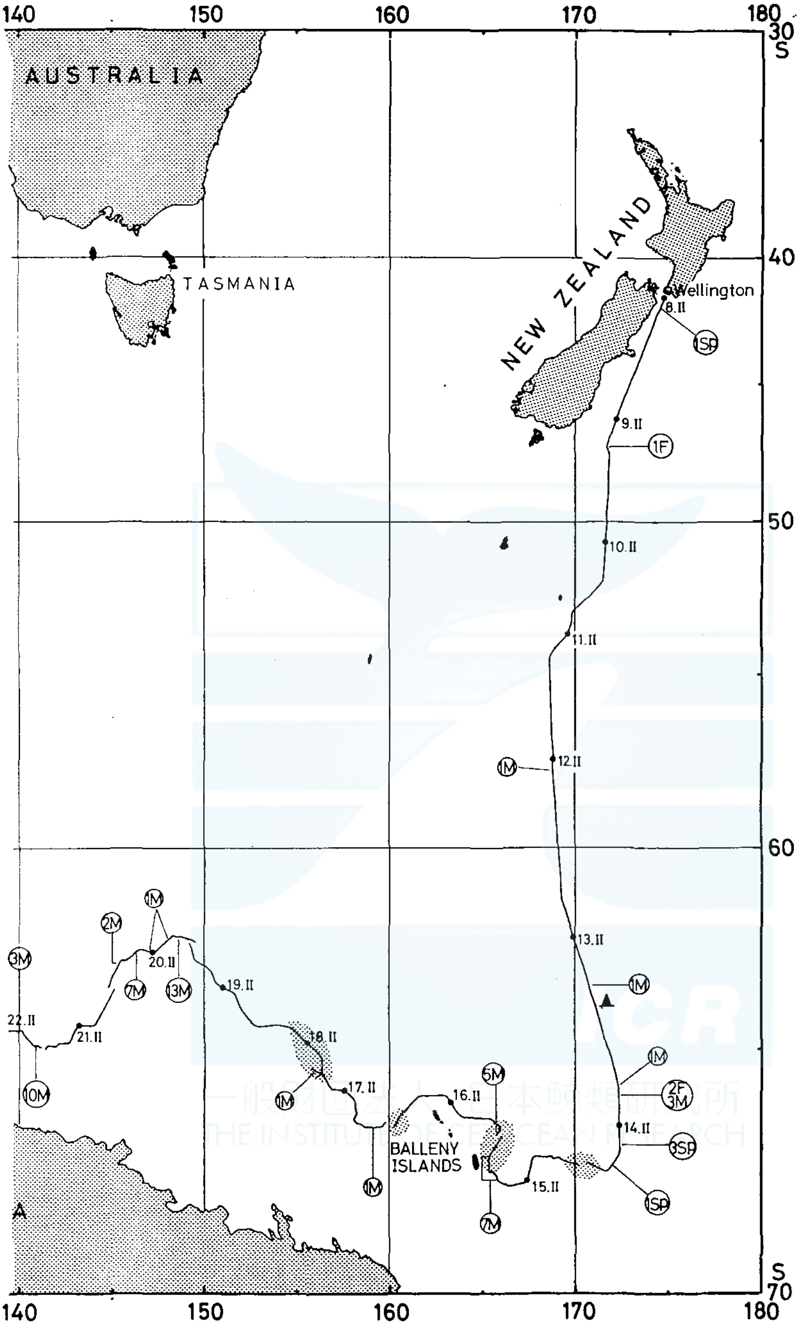


Fig. 2. Voyage of the Konan Maru No. 16 the second period from February 8 to major species sighted, northern limit of courses and range of the krill patch



in the Antarctic whaling grounds during March 8, 1973. Ship's track, whales of icebergs encountered on the traverse observed.

and Leader of the sighting observation; H., Kano (Captain of a whale catcher of the Kyokuyo Co. Ltd.); S., Isobe (Chief Officer of a whale catcher of the Taiyo Gyogyo Co. Ltd.); the officers and crew of the ship. They have excellent experience in whaling more than twenty years. I get on board the ship in order to make some oceanic observations at the surface in the Australian and New Zealand sector of the Antarctic Ocean.

A continuous sighting for whales was usually maintained on the cross net (two watchers) and on the upper bridge (three ones) from dawn untill dusk every day, except on when visibility is poor and heavy seas greatly disturb our sighting observation. We, therefore, can look out over the horizon as far as 6 to 7 nautical miles from the cross net in good visibility. On all nights in higher latitudes than about 60° S except on when the weather or schedule gave us reason to steam, we lay stopped to avoid missing whales in the hours of darkness. For the same reason we steamed slow speed in heavy rain, fog and snow; when the weather was very thick we would stop untill it cleared.

WHALES SIGHTED AND MARKED

The voyage of seeking after whales by the Konan Maru No. 16 consisted of two periods in the Australian and New Zealand sector of the Antarctic Ocean from January to March, 1973. The first period was occupied on the passage from Hobart to Wellington between January 9 and February 6 (Fig. 1). In the second period the whale sighting was occupied on the course from Wellington to Freemantle during February 8 and March 8 (Fig. 2). There is no need to describe in detail the whole of about eight weeks occupied in sighting for whales, but reference should be made to the ship's track, location of major whales encountered, distribution of observed edge of the pack-ice and some oceanic conditions at the surface in Figs. 1–6, and in Tables 1 and 2. In general it may be said that the Konan Maru No. 16 steered easterly courses in the first period and westerly ones in the second period by passing through the grounds in which favorite haunts and dense local concentrations of the blue, fin and humpback whales had been located in the early Antarctic whaling age.

As is given in Tables 1 and 2, and Figs. 1 and 2, major whales sighted in the two periods are not as great as we had hoped, except the minke and sperm whales. We could not saw the blue and right whale at all, and fin whales encountered was 20 in about two months. I wonder whether the very few numbers of the fin sighted are reflected in the size of their stocks in the Australian and New Zealand sector of the Antarctic Ocean? 19 among 20 fins were distributed in the South Pacific Antarctic Ridge region.

Although we observed on the grounds in which most humpback whales had been taken by early pelagic expeditions, only 7 individuals were encountered there. Two humpabacks sighted in 60°53′S, 116°30′E on February 28 were adult and calf. It may be said the stock of the southern humpback groups IV and V does not recovered yet well.

We observed 16 sei whales, 8 of which were distributed in the Subtropical

TABLE 1. VOYAGE OF THE KONAN MARN NO 16 TO THE AUSTRALIAN AND NEW ZEALAND SECTOR OF THE ANTARCTIC OCEAN. WHALES SIGHTED AND WHALES MARKED EACH DAY.

Date		Noon	Position	Sighted		Sea condition (1)	Visibility (2)	Major species of whales sighted					Whales marked			
				Distances (naut. mile)	Hours (h.m.)			Fin	Hump.	Sei	Minke	Sperm	Fin	Hump.	Sei	Sperm
10	I	46°29′S	147°47′E	143	15 30	Bad	Good			4						
11		50°35′S	147°54′E	188	16 00	Bad	Moderate									
12		55°31′S	147°56′E	207	16 40	Good	Moderate				2					
13		61°01′S	149°25′E	238	16 20	Moderate	Bad				3					
14		64°05′S	149°25′E	160	16 00	Bad	Bad				8					
15		63°40′S	152°41′E	168	17 20	Moderate	Bad				5	1				
16		61°42′S	154°43′E	180	16 35	Moderate	Good				5					
17		60°42′S	158°11′E	207	16 55	Bad	Good				1					
18		62°51′S	162°52′E	203	17 30	Bad	Good				3	3				2
19		65°58′S	164°38′E	205	16 50	Moderate	Moderate				5	2				
20		63°53′S	170′26′E	195	16 30	Bad	Good				2	1				
21		64°49′S	176°40′E	211	17 05	Moderate	Good				9	5				
22		65°20′S	177°54′W	183	15 20	Moderate	Good	11			7		2			
23		66°46′S	175°12′W	183	16 50	Good	Good				8	5				
24		66°11′S	171°23′W	207	15 40	Good	Good				5	3				
25		64°18′S	164°40′W	228	15 55	Moderate	Good				7	1				
26		66°00′S	158°24′W	205	17 15	Moderate	Good	6		3	5		3		1	
27		64°39′S	157°26′W	12	1 10	Good	Bad				1					
28		63°48′S	155°36′W	221	17 00	Moderate	Good			4	7	2			1	
29		62°27′S	158°47′W	211	16 55	Moderate	Good		3			1		2		
30		60°43′S	163°27′W	201	16 15	Moderate	Good									
31		58°18′S	167°18′W	196	16 45	Moderate	Moderate			1						
1	II	55°57′S	170°43′W	205	16 40	Bad	Bad				1					
2		53°57′S	173°32′W	116	15 50	Bad	Good									
3		52°26′S	176°11′W	no sighting												
4		50°38′S	179°20′E	160	12 50	Moderate	Bad									
5		47°21′S	176°13′E	197	14 40	Moderate	Good					1				
6		43°34′S	175°27′E	183	14 35	Moderate	Good			4*		1				
27	working days		Total	5,013	422 55			17	3	12+4*	84	26	5	2	2	2
8		41°36′S	174°44′E	112	8 00	Moderate	Good									
9		46°16′S	172°12′E	148	14 20	Moderate	Good	1								
10		50°44′S	171°36′E	154	14 15	Bad	Bad									
11		53°47′S	169°29′E	no sighting												
12		57°26′S	168°52′E	159	15 10	Bad	Good				1					
13		62°16′S	169°54′E	201	15 10	Moderate	Good				1					
14		66°36′S	172°21′E	182	15 40	Moderate	Good	2			4	4				
15		67°46′S	167°22′E	194	15 40	Moderate	Good				7					
16		66°10′S	163°15′E	195	16 00	Bad	Moderate				5					
17		65°42′S	157°33′E	155	11 20	Moderate	Good				1					
18		64°53′S	155°33′E	93	14 00	Bad	Moderate				1					
19		63°31′S	151°00′E	163	15 30	Bad	Good									
20		62°42′S	147°21′E	174	14 35	Moderate	Good				24					

