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OSTEOLOGICAL STUDY OF THE BRYDE'S WHALE FROM THE CENTRAL SOUTH PACIFIC AND EASTERN INDIAN OCEAN

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ABSTRACT

A complete set of skeleton of the Bryde's whale was obtained in the 1977–78 season and a skull and mandibles of the same species in the following season, from central South Pacific and eastern Indian Ocean respectively, based on a special permit for scientific researches. In addition nasal bones were collected from five animals in both seasons. All of these whales belonged to the offshore form of the Bryde's whale. Study of these bones has confirmed the reliability of the osteological characters of the Bryde's whale hitherto obtained in the past study, especially the shape of nasal bones.

INTRODUCTION

The osteological study of the Bryde's whale, *Balaenoptera edeni* has been very limited, though it is now well known that this species is widely distributed in the both hemispheres, in tropical and subtropical waters between 40°N and 40°S Latitudes.

Lönnberg (1931) studied a skeleton of *Balaenoptera brydei* (=*edeni*) which was presented from Captain C. O. Johnson, a female specimen caught on 10 March 1929 from the coast of South Africa. He compared this skeleton with skeletons of the sei whale, *Balaenoptera borealis* from the coast of Norway and from South Georgia, both kept in his museum, R. Natural History Museum at Stockholm, in addition to statements in the literature (Andrews, 1916: Miller, 1924 etc).

Junge (1950) studied a skeleton of fin whale that was cast ashore on the coast of Pulu Sugi, one of the smaller islands of the Rhio Archipelago between Singapore and the Smatran coast in July 1936 and concluded that this whale is identical with *B. edeni* Anderson 1879. He also examined a skeleton of *B. brydei* from Saldanha Bay, South Africa and an incomplete skelton of *B. edeni* both preserved at the British Museum and got to a conclusion that *B. edeni* and *B. brydei* are to be considered conspecific, which makes the name *Balaenoptera brydei* Olsen a junior synonym of *Balaenoptera edeni* Anderson.

Anderson (1879) made studies of the Sittang whale, stranded on 18 June 1871 in a creek named Thyabu Choung, which runs into the Gulf of Martaban, Burma. He has studied the skeleton of this whale and named it *Balaenoptera edeni*, in re-

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cognition of the Hon'ble Ashley Eden, the Chief Commissioner of British Burma, having been the means of saving this whale to science. He also reports " six pieces of short balene (=baleen) accompanied the other remains of this whale, they were all of one size, or nearly so, with the exception of one small white piece, evidently only a portion of a flake. The five remaining pieces are triangular, with about 12 inches (30.48 cm) of length and a maximum breadth at the base of 6 inches (15.24 cm). Their basal margins are uninjured, as the plates had evidently been drawn out of the decaying mucous membrane. The long curved free border is deeply fringed." He did not compare these baleen plates to those of *B. borealis*, but these proportions would place the animal as an offshore form of Bryde's whale (Omura and Fujino, 1954; Best, 1977).

Omura (1959) also made a study of skeleton of the Bryde's whale, comparing to that of the sei whale, both taken in the waters off Ayukawa, Japan. His conclusion was that the Bryde's whale from the coast of Japan is identical with *B. edeni* Anderson. He further assumed that *B. edeni* is distributed in tropical and subtropical waters of the world between 40°N and 40°S Latitudes.

Soot-Ryen (1961) studied an incomplete skeleton of Bryde's whale stranded on Curacao in 1959. He referred the specimen to *B. brydei* Olsen. He found pronounced differences in various ratios of the skeleton between *brydei* Olsen and *edeni* Anderson than between the two and *borealis* Lesson. His opinion is that untill the external characters and the baleen plates of *edeni* are described, there are reasons to keep the two nominal taxa separate. As already noted, however, baleen plate of *B. edeni* was already described by Anderson (1879).

Mead (1977) found, in several specimens, some of the characters generally used to separate *B. borealis* from *B. edeni* either intermediate or contradictory, particularly the shape of the nasal bones. He examined records of sei whales from the Atlantic coast of the United States and identified the specimen of the pollack whale reported by Miller (1924) as *B. edeni*. He describes that this was confirmed by an examination of the baleen, which is clearly that of *B. edeni*. This Miller's pollack (=sei) whale was used for the comparison of *B. brydei* and *B. edeni* by Lönnberg (1931) and Junge (1950). The re-examination of skeleton of the Bryde's whale, therefore, is needed.

A total of 459 Bryde's whales were taken by Japanese whaling expeditions in the Coral Sea, South Pacific and Indian Ocean during three successive seasons from 1976–77 to 1978–79 by a special permit from the Japanese government for purposes of scientific research. Reports on these whales taken were already published (Ohsumi, 1978; Ohsumi, 1979; Ohsumi, 1981; Kawamura, 1977; Kawamura, 1978; Kawamura, 1980). A complete set of skeleton was obtained in the 1977–78 season and a skull in the 1978–79 season. In addition to these a part of skull near nasal bones was obtained from five individuals in each of these two seasons for the comparison of the form of the nasals.

Whale specimens taken in the 1977–78 season belong to the offshore form of the Bryde's whale of Best (1977). This was confirmed by the measurements of baleen plates. The length: breadth quotients of the largest plates of these whales were ranged 1.47–2.05, and the mean was 1.81 (FSFRL unpublished data). For whales taken in the 1978–79 season no baleen plate was measured, but the skull has very flat rostrum which suggests that this group of whales too belong to the offshore form.

MATERIAL

Materials used in this study are shown in Table 1. Bones obtained in November 1977 or in the 1977–78 Antarctic season were landed at the Port of Chiba, towards the end of April 1978. Most of the bones of the sample no. 77N62 or the skull, mandibles, ribs and most of the vertebrae were then transported by a truck to Hakodate, Hokkaido, and burried in the earth in the campus of Hokkaido University, Faculty of Fisheries, for extraction of oils contained in them. Tendon or other soft parts attached to bones had already been cleaned on the factory ship.

Flippers, chevron bones and so-called " Mitsuya " in Japanese or the hindmost part of the vertebral column where tail flukes attaches, were brought frozen and these were transported to WRI, where they were also burried in the earth, after enclosed in mosquito nets made of synthetic fibre, in order to prevent from missing of small bones. Most of chevron bones, and nasals and their surrounding bones, were also transported to WRI where they were also burried in the earth, but without using mosquito nets.

The bones which were burried in the campus of the Hokkaido University were dug out from the earth on 7–8 May 1980, after about two years, and the observation, measurements and photography of bones were made on the following days.

The bones which were burried in WRI were dug out in November 1979. Some of the vertebrae were still attached to blubber and it was removed by boiling.

The skull and mandibles taken in the 1978–79 season were burried in the sand of the Kamogawa Sea World, an aquarium in Kamogawa, Chiba. These

TABLE 1. CATCH PARTICULARS OF WHALES FROM WHICH MATERIALS FOR THIS STUDY WERE OBTAINED

Whale no.	Date of catch	Position of catch		Body length	Sex	Material obtained
		Lat.	Long.			
77N06	1 Nov. 1977	25°12′S	177°44′W	13.5 m	M	Nasals
77N07	1 Nov. 1977	25°08′S	177°55′W	13.4	M	Nasals
77N09	8 Nov. 1977	26°30′S	170°58′W	13.8	M	Nasals
77N10	8 Nov. 1977	26°57′S	171°26′W	11.9	M	Nasals
77N11	9 Nov. 1977	27°52′S	175°03′W	14.6	M	Nasals
77N62	14 Nov. 1977	28°32′S	179°41′W	14.7	F	Complete set of skeleton
78N29	7 Nov. 1978	12°49′S	114°47′E	10.9	M	Nasals
78N31	7 Nov. 1978	12°46′S	114°50′E	12.8	M	Nasals
78N32	7 Nov. 1978	12°42′S	114°39′E	12.3	M	Nasals
78N33	7 Nov. 1978	12°31′S	114°18′E	14.2	F	Skull and mandibles
78N41	7 Nov. 1978	12°07′S	113°57′E	12.6	F	Nasals
78N49	7 Nov. 1978	10°54′S	112°30′E	13.9	F	Nasals

bones were dug out in October 1980, after about one and a half years. Observation and measurements of these bones were made successively.

Nasal bones, taken with surrounding bones from five individuals in that season were sent to WRI, where they were burried in the earth for about two years and then dug out.

All of these whales belonged to offshore form of the Bryde's whale of Best (1977),as stated already.

SKULL

(Plates I-IV)

The most conspicuous characters of the skull of *B. edeni* compared with *B. borealis* are the following: (1) In the lateral view the rostrum is very flat and pointing straight forward. The ventral surface of the maxillaries is less concave. (2) In the dorsal view outer margin of the rostrum is convex in *B. edeni* whereas more straight in *B. borealis*, hence rostrum at its middle is broader in *B. edeni*. The front margin of nasals is concave or straight and bent forward on the outer side in *B. edeni*, but convex and never bending forward on the outer side in *B. borealis*. It is situated strikingly posterior to the anterior border of the posterior maxillary concavity in *B. edeni*, whereas nearly at the same level of the concavity in *B. borealis*. (3) In the inferior view the palatines do not extend so far back in *B. edeni* and the basicranial part of the skull exposed behind the palatines is much longer than broad in *B. edeni*.

Our specimen of 77N62, obtained from central South Pacific and 78N33, obtained from eastern Indian Ocean show above characters in general. In both specimens the rostrum is very flat. The premaxillaries, especially their posterior ends, are sunk in between the maxillaries, which together with the little downward curving of the maxillaries cause the flat appearance in profile. In the specimens reported by Anderson (1879), Lönnberg (1931), Junge (1950), Omura (1959), and Soot-Ryen (1961) the rostrum is flat and they all agree in this respect. The flat rostrum of these specimens would place the animal as offshore form as stated below. Junge (1950) reports on the specimen in the British Museum the rostrum is curved downwards. Straight or curved rostrums are thought to be related to the shape of the baleen plates. Best (1977) reports that two distinct forms of the Bryde's whale occur on the west coast of South Africa, termed 'inshore' and 'offshore' forms. A morphological difference between the two forms is in the shape of the baleen plates. The shape of baleen plates of inshore whales is similar to those of the sei whale, but those from offshore whales are shorter and broader. The long baleen plates similar to those of the sei whale were also reported from the coast of Brazil (Omura, 1962) and from the west coast of Kyushu, Japan (Omura, 1977). Omura (1962) showed a drawing of cross section of the rostrum, just cranial to blowholes in the Bryde's and sei whales and showed correlation between the shapes of baleen plates and rostrum. The Bryde's whale with long baleen plates *i.e.* inshore form whales of Best are thought to have downward curving rostrum as in the case of the sei whale, though this has not been confirmed yet.

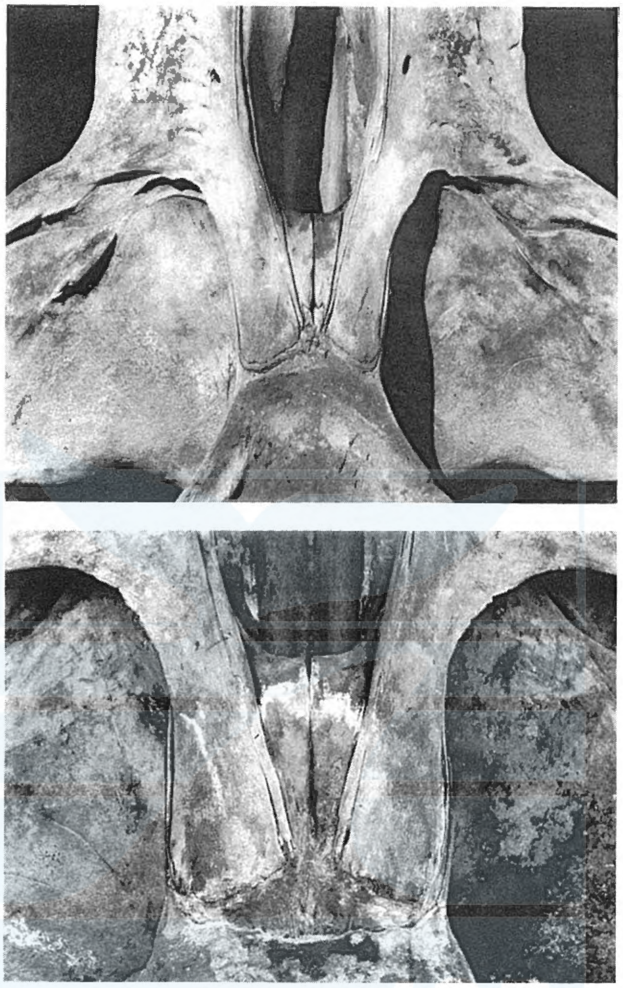

Fig. 1. Nasals of the Bryde's whale.
Upper: Specimen 77N62.
Lower: Specimen 78N33.

In the dorsal aspect, the rostrum of our specimens is long and slender. Anderson (1879) pointed out the long and slender beak of his specimen and thought this is a character which differs materially from *B. schlegeli* (=*borealis*). In the Lönnberg's (1931) specimen of the Bryde's whale, however, the rostrum is shorter and broader than in the sei whale, and Junge (1950) found large individual variations in this character. Position of nasals of our specimens are well behind the anterior border of the posterior maxillary concavity (Plate I, Fig. 1; Plate II, Fig. 1; Fig. 1).

Lönnberg (1931) reported that the flat area formed by the nasals and the posterior ends of the maxillaries is longer than broad in the Bryde's whale, whereas in the sei whale it is square or even broader than long. The Pulu Sugi specimen of

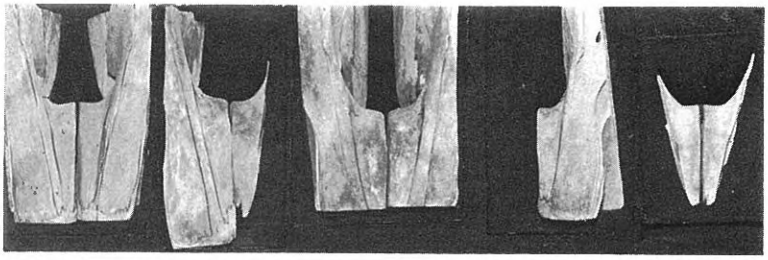

Fig. 2. Nasals of five Bryde's whales from the central South Pacific. From left to right: 77N06, 77N07, 77N09, 77N10, 77N11.

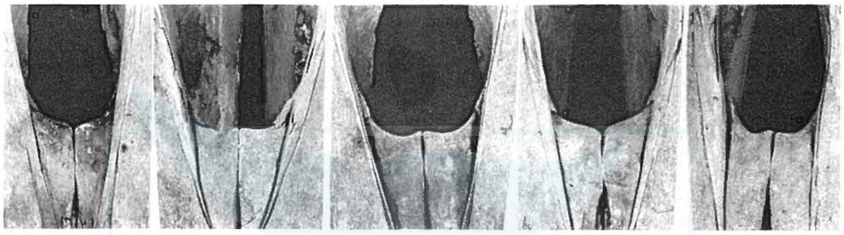

Fig. 3. Nasals of five Bryde's whales from the eastern Indian Ocean. From left to right: 78N29, 78N31, 78N32, 78N41, 78N49.

Junge (1950) also agrees in this respect to Bryde's whale and according to him this is also true in the specimen of *edeni* from Thyabu Choung. In our specimens of 77N62 and 78N33 this area is longer than broad. Junge (1950) described, however, on the London specimen of *brydei* (=*edeni*) this area is broader than long as in the case of Lönnberg's specimen of the sei whale. This character, therefore, is of little value for taxonomic purpose.

The front margin of nasals is concave and bent forward on the outer side in all of our specimens (Figs 1, 2 and 3). This is a striking character which separates *B. edeni* from *B. borealis* in which it is convex or straight and never bending forward on the outer side. This is true in all of the specimens of *B. edeni* reported before, *i.e.* the Sittang whale of Anderson (1879), South African specimen of Lönnberg, Pulu Sugi specimen of Junge (1950), Ayukawa specimen of Omura (1959), and Curacao specimen of Soot-Ryen (1961). Mead (1977) doubted, however, the reliability of this character. This is why we asked the Japanese expeditions to collect a part of skull of the Bryde's whale, around nasals, in the two seasons of 1977–78 and 1978–79, as shown in Table 1. Nasals thus collected are shown in Figs 2 and 3.

As seen in these photographs the front margin of the nasals of *B. edeni* are concave, straight or somewhat convex towards the center, but more important is the fact that they always bending forward on the outer side. We have confirmed that the nasal bone itself is of a light and spongy structure, but it covers completely a thin and subtle membrane of bone which coming up from the maxillary, lying beneath the premaxillary. Thus in *B. edeni* nasals are more firmly fixed than in *B.*

TABLE 2. MEASUREMENTS OF SKULL OF THE SPECIMENS 77N62 FROM THE CENTRAL SOUTH PACIFIC AND 78N33 FROM THE EASTERN INDIAN OCEAN, COMPARING TO THAT FROM THE NORTH PACIFIC

			Length in mm			Percent of skull length		
	Measurements		S. Pacific 77N62	Indian O. 78N33	N. Pacific Omura, 1959	S. Pacific 77N62	Indian O. 78N33	N. Pacific Omura, 1959
1.	Condylo-premaxillary length		3,792	3,422	3,480	100	100	100
2.	Length of beak		2,524	2,137	2,230	66.6	62.4	64.1
3.	Length of premaxillary, along upper surface	R	2,973	2,590	2,640	78.4	75.7	75.9
		L	2,962	2,595		78.1	75.8	
4.	Length of maxillary along upper surface	R	2,846	2,518	2,495	75.1	73.6	71.7
		L	2,812	2,525	2,500	74.2	73.8	71.8
5.	Tip of premax. to post. end of maxillary		3,021	2,719	2,670	79.7	79.5	76.7
6.	Tip of premax. to vertex		2,978	2,635	2,695	78.5	77.0	77.4
7.	Tip of premax. to nasals, mesial		2,699	2,360	2,440	71.2	68.9	70.1
8.	Tip of premax. to ant. end of maxillaries		212	121	183	5.6	3.6	5.3
9.	Tip of premax. to ant. end of vomer		484	251	439	12.8	7.3	12.6
10.	Tip of premax. to ant. end of palatines		2,756	2,292	2,445	72.7	67.0	70.3
11.	Tip of premax. to post. end of palatines, mesial		3,165	2,785	2,909	83.5	81.4	83.6
12.	Tip of premax. to post. end of pterygoid		3,357	3,127	3,225	88.5	91.4	92.7
13.	Greatest breadth of skull at zygomatic process		1,665	1,592	1,615	43.9	46.5	46.4
14.	Breadth of skull at maxillaries		1,565	1,508	1,445	41.3	44.1	41.5
15.	Breadth of skull at frontal plane, post. to premaxillaries		327		217	8.6		6.2
16.	Breadth of skull at orbital process of frontal, center		1,508	1,466		39.8	42.8	
17.	Breadth of beak at base		1,105	961	955	29.1	28.1	27.4
18.	Breadth of beak at middle		664	687	645	17.5	20.1	18.5
19.	Breadth across premaxillaries, greatest		296	301	330	7.8	8.8	9.5
20.	Breadth across premaxillaries, at base of beak		269	270	302	7.1	7.9	8.7
21.	Breadth across premaxillaries, at middle of beak		209	220	219	5.5	6.4	6.3
22.	Length of nasals, mesial		266	229	198	7·0	6.7	5.7
23.	Breadth of nasals at mesial tip		155	165	137	4.1	4.8	3.9
24.	Breadth of nasals at posterior end		45	36	49	1.2	1.1	1.4
25.	Breadth of orbit	R	250	241	234	6.6	7.0	6.7
		L	248	241		6.5	7.0	
26.	Length of supraoccipital from foramen magnum		818	838	835	21.6	24.5	24.0
27.	Breadth of occiput between squamosal sutures		1,148	1,091	1,118	30.3	31.9	32.1
28.	Breadth across occipital condyles		288	285	266	7.6	8.3	7.6
29.	Height of occipital condyle	R	194	196	174	5.1	5.7	5.0
		L	193	193		5.1	5.6	
30.	Breadth of foramen magnum		70	64	53	1.8	1.9	1.5
31.	Height of foramen magnum		86	79	45	2.8	2.3	1.3
32.	Length of mandible, straigth	R	3,500	3,252	3,305	92.3	95.0	95.0
		L	3,516	3,215	3,315	92.7	94.0	95.3

Continued . . .

TABLE 2. Continued.