Continued . . .

TABLE 1. Continued.

Date	Noon Position		Sighted		Sea condition (1)	Visibility (2)	Major species of whales sighted					Whales marked			
			Distances (naut. mile)	Hours (h.m.)			Fin	Hump.	Sei	Minke	Sperm	Fin	Hump.	Sei	Sperm
21	64°24′S	143°07′E	147	12 15	Bad	Moderate									
22	64°17′S	139°06′E	108	9 30	Moderate	Bad				13					
23	64°20′S	137°45′E	no sighting												
24	64°34′S	136°36′E	192	14 30	Maderate	Good				24	4				
25	63°56′S	133°22′E	189	14 35	Moderate	Good				67					
26	63°57′S	126°57′E	206	14 35	Good	Good		2		8	24				
27	63°55′S	121°21′E	199	15 05	Bad	Good				2	1				
28	61°45′S	116°59′E	195	14 00	Bad	Good		2		4					
1 III	58°58′S	115°10′E	177	13 45	Bad	Good				3					
2	55°00′S	114°51′E	107	10 15	Bad	Good				1					
3	52°17′S	115°14′E	166	13 00	Bad	Good									
4	47°36′S	114°54′E	177	12 30	Moderate	Bad									
5	43°20′S	114°54′E	173	12 20	Moderate	Good									
6	39°52′S	115°06′E	159	12 50	Moderate	Good				1					
7	36°23′S	115°02′E	168	14 35	Good	Good					5				6
8	33°23′S	114°40′E	71	6 00	Good	Good					43				
27 working days		Total	4,364	359 25			3	4		167	82				6
54 working days		Sum Total	9,377	782 20			20	7	12+4*	251	108	5	2	2	8

(1), (2) mean value of 06, 08, 10, 12, 14, 16, 18 ships time. * Probably Bryde's whale.

(1) 0~2 Good, 3~5 Moderate, 6~ Bad.

(2) ~6 Good, 5~3 Moderate, 2~ Bad.

TABLE 2. WHALES ESTIMATED TO HAVE BEEN EFFECTIVELY MARKED.

Species	Fin	Hump.	Sei	Minke	Sperm	Total
Whales sighted	20	7	12+4*	251	108	402
Schools encountered	6	3	6+3*	158	76	252
Whales marked effectively	5	2	2		8	16
Marking						
Hit	7	4	4		9	24
Hit-mark protruding						
Possible hit					2	2
No verdict	2				2	4
Richochet	1				1	2
Miss	5	1	2	3	7	18
Total	15	5	6	3	21	50

* Probably Bryde's whale.

Convergence regions, just south of Tasmania and east waters to New Zealand. However, at the begining of March not one sei whale were encountered in the convergence region of the South East Indian Ocean, where most sei whales have been recently taken by Japanese whaling expeditions between December and early February. It is conceivable that 4 sei whales encountered in the east water to New

Zealand were Bryde's whales, judging from their swimming behaviours. They were located over the Mernoo Bank on the Chatham Rise. 7 among other 8 sei whales were distributed in the South Pacific Antarctic Ridge region. That more sei whales were not encountered was likely to due to the possibility that sighting areas was not their major feeding grounds or that we may had been early in the season for them migrating into high latitudes.

The minke whale were encountered in every part of high latitudes south of the Antarctic Convergence compared to the distribution of other baleen whales, and we sighted up to 251 after all. It seems that the great number of the minke whale encountered indicates the large population of the species well.

The number of the sperm whale observed is also rather great. Most of them, except those encountered south of Cape of Leeuwin in South West Australia, were solitary bulls. It seemed that sperm whales sighted south of Cape Leeuwin were main herds, which were distributed on the continental slope. It will be noted that distinct concentration of solitary bulls (24) were lacated between 126° and 128° E on about 64° S.

The whale marks and marking guns were provided us by the Far Seas Fisheries Laboratory, Japanese Fisheries Agency. We used the marks of the International Whale Marking Programe and some of Japanese Fisheries Agency. Tables 1 and 2 show the whales marked during the cruise. We intended have marked as many whales sighted as possible. We were oblidged not to waste much marking time because the time and distance for whale sighting were to be extended.

OCEANIC OBSERVATIONS AT THE SURFACE

Locations of Some Major Oceanic Fronts

Some conspicuous oceanic features of the Antarctic Ocean are the Subtropical and Antarctic Convergences. There has been proposed another oceanic front, which is named the Australasian Subantarctic Front, existing south of the East Indian Ocean, the Australian Continent and the Tasman Sea (Burling, 1961). In this report the location of these oceanic fronts are determined from the steep mridional gradient of the surface salinity and temperature, with refering to some previous works.

Course I: Oceanic observations were made between 44° and 64° S in approximate longitude 148° E from January 9 to 14. The sea surface salinity and temperature along this traverse course have been plotted in Fig. 3. Between 45° and 46° S salinity decrease from 35.2 to 34.8‰ and temperature falls off from 14° to 11°C. These conditions seem to show evidently the Subtropical Convergence region locating south of Tasmania.

A great increase and decrease in temperature and salinity occurred repeatedly between 50° and 53° S. In the region salinity fluctuates from 34.6 to 34.1‰ and temperature varies between 9.5° and 7°C. A character of the Australasian Subantarctic Front is sufficently met with their sharp gradients. As the steep meridional gradient occurred three times, it seems possible, therefore, that the front meandered in the counter-S shape.

Between 53.5° and 55.5° S the surface temperature decrease sharply from 7° to 1.5°C. There is also sharp change in salinity from 34.1 to $33.8\,^{0}/_{00}$ in this zone. These oceanic conditions seem to indicate clearly the Antarctic Convergence.

Course II: Fig. 4 shows a latitudinal change of salinity and temperature at the surface along the traverse course, observed between 42° and 62° S during January 29 to February 6. The convergence region in the eastern waters to New Zealand is generally shown by about from 35.0 to $34.5\,^{0}/_{00}$ and by about from 13° to 16°C in summer (Deacon, 1937; Garner, 1954, 1959). These oceanic parameters were clearly distributed between about 42° and 44.5° S, and the gradient in salinity and temperature are considerably sharp between about 42° and 44.5° S and so it may be con-

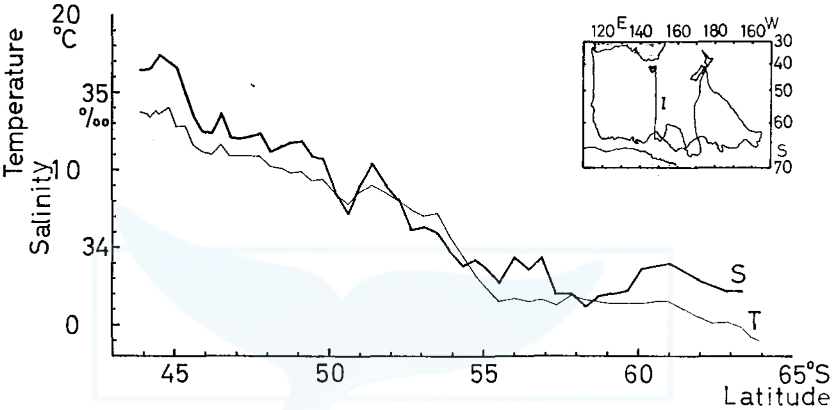


Fig. 3. Surface temperature and salinity along the traverse course I in approximately 148°E (January 10–14, 1973).