Measurements		Length in mm			Percent of skull length		
		S. Pacific 77N62	Indian O. 78N33	N. Pacific Omura, 1959	S. Pacific 77N62	Indian O. 78N33	N. Pacific Omura, 1959
33. Length of mandible, on curve	R	3,649	3,385	3,540	96.2	98.9	101.7
	L	2,646	3,380	3,645	96.1	98.8	104.7
34. Height of mandible at coronoid	R	441+	405+	397	10.8+	11.8+	11.4
	L	450	411	392	11.9	12.0	11.3
35. Height of mandible at proc. articularis	R	288	312	302	7.6	9.1	8.7
	L	287	308	301	7.6	9.0	8.6
36. Height of mandible at middle	R	240	245	214	6.3	7.2	6.1
	L	234	242	217	6.2	7.1	6.2
37. Breadth of mandible at middle	R	160	168		4.2	4.9	
	L	153	168		4.0	4.9	
38. Length of tympanic bulla	R		122			3.6	
	L		124			3.6	

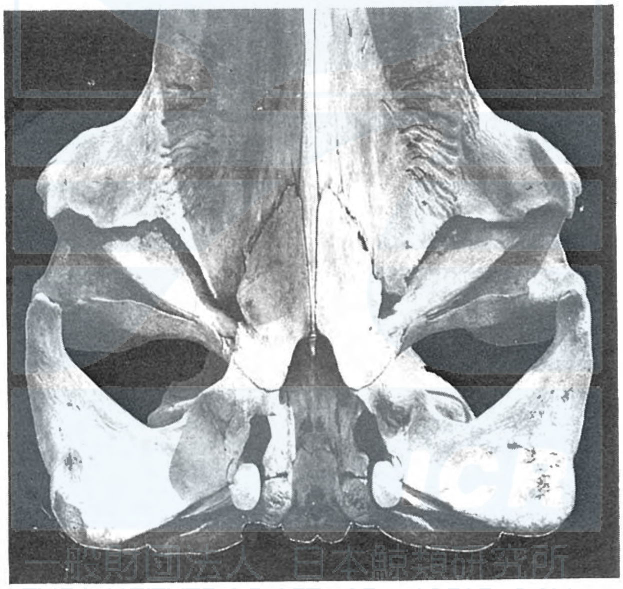

Fig. 4. Inferior view of the skull of the specimen 77N62, showing the basicranial part of the skull exposed behind the palatines.

borealis. In the minke whale, *B. acutorostrata*, those from the North Pacific have sei-whale-type nasals and those from the Antarctic have Bryde's-whale-type nasals (Omura, 1975).

In the inferior view of the skull of *B. edeni* the palatines do not extend so far back and the basicranial part of the skull exposed behind the palatines is much longer than broad (Lönnberg, 1931; Junge, 1950; Omura, 1959). This is true in our specimens of 77N62 (Fig. 4) and 78N33. In the sei whale the extension of the palatine bones so far backward that the position of the basicranial region exposed behind them is squarish in outline instead of longer than broad (Miller, 1924).

Miller (1924) considers the deep and narrow sulcus between the articular and squamosal parts of the squamosal in *B. borealis* as a specific character of the sei whale. Junge (1950) and Omura (1959) found the sulcus is not so deep and narrow in *B. edeni*. In our present specimens too this is true, but it is difficult to conclude whether or not this is an important character which separates *B. edeni* from *B. borealis*.

In Table 2 the measurements of skull of our specimens of 77N62 and 78N33 are shown in actual length of millimeter and percentage figures against the skull length. The corresponding figures of *B. edeni* from the North Pacific are also shown in the table, cited from Omura (1959). There are some differences in the percentage figures of the three specimens, but they are rather small and possibly due to individual variation, rather than racial difference. Junge (1950) gives a table showing proportional distance from nasals to tip of premaxillaries, and breadth of rostrum basally as well as at its middle for each six specimens of *B. borealis* and *B. edeni*, including those reported as *B. brydei*. Much wider differences are observed in this table even in the same species.

MANDIBLES

(Plate III, Figs 1 and 2, Plate IV, Figs 1 and 2)

There are some characters in mandible which are said to separate *B. edeni* from *B. borealis*. One of these is the groove between the angular and articular parts of the mandible in the posterior region. This groove is much deeper in *B. borealis*, but less developed or shallower in *B. edeni*. In this respect our present specimens of *B. edeni* from the southern hemisphere do not differ from that from the North Pacific.

Another difference between *B. borealis* and *B. edeni* is the relation between the articular and angular portions. In *B. borealis* angular portion ends before the hind edge of the articular portion, whereas in *B. edeni* the angular portion is at equal level or projects behind the articular parts (Junge, 1950; Omura, 1959). This is

Fig. 5. Posterior part of the left mandible of the specimen 77N62. Inner view.

true in our present specimens too, and in these two specimens angular portion is projecting behind articular portion. This is clearly shown in Fig. 5.

Omura (1959) describes that the mandible of the Bryde's whale on the coast of Japan is much robust than that of the sei whale, and its cross section at the middle of the mandible is more rounded. Percentages of the breadth against the height of mandible at its middle is about 64% in *B. edeni*, whereas the corresponding figure is about 54% in *B. borealis* in specimens preserved at the National Science Museum in Tokyo. From Table 2 we calculate the percentages in the mandibles from the central South Pacific and from the eastern Indian Ocean and got the figures of 66.7% and 68.6% respectively, in both the right and left mandibles. This shows that mandibles of the Bryde's whales in these oceans are more robust than in those in the North Pacific, but we are not able to compare these with corresponding figures of the sei whale in these oceans.

VERTEBRAE

(Plates VI and VII)

The vertebral formula of our specimen of 77N62 from the central South Pacific is C 7, D 13, L 12, Ca 22, which makes the total number of vertebrae 54. This number of 54 is exactly the same with the number in the Ayukawa specimen of *B. edeni* reported by Omura (1959) from the North Pacific, though the formula is slightly different, or one lumbar less and one more caudal present in the present specimen. All of the epiphyses are completely fused to their centra, and accordingly the whale was physically mature.

The total number of vertebrae of *B. edeni* was reported as 52 or 53 (Andrews, 1879; Lönnberg, 1931; Junge, 1950). In all of these specimens, however, all of the vertebrae were not saved and some numbers were added in estimation. Omura (1959) had an opportunity to observe the Pulu Sugi specimens of *B. edeni* kept at the Rijksmuseum van Natuurlijke Historie in Leiden in 1958 by the courtesy of Dr G.C.A. Junge and measured some of the last caudals. He compared sizes of these vertebrae to those of the Ayukawa specimen and got to a conclusion that the total number of the Pulu Sugi specimen should be 54, instead of 52 or 53. Omura (1966) expressed, however, the need of the exact counting of the number of vertebrae of *B. edeni* from other localities. And this was done in the present specimen from the central South Pacific. Omura and Fujino (1954) report that they counted the number of vertebrae of then so-called sei whales processed at landstations on the coast of Japan in 1953. In these days they separated so-called sei whales into two categories of northern and southern types. Later it was proved that the northern type is nothing but *B. borealis* and the southern type *B. edeni*. They found that in *B. borealis* the total number of vertebrae is 56 (2 individuals), but in *B. edeni* they were 54 (5 individuals) and 55 (8 individuals). The total number of vertebrae in *B. borealis* has been well established as 56–57, and it is proved that the number in *B. edeni* is 54–55.

The front view of the cervicals are given in Plate VII. In this specimen the 3rd and 4th cervicals are fused together completely and they can not be separated.

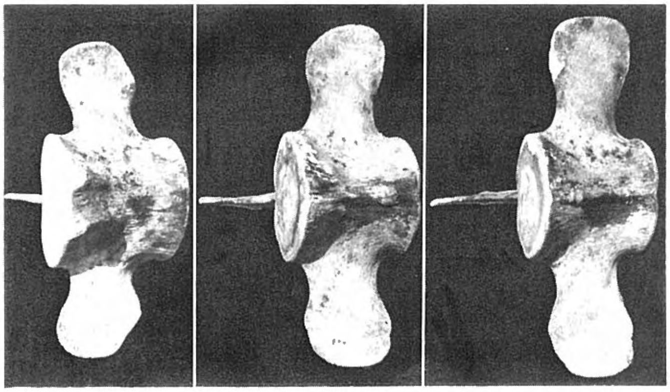

Fig. 6. Inferior view of some of vertebrae of the specimen 77N62.
Left: 34th vertebra.
Center: 33rd vertebra.
Right: 32nd vertebra.

The shapes of each cervicals are similar in general to the Ayukawa specimen reported by Omura (1959). In the 6th cervicals, however, complete rings are not formed by dia- and parapophyses and narrow spaces are present between these processes, whereas in the South African specimen of Lönnberg (1931) and in Ayukawa specimen of Omura (1959) complete rings are formed. These differences are thought, however, subject to individual as well as age variations and may have very little taxonomic value. In the Pulu Sugi specimen of Junge (1950) rings are not formed in the 4th and 6th cervicals. In the 7th cervical parapophyses are reduced to a small notch on the vertebral body. This is so in other specimens of *B. edeni* ever reported.

The number of dorsal (thoracic) vertebrae counts 13. This corresponds to the number of pairs of ribs. In the 20th vertebra or 13th dorsal the distal ends of the transverse processes are somewhat thickened and have no clear articulating facet for ribs. In the succeeding vertebrae no such thickning of transverse processes present.

The last lumbar vertebra is separated from the 1st caudal by absence of chevron bone at its ventro-posterior end. The first chevron bone is usually small and in this case the right and left laminae are not united into a mass but separated. The articulating facet on the ventro-posterior end of the preceding vertebra is, therefore, not always clear. In the succeeding vertebra, however, this articulating facet is very clear, because of the 2nd chevron is quite big and united into a mass.

In Fig. 6 are shown the inferior and posterior ends of the 32nd, 33rd and 34th vertebrae. As clearly seen in these potographs no articulating facet is present in the 32nd vertebra, small facet in the 33rd, and very clear one in the 34th vertebra. Accordingly we assigned the 33rd vertebra as the 1st caudal vertebra. De Smet (1977) raised some problems in the regions of the cetacean vertebral column and proposed a new method of expressing the number of vertebrae.

He describes, however, that in ' most of the reports of Japanese cetologists ' ' the slightest indication as to how the categories are distinguished.' We like to refer here, therefore, some description on this point from Omura (1959). He described that ' The first 12 dorsal (=thoracic) vertebrae have more or less well marked facets at the distal ends of the transverse processes for the articulation of the ribs. The 13th dorsal vertebra has a well marked facet at the distal end of the right transverse process, but on the left no such facet present, though the distal end of the process is somewhat thickened.

He further described that " The 1st caudal vertebra is detected by the presence of bifurcated median carina on the inferior side of the vertebral body." These are the basis that he determined the vertebral formula of this specimen is C 7, D 13, L 13, Ca 21, Total 54. In the present specimen of *B. edeni* from the central South Pacific the formula is similarly decided as C 7, D 13, L 12, Ca 22, Total 54, as stated already.

De Smet (1977) proposing new formula dividing the cetacean vertebrae into following 6 regions.

1. *Cervical vertebrae* (vertebrae cervicales: Cv.): the seven vertebrae which are found between the skull and the first vertebra which possesses a complete rib; if there is a coalescence between several vertebrae it is shown in brackets or with a+sign; *e.g.* Cv. 7, or Cv. (7) or Cv. (2)+5.
2. *True thoracic vertebrae* (vertebrae thoracicae verae: Th. v.): the vertebrae which exhibit on their transverse process an articular facet for the tuberculum or for the capitulo-tuberculum of the corresponding rib (even if such a facet is not present for both ribs).
3. *Intermediary thoracolumbar vertebrae* (vertebrae intermediate thoracolumbales: I. Thl.): the vertebrae which are accompanied by a rib or the rudiment of a rib (whether on one side or on both sides) but which have no articular facets on the two transverse processes or which are joined to a rib by a ligament.
4. *X Vertebrae* (vertebrae X: X): well-developed vertebrae, placed within the trunk, which are neither a relationship with a rib nor carry a chevron bone on their cranio-ventral border: this series is homologous with the lumbar vertebrae, with the sacral vertebrae and with some others such as the postsacral vertebrae of Slijper and the first caudal of Knauff.
5. *Y Vertebrae* (vertebrae Y: Y): those vertebrae which are preceded by a chevron bone; this is attached to their cranio-ventral border, but in fact it articulates better with the vertebra in front; in reality the bone can be incomplete or much reduce or coalesced with another.
6. *Z Vertebrae* (vertebrae Z: Z): these are the small vertebrae of the terminal part of the column, they have no chevron bones and they are found in the flukes.

If we adopt the new system of formula proposed by him then the formula for our specimen 77N62 are the following:

Cv.=(2)+5, Th.v.=12, I.Thl.=1, X=13, Y=17, Z=4, Total=54

There are some doubt, however, in adopting this formula. One is the distinction between Th.v. and I.Thl. Th.v. is defined as ' which exhibit on their transverse process an articular facet '. In our specimen of 77N62 no clear articulating facet for ribs is present in the 20th vertebra, but the distal ends of the transverse processes are somewhat thickened, contrally to the succeeding one, as already stated. In the Ayukawa specimen (Omura, 1959) the 13th dorsal vertebra had a well marked articulating facet on the right side, but no such facet was present on the left side, though the distal end of the process was somewhat thickened. It is thought better to include the 20th vertebra into the category of Th.v. and making this number 13, instead of 12, and I.Thl.=0. It is true that in some specimens the last rib or ribs are very small, compared with the preceding ribs. Omura *et al.* (1971) report an unpaired and very short rib in the black right whale from the coast of Japan. It is possible that such rib or ribs are floating. They also reported that in one specimen of the black right whale the first dorsal vertebra is completely fused to a fused mass of the cervicals, or the first 8 vertebrae are fused into a mass. In these cases the expression is very difficult.

We like to raise here some other difficulties in adopting the new formula. In practice it is very difficult to count the exact number of the chevron bones, especially in the larger cetaceans. In our case of the specimen 77N62 a special care was taken, in order to secure very small bones, as already stated. Thus we got 17 (or pairs of) chevron bones. Among these 5 (pairs) were obtained from the region of tail flukes. In the usual practice these can not be collected. In the former reports of the Bryde's whale the total number of chevron bones are reported: 11 (Lönnberg, 1931), 11 (Junge, 1950), and 12 (Omura, 1959). These are all incomplete and it is possible that none of those in the region of tail flukes was collected. Separation of Y and Z vertebrae, therefore, may lead to a confusion.

Lastly the definition of Y vertebrae is those vertebrae which are preceded by a chevron bone. The chevron bone, however, articulates to the ventro-posterior end of the preceding vertebra, as he mentioned, and it is thought that the change of definition might not be needed. There exist very clear articulating facet both in the vertebral body and superior margin of the chevron bone, as shown in Figs 6 and 8.

The most remarkable difference in vertebrae other than total number which separate *B. edeni* from *B. borealis* is the strong backward inclination of the spinous processes in the former species (Anderson, 1879; Lönnberg, 1931; Junge, 1950; Omura, 1959). This inclination begins towards the middle of the dorsal vertebrae and increases till it reaches the maximum at about 27th vertebra (or the 7th lumbar) and then decreases. This is clearly shown in Pl. VI, Figs 1 and 2. In general the degree of inclination and its tendency are similar to the Ayukawa specimen of *B. edeni* (Omura, 1959).

In Table 3 the measurements of vertebrae of the specimen 77N62 are shown. In this table also included the degree of the inclination of spinous processes of the lumbar vertebrae. These were measured as the distance at which the vertical plane along the posterior surface of the vertebral body reaches the upper margin of the spinous process reckoned from the posterior upper angle of the process.

TABLE 3. MEASUREMENTS OF VERTEBRAE OF THE SPECIMEN 77N62 (IN MM)

Serial No.	Vertebral No.	Greatest breadth	Greatest height	Centrum			Note
				Breadth	Height	Length	
1	C 1	487	323	276	195	121	
2	2	861	326	288	172	81	
3	3	707	323	229	172	127	Completely fused
4	4	739	325	225	177		
5	5	716	323	219	175	66	
6	6	653	345	217	180	72	
7	7	636	379	220	180	78	
8	D 1	623	368	222	176	93	
9	2	635	390	228	172	117	
10	3	636	456	240	174	139	
11	4	694	503	239	172	159	
12	5	758	526	240	169	175	
13	6	845	573	237	172	189	
14	7	895	600	236	167	198	
15	8	928	626	233	167	209	
16	9	963	628	238	176	215	
17	10	1,003	646	240	176	223	
18	11	1,042	665	247	179	227	
19	12	1,079	666	246	179	232	
20	13	1,100	680	251	182	241	Backward inclination of S.P.*
21	L 1	1,064	695	254	180	244	141
22	2	1,068	697	256	185	251	195
23	3	1,070	697	251	198	256	213
24	4	1,069	711	258	204	262	250
25	5	1,053	757	258	217	265	249
26	6	1,034	749	256	215	270	259
27	7	1,003	737	260	215	274	256
28	8	972	720	264	214	278	246
29	9	953	721	264	212	282	246
30	10	911	719	267	214	288	244
31	11	870	714	273	219	294	192
32	12	860	714	281	226	294	123
33	Ca 1	796	714	288	234	295	
34	2	734	697	291	241	294	
35	3	710	638	289	244	293	
36	4	647	556	294	244	289	
37	5	576	460	306	243	284	Transverse processes perforated
38	6	497	437	308	241	280	„
39	7	427	392	304	236	271	„
40	8	374	385	297	234	263	„
41	9	336	351	286	230	256	„
42	10	298	330	271	225	238	„
43	11	262	278	245	227	220	„
44	12	237	235	224	208	178	
45	13	206	218	195	175	127	

Continued . . .

TABLE 3. Continued.

Serial No.	Vertebral No.	Greatest breadth	Greatest height	Centrum			Note
				Breadth	Height	Length	
46	14	181	174	173	145	103	
47	15	—	151	152	125	96	
48	16	—	134	122	113	87	
49	17	—	116	102	100	78	
50	18	—	94	84	81	69	
51	19	—	67	70	62	59	
52	20	—	—	56	47	52	
53	21	—	—	42	32	45	
54	22	—	—	27	18	27	

* See text.

These figures are quite similar to those reported by Omura (1959) to his Ayukawa specimen.

RIBS
(Plate V)

The specimen 77N62 has thirteen pairs of ribs. The first pair of ribs are deeply bifurcated at the head by narrow cleft, and broadly expanded at the distal end (Fig. 7). The anterior head ariculates with the diapophyse of the seventh cervical and the posterior head with the first thoracic vertebra which indicates that possibly the cervical and the first thoracic ribs have ankylosed into one body.

Anderson (1879) reports that in his type specimen of *B. edeni* only a fragment of the first rib of the left side and the entire sixth rib of the same side were saved. As the former he describes that it is single headed, and the head and tubercle are well-developed. Other specimen of *B. edeni* ever reported, however, all have bifurcated first rib. In *B. borealis* also the first rib is double-headed and the separation of the two species by this character is not possible. This may serve, however, to separate these two species from other species of baleen whales.

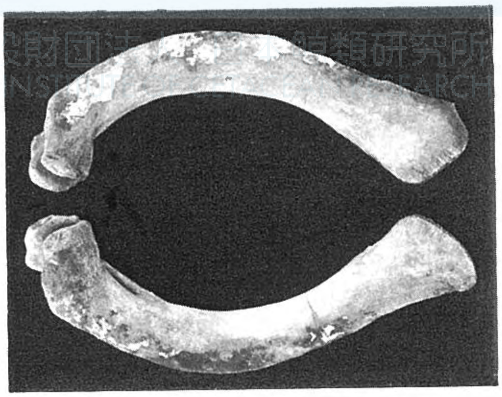

Fig. 7. First ribs of the specimen 77N62, showing bifurcated head. Posterior view.

In other specimens of *B. edeni* also thirteen pairs of ribs were present. Among them the thirteenth rib has length nearly same with that of the twelfth in the Pulu Sugi specimen of Junge (1950) and the Ayukawa specimen of Omura (1950), but in the South African specimen of Lönnberg (1931) the thirteenth rib was rudimental and short and slender. In the present specimen of 77N62 the thirteenth is shorter than any of the proceeding one except the first, but it can not be said as rudimental as shown in Plate V, Fig. 1.

In some of the ribs there is a rudiment of a capitulum and collum as in the most cases of the baleen whales, and these are thought to be of less importance in the taxonomic study. In the baleen whales ribs and sternum are less developed compared with the toothed whales. In the former the thoracic structure is more flexible than in the latter that allow the thorax to collapse more easily as the hydrostatic pressure increases, an adaptation for aquatic life and in particular for deep diving.

The measurements of ribs of the present specimen are shown in Table 4.

TABLE 4. MEASUREMENTS OF RIBS OF THE SPECIMEN 77N62 (IN MM)

Rib No.	Right*	Left*
1	950	968
2	1,358	1,370
3	1,530	1,555
4	1,652	1,637
5	1,736	1,718
6	1,772	1,760
7	1,750	1,740
8	1,681	1,672
9	1,611	1,590
10	1,550	1,530
11	1,455	1,454
12	1,435	1,240+ (tip broken)
13	1,039	1,025

* Straight length.

CHEVRON BONES

(Fig. 8)

As already stated sixteen chevron bones were collected. It is thought, however, one was missed at the time of dismembering the whale carcass. Among them eleven were collected on the factory ship when treating the whale body, but in a state of long strip of meat and tendon which surrounds these bones, and not separately. These were sent to WRI as frozen. Five chevrons were obtained from a mass of posterior caudal vertebrae and connective tissue called 'Mitsuya' in Japanese, as stated already. Thus chevron bones were collected divided into two parts. The last of the first group or the eleventh was broken. Comparing the sizes of this bone and the chevron found at the anterior most part of 'Mitsuya' we think that one was lost at the time of treating the whale body, which makes the total number of chevron bones seventeen.

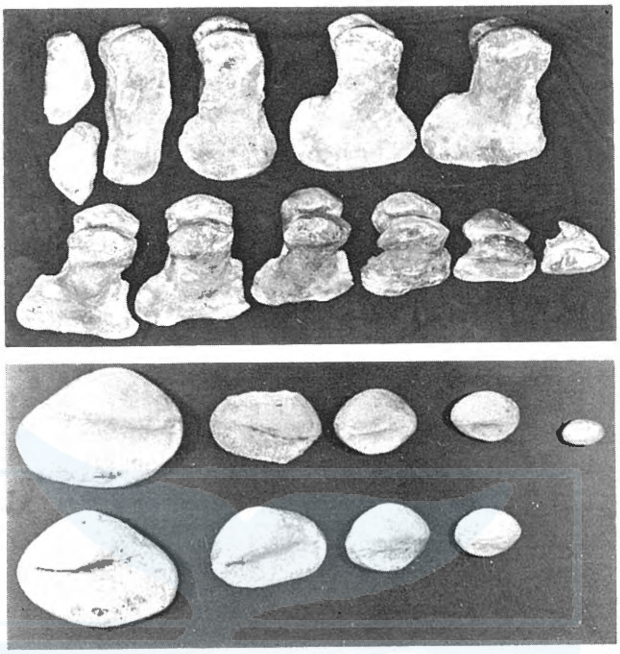

Fig. 8. Chevron bones of the specimen 77N62.
Upper: 1st-11th chevrons. In 1st chevron right and left laminae are not united into a mass, but separated. Others all united.
Lower: 13th-17th. These chevrons were obtained from the region of tail flukes. All are not united. One lamina of the last was missed?

TABLE 5. MEASUREMENTS OF CHEVRON BONES OF THE SPECIMEN 77N62 (IN MM)

No.	Height	Breadth	Distance*	Note
1	157	86	71	Two laminae are not united
	138	81		
2	267	101	137	
3	266	165	143	
4	259	210	148	
5	242	212	136	
6	212	203	130	
7	198	183	132	
8	184	170	118	
9	152	151	117	
10	110	141	110	
11	69	114+	97	Partly broken
12				See text
13	48	71	57	Two laminae are not united
14	32	51	44	,,
15	26	38	38	,,
16	22	30	27	,,
17	11	19	?	Only one lamina saved

* Distance of right and left laminae at their superior margin (outside).

Measurements of chevron bones are shown in Table 5.

SCAPULLAE

(Plate V, Fig. 2)

Both scapullae were preserved. They are quite similar to that of the Ayukawa specimen of Omura (1959). The greatest breadth of the right and left scapullae are 1,021 and 1,013 mm respectively and the height is 57–58% of the breadth, not differing greatly from the Ayukawa specimen. Acromion is well developed and the coracoid is also developed, but the latter is a little shorter than that in the Ayukawa specimen. In general no special feature is observed from other specimens of *B. edeni*.

Measurements of scapullae are shown in Table 6.

TABLE 6. MEASUREMENTS OF SCAPULLAE OF THE SPECIMEN 77N62 (IN MM)

Measurements	Right	Left
Greatest breadth, straight	1,021	1,013
Greatest height	593	581
Length of acromion	279	279
Breadth of acromin at middle	100	101
Length of coracoid	123	126
Length of glenoid fossa	184	188
Breadth of glenoid fossa	138	136

HUMERUS, RADIUS, AND ULNA

(Plate VIII, Figs 1 and 2)

These bones are quite similar to those of the Ayukawa specimen of *B. edeni* reported by Omura (1959), but somewhat larger in general, due to larger size of the whale body. Epiphyses of humerus and proximal epiphyses of radius and ulna are all completely fused to their main body, but distal epiphyses of the latter two are not fused. No special feature was observed in these bones. Measurements of these bones are shown in Table 7.

TABLE 7. MEASUREMENTS OF HUMERUS, RADIUS AND ULNA OF THE SPECIMEN 77N62 (IN MM)

Measurements	Right	Left
Humerus		
Greatest length	396	386
Width at middle	159	158
Radius		
Greatest length	672	676
Width at middle	111	116
Ulna		
Length at middle*	624	628
Width at middle	70	65

* Excluding olecranon

CARPALS AND PHALANGES
(Plate VIII, Figs 3 and 4)

These bones are of no special feature and their measurements are shown in Table 8.

TABLE 8. MEASUREMENTS OF PHALANGES OF THE SPECIMEN 77N62 (IN MM)

Measurements	Right				Left			
	I	II	III	IV	I	II	III	IV
Length								
1st phalanx	135	141	132	112	136	144	131	110
2nd phalanx	131	137	122	85	132	136	122	92
3rd phalanx	104	109	105	77	106	107	105	75
4th phalanx	77	84	85	missed	76	83	80	42
5th phalanx	53	64	63	—	53	63	57	—
6th phalanx	—	48	44	—	—	47	42	—
7th phalanx	—	37	27	—	—	missed	24	—
Width at middle								
1st phalanx	50	48	44	42	52	47	42	43
2nd phalanx	31	47	43	30	31	48	43	28
3rd phalanx	23	38	31	18	23	37	30	17
4th phalanx	17	34	26	missed	19	34	24	10
5th phalanx	12	32	22		14	30	21	—
6th phalanx	—	30	20		—	29	19	—
7th phalanx	—	27	19		—	missed	18	—

PELVIC BONES

Pelvic bones of our specimen 77N62 are shown in Fig. 9. These are slender and flat bone, but widened at promontories. Remnants of the femur are attached. The length of these pelvic bones are 276 and 275 mm respectively.

Lönnberg (1931) reports the pelvic bones of the Bryde's whale. His main

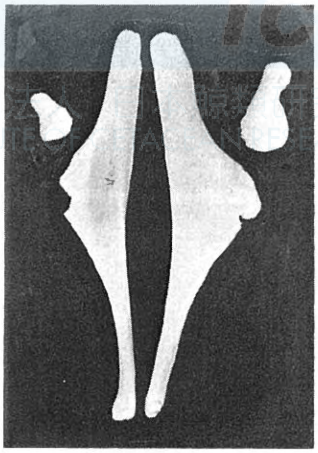

Fig. 9. Pelvic bone of the specimen 77N62.

specimen of skeleton was not accompanied by any pelvic bone and later these bones were sent to him from another specimen. These pelvic bones are well developed and furnished with well developed remnant of femur. He describes these bones in detail. In the minke whale, *Balaenoptera acutorostrata*, from the Antarctic the pelvic bone subjects to very wide individual variation (Omura, 1980). It is thought, therefore, these bones have less taxonomic values.

OTHER BONES

The sternum is a ‘ cross-shaped ’ small bone (Fig. 10). Its breadth is 327 mm and the length is 231 mm. In the other specimens too the sternum is cross-shaped in general (Lönnberg, 1931; Junge, 1950; Omura, 1959), but there are slight difference in the proportion of length and breadth. Also in the sei whale the sternum is similar in shape and possibly this bone has no special importance from the standpoint view of taxonomy.

The hyoid bones (Fig. 11) were also secured. The overall length of the combined bone of basihyal and thyrohyals is 904 mm on curve. And the heights at promontory and at middle are 247 and 153 mm respectively. The lengths of stylohyals are 451 and 460 mm and their breadths are 140 and 139 mm respectively. In general the shape of stylohyals is broad and much curved forwards in *B. borealis*, whereas less broad and less curved in *B. edeni* (Omura, 1964). There are, how-

Fig. 10. Sternum of the specimen 77N62.

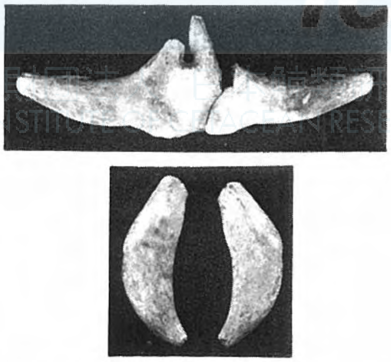

Fig. 11. Hyoid bone of the specimen 77N62.
Upper: Combined bone of basi- and thyrohyals. Partly broken.
Lower: Stylohyals

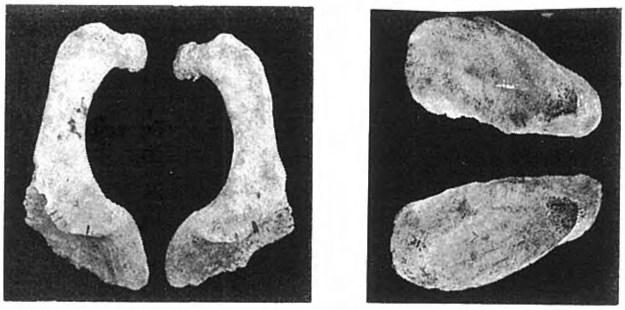

Fig. 12. Malars (left) and lachrymals (right) of the specimen 78N33.

ever, very wide range of variation and these two species can not be separated by this character alone.

In Fig. 12 are shown the malars and lachrymals. These bones are of no special importance in the present study.

DISCUSSION

As stated in the foregoing chapters there are some charcters of skeleton which separate the offshore form of *B. edeni* from *B. borealis*. These have been already recognized in the past study, but it is now confirmed by the present study on new specimens obtained from other localities than ever reported. These are as follows:

A. skull
  1. In the lateral view the rostrum is very flat. It is possible, however, in whales which have narrow and long baleen plates, *e.g.* inshore form of Bryde's whales by Best (1977), that the rostrum may be curved downwards as in the case of *B. borealis*.
  2. In the dorsal view outer margin of the rostrum is more or less convex, whereas more straight in *B. borealis*.
  3. The front margin of nasals is concave or straight and bent forward on the outer side, but convex in *B. borealis* and never bent forward on the outer side.
  4. The front margin of nasals is situated strikingly posterior to the anterior border of the posterior maxillary concavity, whereas nearly at the same level in *B. borealis*.
  5. In the inferior view palatines do not extend so far back and the basicranial part of the skull exposed behind the palatines is much longer than broad. In *B. borealis* this area is squarish or broader than long.

B. Mandible
  6. The groove between the angular and articular parts is shallow, whereas much deeper in *B. borealis*.
  7. The posterior end of the angular portion is at equal level or projects behind the articular portion, but it ends before the posterior end of the articular portion in *B. borealis*.

8. The cross section of the mandible at its middle is much rounded than in *B. borealis*.

C. Vertebrae

9. The number of vertebrae is 54–55, whereas 56–57 in *B. borealis*.

10. Spinous processes of the vertebrae in the region from the middle of the dorsals to the beginning of caudals show strong backward inclination, whereas no such inclination is observed in *B. borealis*.

D. Ribs

11. The first rib is deply bifurcated at the head by a narrow cleft, both in *B. edeni* and *B. borealis*. This character may serve, however, to separate the two species from other species of baleen whales.

We consider that above characters are well established, especially the shape of the nasal bone is very important. Mead (1977), however, have not relied upon skeletal characters, as several of his specimens appear to be either intermediate or contradictory in some of the characters, particularly the shape of the nasal bones. He identified the whale which was reported as *B. borealis* by Miller (1924) as *B. edeni* and described that ' This is confirmed by an examination of the baleen, which is clearly that of *B. edeni* '.

We like to discuss about this whale based on the paper by Miller (1924). This is a 13.7 m male *Balaenoptera* stranded at Pablo Beach (now Jacksonville Beach), Florida (No. 236680, U.S. National Museum). The baleen plate of this whale is narrow and long and show typical sei-whale-type (Pl. 21, Fig. 3 of Miller). According to Miller this plate is taken from near middle of series and ' whalebone plates uniformly blackish horn color, the extremely fine and hairlike bristles a very pale horn color appearing conspicuously whitish by contrast '. The front margin of nasals is convex and not bent forward on the outer side, and is situated nearly at the same level of the anterior border of the posterior maxillary concavity (Pl. 1). The rostrum is bending downwards (Pl. 3) and its outer margin is nearly straight (Pls 1 and 2). The angular portion of the mandible ends before the end of the articular portion (Pl. 3, Figs 2 and 3). The breadth of mandible at its middle is about 55% of the height (estimated from Pl. 3, Figs 2 and 4). The strong backward inclination of the spinous processes of lumbar vertebrae is not observed (Pls 12 and 13).

All of these suggest strongly that the Pablo Beach whale is in fact a sei whale *B. borealis*. Our conclusion on this whale is, therefore, re-examination of the baleen plate of this whale is needed.

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We are much indebted to crew of the *Nisshin Maru No. 3* and staff of the Kyodo Hogei K. K. for securing and transporting the skeleton used in this study.

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EXPLANATION OF PLATES

PLATE I

Skull of the specimen 77N62 of the Bryde's whale from the central South Pacific.

Fig. 1. Dorsal view.
Fig. 2. Ventral view.
Fig. 3. Lateral view.

PLATE II

Skull of the specimen 78N33 of the Bryde's whale from the eastern Indian Ocean.

Fig. 1. Dorsal view.
Fig. 2. Ventral view.
Fig. 3. Lateral view.

PLATE III

Skull and mandibles of the specimen 77N62 of the Bryde's whale from the central South Pacific.

Fig. 1. Right mandible. Lateral and inner view.
Fig. 2. Left mandible. Lateral and outer view.
Fig. 3. Skull. Posterior view.

PLATE IV

Skull and mandibles of the specimen 78N33 of the Bryde's whale from the eastern Indian Ocean.

Fig. 1. Right mandible. Lateral and inner view.
Fig. 2. Left mandible. Lateral and inner view.
Fig. 3. Skull. Posterior view.

PLATE V

Ribs and scapullae of the specimen 77N62 of the Bryde's whale from the central South Pacific.

Fig. 1. Right and left ribs.
Fig. 2. Right and left scapullae.

PLATE VI

Vertebrae of the specimen 77N62 of the Bryde's whale from the central South Pacific.

Fig. 1. Cervical and dorsal vertebrae.
Fig. 2. Lumbar vertebrae.
Fig. 3. Caudal vertebrae.
Fig. 4. Caudal vertebrae obtained from the region of the tail flukes.

PLATE VII

Cervical vertebrae of the specimen 77N62 of the Bryde's whale from the central South Pacific. Anterior views.

Fig. 1. Atlas.
Fig. 2. Axis.
Fig. 3. Combined bone of Nos 3 and 4.
Fig. 4. No. 5.
Fig. 5. No. 6.
Fig. 6. No. 7.

PLATE VIII

Bones in flipper of the specimen 77N62 of the Bryde's whale from the central South Pacific.

Fig. 1. Humerus, radius and ulna in the right flipper.
Fig. 2. Humerus, radius and ulna in the left flipper.
Fig. 3. Carpals and phalanges in the right flipper.
Fig. 4. Carpals and phalanges in the left flipper.

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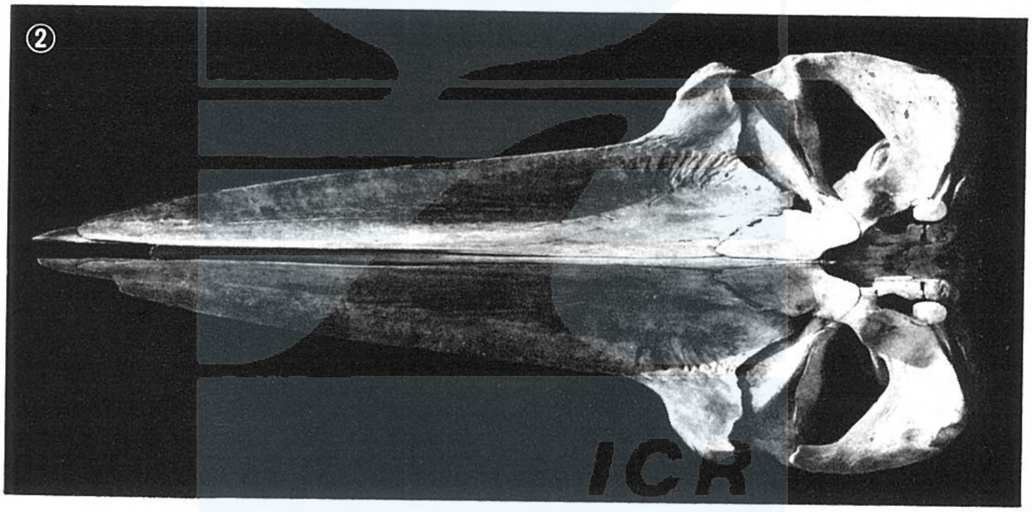

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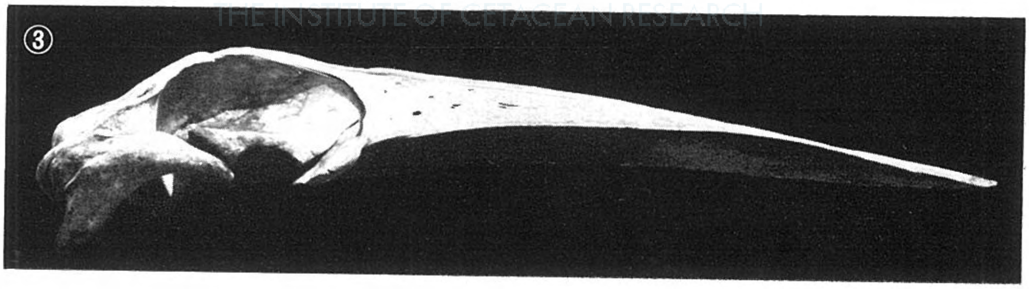

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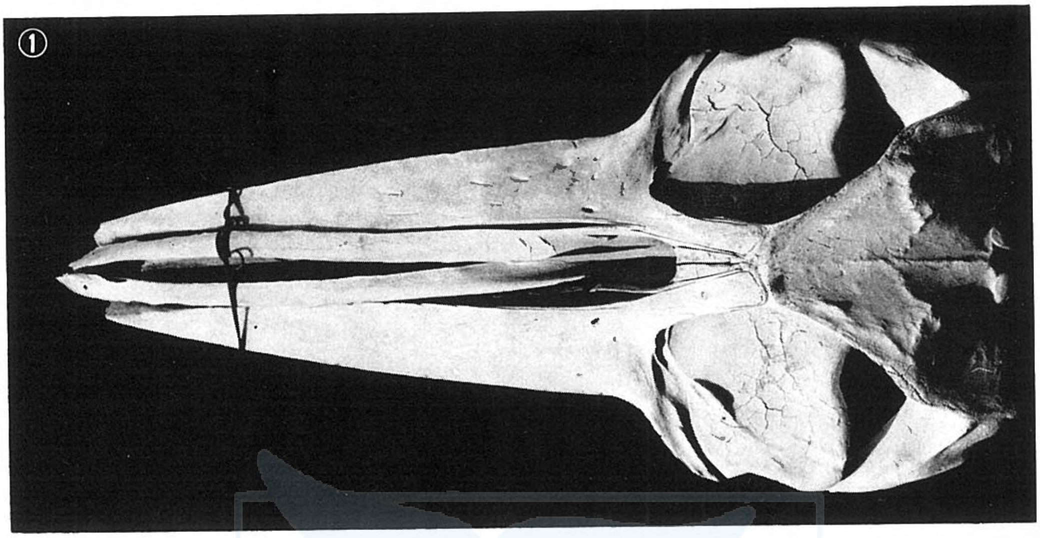