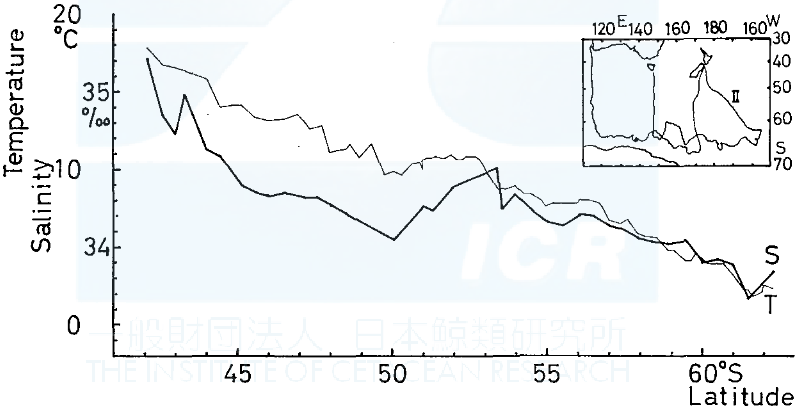


Fig. 4. Surface temperature and salinity along the traverse course II (January 29–February 6, 1973).

cluded that the Subtropical Convergence region present between 42° and 44.5° S. A sudden increase in salinity near 43° 15′ S seems to suggest the curvature of the convergence and the southward tangue-shaped extension of the Subtropical Water.

Temperature fall off from about 4° to 2°C and salinity also decrease from about 33.9 to 33.7‰ between 60° 45′ and 61° 30′ S. These conditions met sufficently with characters of the Antarctic Convergence.

Course III: The observation of the surface salinity and temperature were made between 43° and 67° S from February 8 to 14. The meridional change of the surface salinity and temperature along this traverse section are given in Fig. 5.

As already mentioned in the Course II, the Subtropical Convergence region in the eastern waters to New Zealand is generally defined with salinity 35.0 to 34.5‰ and temperature 13° to 16°C in summer. These oceanic conditions are sufficiently presented in the region between 43° and 45° S, where steep meridional gradients in salinity and temperature occur.

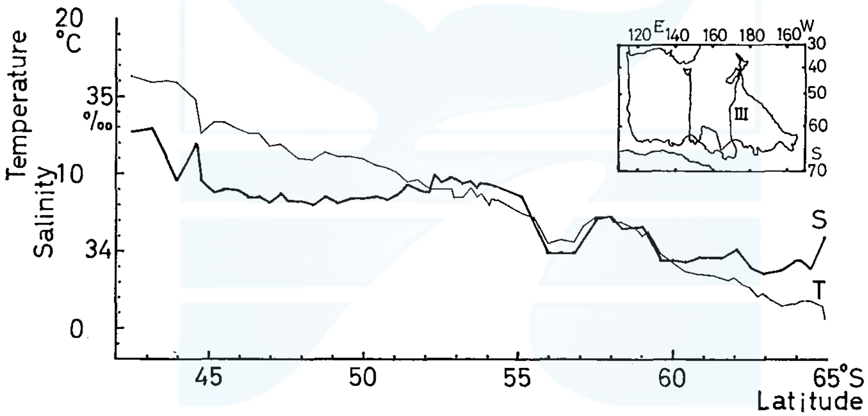


Fig. 5. Surface temperature and salinity along the traverse course III in approximately 170°E (February 8–14, 1973).

The sharp salinity increase in the Subtropical Convergence region seems that its water mass belongs to the Southland Current system. The current, which is a branch of the Tasman Current having characters of the Subtropical Water, passes through the Fouevaux Channel from the Tasman Sea, flows northward along the coast of the South Island and extends to off Banks Peninsula in the latitude about 44° S (Brodie, 1960; Garner, 1961).

It seems possible that the steep meridional gradient in salinity and temperature between 55° and 57.5° S show an oceanic front and a curvature of the West Wind Drift. The Subantarctic Slope of the Campbell Plateau locates just between 55° and 56° S on this traverse course. The sounding variation could have influence on the current.

The surface temperature falls sharply off from 6.5° to 4°C between 59° and 60° S and salinity also decrese sharply in the region. These steep gradient suggest evidently the Antarctic Convergence.

Course IV: Fig. 6 shows the meridional variation of the surface salinity and temperature along this traverse course, observed for the period from February 8 to March 8.

It is every difficult to define the Subtropical and Antarctic Convergence regions on account of irregular temperature and salinity changes. The salinity variation between about 35° and 40° S, where the location of the Subtropical Convergence region is expected, do not give a simple steep gradient but repeats a sharp decrease and increase. However, a more steep gradient of temperature occurs between 39.5° and 40.5° S, with a sharp salinity gradient. It is quite possible that these steep gradient in the region indicate the Subtropical Convergence region. As the temperature change from 17.5° to 14°C and salinity fluctuate between 35.6 and $34.9^{0}/_{00}$ in that region, these conditions support that estimation.

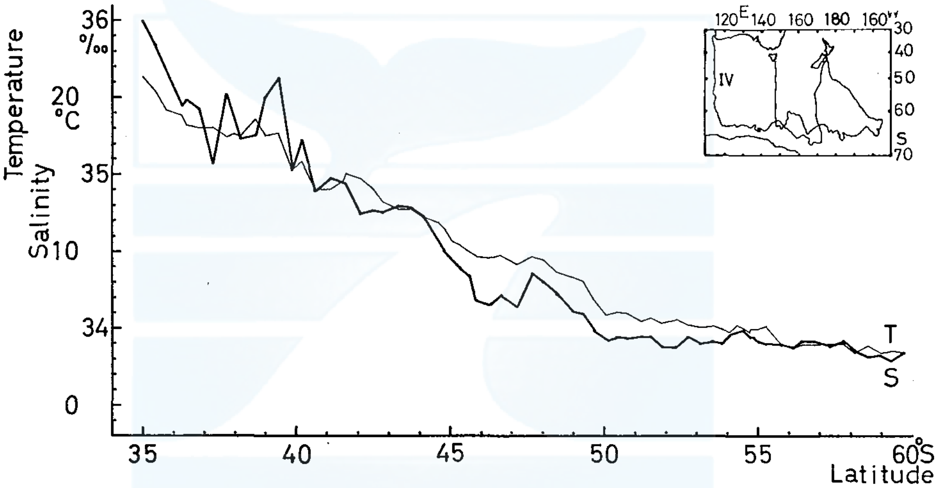


Fig. 6. Surface temperature and salinity along the traverse course IV in approximately 115°E (February 27–March 8, 1973).

Going north from the Antarctic Continent the surface temperature increases slowly untill the region between 50° and 49° S is reached where the relatively rapid increase of some 2°C occurs. Although the rapid increase in temperature and salinity suggests the Antarctic Convergence, the temperature 5° to 7°C in the zone seems to be relatively higher than ones of the convergence defined by previous works (Deacon, 1937; Mackintosh, 1964; Houtman, 1968). The high temperature may be partly caused by rare heating by the solar radiation. It may be defined here that the Anarctic Convergence existed between 50° and 49° S on this traverse cource.

The salinity change sharply from 34.7 to $34.2^{0}/_{00}$ between about 44.5° and 46° S south of the Subtropical Convergence. The center of the steep salinity gradient range is about $34.5^{0}/_{00}$ and locates at 45° S. The surface temperature range in the zone, however, is higher than that which is an indication of the Australasian Subantarctic Front. The reason may be partly caused by unusual heating of the solar radiation as well as in the Antarctic Convergence region. The Australasian Subantarctic Front, therefore, is defined here to be located between 44.5° and 46° S.

Distribution of Pack-Ice, Icebergs and Patch of Krill

The information on the distribution of the Antarctic sea ice will be some help to the study of oceanic problems in the Antarctic Ocean. Although the available observation in old times are quite inadequete for a detailed account of the distribution and movements of the pack-ice and icebergs as a whole, there are some published works on the distribution of the pack-ice edge; papers by Hansen (1934) and Mackintosh and Herdman (1940) were vased on whaling factory ships and oceanograraphical research vesseles. Recent ones, however, have been established on photographs from satellites (Prehoehl, 1966; Sissalia *et al.*, 1972).

Records on the observed position of the northern limits of the pack-ice and icebergs at differnt times during the cruise are plotted in Figs. 1 and 2.

The observed pack-ice was the very close one and the melting drift ice. The very close pack-ice was encountered only in the vicinity of 64° S, 150° E on January 14 and 15. The melting drift-ice, on the other hand, were observed at different places.

As it is wellknown that icebergs are located up to about 60° S south of Australia and New Zealand, the northern limit of the distribution on icebergs are shown on only for traverse course across the Antarctic Ocean (Figs. 1 and 2). On the Course I a typical tabular iceberg was first encountered in 56° 02′ S, 148° 13′ E on January 12. The last iceberg observed on the traverse course II was in 62° 30′ S, 157° 00′ E south of the Antarctic Convergence on January 29. It was very large and typical tabular iceberg. On the Course III from New Zealand to the Balleny Islands an iceberg was sighted in 63° 50′ S, 171° 00′ E fruther south of the Antarctic Convergence on February 13. The northern limit of the distribution of iceberg on the traverse Course IV was in 60° 30 ′S, 116° 20′ E on March 2, further south of the Antarctic Convergence.

As mentioned above, it seems that icebergs were not distributed across the Antarctic Convergence in the Australian and New Zeland sector between January and March, 1973.

The Antarctic krill, mainly *Euphausia superba*, have been recently regarded as the latent fishery resources, since its standing crop is vast. Its recources has been hoped for food ones as the world population has been gradually increasing.

The krill is often found in very dense concentrations at the surface. They are called patch and swarm. In this report the geographical distribution of the krill patch at the surface is shown (Figs. 1 and 2), but relationship between it and the oceanic conditions will be discussed in another report.

Patches of the krill were roughly distributed south of 63° S between 148° E and 155° W. In the region they were distributed in temperatures less than 2°C, which retains characters of the Anarctic Winter Water, and most of them were encountered in temperatures between −0.5° and 1.5°C.

ACKNOWLEDGEMENTS

I am greatly indebted to Captain and chief investigator Tatsumi Yamada, his crew of the Konan Maru No. 16, Mr. Hayato Kano of the Kyokuyo Co. Ltd. and Mr. Sadao Isobe of the Taiyo Gyogyo Co. Ltd. for observing on whales and oceanic conditions.

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FATTY ACID COMPONENT OF DIFFERENT BLUBBER OIL OF FINLESS PORPOISE

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ABSTRACT

This paper describes the fatty acid components of oils contained in different blubbers of Finless porpoise, *Neophocaena phocaenoides*. The sample oils were almost entirely triglycerides, but contained only trace amouts of sterols and sterolesters.

The fatty acid components of oils extracted from different blubbers of Finless porpoise contained chiefly $C_{16:1}$ (38.39–48.89%), $C_{14:0}$ (9.00–13.92%), $C_{14:1}$ (8.75–12.36%) and $C_{16:0}$ acids (7.22–11.80%). Although the proportion of fatty acid components contained in this experimental Finless porpoise deviated slightly from other dolphins and porpoises, and also was only a low level of *iso*-valeric acid which was comparatively much in dolphin and porpoise oil, the distribution pattern was comparable to those of dolphin and porpoise as reported by others.

INTRODUCTION

In the previous paper (Tsuyuki and Itoh, 1969), we reported that the blubber oil of an adult Finless porpoise consisted of 26 kinds of fatty acids with 8 to 22 carbon atoms, including mainly $C_{16:1}$ and $C_{18:1}$ acids.

This paper is concerned with the fatty acid components and distribution patterns of oils extracted from different part of a newly-born Finless poroise, *Neophocaena phocaenoides*, who was caught off the coast of Kawasaki, Kanagawa Prefecture, Japan, in June 1973. The mammal was a female with the size of 71.5 cm in length and 6.15 kg in weight.

We are much indebted to Dr. Toshio Kasuya who presented us the blubbers of Finless black porpoise.

MATERIAL AND METHODS

The sample oils were extracted from five different blubbers of the Finless porpoise by a high-speed blending with chloroform/methanol (2/1, v/v). The blubbers were front part of blow hole, dorsal part, thoracic part, tail part and dorsal fin. The properties of extracted oils are shown in Table 1. The sample oils were developed in thin layer chromatography on 0.25 mm thick layers of silicic acid

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(Wakogel B-5, Wako-Junyaku-Kogyo) with pertroleum ether-ethyl ether-glacial acetic acid (90/10/1, v/v/v). Each blubber oil consisted of almost triglycerides respectively, having trace amount of cholesterols and cholesterolesters.

TABLE 1. PROPERTIES OF DIFFERENT BLUBBER OILS OF FINLESS PORPOISE.

Blubbers	Front of blow hole	Dorsal	Thoracic	Tail	Dorsal fin
Appearance (at 30°C)	Yellowish liquid	Yellowish liquid	Yellowish liquid	Whitish liquid	Whitish liquid
Oil content (%)	30.0	46.7	42.2	19.4	5.3
Refractive index (at 40°C)	1.4546	1.4596	1.4586	1.4592	1.4597
Acid value	0.54	0.89	0.95	0.61	0.55
Iodine value (Wijs)	60.8	71.4	68.8	77.8	84.1
Saponification value	213.4	220.4	221.4	225.5	224.3
Unsaponifiables (%)	1.49	0.83	0.64	1.44	0.37

Gas liquid chromatography (GLC) was conducted with a Shimadzu Instrument, Model 4PTF, using 267 cm × 3.0 mm id glass column packed with 5% diethyleneglycol succinate (DEGS) on 80–100 mesh Chromosorb W (AW, DMCS) and a hydrogen ionization detector. Shortchain components were resolved thermally at column temperature programming the range of 70–190°C, 4°C per minute. Long-chain components were analyzed at column temterature of 205°C isothermally. The fatty acid methyl esters of sample oils were esterified by BF_3-methanol reagent according to the method of Metcalfe *et al* (1966). The methyl esters were purified by thin layer chromatography in petroleum ether-ethyl ether-glacial acetic acid (90/10/1, v/v/v) at low temperature and nitrogen atmosphere to prevent losses of short-chain components. The GLC peaks were identified by the use of pure standards (Apllied Science Laboratories, Inc.) and polyunsaturated component peaks were identified by the difference between GLC patterns before and after hydrogenation with platinum black reagent at the regular intervals. All fatty acid peaks obtained on chromatogram were reported as weight percentages of total known fatty acids presented by the method of Magidman *et al.* (1962).

RESULTS AND DISCUSSION

The fatty acid components of different blubber oils in this Finless porpoise are listed in Table 2. The five different blubber oils have 44 kinds of fatty acids with the range of 8 to 22 carbon atoms, and the fatty acid components and distributions of those oils are entirely to be the same pattern. The most prominent fatty acids in different blubber oils are 38.39% to 48.89% of $C_{16:1}$ acid; 9.00% to 13.92% of $C_{14:0}$ acid; 8.75% to 12.36% of $C_{14:1}$ acid; 7.22% to 11.80% of $C_{16:0}$ acid; 4.67% to 6.46% of $C_{18:1}$ acid, respectively. The total percentages of the above metnioned five fatty acids in all fatty acids are respectively 77.26% of front blubber of blow hole, 87.35% of dorsal blubber, 85.51% of thoracic blubber, 83.33% of tail blubber and 82.39% of dorsal fin blubber. The percentages of total saturated acids vary

TABLE 2. FATTY ACID COMPONENT OF DIFFERENT BLUBBER OILS OF FINLESS PORPOISE.