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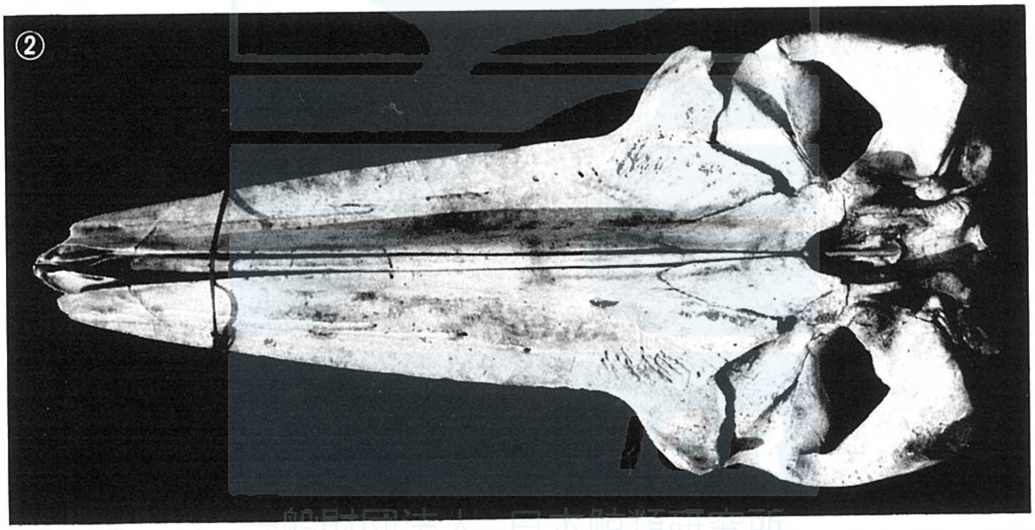

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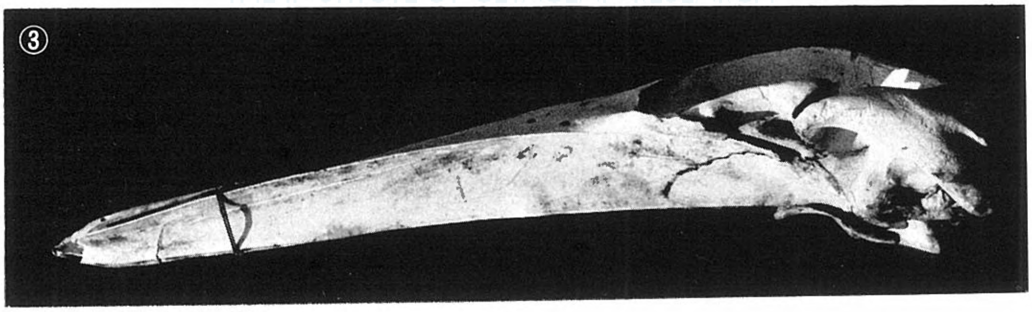

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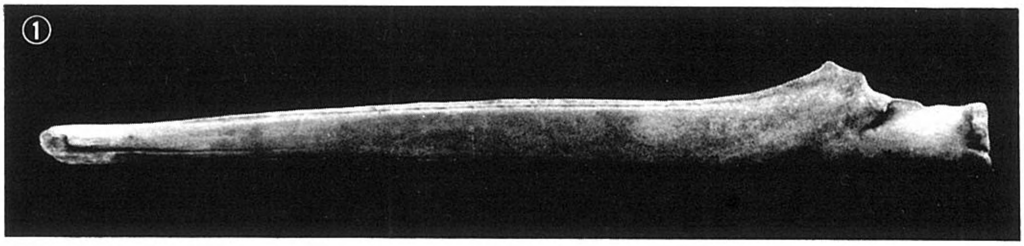

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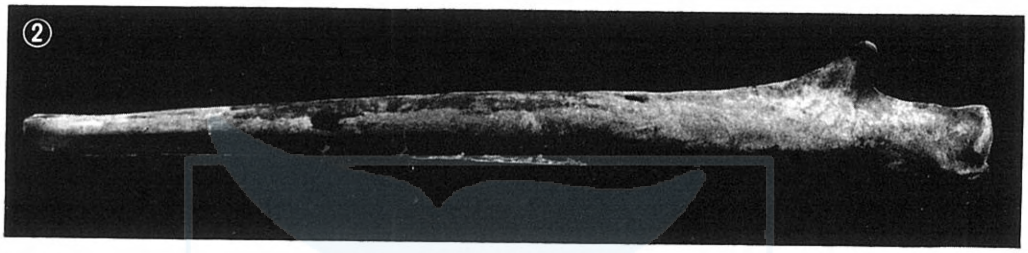

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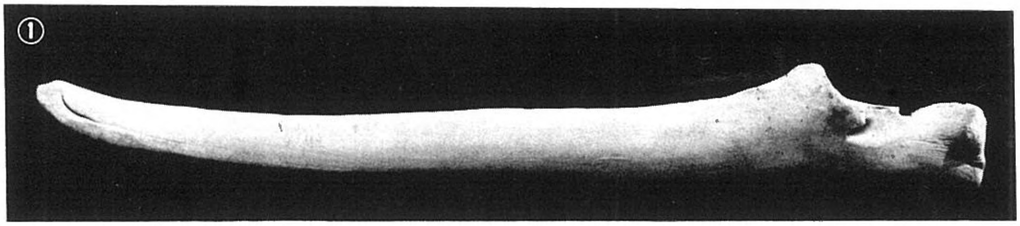

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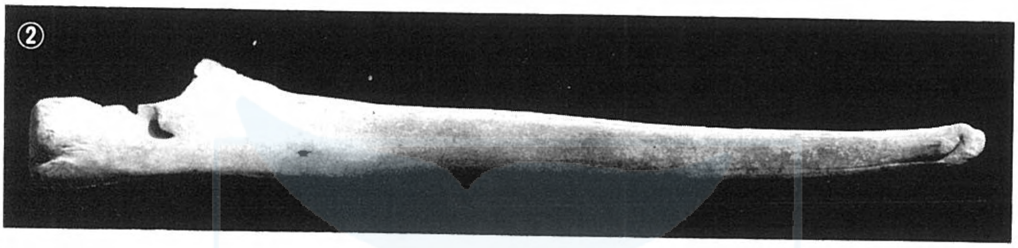

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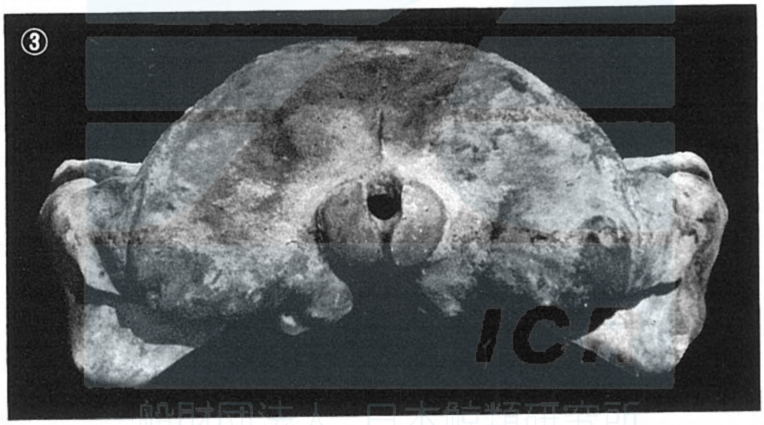

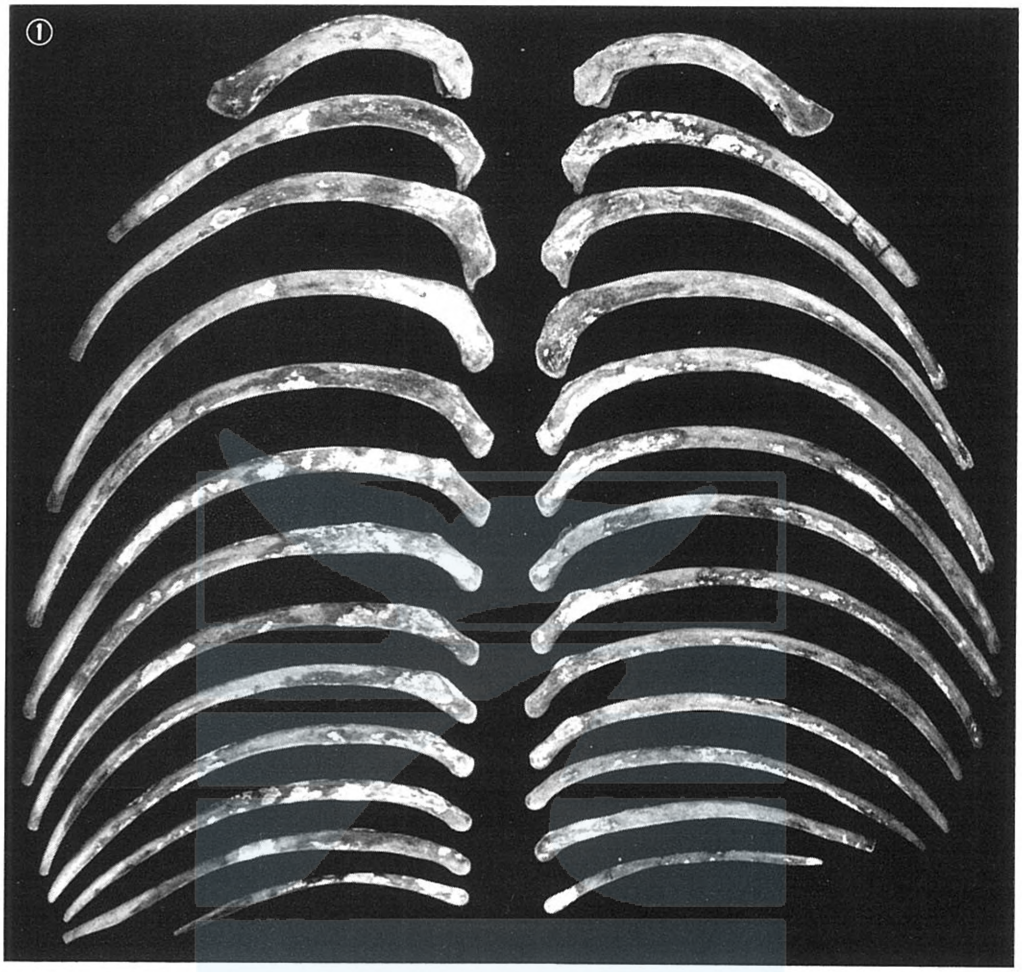
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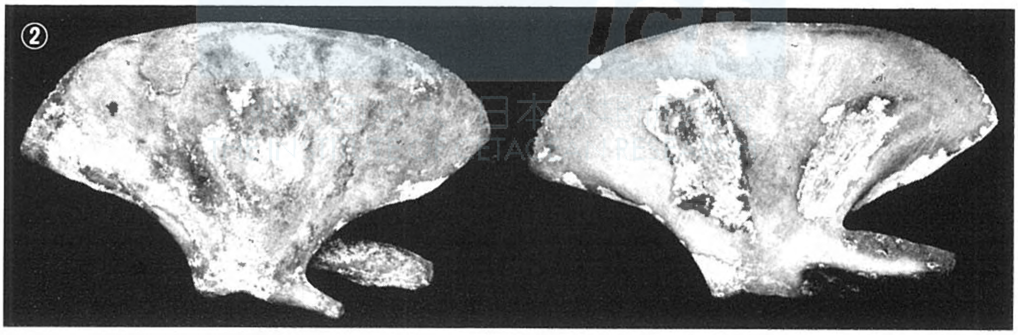
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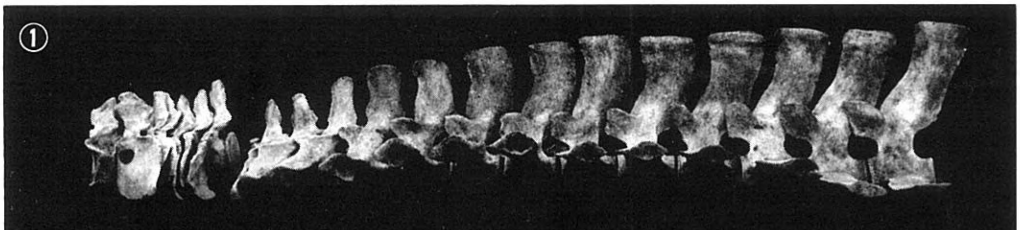

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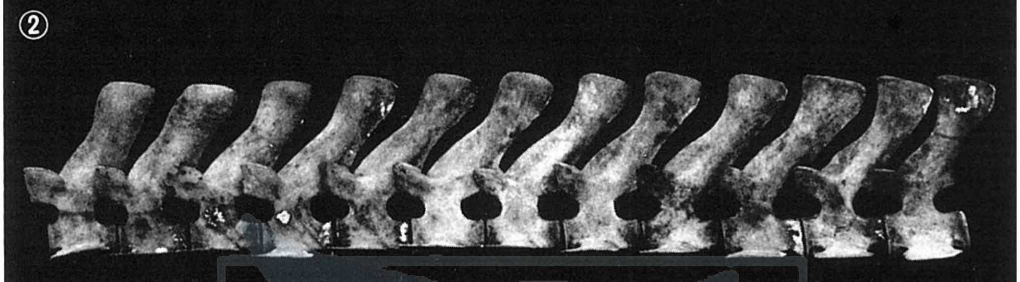

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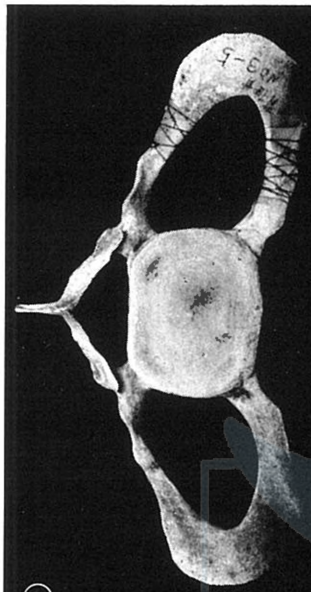

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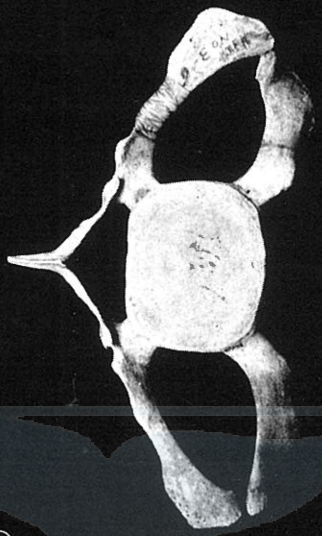

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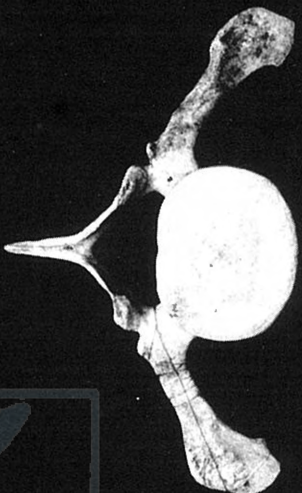

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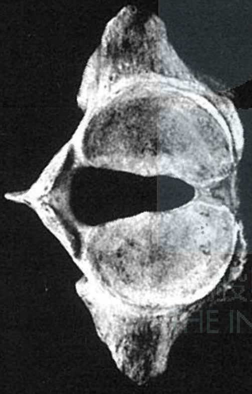

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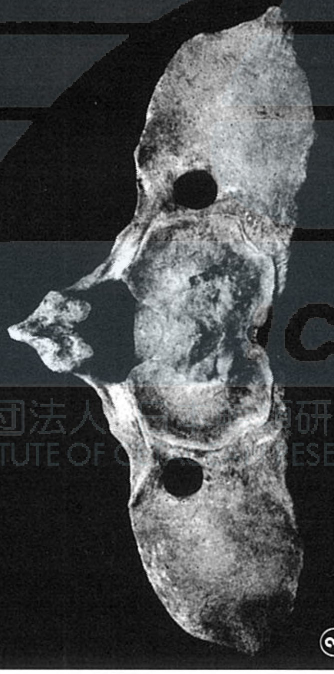

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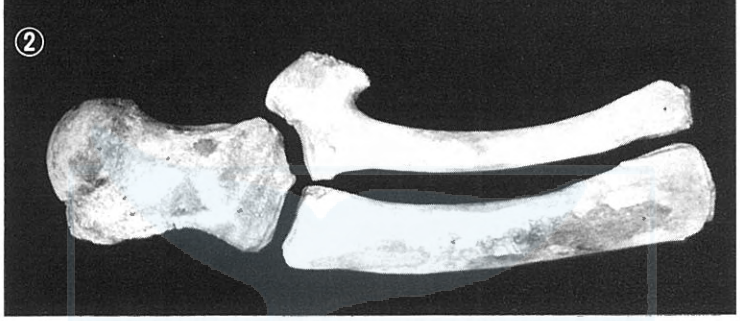
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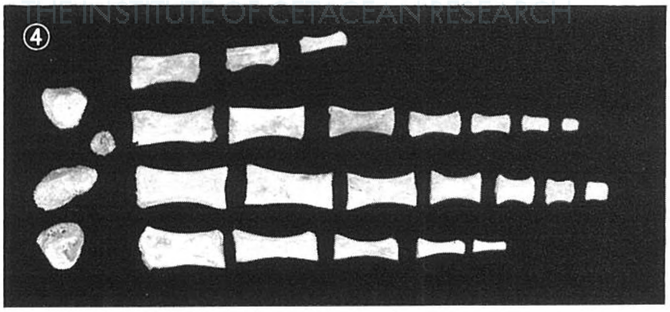
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BODY AND ORGAN WEIGHT OF STRIPED AND SPOTTED DOLPHINS OFF THE PACIFIC COAST OF JAPAN

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ABSTRACT

Weights of body and thirteen organs of striped and spotted dolphins off the Pacific coast of Japan are presented in relation to age, body length and body weight. Sexual dimorphism is observed on body weight, and muscle, bone and spleen weight indicating that males have larger weight than females. Actual weights of organs attain the plateau at about 15 years, at 8 to 10 years, or at 2 years of age. Growth of organs expressed by the relative organ weight is classified into three types: (1) the ratio increases in the prenatal stage, then decreases in the juvenile stage, (2) the ratio increases in both stages, (3) the ratio decreases in the former stage, then increases in the latter. Growth coefficients of five organs (muscle, bone, kidney, pancreas and stomach) are larger in the postnatal stage than in the prenatal stage, while in other eight organs (viscera, blubber, brain, heart, lungs, liver, intestine and spleen) the growth pattern is reverse. The striped dolphin has heavier heart and longer intestine than the spotted dolphin of the same region. Present results were compared between published records of some cetaceans.

INTRODUCTION

Informations on organ weight are valuable for understanding of growth and physiological condition of the animals. Especially, in the study of the accumulation of organochlorines and heavy metals in the striped dolphin, *Stenella coeruleoalba* (Meyen, 1833), and the spotted dolphin, *Stenella attenuata* (Gray, 1846), being conducted by our project team, these informations are expected to be useful for estimating the amount of residues deposited in the organs from the data of concentration.

The weight of various organs of *Stenella* has been reported by several scientists. Organ weight of striped dolphins in the Mediterranean Sea was obtained from 12 juvenile or subadult dolphins (range: 147–196 cm in body length) (Gihr and Pilleri, 1969). Perrin and Roberts (1972) reported organ weight of 68 eastern Pacific spotted dolphins (range: 78–218 cm), and 14 eastern Pacific spinner dolphins (range: 105–177 cm). However, they did not analyze the relationship of organ weight and age, but the relationship of organ weight and body weight. The analysis of the former relationship is considered to throw a light on the further under-

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standing of growth of the species.

The present study was undertaken to describe and analyze the growth of organs in the striped and spotted dolphins, and to compare the growth pattern of the species with that of other cetaceans.

MATERIALS AND METHODS

Specimens used in the present study were obtained from 11 schools of *S. coeruleoalba* and 5 schools of *S. attenuata* caught at Kawana (34°56′N, 139°09′E), Futo (34°56′N, 139°09′E) or Taiji (33°35′N, 135°57′E) on the Pacific coast of Japan. The date covers 5 fishing seasons from 1968 to 1979 (Table 1).

Striped dolphins collected from 2 schools at Taiji on 18 December, 1978 (Date of the driving: 17 December, 1978) and 5 December, 1979 (Date of the driving: 4 December, 1979) were stored frozen at −20°C or less for about three months, and then their organs were accurately weighed in the laboratory. Organs under

TABLE 1. LIST OF THE SPECIMENS USED IN THE PRESENT STUDY

Date of examination	Locality	Number of specimens			
		Fetus	Female	Male	Total
Stenella coeruleoalba					
18 XI '68	Kawana	— (17)	— (—)	— (—)	— (17)
18 X '70	Kawana	— (—)	2 (1)	6 (3)	8 (4)
22 X '70	Futo	3 (1)	— (—)	— (—)	3 (1)
25 X '70	Kawana	— (—)	— (—)	1 (—)	1 (—)
25 XI '70	Kawana	— (—)	7 (6)	1 (1)	8 (7)
26 XI '70	Kawana	— (2)	— (—)	— (—)	— (2)
27 XI '70	Kawana	— (2)	— (—)	— (—)	— (2)
30 XI '70	Futo	— (9)	— (—)	— (—)	— (9)
2 XII '70	Kawana	— (4)	2 (3)	1 (2)	3 (7)
3 XII '70	Kawana	— (2)	— (—)	— (—)	— (2)
10 XII '70	Kawana	— (—)	1 (1)	— (—)	1 (1)
15 XII '71	Kawana	— (23)	1 (—)	12 (—)	13 (23)
19 XII '78	Taiji	11 (11)	11 (11)	9 (9)	31 (13)
6 XII '79	Taiji	4 (4)	8 (8)	1 (1)	13 (13)
15 XII '79	Taiji	1 (1)	— (—)	— (—)	1 (1)
unknown	Kawana	— (9)	— (—)	— (—)	— (9)
Total		19 (83)	32 (30)	31 (16)	82 (129)
Stenella attenuata					
22 X '70	Kawana	— (—)	8 (4)	2 (1)	10 (5)
25 X '70	Kawana	— (12)	— (—)	— (—)	— (12)
31 X '70	Futo	— (1)	— (—)	— (—)	— (1)
6 XI '70	Futo	— (3)	7 (—)	3 (—)	10 (3)
10 XI '70	Kawana	— (—)	23 (19)	12 (11)	35 (30)
12 XI '70	Kawana	— (7)	— (—)	— (—)	— (7)
16 XI '70	Futo	— (37)	— (—)	— (—)	— (37)
Total		— (60)	38 (23)	17 (12)	55 (95)

Figures in parentheses indicate the number of individuals which were measured of their body weight only.

1 kg, those from 1 to 10 kg and those over 10 kg were measured in 0.1 g, 1 g and 10 g unit, respectively. In striped and spotted dolphins collected at Kawana and Futo between 1968 and 1971, lungs, liver and intestine were weighed in 10 g unit with spring scale in the field, and the other organs examined were weighed to 0.1 g in the laboratory within 24 hours after death. Body weight of the dolphins of the former case was measured in laboratory in 100 g unit before the dissection, and in the latter case it was obtained by combining the following two values; the body weight excluding viscera weighed by fishermen to the nearest 1 kg and the viscera weight obtained by Miyazaki as mentioned above. In both cases, the body weight of pregnant females having fetus was measured excluding the fetal and placental weight. Few females with corpus luteum and having no fetus are tentatively dealt as pregnant.

On 5 December 1979 only four pregnant females were collected at Taiji, and they show the extraordinary values of viscera, bone, heart and lungs weight compared with the females of the same sexual condition of the other fishing seasons. The difference is statistically significant ($p<0.001$). Although true reason of this difference is not clear, it will be reasonable to ignore these extraordinary data. In this report, these data are presented in Appendix Tables and text figures, but they are excluded from the following analyses.

Muscle was weighed after chipping it from bone as much as possible, but some fragments of muscle were not able to be completely separated from bone. Thus, the muscle weight presented here shows slightly lower value than the real weight while the bone weight slightly higher than the real. Brain weight was measured after opening the skull. Stomach was weighed after separating four compartments and removing their contents, while intestine was weighed without removing the content because of difficulty of removing them.

The fetal age calculated from the fetal growth curve of Miyazaki (1977) is used in plotting the organ or body weight data in text figures. However, for the description and analyses of growth pattern the fetal stage is divided into three stages, the early (0–20 cm in body length), the middle (20–60 cm) and the late (60 cm–) fetal stages.

Based on Kasuya's method (1976) of age determination developed for the striped and the spotted dolphins, age was determined by counting the growth layers in dentine for the animals younger than 11 years and those in cementum for older animals. In the young animal of 177 cm or less in body length, age was estimated from age-body length relationship of *S. coeruleoalba* of Miyazaki (1977). The striped dolphins having the left testis exceeding 15.5 g were defined as the mature individual.

Weights of 13 organs (muscle, blubber, bone, viscera, heart, lungs, liver, kidney, pancreas, stomach, intestine, spleen and brain) of *S. coeruleoalba* were analyzed against age, body weight and body length However, in *S. attenuata* the latter eight organs were analyzed only in relation to the body weight and body length. The relationship of organ weight and body weight were calculated for the equation $\mathrm{Log}\,Y=a+b\,\mathrm{Log}\,X$ by the least squares method, where Y represents organ weight in g, X, body weight in g, and b, Huxley's (1932) " growth coefficient ". The growth coefficients of the relationship between organ weight and body weight were obtained excluding pregnant females. This equation was also used for the relationship between body weight (Y in g) and body length (X in cm). All the correlations examined in this study were statistically significant ($p<0.001$). All the data analyzed in this study are shown in Appendix Tables 1, 2 and 3.

RESULTS

Body weight

Body weights of 83 fetal and 29 postnatal striped dolphins are plotted on age (Fig. 1). The growth in the first two years is rapid. The body weights at the age of 1 year (49 kg) and 2 years (61 kg) are about 4 and 5 times as much as the value of 12 kg at birth, respectively. Since the body weight of the pregnant females is not significantly different from that of the non-pregnant adult females ($0.2<p<0.3$), the body weights of these females are not dealt separately in this section. As shown in Fig. 1, body weight of striped dolphins attains the plateau at the age of 15 years. The asymptotic body weights calculated as the mean of four males and 10 females

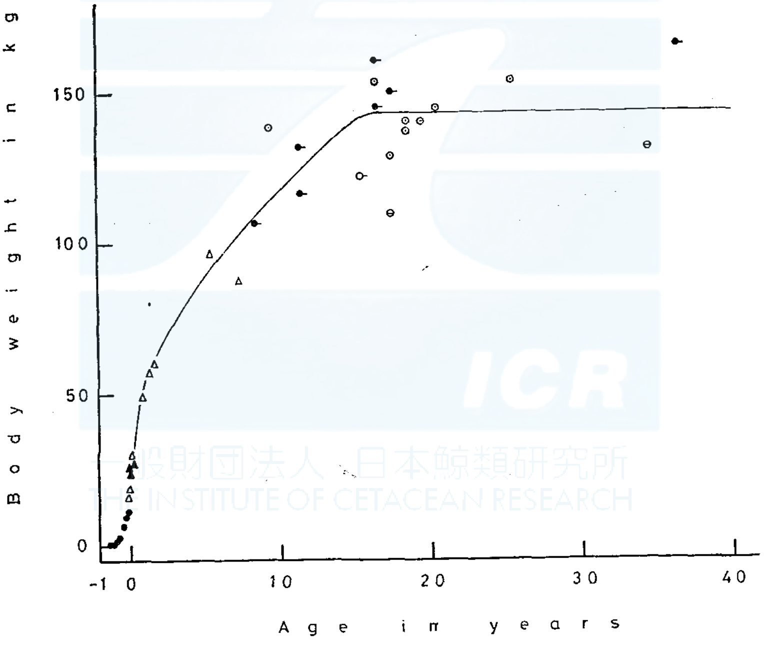

Fig. 1. The relationship between body weight and age in the striped dolphin off the Pacific coast of Japan. Closed circle with bar indicates mature male, open circle with dot pregnant female, open circle with external bar resting female, open circle with internal bar lactating female, closed triangle immature male, open triangle immature female, and closed circle the mean of fetuses in each 10 cm of body length interval.

over 15 years of age are 157.5 kg and 135.9 kg, respectively. The difference between sexes is significant ($p<0.02$).

The relationships between body weight and body length given in Table 2 are obtained from 83 fetal and 46 postnatal striped dolphins (16 males and 30 females), and 60 fetal and 35 postnatal spotted dolphins (12 males and 23 females). As the relationship of body weight and body length in the striped dolphins can be expressed by two equations (Fig. 2), the two regression lines are calculated for 9 fetuses below 7 cm of body length and for 74 fetuses of 7 cm or more. The value b for the former stage is 1.563 and is certainly lower than 2.779 of the value for the latter stage. The value of b of all the postnatal females is 2.910 and is close to 2.975 of the postnatal males. These two values are higher than above two values of fetuses.

All fetuses of the spotted dolphins presented here range from 6.5 to 29.5 cm in body length. The body weight-body length relationship of the species in this range can be shown by a single equation (Fig. 3). The value of growth coefficient b of these fetuses is 2.859, and is higher than any of the two values calculated for the fetal striped dolphins (Table 3). Since body weight of the postnatal spot-

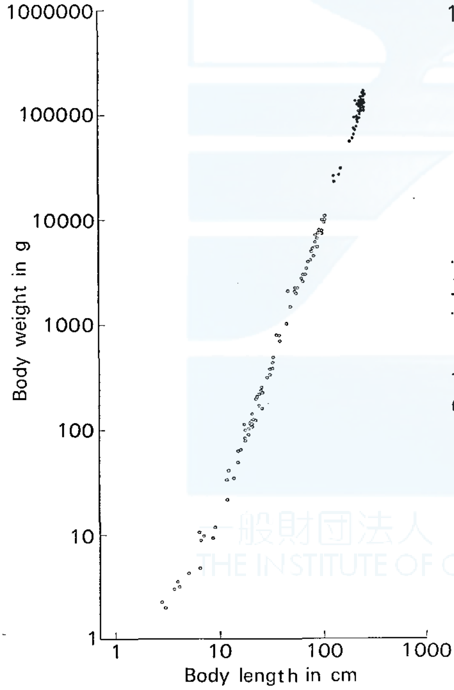

Fig. 2.

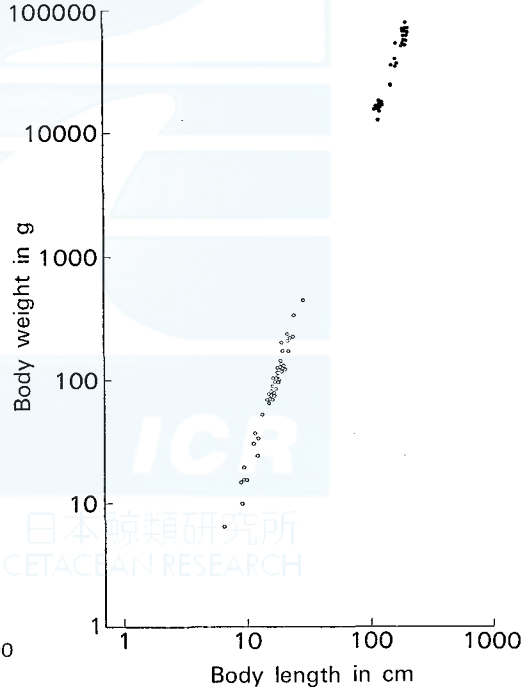

Fig. 3.

Fig. 2. The relationship between body weight and body length in the striped dolphin off the Pacific coast of Japan. Open circle indicates fetuses and closed circle postnatal animals.

Fig. 3. The relationship between body weight and body length in the spotted dolphin off the Pacific coast of Japan. Open circle indicates fetuses and closed circle postnatal animals.

TABLE 2. RELATIONSHIP BETWEEN BODY WEIGHT (G) AND BODY LENGTH (CM) IN *STENELLA COERULEOALBA* AND *STENELLA ATTENUATA*

	S. coeruleoalba				*S. attenuata*			
	a	b	r	Sample size	a	b	r	Sample size
Fetal samples								
Samples less than 7 cm	−0.402	1.563	0.906	9				
Samples of 7 cm and more	−1.507	2.779	0.997	74				
Samples in total	−1.214	2.602	0.995	83	−1.575	2.859	0.962	60
Postnatal samples								
Samples of male	−1.856	2.975	0.980	16				
Samples of female	−1.737	2.910	0.986	30				
Samples collected in 1970–1977	−1.709	2.897	0.943	17				
Samples collected in 1978 & 1979	−1.796	2.943	0.994	29				
Samples in total	−1.767	2.927	0.983	46	−1.900	2.928	0.981	35
Fetal and Postnatal samples								
Fetuses of 7 cm and more, and postnatal samples in total	−1.612	2.853	0.999	120				
Both fetal and postnatal samples in total	−1.391	2.742	0.997	129	−1.368	2.690	0.997	95

Values of a, b, and correlation coefficient r in linear regression equation $\text{Log } Y = a + b \text{ Log } X$, where Y=body weight (g) and X=body length (cm).

ted dolphins was measured with the loss of some blood and fluid, the growth coefficient of the species has to be compared with the corresponding value of the striped dolphins obtained by the same method (1970–1977 data). The value b in the former species is 2.928 and is close to the value of 2.897 in the latter species. These values are slightly higher than 2.859 of the prenatal spotted dolphins. This suggests that, in both species, the growth coefficient of the postnatal dolphins may be slightly higher than that of the prenatal stage.

Organ weight

When the sum of the proportional weights is compared with the body weight measured before dissection, the values of 42 striped dolphins collected in 1978 and 1979 come between 85.9 and 100% (Appendix Table 1). The mean of the loss through the dissection is only 3.4%, and is negligible.

As shown in this section, the adult males exceed the adult females in the weight of muscle, bone and spleen. In the weight of all the 13 organs examined in this study, the mean value of the pregnant females show no significant difference from the corresponding values of the non-pregnant adult females (at $p=0.05$). Among major four components (muscle, blubber, bone and viscera), the muscle has the highest growth coefficient value, and is followed by blubber, viscera and bone (Table 3).

Muscle: Muscle weight is plotted on age for 41 striped dolphins (13 fetuses, and 10 male and 18 female postnatals) (Fig. 4). The increase of muscle weight in the

TABLE 3. RELATIONSHIP BETWEEN ORGAN WEIGHTS AND BODY WEIGHT FOR *STENELLA COERULEOALBA* AND *STENELLA ATTENUATA*

Organs	Stage	*S. coeruleoalba*				*S. attenuata*			
		a	b	r	Sample size	a	b	r	Sample size
Heart	prenatal	−2.2644	1.0833	0.9782	17				
	postnatal	−1.6983	0.9177	0.9454	31	−1.8788	0.9213	0.9714	34
	total	−1.8665	0.9565	0.9858	48				
Lungs	prenatal	−1.3167	1.0104	0.9948	17				
	postnatal	−0.0264	0.6543	0.8838	34	−0.6814	0.7849	0.9117	38
	total	−0.5534	0.7691	0.9752	51				
Liver	prenatal	−1.5375	0.9765	0.9873	16				
	postnatal	−1.1591	0.8693	0.9427	34	−0.3599	0.7316	0.9358	38
	total	−1.2612	0.8922	0.9896	50				
Left kidney	prenatal	−2.2526	0.9819	0.9817	17				
	postnatal	−2.8761	1.0501	0.9742	32	−2.7986	1.0744	0.9780	15
	total	−1.8665	0.8495	0.9832	49				
Pancreas	prenatal	−3.6990	1.1311	0.4609	5				
	postnatal	—	1.5107	0.8800	29	−3.5229	1.1668	0.9531	27
	total	−3.3979	1.3027	0.9331	34				
First stomach	prenatal	−2.7932	1.0023	0.9883	14				
	postnatal	−5.0000	1.5634	0.9673	29	−4.2218	1.4174	0.9027	28
	total	−3.7447	1.2605	0.9833	43				
Second stomach	prenatal	−2.8601	0.9890	0.9857	14				
	postnatal	−3.4559	1.1566	0.9512	29	−3.3098	1.1681	0.9802	28
	total	−3.3768	1.1373	0.9885	43				
Intestine	prenatal	−2.6536	1.2375	0.9959	15				
	postnatal	−1.5538	0.9825	0.9452	34	−1.4629	0.9851	0.9616	38
	total	−2.3161	1.1396	0.9927	49				
Spleen	prenatal	−3.8861	1.1374	0.8160	12				
	postnatal	−1.1532	0.5267	0.5528	34	−0.7820	0.4590	0.5702	28
	total	−2.7645	0.8538	0.8791	46				
Brain	prenatal	−1.9508	1.1488	0.9965	15				
	postnatal	1.8742	0.2140	0.8279	22				
	total	−0.6894	0.7528	0.9420	37				
Muscle	prenatal	−1.1032	1.1296	0.9963	13				
	postnatal	−1.0747	1.1585	0.9966	21				
	total	−1.3338	1.2076	0.9980	34				
Blubber	prenatal	−1.6247	1.2718	0.9990	13				
	postnatal	0.0487	0.8419	0.9923	21				
	total	−0.9170	1.0474	0.9908	34				
Bone	prenatal	0.1726	0.7843	0.9820	14				
	postnatal	−0.3801	0.8996	0.9742	21				
	total	0.1226	0.7971	0.9921	35				
Viscera	prenatal	−1.2337	1.1050	0.9961	14				
	postnatal	−0.3234	0.8653	0.9853	21				
	total	−0.8263	0.9733	0.9946	35				

Values of a, b, and correlation coefficient r is linear regression equation Log Y=a+b Log X, where Y=organ weight (g) and X=body weight (g).

first two years is rapid, and slows between the age of 3 and 15 years. After the age of 15 years, the weight attains the plateau. In this age range, the mean weight of males is 87,375 g (n: 4, range: 78,460–91,430 g) and is larger than 74,624 g (n: 10, range: 58,910–86,000 g) of females. The sexual difference of the mean weights is significant ($0.01<p<0.02$).

The ratio of muscle to body weight for 41 striped dolphins is plotted on age (Fig. 5). This ratio is positively correlated with age in the fetal stage. Then, it increases faster from birth to the age of 2 years when the value attains around 50%. After this age the ratio for 20 striped dolphins remains nearly constant within the range of 49.8 to 59.8% (mean: 54.5%).

Blubber: Blubber weight is plotted against age for 42 striped dolphins (14 fetuses, and 10 male and 18 female postnatals) (Fig. 6). Increase of blubber weight stops around the age of 15 years. The mean weight of 14 striped dolphins over this age is 24,663 g (17,090–31,390 g). In this age range there is no significant sexual

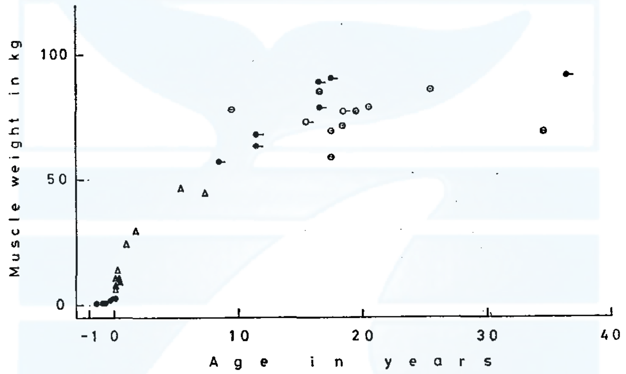

Fig. 4. The relationship between muscle weight and age in the striped dolphin off the Pacific coast of Japan. For marks see Fig. 1.

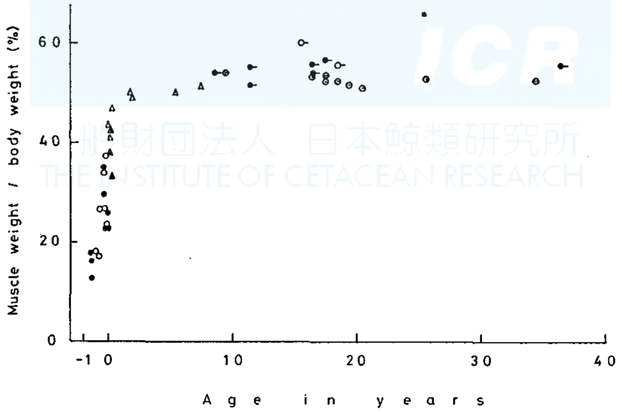

Fig. 5. The relationship between the relative muscle weight and age in the striped dolphin off the Pacific coast of Japan. Closed circle indicates male fetus and open circle female fetus. For other marks see Fig. 1.

difference in the mean blubber weight ($0.8<p<0.9$).