Fatty acids	Blubbers				
	Front of blow hole	Dorsal	Thoracic	Tail	Dorsal fin
Saturated					
Iso 5:0	2.55	1.07	0.71	0.46	2.30
6:0	0.24	0.16	0.13	0.30	0.45
8:0	0.29	0.26	0.31	0.37	0.32
Iso 10:0	0.14	trace	trace	0.09	0.04
10:0	0.85	0.49	0.57	0.41	0.31
Iso 11:0	0.04	trace	trace	0.05	0.03
11:0	0.25	0.12	0.11	0.16	0.14
Iso 12:0	0.70	0.25	0.27	0.31	0.24
12:0	3.14	2.15	2.24	1.81	1.53
Iso 13:0	0.47	0.08	0.12	0.21	0.28
13:0	0.15	0.01	0.08	0.07	0.08
Iso 14:0	0.98	0.28	0.34	0.53	0.43
14:0	13.85	12.89	13.92	10.77	9.00
Iso 15:0	2.46	1.15	1.55	2.13	1.70
15:0	0.53	0.29	0.51	0.45	0.48
Iso 16:0	2.44	0.70	0.89	1.47	1.15
16:0	11.31	10.33	11.80	8.16	7.22
17:0	0.34	0.27	0.42	0.34	0.38
18:0	0.02	0.12	0.13	0.10	0.09
20:0	0.02	0.04	0.02	0.03	0.01
Total saturated	40.77	30.67	34.12	28.22	26.18
Monounsaturated					
6:1	0.52	0.32	0.29	0.43	0.77
8:1	0.08	0.09	trace	0.22	0.07
10:1	0.51	0.66	0.76	0.69	0.67
12:1	0.89	0.70	0.75	0.92	0.91
14:1	8.75	10.57	10.35	12.15	12.36
16:1	38.39	48.89	44.72	46.80	47.35
18:1	4.96	4.67	4.72	5.45	6.46
20:1	0.07	0.08	0.05	0.07	0.08
22:1	0.05	0.04	0.04	0.08	0.08
Total monounsaturated	54.22	66.02	61.68	66.81	68.75
Polyunsaturated					
12:2	0.53	0.51	0.55	0.65	0.73
14:2	1.75	0.47	0.94	1.11	1.01
16:2	0.32	0.14	0.31	0.24	0.29
16:3	0.22	0.26	0.44	0.28	0.24
18:2	0.99	0.83	0.81	1.09	1.36
18:3	0.23	0.29	0.30	0.44	0.42
18:4	0.05	0.03	0.03	0.04	0.04
20:2	0.09	0.06	0.09	0.10	0.10
20:3	0.18	0.17	0.15	0.28	0.19
20:4	0.17	0.13	0.11	0.19	0.15
20:5	0.08	0.05	0.07	0.06	0.05
22:2	0.02	0.02	0.02	0.05	0.04
22:3	0.06	0.02	0.08	0.04	0.07
22:5	0.11	0.15	0.12	0.14	0.14
22:6	0.21	0.18	0.18	0.26	0.24
Total polyunsaturated	5.01	3.31	4.20	4.97	5.07
	100.00	100.00	100.00	100.00	100.00

from 26.18% to 40.77% and similarly those of total unsaturated acids vary from 59.23% to 73.82%. Among the saturated acids, $C_{16:0}$ and $C_{14:0}$ acids are the main constituents in those oils. The proportions of fatty acids with more than 20 carbon atoms and the range of 6 to 8 carbon atoms have very small amounts.

In comparison with the previous study (Tsuyuki and Itoh, 1969), the most prominent fatty acids of the blubber oil in previous work were 26.9% of $C_{16:1}$, 20.4% of $C_{18:1}$ and 8.4% of $C_{14:0}$ acids. Among those fatty acids, $C_{18:1}$ acid is notably different to this experimental blubber oils which contained 4.67% to 6.46%. $C_{16:1}$ and $C_{14:0}$ acids of the former oil were reversely lower amounts than 38.39% to 48.89% and 8.75% to 12.36% of the latter oils respectively. The ratio of total saturated acids *vs* total unsaturated acids in the latter oils somewhat close to that of the former oil. The latter oils contained proportionately larger amounts of short-chain length acids than the former oil, but the levels of $C_{22:5}$ and $C_{22:6}$ acids of poly-unsaturated acid were found to be the lower levels than those ($C_{22:5}$ 3.9%, $C_{22:6}$ 5.3%) of the former oil. Although the fatty acid proportion in the oils of the newly-born Finless porpoise in this study and the adult Finless black porpoise in the previous study had thus difference, there were obviously a similar pattern in the fattly acid distribution.

On the other hand, the proportion and distribution of the fatty acid component in this experimental dolphin oil are assumed to be nearly similar to the results of a number of studies in other dolphin oils as reported by others, but isovaleric acid from 0.46% to 2.55% in this study was comparatively small amount for the reason that the sample was blubber tissue.

SUMMURY

1. The properties and fatty acid components of oils contained in different blubbers of Finless black porpoise, *Neophocaena phocaenoids*, have been studied.

2. The fatty acid components chiefly consisted of $C_{14:0}$, $C_{14:1}$, $C_{16:0}$, $C_{16:1}$ and $C_{18:1}$ acids in different blubber oils.

3. The fatty acid distributtion patterns in different bubber oils were almost similar to each other.

4. The Finless black porpoise oil had the fatty acid pattern which was characteristic of dolphin and porpoise oil.

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FATTY ACID COMPONENT OF SENEGAL MANATEE FATS

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ABSTRACT

The fats in cerviel, thoracic and dorsal fatty tissues, and thoracic muscle tissue of Senegal manatee, *Trichechus senegalensis*, were analyzed for total lipid content and fatty acid components. Although the above three fatty tissues of Senegal manatee contained very rich amounts of fat, the muscle tissue contained consisderably small quantity of fat.

The fatty acid components of Senegal manatee fats contained high levels of $C_{14:0}$ (14.97–18.66%), $C_{16:0}$ (24.57–27.78%), $C_{16:1}$ (6.69–7.32%) and $C_{18:1}$ acids (36.86–39.75%), and had a unique proportion with higher levels of saturated acids (50.16–52.93%). Although the fatty acid component and distribution pattern in Senegal manatee fats deviated from most of marine and fresh water mammals, those was nearly closed to that of Dugong fat.

INTRODUCTION

Manatees—sea cows—are completely aquatic and live solely on vegetation beneath the water along coasts, and in estuaries and rivers. They are named as *Trichechus manatus* in rivers and off coasts of Florida to British Guiana, as *T. inunguis* in rivers of Brazil and as *T. selegalensis* in rivers of West Africa. Their adults reach up to 3 m in length and have remarkably fatty tissue body.

We have investigated the fatty acid component of Senegal manatee, *T. senegalensis*, fats. No previous studies of *T. senegalensis* fat have been reported in the literature.

Greatest thanks are due to Mr. Kazue Nakamura of the Kanagawa Prefectural Museum who was kindly enough to present us the Senegal manatee fat.

MATERIAL AND METHODS

The Senegal manatee, *T. senegalensis*, studied was caught by trawling at 60 km of upper stream from the estuary of the Gambia river of West Africa in January 1973. The mammal was an immature male of about 158.0 cm in length. The portions of cervical, dorsal and thoracic fatty tissues, and thoracic muscle tissue were cut up into small pieces and respectively extracted several times with chloroform—methanol (2: 1) using a high-speed blender. The solvent was dried with anhydrous

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sodium sulfate and completely distilled off under high vacuum. The properties of recovered sample fats are shown in Table 1. Each sample fat was then subjected to preparative thin layer chromatography on 0.25 mm thick layers of silicic acid (Wakogel B—5, Wako-Junyakaku-Kogyo) developed with petroleum ether—ethyl ether—glacial acetic acid (90: 10: 1). The fats in the above three fatty tissues were almost entirely triglycerides and slightly the spots of cholesterol and cholesterol esters. On the other hand, the fat from thoracic muscle tissue was almost triglycerides similar to other sample fats. It had not only cholesterol and cholesterol esters, but also slightly phosphatides. The sample fats in cervical, dorsal and thoracic fatty tissues were softenend at 33.9–34.2°C and cleared finally at 35.4–36.0°C in 1 mm id capilary. The fat from thoracic muscle tissue was softened at 32.6–34.1°C and cleared at 35.0°C.

The sample fats converted to fatty acid methyl esters by the method of Metcalfe *et al.* (1966), using BF_3-methanol reagent. So as to purify, the fatty acid methyl esters were then subjected to preparative thin layer chromatography on 2.00 mm thick layers of Wakogel B-5 developed with petroleum ether—ethyl ether—glacial acetic acid (90: 10: 1).

TABLE 1. PROPERTIES OF DIFFERENT TISSUE FATS OF SENEGAL MANATEE.

	Fatty tissues			Thoracic muscle tissue
	Cervical	Dorsal	Thoracic	
Appearance (at 30°C)	Whitish semi-solid	Whitish semi-solid	Whitish semi-solid	Yellowish semi-solid
Oil content (%)	78.0	69.1	71.8	5.8
Refractive index (at 50°C)	1.4527	1.4531	1.4532	1.4536
Acid value	0.21	0.29	0.24	0.32
Iodine value	48.1	47.3	46.9	47.4
Saponification value	209.1	210.8	209.2	207.7
Unsaponifiables (%)	0.34	0.38	0.35	0.51

The gas liquid chromatography (GLC) analyses of methyl ester samples were performed with Shimadzu Model 4PTF apparatus using a hydrogen ionization detector under the following conditions: 267 cm by 3 mm diameter glass column containing 5% DEGS on Chromosorb W (AW, DMCS), and operating at the temparature programmed from 70–190°C, 4°C per minute for short-chain components and isothermally at the temparature 205°C for long-chain components. The carrier gas was flowed at the rate of 35 ml per minute by nitrogen gas.