The ratio of blubber to body weight for 41 striped dolphins is plotted on age (Fig. 7). The rapid increase of the ratio starts at the middle fetal stage and attains the maximum value on the nearterm fetus. Then, it is followed by a rapid decrease in the neonatal stage. After the age of 2 years the ratio of 20 striped dolphins becomes constant within the range of 14.0 to 19.2% (mean: 17.3%).

Bone: Bone weight is plotted on age for 42 striped dolphins (14 fetuses, and 10 male and 18 female postnatals) (Fig. 8). Rapid increase is observed in the first two years after birth. The weight increases up to the age of around 15 years and attains the plateau at this age. In the age range above 15 years, the mean bone weight of 4 males is 18,620 g (range: 17,900–19,650 g) and is significantly larger than 14,502 g (11,300–16,800 g) of 10 females ($p<0.001$).

The ratio of bone to body weight for 42 striped dolphins is plotted against age (Fig. 9). The ratio decreases rapidly from the middle to the late fetal stage, then

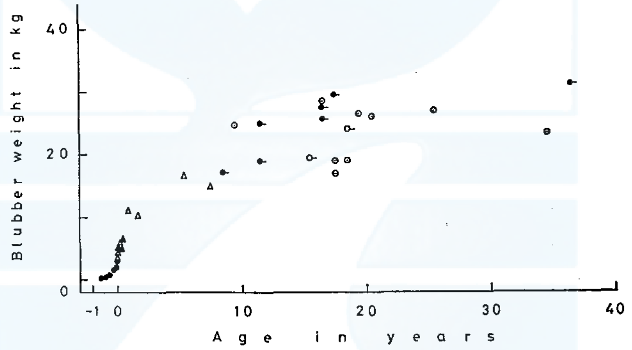

Fig. 6. The relationship between blubber weight and age in the striped dolphin off the Pacific coast of Japan. For marks see Fig. 1.

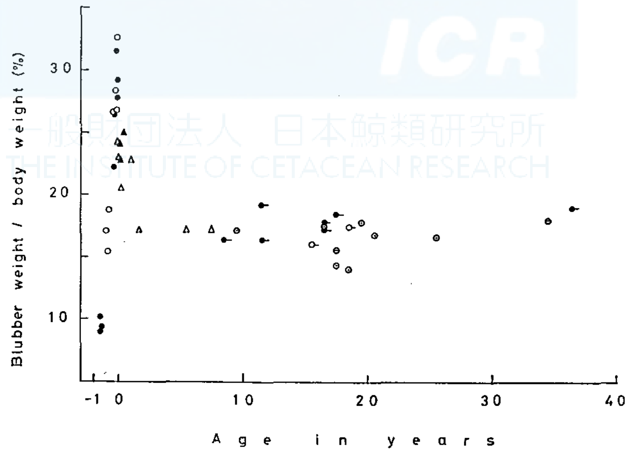

Fig. 7. The relationship between the relative blubber weight and age in the striped dolphin off the Pacific coast of Japan. For marks see Fig. 5.

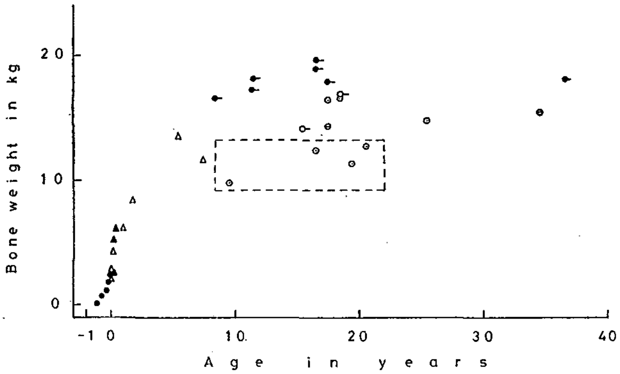

Fig. 8. The relationship between bone weight and age in the striped dolphin off the Pacific coast of Japan. For marks see Fig. 1. The pregnant females surrounded by dotted line were collected on 5 December 1979.

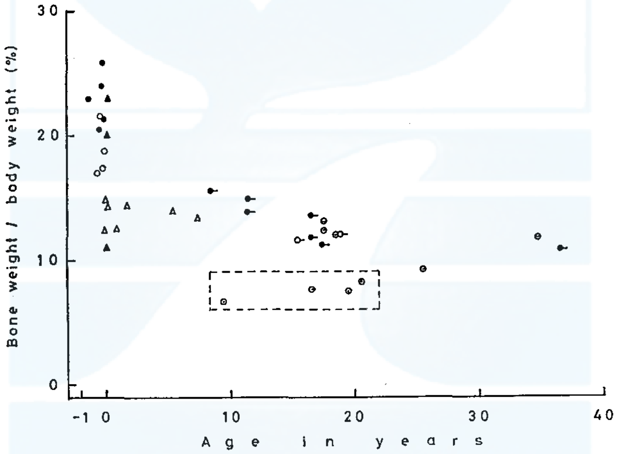

Fig. 9. The relationship between the relative bone weight and age in the striped dolphin off the Pacific coast of Japan. For marks see Figs 5 and 8.

it decreases at slower rate until the age of 2 years. After this age, the ratio of 16 striped dolphins becomes constant within the range of 9.7 to 15.6% (mean: 12.7%).

Viscera: Fig. 10 shows the relationship between viscera weight and age of 42 striped dolphins (14 fetuses, and 10 male and 18 female postnatals). The weight increases till the age of around 15 years, and then becomes constant. In the age range above 15 years, the mean weight of 11 striped dolphins is 13,764 g (range: 11,120–17,180 g).

The ratio of viscera to body weight for 42 striped dolphins rapidly increases from the middle to the late fetal stage, and sharply decreases after birth (Fig. 11). After the age of 2 years, the ratio continues to decrease at slower rate in the range of 7.8 to 13.1% (n: 16, mean: 9.8%).

Brain: Brain weight is plotted on age for 46 striped dolphins (17 fetuses, and 10

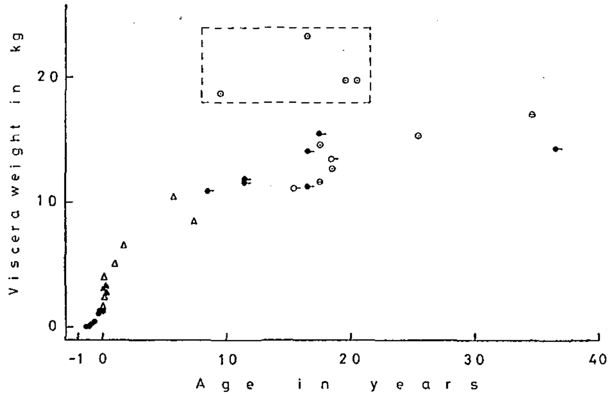

Fig. 10. The relationship between viscera weight and age in the striped dolphin off the Pacific coast of Japan. For marks see Figs 1 and 8.

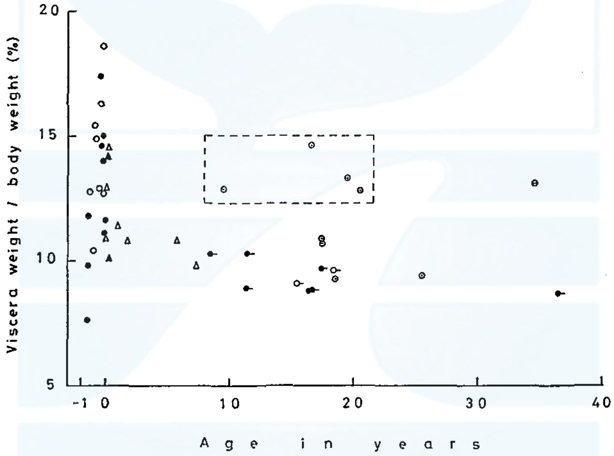

Fig. 11. The relationship between the relative viscera weight and age in the striped dolphin off the Pacific coast of Japan. For marks see Figs 5 and 8.

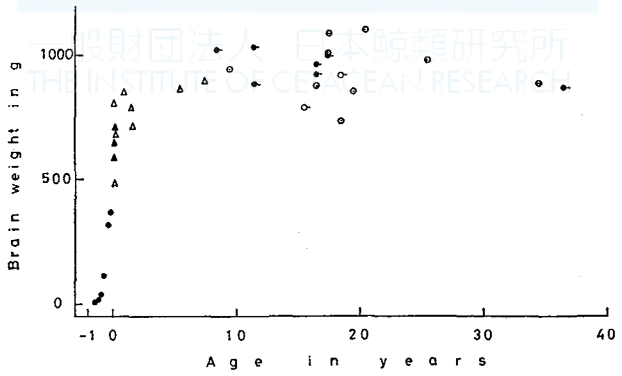

Fig. 12. The relationship between brain weight and age in the striped dolphin off the Pacific coast of Japan. For marks see Fig. 1.

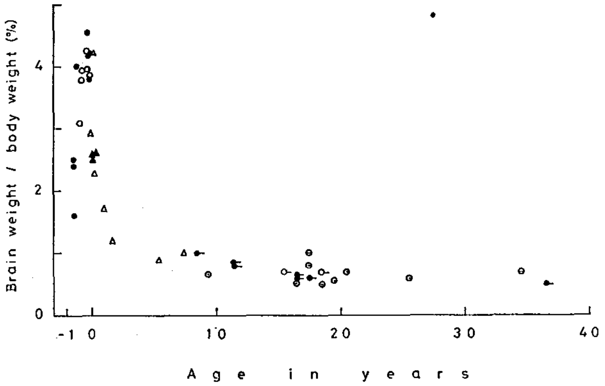

Fig. 13. The relationship between the relative brain weight and age in the striped dolphin off the Pacific coast of Japan. For marks see Fig. 5.

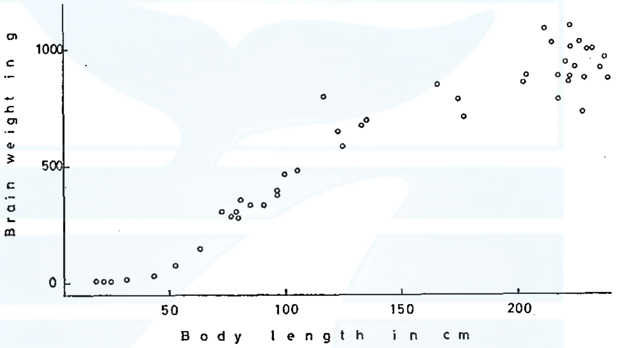

Fig. 14. The relationship between brain weight and body length in the striped dolphin off the Pacific coast of Japan.

male and 19 female postnatals) (Fig. 12). The weight rapidly increases from the middle fetal stage to the age of 2 years, then it increases at slower rate until the age of 8 years. In the animals over 8 years of age, the weight becomes constant within the range of 731 to 1,097 g (n: 18, mean: 935 g). The mean brain weight of adult animals shows no significant sexual difference ($0.5<p<0.6$).

The ratio of brain to body weight for 42 striped dolphins is plotted against age (Fig. 13). The ratio rapidly increases from the middle to the late fetal stage, but sharply decreases from birth to the age of 2 years. Then the ratio stays almost constant within the range of 0.53 to 1.01% (n: 20, mean: 0.72%).

The value of the growth coefficient calculated for 15 prenatal striped dolphins is 1.1488. This is contrasted with the low value of 0.2140 of 22 postnatal individuals of the same species (Table 3).

Figure 14 shows the relationship between brain weight and body length for 46 striped dolphins. The brain weight increases lineally from 45 to 140 cm in body length, then the increase becomes at lower rate and finally stops after body length of 210 cm, where the species attain sexual maturity.

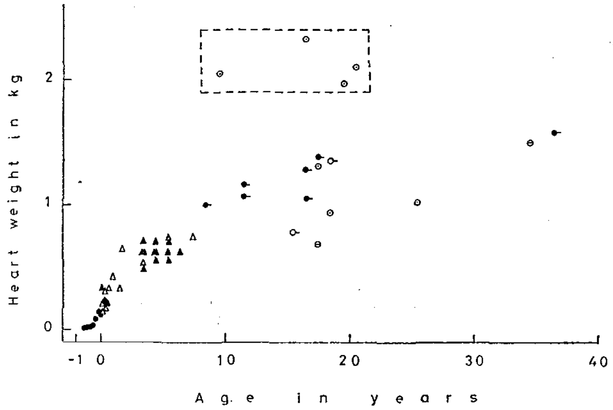

Fig. 15. The relationship between heart weight and age in the striped dolphin off the Pacific coast of Japan. For marks see Figs 1 and 8.

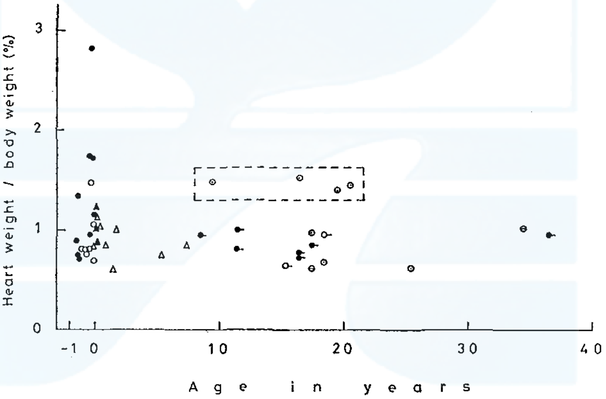

Fig. 16. The relationship between the relative heart weight and age in the striped dolphin off the Pacific coast of Japan. For marks see Figs 5 and 8.

Heart: Heart weight is plotted on age for 64 striped dolphins (19 fetuses, and 23 male and 22 female postnatals). The weight increases rapidly from birth to the age of 2 years, then increases slowly till 15 years of age. After this age, the weight attains the plateau (Fig. 15) with the mean weight of 1,170 g (n: 11, range: 683–1,580 g). In this age range there is no significant sexual difference in the mean heart weight ($0.2 < p < 0.3$).

The ratio of heart to body weight is plotted against age for 45 striped dolphins (Fig. 16). The ratio increases from the middle to the late fetal stage, but sharply decreases from birth to the age of 2 years when it attains the value of about 0.9%. In the animals over 2 years of age, the ratio of 11 striped dolphins remains nearly constant within the range of 0.62 to 1.15% (mean: 0.845%).

The relative growth coefficient for 31 postnatal striped dolphins is 0.92 and is same with 0.92 for 34 postnatal spotted dolphins. However, these values are lower than 1.08 of 17 prenatal striped dolphins (Table 3).

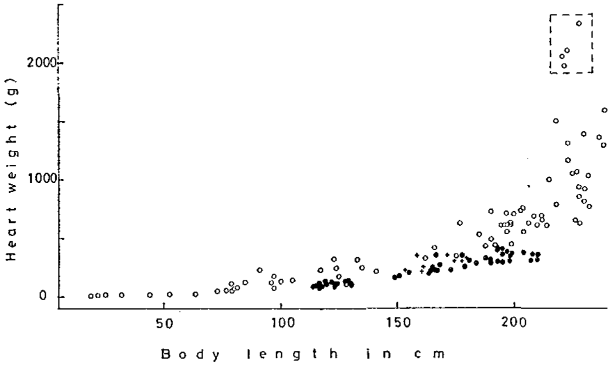

Fig. 17. The relationship between heart weight and body length in the populations of *Stenella*. Open circle indicates the striped dolphin off the Pacific coast of Japan, closed circle the spotted dolphin off the Pacific coast of Japan and double crosses the striped dolphin in the Mediterranean Sea. For marks see Fig. 8.

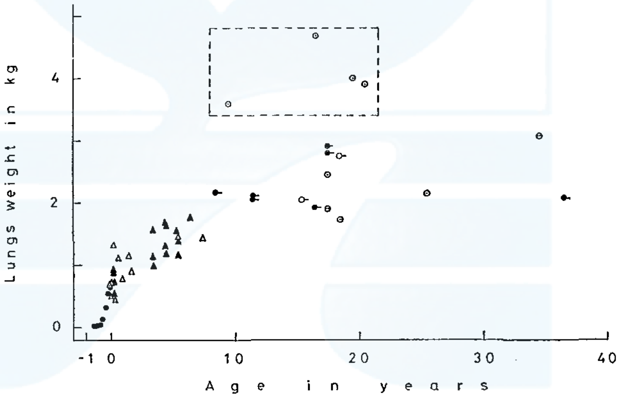

Fig. 18. The relationship between lungs weight and age in the striped dolphin. For marks see Figs 1 and 8.

Comparison of the heart weight-body length relationship between two species of *Stenella* indicates that the striped dolphins off the Pacific coast of Japan have heavier heart than the spotted dolphins of the same body length in the same area (Fig. 17). Heart weight of the striped dolphins from Japanese areas shows a large individual variation at body lengths of 220 cm or more, where the species attains sexual maturity. The weight of the striped dolphins in the Mediterranean Sea (Gihr and Pilleri, 1969) was distributed in the individual variation of the species from Japanese areas (Fig. 17).

Lung: The weight of lungs is plotted on age for 64 striped dolphins (19 fetuses, and 23 male and 22 female postnatals) (Fig. 18). The increase of the weight is rapid in the first two years, and stops at the age of about 15 years. After this age, the mean weight of lungs of 11 striped dolphins is 2,347 g (range: 1,722–3,070 g). In this age range there is no significant sexual difference in the mean weight of

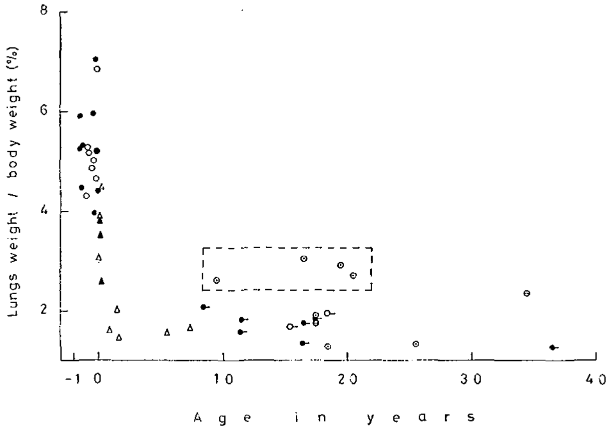

Fig. 19. The relationship between the relative lungs weight and age in the western Pacific striped dolphin. For marks see Figs 5 and 8.

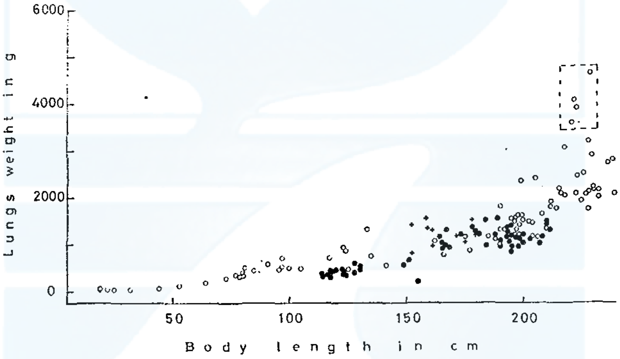

Fig. 20. The relationship between lungs weight and body length in the populations of *Stenella*. For marks see Figs 8 and 17.

lungs $(0.6<p<0.7)$.

The ratio of lungs to body weight is plotted against age for 45 striped dolphins (Fig. 19). The ratio increases from the middle to the late fetal stage, then it decreases sharply until the age of 2 years. After this age the ratio stays nearly constant within the range of 1.26 to 2.35% (n: 16, mean: 1.69%).

Table 3 shows the relative growth coefficient of the weight of lungs. The value of 0.654 obtained from 34 postnatal striped dolphins is obviously lower than 1.01 of 17 prenatals of the same species, and is also slightly lower than 0.785 of 38 postnatal spotted dolphins.

The relationship between the weight of lungs and body length in the two species of *Stenella* is shown in Fig. 20. The weight of lungs of striped dolphins off the Pacific coast of Japan appears to be different neither from the same species in the Mediterranean Sea nor the spotted dolphins in the Japanese waters.