The fatty acids were identified by comparison with standard mixtures (Applied Science Laboratories, Inc.) and GLC analyses with the same apparatus under the same conditions between before and after hydrogenation by platinum black reagent at the regular intervals. All fatty acid peaks were caluculated as weight percentages of total known fatty acids presented by the method of Ettre and Kabot (1962).

TABLE 2. FATTY ACID COMPONENT OF DIFFERENT TISSUE FATS OF SENEGAL MANATEE.

Fatty acids	Fatty tissues			Thoracic muscle tissue
	Cervical	Dorsal	Thoracic	
Saturated				
6:0	0.81	trace	0.72	—
8:0	0.31	0.19	0.27	0.16
10:0	3.14	1.59	2.52	2.09
12:0	1.65	1.30	1.54	1.70
Iso 14:0	0.04	trace	trace	0.05
14:0	15.98	14.97	18.66	15.72
15:0	0.50	0.28	0.42	0.33
Iso 16:0	0.31	0.37	0.35	0.08
16:0	24.82	27.78	24.57	26.12
17:0	0.54	0.47	0.36	0.55
18:0	2.73	2.53	2.77	2.84
19:0	0.09	0.05	0.04	0.02
20:0	0.74	0.63	0.70	0.54
Total saturated	51.66	50.16	52.93	50.21
Monounsatrated				
12:1	0.14	trace	0.09	0.11
14:1	0.41	0.28	0.36	0.33
16:1	7.18	7.30	6.69	7.32
18:1	37.60	39.75	36.86	39.17
20:1	0.33	0.21	0.25	0.21
22:1	0.26	0.20	0.19	0.24
Total monounsaturated	45.92	47.74	44.71	47.38
Polyunsaturated				
14:2	0.36	0.27	0.35	0.33
16:2	0.24	0.42	0.28	0.30
16:3	0.49	0.42	0.43	0.46
18:2	0.32	0.22	0.34	0.41
18:3	0.41	0.28	0.40	0.51
20:2	0.20	0.22	0.24	0.13
20:3	0.04	0.05	0.03	0.02
20:4	0.06	0.04	0.04	0.02
22:2	0.06	0.05	0.04	0.05
22:3	0.04	trace	0.02	0.01
22:5	0.09	0.06	0.08	0.07
22:6	0.11	0.07	0.11	0.10
Total polyunsaturated	2.42	2.10	2.36	2.41
	100.00	100.00	100.00	100.00

RESULTS AND DISCUSSION

The properties of fats extracted from different tissues of the experimental Senegal manatee are shown in Table 1. High amounts of fat content were observed in cervical, dorsal and thoracic fatty tissues as 78.0%, 69.1% and 71.8% respectively. But thoracic muscle tissue contained only a small amount fat of 5.8%. It can be seen that other properties are nearly closed to each other.

The fatty acid components of fats contained in different tissues of the African manatee are listed in Table 2. The sample fats were found to consist of 31 kinds of fatty acids with 6 to 22 carbon atoms, but the proportion of $C_{6:0}$ acid absents in thoracic muscle tissue fat. The fatty acid components and distribution patterns were very closed to each other. High amounts of $C_{14:0}$ (14.97–18.66%), $C_{16:0}$ (24.57–27.78%), $C_{16:1}$ (6.69–7.32%) and $C_{18:1}$ acids (36.86–39.75%) were observed in all tissue fats. The combined percentages of $C_{14:1}$, $C_{16:0}$, $C_{16:1}$ and $C_{18:1}$ acids were respectively 85.58% of cervical fat, 89.80% of dorsal fat, 87.05% of thoracic fat and 91.53% of thoracic muscle fat in total each fatty acid. The main constituents of the saturated acid were similarly $C_{14:0}$ and $C_{16:0}$ acids whereas the monounsaturated acids were $C_{18:1}$ and $C_{16:1}$ acids. The least amounts of polyunsaturated acids with more than double bonds were contained 2.42% of cervical fat, 2.10% of dorsal fat, 2.36% of thoracic fat and 2.41% of thoracic muscle fat. It is interesting to note that 97.58%–97.90% of total fatty acids were only saturated and monounsaturated acids. The African manatee fats consist of the highest amounts of total saturated acids. The ratio of total saturated acids *vs* unsaturated acids is about half and half as followed: 51.66% *vs* 48.34% of cervical fat, 50.16% *vs* 49.84% of dorsal fat, 52.93% *vs* 47.07% of thoracic fat and 50.21% *vs* 49.79% of thoracic muscle fat, respectively.

In the comparison with the fat contained in Dugong, *Halicore dugong* (Tsuyuki and Itoh, 1967), the Senegal manatee fats are most nearly allied to its fat. The Dugong fat was observed the high amounts of $C_{14:0}$ (9.8%), $C_{16:0}$ (23.0%), $C_{16:1}$ 7.7%) and $C_{18:1}$ acids (41.3%) being similar to the Senegal manatee fats. The fatty acids of $C_{10:0}$ (0.1%), $C_{12:0}$ (0.2%) and $C_{14:0}$ (9.8%) contained in the Dugong fat were slightly smaller levels than those of the Senegal manatee fats. But the fatty acids of $C_{14:0}$ (0.8%), $C_{14:2}$ (0.9%), $C_{16:2}$ (1.6%), $C_{17:0}$ (1.2%), $C_{18:2}$ (3.4%) and $C_{18:3}$ (4.1%) contained in the Dugong fat were reversely higher levels than those of the Senegal manatee fats. It is a point of interest that the fatty acids with more than 20 carbon atoms were not observed in the Dugong fat with exception of $C_{20:0}$ (1.7%) and $C_{20:4}$ (1.5%). Although the fatty acid component and distribution pattern between the Senegal manatee and the Dugong fats were nearly symmetrical for most fatty acids, those deviated from most of marine and fresh water mammal fats.

SUMMARY

1. The properties of fats contained in different tissues of Senegal manatee, *T. senegalensis*, was studied.

2. The fatty acid components of different fatty tissues and muscle tissue fats extracted from the mammal had been determined by GLC analysis.

3. It was confirmed that four main fatty acids of $C_{14:0}$, $C_{16:0}$, $C_{16:1}$ and $C_{18:1}$ accounted about 90% of total fatty acids in those tissue fats; 26 others were found in only low quantities.

4. The Senegal manatee fat was nearly similar to the Dugong fat in the fatty acid component and distribution pattern.

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THE HYOID BONES OF TWO KINDS OF HARBOUR SEALS IN THE ADJACENT WATERS OF HOKKAIDO

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ABSTRACT

The hyoid bones of the harbour seal in the adjacent waters of Hokkaido were examined, and remarkable differences were found between those of the ice-breeding and the land-breeding harbour seals. The land-breeding harbour seal completely lost their tympanohyals. Moreover their stylohyals were quite small and their proportional length was about one tenth of that of the ice-breeding seal. However, in the epihyals the land-breeding seal possessed the longer bones than the ice-breeding seal.

INTRODUCTION

The hyoid bones have been considered to be a systematic character in the whales (Omura, 1964), however, in the seal careful consideration has never been given to the hyoid bones. In the adjacent waters of Hokkaido, there were found two kinds of harbour seals; the ice-breeding harbour seal and the land-breeding harbour seal (Inukai, 1942; Belkin, 1964; Naito and Nishiwaki, 1972 a, b, etc.). The morphological studies on these harbour seals were performed in Hokkaido from 1969 to 1971. In these studies, I found the incomplete hyoid bones in the land-breeding seal while the normal hoid bones were found in the ice-breeding seal, and the outline of this difference between them was already reported quite briefly (Naito and Nishiwaki, 1972b). In the present paper some measurements of the hyoid bones of these seals were examined. But further studies on this problem are required to clarify the systematic or taxonomical problems of the North Pacific harbour seals.

Concerning the scientific name of the above harbour seals, I had already used "*Phoca vitulina largha*" for the ice-breeding seal and "*Phoca kurilensis*" for the land-breeding seal in my previous papers, however, in the present paper I do not use these names, for systematical studies on the North Pacific harbour seals have been advancing in recent years and taxonomical reconsideration on these seals seems to be required (Fay and Burns, private communication).

MATERIALS AND METHODS

The ice-breeding seals were caught at the Okhotsk coast of Kitami district and the Shiretoko Peninsula where the sealing on this kind of seal is active, and the land-breeding seal was caught at the Pacific coast of the Nemuro Peninsula where this kind of seal is dominant. Thirty three hyoid bones of the ice-breeding seal and 10 hyoid bones of the land-breeding seal were collected as materials. Since samples are quite short in the land-breeding seal, it was difficult to compare the hyoid bones between above two kinds of seals by the same age and the same sex.

The hyoid bones were taken off from the tongue. Then each bone of the hyoid was separated and measured. The cartilagionous tympanohyals taken off from the tympanic bullae were not measured, for their length and shape were much changed after drying.

GENERAL DESCRIPTION AND MEASUREMENTS

It is usually thought that the hyoid bones of the harbour seals are consisted of eleven bones such as one basihyal, 2 thyrohyals, 2 keratohyals, 2 epihhyals, 2 stylohyals and 2 tympanohyals (Plate I, II). All of these hyoid bones are seemed to be normally found in the pinnipeds. I had examined and found the same composition of the hyoid bones in the ribbon seal and ringed seal collected from the Sea of Okhotsk, and also in the steller sea lion and the south American sea lion Otaria byronia. Each of the hyoid bones of these animals were found to be well developed. However, the hyoid bones of the land-breding harbour seal in the present work appeared to be quite different from those of above mentioned animals.

The cartilagionous tympanohyals which connect with the tympanic bullae in

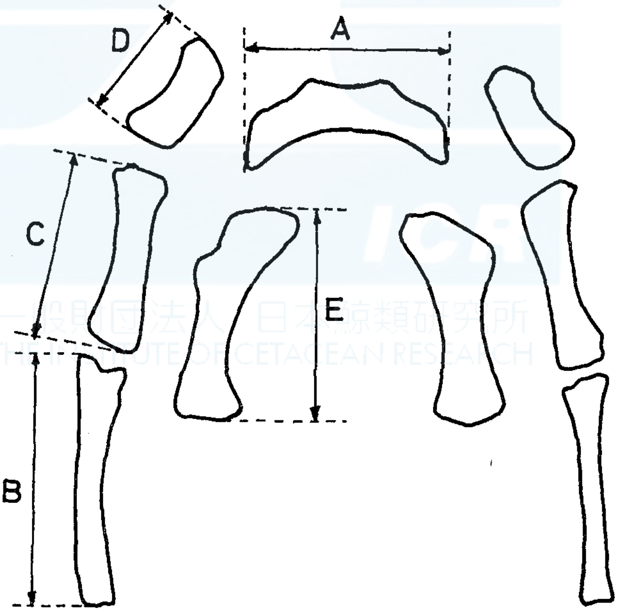

Fig. 1. The positions of the measurements. L, length of basihyal; B, length of stylohyal; C, length of epihyal; D, length of heratohyal; E, length of thyrohyal.

above animals were almost undeveloped and hard to find out in the land-breeding harbour seal. Therefore one end of the stylohyals were free in the tongue with the other end connecting with the epihyals. While in the ice-breeding harbour seal, these tympanohyals were well developed and were completely connected with the posterior part of tympanic bullae crossing over the surface of it from anterior part.

The second remarkable difference between the ice-breeding and the land-breeding harbour seals was found in the stylohyals. The stylohyals of the ice-breeding seal were thin and slender but well developed in its length. Most of these bones were almost round and straight but some were found to be slightly curved, and the epihyal side of these bones was thickened while the other side was less thickened. In the land-breeding harbour seal these stylohyals were incomparablly different from those of the ice-breeding one. They were quite small like a minute fragment, and it seemed to be easily failed to be found out in the young seal, while these bones were solid and firm like other hyoid bones in the adult seal. The forms of these bones were full of variety, and they differ much even between left and right bones.

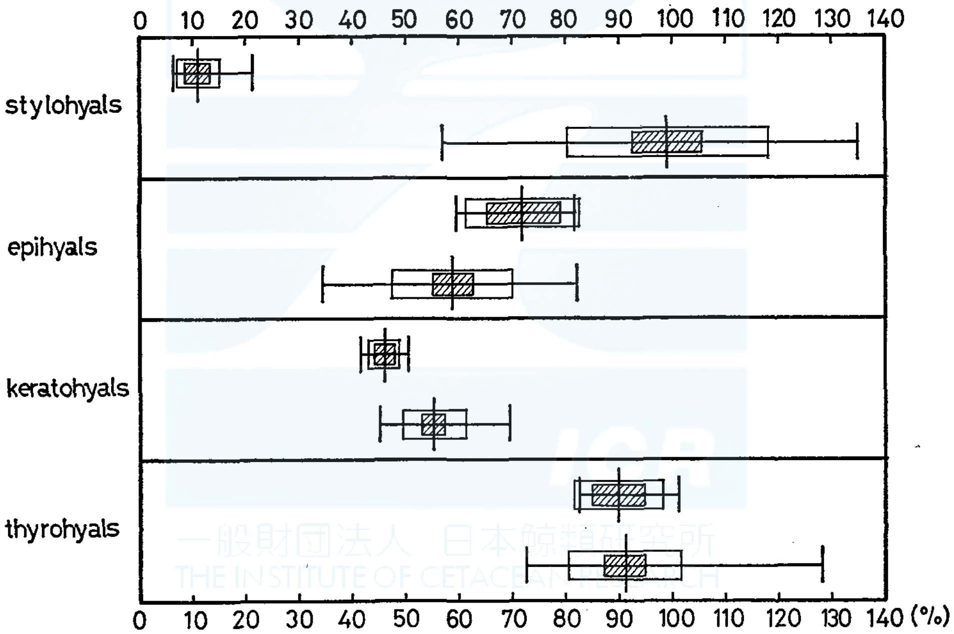

Fig. 2. Proportional length of each bone of the hyoid against the basihyal length. The horizontal line, range; vertical line, mean; outer box, standard deviation; inner box, standart error. Upper, land-breeding harbourseal; lower, ice-breeding harbour seal

Other hyoid bones did not show much obvious differences in above two kinds of harbour seals. In the land-breeding seal, however, the epihyals, keratohyals and thyrohyals showed massive and firm more than those of the ice-breeding seal.

Concerning the shapes of epihyals and keratohyals, they showed a little difference between above two kinds of seals. The epihyals of the ice-breeding seal were thin in center part and thick in both ends while those of the land-breeding seal were tapered, thick in the keratohyal side and thin in the stylohyal side. The keratohyals of the ice-breeding seal were also thick in both ends and thin in center, but those of the land-breeding seal were very short and no constricted or narrow parts were found.

The measurements were made on each hyoid bone (Fig. 1), and the proportional length of stylohyals, epihyals, keratohyals and thyrohyals was calculated in percentage against the basihayals. The average length of left and right bone was used for calculation. The artithmetic mean, standard variation and standard error were also calculated for the sake of comparison. The calculated results were shown in figure 2. As shown in this figure, the most obvious difference was found in the stylohyals. The proportional length of the land-breeding harbour seal was about one tenth of that of the ice-breeding harbour seal. The proportional length of epihyals was larger in the land-breeding seal than in the ice-breeding seal. In the keratohyals, the ice-breeding seal was larger. In the thyrohyals, both seals showed almost same proportional length, and as a matter of fact the shape of these bones showed better resemblance than others.

DISCUSSION

There were definite differences in the hyoid bones between the ice-breeding and the land-breeding harbour seals in Hokkaido. The land-breeding seal possessed a minute stylohyals and no tympanohyals while the ice-breeding seal possessed well developed these bones. It is of interest to consider above differences from the point of view of systematics of the North Pacific harbour seals.

In the North Pacific, there seems to be three kinds of harbour seals; the ice-breeding seal in the Bering Sea and the Sea of Okhotsk, the land-breeding seal in the Pacific coast of North America from Alaska to as far south as Mexico, and also land-breeding seal from the Aleutian Islands to as far west as the Kuril Islands and Hokkaido. The systematics of above three kinds of seals are still uncertain. Especially the systematic relation between above two kinds of land-breeding seals is quite unknown. Newby informed me in his private communication that the land-breeding harbour seal in Washington possessed the normal hyoid bones. Fay and Burns also informed me in their private communication that the incomplete hyoid bones were found in the harbour seal in Alaska where above three kinds of harbour seals seem to be common. However, we have quite short data to discuss the systematics of the North Pacific harbour seals by means of the hyoid bones.