Liver: Based on 63 striped dolphins (18 fetuses, and 23 male and 22 female postnatals), the relationship between liver weight and age is shown in Fig. 21. The

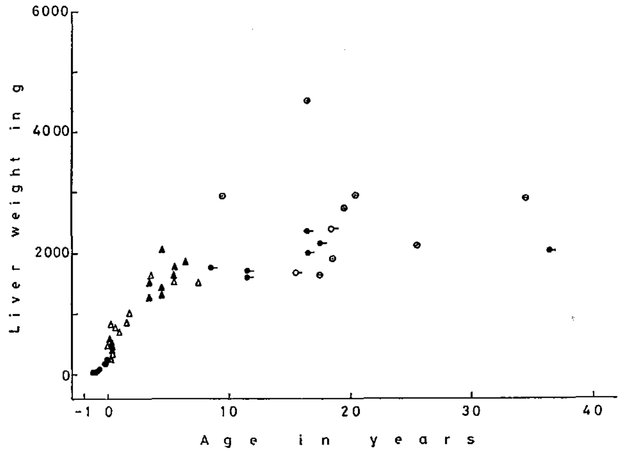

Fig. 21. The relationship between liver weight and age in the striped dolphin off the Pacific coast of Japan. For marks see Fig. 1.

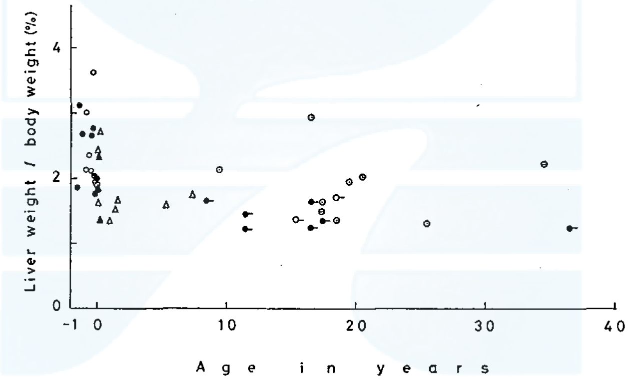

Fig. 22. The relationship between the relative liver weight and age in the striped dolphin off the Pacific coast of Japan. For marks see Fig. 5.

weight increases rapidly in the first two years, then the increase becomes slower until the age of 15 years. After this age the weight attains the plateau with the mean of 2,399 g (n: 14, range: 1,650–4,510 g). In the animals of this age range, there is no significant sexual difference in the mean liver weight ($0.5<p<0.6$).

The ratio of liver to body weight is plotted on age for 44 striped dolphins (Fig. 22). The ratio increases from the middle to the late fetal stage, then decreases sharply until the age of 2 years. After this age the ratio stays nearly constant within the range of 1.22 to 2.94% (n: 20, mean: 1.67%).

The growth coefficient of liver weight is shown in Table 3. The value for 34 postnatal striped dolphins is 0.869. This is lower than 0.997 for 16 prenatal individuals of the same species, but is higher than 0.732 for 38 postnatal spotted dolphins.

The relationship between liver weight and body length of the two species of

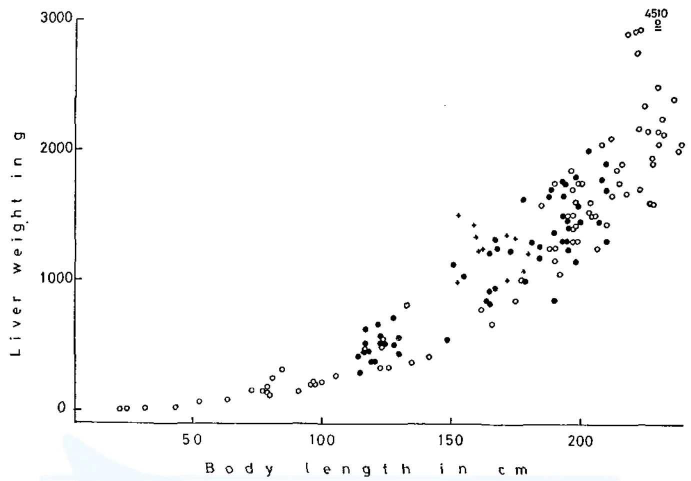

Fig. 23. The relationship between liver weight and body length in the populations of *Stenella*. For marks see Fig. 17.

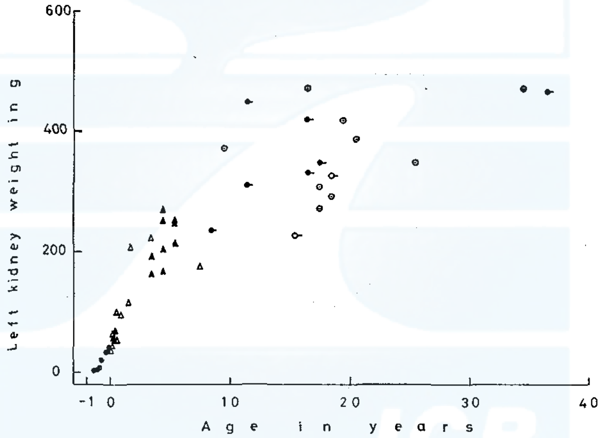

Fig. 24. The relationship between the left kidney weight and age in the striped dolphin off the Pacific coast of Japan. For marks see Fig. 1.

Stenella is shown in Fig. 23. The liver weight of the striped dolphins off the Pacific coast of Japan appears to be almost similar to the same species in the Mediterranean Sea and the spotted dolphins in the Japanese waters.

Kidney: Since the mean weight of kidneys of the striped dolphins shows no significant bilateral asymmetry ($p > 0.9$), only the left kidney is plotted in the present study on age for 61 striped dolphins (19 fetuses, and 20 male and 22 female postnatals) (Fig. 24). The weight continues to increase till 15 years of the age, and then attains the plateau. The mean weight of the left kidneys of 14 striped dolphins over 15 years of age is 362 g (range: 216–475 g). In this age range, the sexual difference of the mean left kidney weight is not significant ($0.7 < p < 0.8$).

The ratio of kidneys to body weight increases from the early to the middle

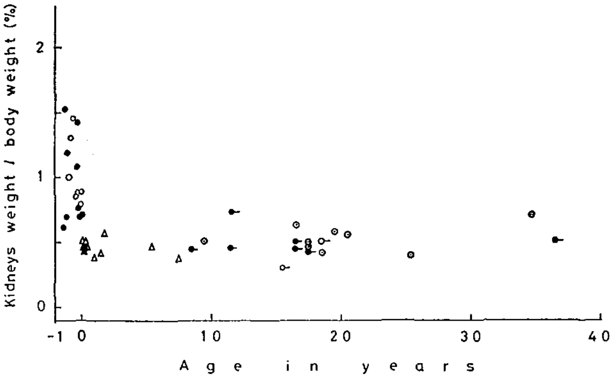

Fig. 25. The relationship between the relative kidneys weight and age in the striped dolphin. For marks see Fig. 5.

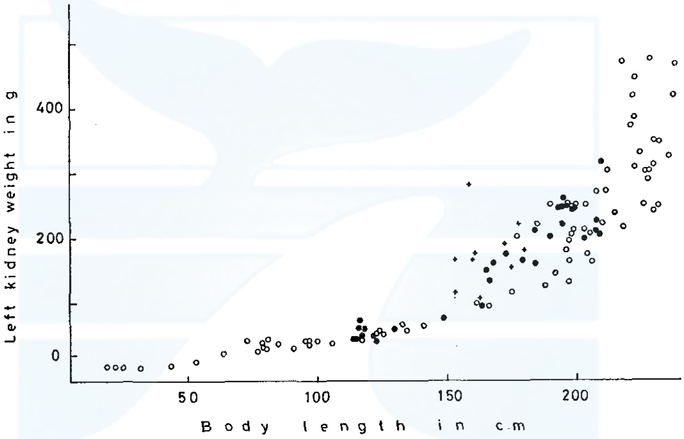

Fig. 26. The relationship between the left kidney weight and body length in the populations of *Stenella*. For marks see Fig. 17.

fetal stage, but after the latter stage it sharply decreases until the age of around 2 years (Fig. 25). After this age the ratio becomes constant within the range of 0.31 to 0.74% (n: 20, mean: 0.50%).

Table 3 shows the growth coefficient of the left kidney weight. The value of 1.05 for 32 postnatal striped dolphins is close to that of 1.07 for 15 postnatal spotted dolphins. However, these values are slightly higher than 0.982 of the corresponding value of 17 prenatal striped dolphins.

The relationship of the left kidney weight to body length of the two species of *Stenella* is shown in Fig. 26. The kidney weight of striped dolphins off the Pacific coast of Japan is almost similar to the same species in the Mediterranean Sea and the spotted dolphins in the Japanese waters.

Pancreas: Pancreas weight is plotted on age for 36 striped dolphins (22 male and 14 female postnatals) (Fig. 27). The weight increases rapidly to the age of 8

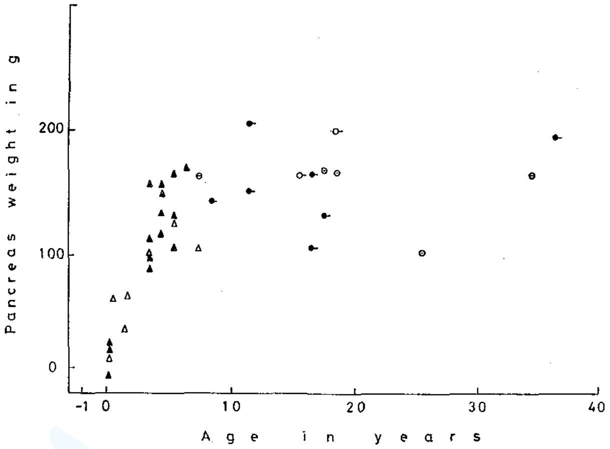

Fig. 27. The relationship between pancreas weight and age in the striped dolphin off the Pacific coast of Japan. For marks see Fig. 1.

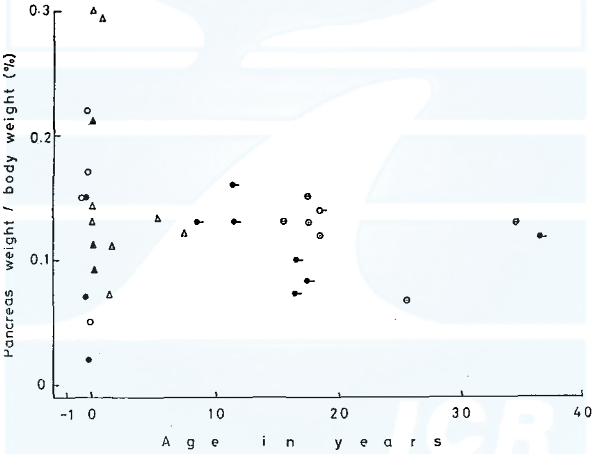

Fig. 28. The relationship between the relative pancreas weight and age in the striped dolphin off the Pacific coast of Japan. For marks see Fig. 5.

years, and the increase becomes slow between the age of 8 and 15 years. After the age of 15 years, the weight attains the plateau, and gives the mean weight of 157 g (n: 11, range: 102–200 g). In the animals of this age range, the mean weights of pancreas show no significant sexual difference ($0.5<p<0.6$).

The ratio of pancreas to body weight is plotted on age for 32 striped dolphins (Fig. 28). Although the ratio shows larger individual variation in both the new-born calves and in the adult animals, it becomes constant after 2 years of the age. The ratio ranges from 0.067 to 0.16% (n: 16, mean: 0.12%).

The growth coefficient of pancreas weight is shown in Table 3. The coefficient 1.56 calculated for 29 postnatal striped dolphins is higher than any of 1.13

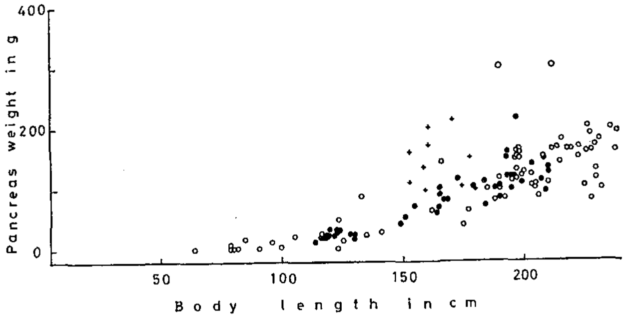

Fig. 29. The relationship between pancreas weight and body length in the populations of *Stenella*. For marks see Fig. 17.

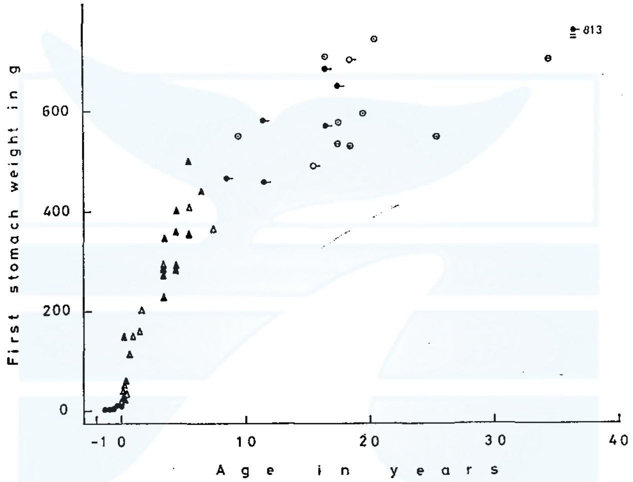

Fig. 30. The relationship between the first stomach weight and age in the striped dolphin off the Pacific coast of Japan. For marks see Fig. 1.

for 5 prenatal of the same species or 1.17 for 27 postnatal spotted dolphins.

Figure 29 shows the relationship between pancreas weight and body length. This indicates that the striped dolphins off the Pacific coast of Japan have almost same pancreas weight to the spotted dolphins in the same area. The pancreas weight of the striped dolphins in the Mediterranean Sea shows considerably higher value than those of the striped and the spotted dolphins off the Pacific coast of Japan.

Stomach: Although each compartment of stomach cannot be recognized in the fetus below 3 cm in body length, the differentiation of the first and the second stomach was observed in the fetus over 12 cm in body length. On the other hand, the differentiation of the third and the fourth stomach was able to be observed at about the body length of 60 cm, or about 4—5 months after the differentiation of the first and the second stomach.

Weights of the first and the second stomach are plotted on age for 55 striped

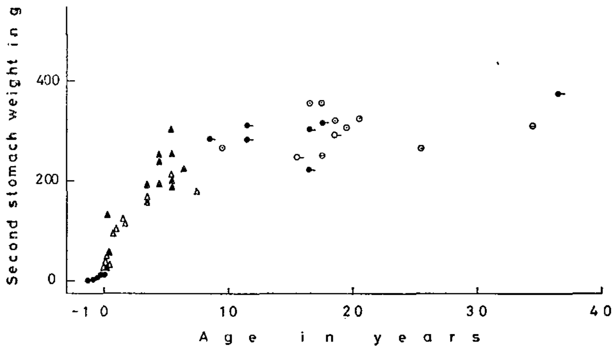

Fig. 31. The relationship between the second stomach weight and age in the striped dolphin off the Pacific coast of Japan. For marks see Fig. 1.

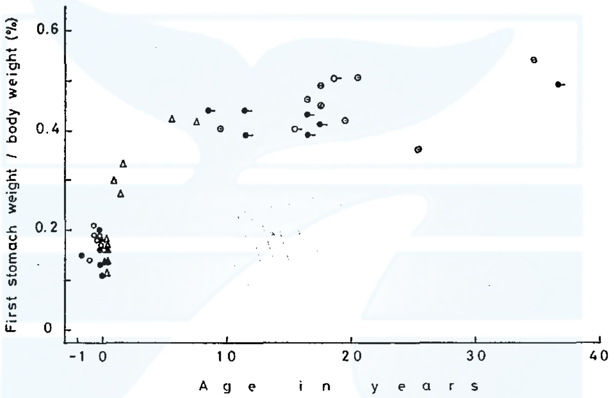

Fig. 32. The relationship between the relative first stomach weight and age in the striped dolphin off the Pacific coast of Japan. For marks see Fig. 1.

dolphins (10 fetuses, and 23 male and 22 female postnatals) (Figs. 30 and 31). The weight of the first stomach increases rapidly from birth to the age of 15 years, then attains the plateau. On the other hand, the rapid growth of the second stomach lasts only till the age of 8 years, then it slows until the cessation of the growth at the age of 15 years. In 14 striped dolphins above 15 years, the mean weights of the first and the second stomach are 633 g (range: 491—813 g) and 302 g (220—375 g), respectively. The sexual difference of the mean weight of the first or the second stomach is not statistically significant ($p>0.2$). Comparison of the first stomach with the second stomach of the striped dolphins shows that the age when the weight of the first stomach starts to exceed that of the second stomach is around 2 years, and this age is close to the age at the completion of weaning in the species (Miyazaki, 1977).

In the 23 adult striped dolphins, the mean weight of the third stomach is 106 g (range 56—194 g), and is 1.6 times as large as that of the fourth stomach (mean: 67.8 g, range: 23—145 g).

Figures 32 and 33 show the relationship between the relative weight of the

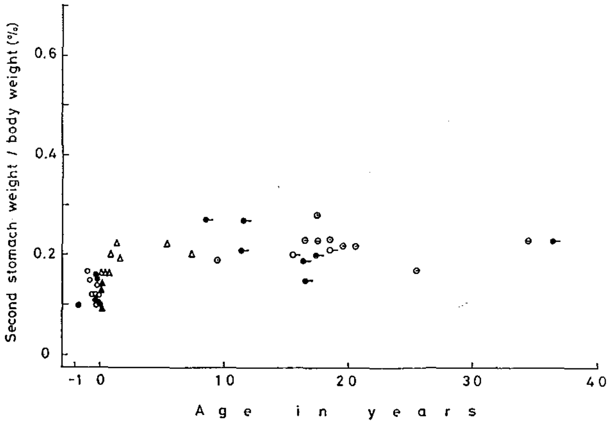

Fig. 33. The relationship between the relative second stomach weight and age in the striped dolphin off the Pacific coast of Japan. For marks see Fig. 5.

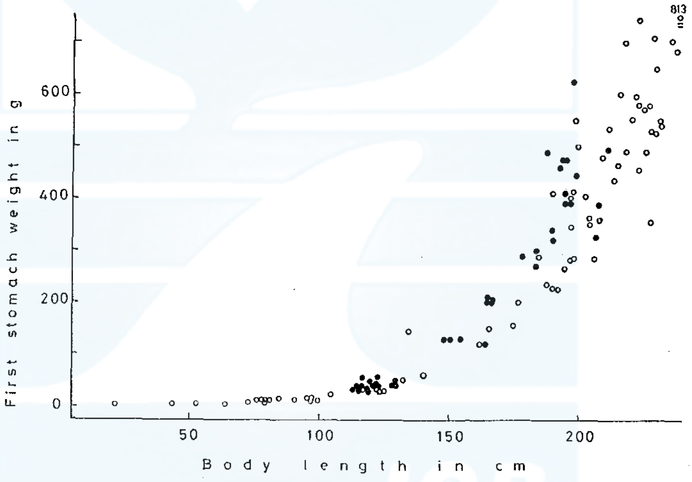

Fig. 34. The relationship between the first stomach weight and body length in the populations of *Stenella*. For marks see Fig. 17.

first or second stomach and the age. The values of both compartments decrease slightly from the middle to the late fetal stage, and show the rapid increase after birth. The relative weight of the first stomach becomes constant after 8 years of the age within the range of 0.36 to 0.54% of body weight (n: 17, mean: 0.44%). On the other hand the value of second stomach remains nearly constant after the age of 2 years within the range of 0.15 to 0.28% of body weight (n: 20, mean: 0.22%).

Table 3 shows the relative growth coefficient of stomach. In case of 14 prenatal striped dolphins, the growth coefficient of the first stomach is 1.00 and close to 0.989 of the corresponding value of the second stomach. However, in 29 postnatal individuals of the species the value of the first stomach 1.56 is higher than

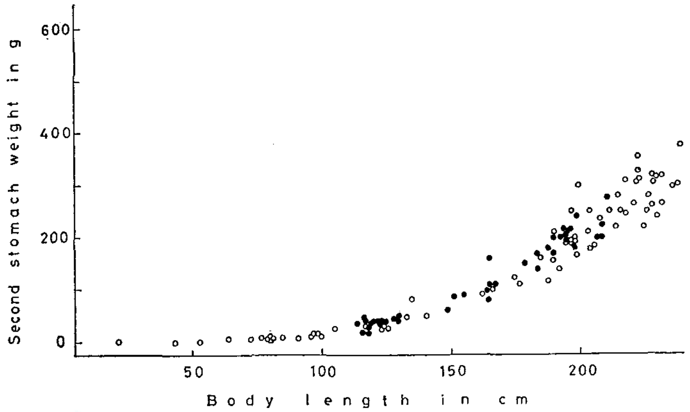

Fig. 35. The relationship between the second stomach weight and body length in the populations of *Stenella*. For marks see Fig. 17.