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APPENDIX

MEASUREMENTS OF HYOID BONES
(upper, right; lower, left; in mm)

The ice-breeding seal:

Body length	Age	Sex	Basihyals	Thyrohyals	Keratohyals	Epihyals	Stylohyals
155	8	F	24.7	23.3	17.0	13.1	26.4
				22.2	16.8	13.4	26.1
140	7	F	22.1	21.5	11.7	14.6	24.2
				19.4	12.6	11.3	25.1
166	11	M	24.6	23.3	14.7	15.5	28.2
				24.2	13.7	16.1	27.6
153	18	F	23.7	20.8	16.0	14.1	23.7
				—	—	14.8	23.2
111	0	F	17.2	—	10.5	9.1	17.8
				15.3	9.6	—	18.1
149	3	M	25.0	20.9	13.9	15.6	26.0
				21.0	12.8	13.8	26.6
142	4	F	23.6	20.6	11.1	13.0	24.8
				20.2	10.6	12.2	24.7
—	—	M	22.9	23.1	13.3	15.8	29.9
				—	12.0	—	28.5
162	12	F	22.4	22.7	11.3	14.5	27.8
				22.1	12.1	15.0	28.0
149	6	F	22.2	16.8+	13.7	14.4	13.7
				29.3	13.3	15.2	13.1
162	20	F	23.6	25.2	16.8	14.0	28.9
				25.1	16.1	15.0	28.5
176	22	M	26.5	22.3	15.6	15.9	27.2
				22.6	13.7	16.0	28.9
139	7	F	22.3	20.8	12.2	16.8	26.3
				21.9	12.0	16.9	—
110	1	M	16.3	20.9	11.0	7.2	17.0
				—	—	—	17.6
—	1	M	20.0	15.1	10.5	7.9	14.9
				15.2	10.1	8.1	15.2
91	6	M	17.8	12.8	9.0	7.4	13.5
				13.1	8.9	8.6	14.0
132	3	M	22.2	20.1	10.8	14.1	22.9
				20.0	10.8	13.2	22.4
152	4	F	25.1	23.0	11.5	15.2	25.5
				23.3	11.3	—	25.5
127	1	M	20.4	17.2	10.0	12.0	18.9
				—	10.1	12.0	20.0
—	18	M	27.0	27.8	13.5	17.9	27.1
				27.5	14.8	19.5	28.1
139	2	M	24.5	18.5	11.8	13.8	22.5
				19.0	11.8	15.0	21.7
155	18	F	22.5	19.2	13.3	15.1	24.0
				18.2	14.0	14.5	23.5
126	1	F	20.8	—	11.8	11.7	14.5
				19.2	14.0	11.8	15.3
155	26	M	26.1	22.1	14.5	18.0	27.0
				—	14.0	19.1	26.8
94	0	F	18.2	14.8	10.0	8.1	17.1
				15.0	11.0	6.7	17.8

Continued . . .

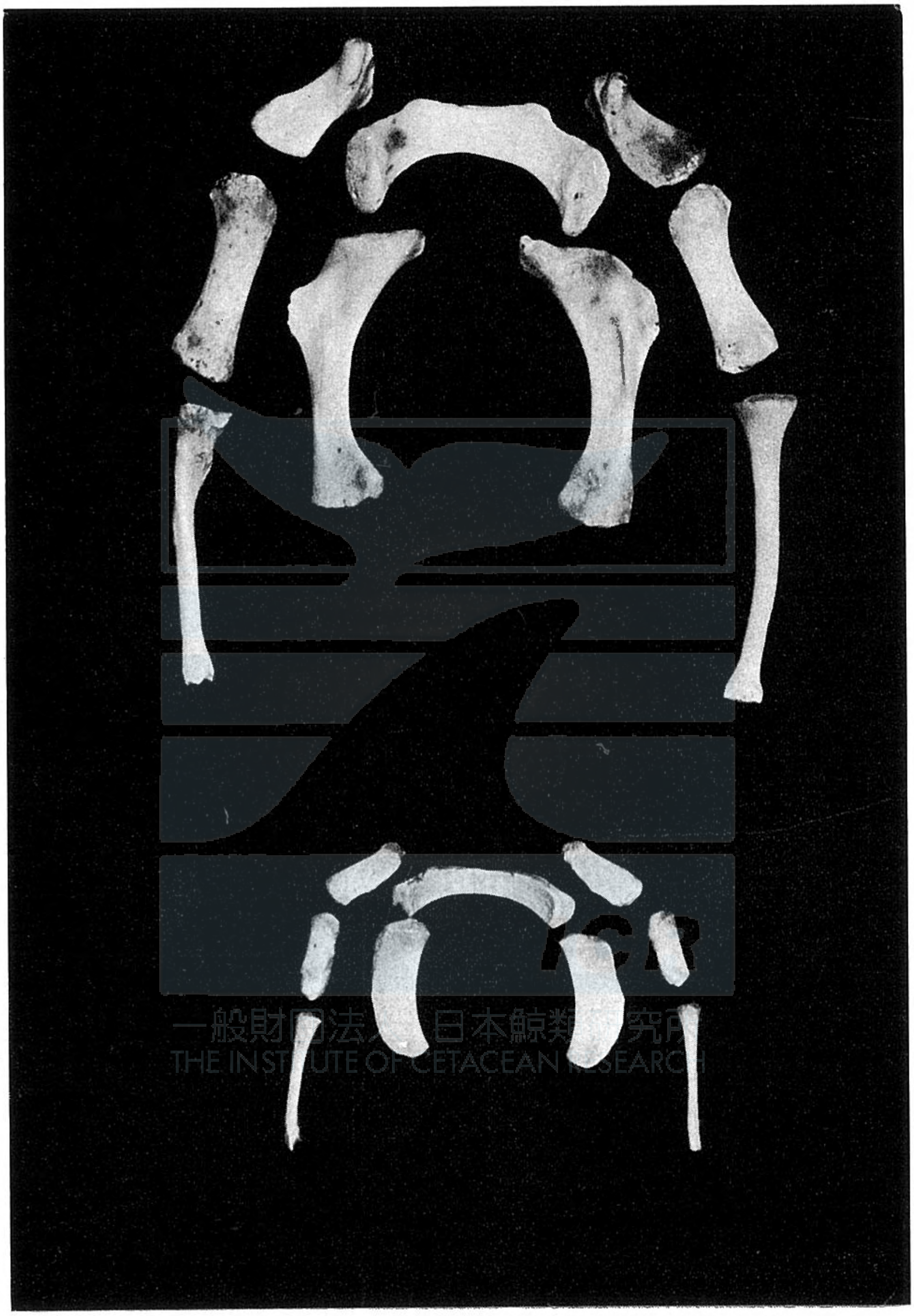
APPENDIX Continued.

Body length	Age	Sex	Basihyals	Thyrohyals	Keratohyals	Epihyals	Stylohyals
149	2	F	20.5	21.3 21.9	11.1 11.5	15.0 14.5	27.9 27.4
136	2	M	22.8	18.8 18.9	12.1 12.2	10.1 11.3	21.2 21.1
108	1	F	20.5	17.2 17.8	10.2 9.9	10.8 11.1	19.0 18.9
114	0	F	21.2	17.2 17.2	11.1 10.1	11.8 13.2	11.1 17.1
163	18	M	23.8	26.5 26.5	15.1 12.1	19.5 19.6	28.6 29.0
88	0	M	16.7	13.9 13.0	— 7.9	— 6.2	— 14.3
97	0	M	17.5	14.2 13.3	9.5 11.2	6.6 5.7	16.0 16.2
169	25	F	25.3	26.9 26.5	13.6 14.0	17.6 18.1	29.3 26.1
The land-breeding seal:							
152	3	M	24.9	21.3 20.6	12.0 12.0	17.2 17.5	2.2 2.3
178	7	M	28.3	27.3 27.8	13.8 14.0	23.1 23.7	6.1 6.0
140	4	F	22.1	19.8 19.5	10.5 10.5	16.5 16.3	2.1 1.8
104	0	M	15.0	13.8 13.3	6.9 6.9	9.0 8.9	1.5 1.6
149	3	F	24.8	22.3 22.2	10.1 10.7	16.8 16.7	2.1 2.2
104	0	M	17.5	15.1 14.3	7.7 7.9	12.1 11.6	2.1 —
168	7	F	23.9	24.5 23.9	12.1 —	19.4 19.8	2.4 2.4
144	3	M	22.8	19.0 19.1	10.1 10.5	15.4 15.2	1.9 1.5
151	4	F	26.1	23.1 23.1	11.9 11.5	19.0 18.1	2.5 2.0

EXPLANATION OF PLATES

PLATE I. Hyoid bones of the ice-breeding harbour seal. The tympanohyals are cut off. (upper, adult; lower, pup)

PLATE II. Hyoid bones of the land-breeding harbour seal. (upper, adult; lower, pup)



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