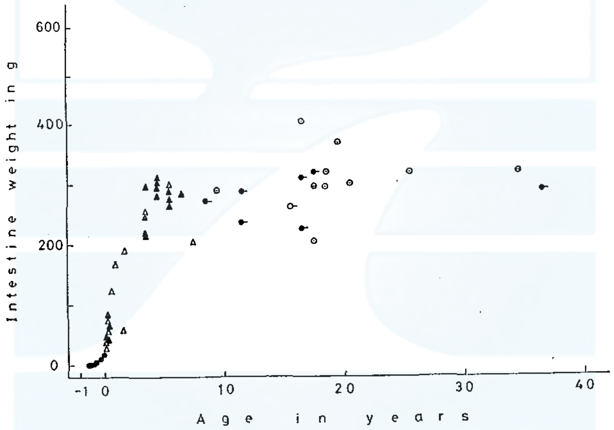

Fig. 36. The relationship between intestine weight and age in the striped dolphin off the Pacific coast of Japan. For marks see Fig. 1.

1.16 of the second stomach. This means that the relative growth of the first stomach is almost same to the second stomach in the prenatal stage, but in the postnatal stage the first stomach grows faster than the second stomach.

Figures 34 and 35 indicate that the stomach weight of the striped dolphins off the Pacific coast of Japan is almost similar to the same species in the Mediterranean sea and the spotted dolphins in Japanese waters.

Intestine: Intestine weight is plotted on age for 61 striped dolphins (17 fetuses, and 23 male and 21 female postnatals) (Fig. 36). The weight increases rapidly from birth to the age of 8 years, then it becomes constant within the range of 2,020 to 4,040 g (n: 18, mean: 2,956 g). There is no sexual difference of mean intestine weight in these individuals above 8 years ($0.2<p<0.3$).

Figure 37 shows the relationship between intestine length and age of 26 striped

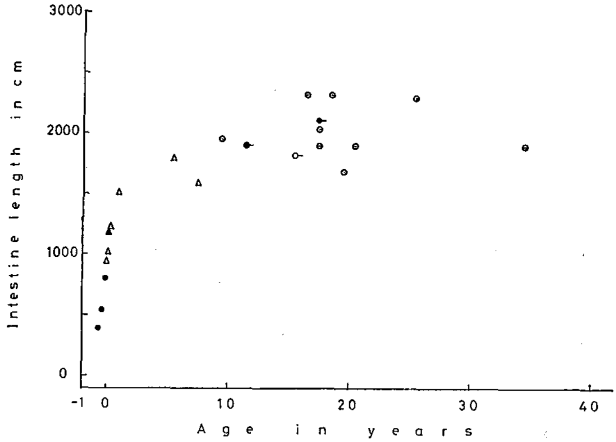

Fig. 37. The relationship between intestine length and age in the striped dolphin off the Pacific coast of Japan. For marks see Fig. 1.

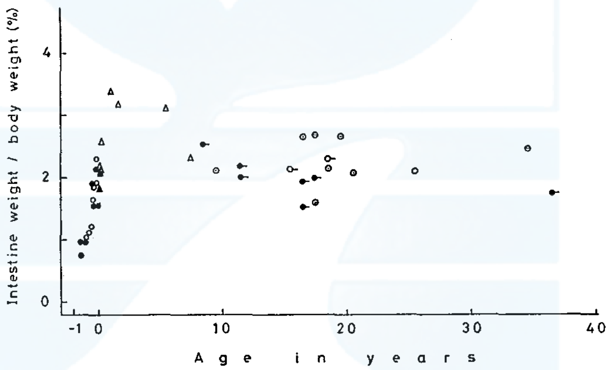

Fig. 38. The relationship between the relative intestine weight and age in the striped dolphin off the Pacific coast of Japan. For marks see Fig. 5.

dolphins (7 fetuses, and 3 male and 16 female postnatals). Intestine length increases rapidly from the middle fetal stage to the age of 2 years, then at a slower rate until 15 years when the increase stops. The mean intestine length of 10 individuals over 15 years of age is 2,2026 cm (range: 1,687—2,325 cm).

The ratio of intestine weight to body weight is plotted on age for 41 striped dolphins (Fig. 38). It increases rapidly from the middle fetal stage to the age of 2 years, then decreases until the age of about 10 years. After this age, the ratio becomes constant within the range of 1.56 to 2.69% (n: 16, mean: 2.14%).

Table 3 shows the relative growth coefficients of intestine weight. The value 0.983 of 34 postnatal striped dolphins is close to 0.985 of 38 postnatal spotted dolphins, but they are smaller than 1.24 of 15 prenatal striped dolphins.

The relationships between intestine weight and body length of striped and spotted dolphins off the Pacific coast of Japan are shown in Fig. 39. No difference is expected between two species.

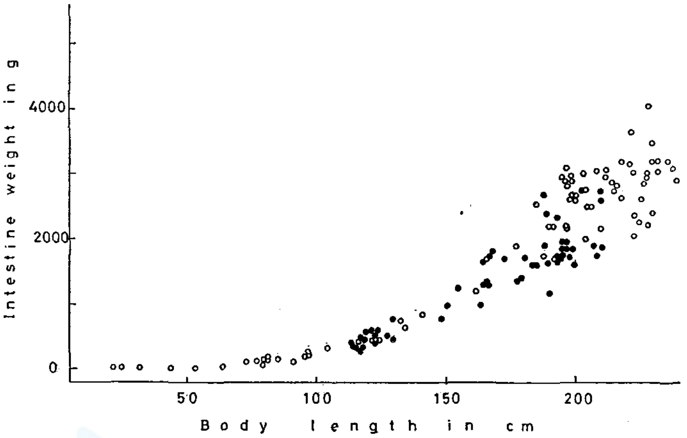

Fig. 39. The relationship between intestine weight and body length in the populations of *Stenella*. For marks see Fig. 17.

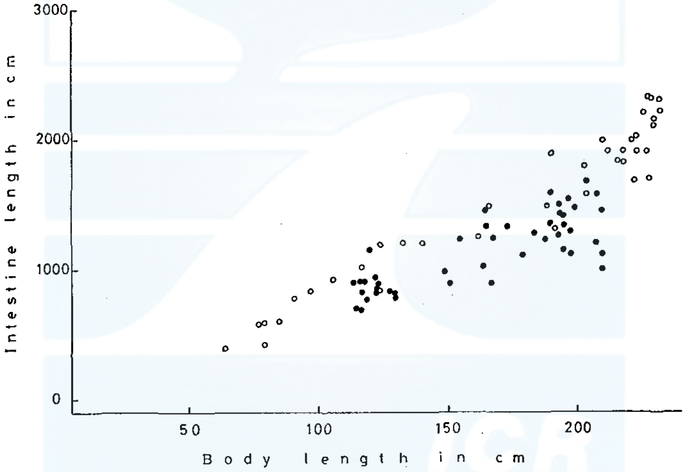

Fig. 40. The relationship between intestine length and body length in the populations of *Stenella*. For marks see Fig. 17.

Figure 40 shows the relationship between intestine length and body length. There is no available data in the early fetal stage. In the striped dolphins off the Pacific coast of Japan, the intestine length increases lineally from the middle fetal stage to the body length of about 120 cm, where some of individuals start to feed the solid food (Miyazaki, 1977). The length increases at lower rate between 120 and 190 cm in body length. After this stage it grows at higher rate. Comparison of intestine length between spotted and striped dolphins of the same body length off the Pacific coast of Japan shows that the latter species has longer intestine than the former species.

Spleen: Spleen weight is plotted on age for 58 striped dolphins (14 fetuses, and

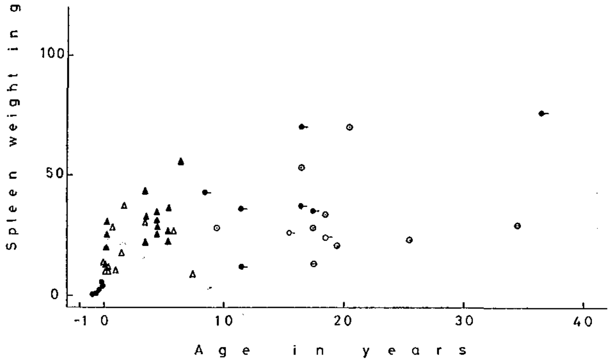

Fig. 41. The relationship between spleen weight and age in the striped dolphin off the Pacific coast of Japan. For marks see Fig. 1.

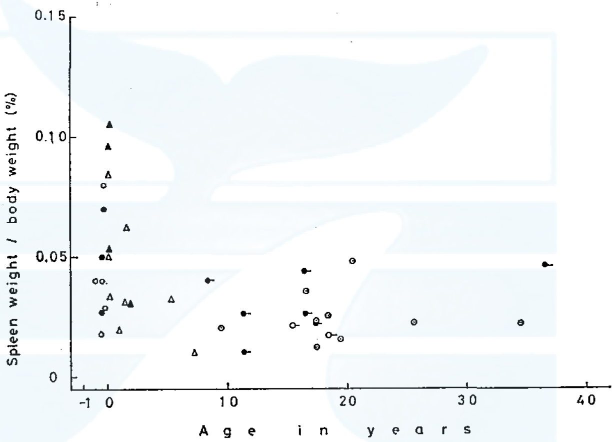

Fig. 42. The relationship between the relative spleen weight and age in the striped dolphin off the Pacific coast of Japan. For marks see Fig. 5.

22 male and 22 female postnatals) (Fig. 41). The weight increases rapidly for about 2 years after birth, then it becomes difficult to find any trend owing to large individual variation. In the 62 postnatal striped dolphins, the mean weight of spleens of 30 males is 43.9 g (range: 12—110 g) and is significantly larger than that of 26.7 g (8.2—69.8 g) for 32 females ($p<0.01$).

The ratio of spleen to body weight is plotted against age for 38 striped dolphins (Fig. 42). It increases rapidly from the middle fetal stage to the neonatal stage, and before reaching at the age of 2 years it sharply decreases to the value of the former stage. After this age the ratio becomes constant within the range of 0.009 to 0.048% (n: 20, mean: 0.026%).

The relative growth coefficients of spleen are shown in Table 3. In 12 prenatal striped dolphins the coefficient is 1.14 and higher than 0.527 of 34 postnatals of the same species. The latter figure is slightly higher than 0.459 of 28 postnatal spotted dolphins. The increase of spleen weight, both in striped and spotted dol-

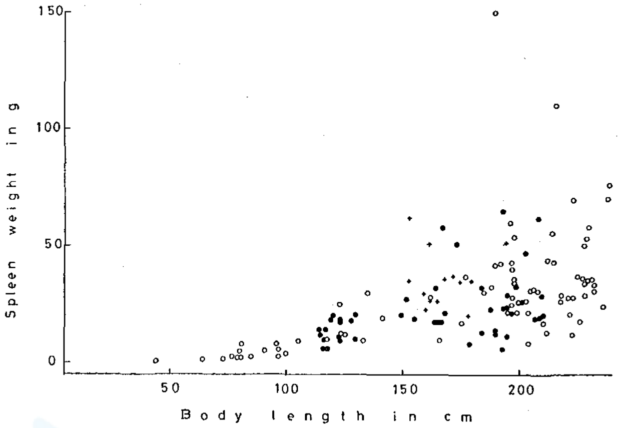

Fig. 43. The relationship between spleen weight and body length in the three populations of *Stenella*. For marks see Fig. 17.

phins, stops at the length of 150 cm. The individual variation of the weight is large (Fig. 43). In the striped dolphins off the Pacific coast of Japan the mean spleen weight of males is significantly larger than that of females in the body length of 150 cm or more ($p<0.001$). However, in the spotted dolphins of the same area there is no significant sexual dimorphism in the spleen weight ($0.1<p<0.2$).

DISCUSSION

The organs of the striped dolphins are classified into the following three groups based on the age when actual weight of organ attains the plateau. (1): Organs that attain plateau around 15 years of age: muscle, blubber, bone, viscera, heart, lungs, liver, kidney, pancreas and stomach. (2): Organs that attain plateau around 8 or 10 years of age: brain and intestine. (3): Organs that attain plateau at the neonatal stage: spleen. According to Kasuya (1976) and Miyazaki (1977), the mean age at the attainment of sexual maturity in the striped dolphins is about 9 years. Then, it can be said that the age when the growth of brain or intestine stops seems to coincide with this age. From the feature of the mean growth curve, Kasuya (1976) reported that the age at the attainment of asymptotic length of the species is about 17 years in females and about 21 years in males. The osteological study by Itō and Miyazaki (unpublished) showed that the physically mature striped dolphin starts to appear at the age of 16 years. Accordingly, it is reasonable to expect that the mean age at the attainment of physical maturity might come to the range of 16 to 20 years of age. Therefore, growth of the above ten organs of Group (1) is considered to stop nearly at the attainment of physical maturity. Among 13 organs examined here, spleen appears to be an exceptional organ of which growth stops in the neonatal stage. Based on the growth pattern of the relative organ weight in the prenatal and juvenile stages, the organs can be classified into the following three types. As there are few available data for the early fetal stage, the growth pattern of the stage is not considered.

Type I: The ratio increases sharply from the middle to the late fetal stage. After birth it decreases rapidly until the age of about 2 years, then becomes constant. Ten organs (blubber, bone, viscera, brain, heart, lungs, liver, kidney, pancreas and spleen) belong to this Type. Among them, bone, viscera and brain show slight decrease after about 2 years.

Type II: The ratio increases in the fetal stage and continues to increase in the juvenile stage. This type includes muscle and intestine. The ratio of muscle attains the plateau at the age of 15 years. In the case of intestine the ratio attains the plateau after slight decrease between 2 and 10 years.

Type III: The ratio decreases from the middle fetal stage to birth, then increases in the juvenile stage. This type is represented by the first and the second stomach. The relative organ weights of the first and of the second stomach attain the plateau at the age of about 15 and 2 years, respectively.

Figure 44 shows the least squares regressions of the relationship between body weight and body length of three species of *Stenella*. As the body weight of the spotted dolphins off the Pacific coast of Japan was measured with the loss of some blood and fluid, they were excluded from the following discussion. For *S. graffmani* = *S. attenuata* (*fide* Perrin, 1975) and *S. longirostris*, the equation of this relationship was calculated from data of Perrin and Robert (1972) by means of the least squares method ($\mathrm{Log}\ Y=a+b\ \mathrm{Log}\ X$, Y: body weight in g, X: body length in

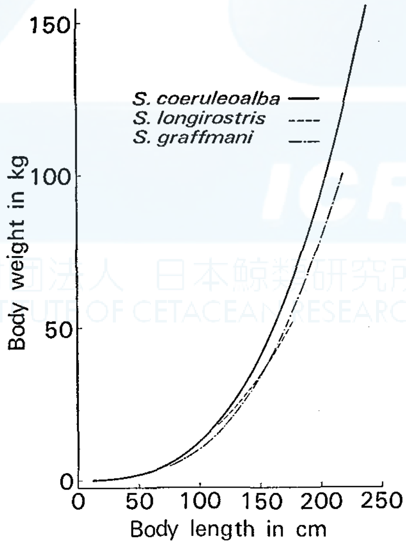

Fig. 44. Comparison of the relationship of body weight to body length in the populations of *Stenella*. These lines are obtained from the equation calculated on the relationship (see text).

cm). The relationships indicate that *S. coeruleoalba* off the Pacific coast of Japan has larger body weight than any of *S. attenuata* or *S. longirostris* in the eastern Pacific.

The growth coefficients of 13 organs are shown in Table 3. The coefficients of muscle, bone, kidney, pancreas and stomach is higher in the postnatal stage than in the prenatal stage. This means that these five organs grow faster in relation to the increase of the body weight in the former stage than in the latter stage. On the other hand, other 8 organs (blubber, viscera, brain, heart, lungs, liver, intestine and spleen) show reverse growth pattern. The growth pattern of brain obtained in this study appears to be similar to the result of Pirlot and Kamiya (1975).

Table 4 shows the relative growth coefficients of some organs of three species of *Stenella*. The significant difference of growth coefficient between populations was tested at $p=0.05$ only for the organs represented by 30 or more data. The above analysed on heart, lungs and liver are appropriate for the three populations of the dolphins, because the data of the western Pacific spotted and striped dolphins and of the spotted dolphins in the eastern Pacific cover a wide range of the growth stage. The growth coefficient of the heart for the spotted dolphins off the Pacific coast of Japan is close to that of the striped dolphins of the same areas, but the coefficient of the former species is significantly higher than that of the spotted dolphins in the eastern Pacific. The difference of the coefficients of liver between above two populations of the spotted dolphins is significantly larger than that between the striped and spotted dolphins in the same region. In case of lungs, there is no significant difference of the coefficient between the above three populations of two species of *Stenella*. From these informations it is suggested that the growth coefficient of organs may not be always the diagnostic character for the species, and in some cases the difference of the coefficients between populations of the same species is larger than their difference between species.

TABLE 4. THE GROWTH COEFFICIENT AND ITS 95% CONFIDENCE RANGE ON THE RELATIONSHIP BETWEEN ORGAN WEIGHT AND BODY WEIGHT IN *STENELLA*.[1]

Organs	*S. coeruleoalba*		*S. attenuata*		*S. longirostris*
	Mediterranean[2]	W. Pacific[3]	W. Pacific[4]	E. Pacific[5]	E. Pacific[6]
Heart	1.014 (7)	0.957(48) ±0.024	0.921(34) ±0.081	0.769(47) ±0.026	0.820(13)
Lungs	0,640 (7)	0.769(51) ±0.050	0.785(38) ±0.121	0.880(35) ±0.037	0.947 (4)
Liver	0.684 (7)	0.892(50) ±0.040	0.732(38) ±0.094	1.129(60) ±0.041	0.608(13)
Left kidney	0.960 (7)	0.850(49)	1.074(15)	—	—
Pancreas	0.438 (7)	1.303(34)	1.167(27)	—	—
Spleen	0.798 (7)	0.854(46)	0.460(28)	♂1.010(36) ♀1.057(24)	—
Brain	0.569(10)	0.753(37)	—	—	—

1): Figures in parentheses indicate the number of specimens

2): Gihr and Pilleri (1969). 3) and 4): Present data. 5) and 6): Perrin and Roberts (1972).

TABLE 5. MEAN WEIGHT OF BLUBBER, MUSCLE, BONE AND VISCERA IN SOME CETACEANS EXPRESSED OF BODY WEIGHT. FIGURES OTHER THAN *S. COERULEOALBA* WERE CITED FROM BRYDEN (1972).

Species	Blubber	Muscle	Bone	Viscera
P. catodon	34	35	11	8
B. musculus	27	40	16	11
B. physalus	24	45	17	10
B. borealis	22	62	15	9
E. sieboldi	40	30	14	13
*S. coeruleoalba**	17.3	54.5	12.7	9.8
	(14.1-19.2)	(49.8-59.8)	(9.7-15.0)	(7.8-15.1)

* Body weight was measured before dissection.
Figures in parentheses indicate range.

TABLE 6. THE WEIGHT OF ORGANS EXPRESSED AS A PERCENTAGE OF BODY WEIGHT IN SOME CETACEANS. FIGURES OTHER THAN *S. COERULEOALBA* WERE CITED FROM BRYDEN (1972).

Species	Brain	Heart	Lungs	Liver	Kidneys	Pancreas	Spleen	Stomach	Intestine
P. catodon	0.021	0.3	0.9	1.6	0.5	0.07	0.01	0.8	1.6
D. leucas	0.78	0.6	3.7	1.5	0.4	—	0.03	—	—
T. truncatus	1.45	1.0	2.9	2.2	1.1	—	0.09	—	—
P. phocoena	1.22	0.8	3.5	3.2	0.8	0.16	0.02	—	—
B. musculus	0.011	0.5	0.8	1.2	0.4	—	0.02	0.5	1.4
B. physalus	0.014	0.7	0.8	1.0	0.4	—	—	0.6	1.9
B. borealis	—	0.4	0.8	1.3	0.4	—	—	1.0	2.5
E. sieboldi	0.004	0.5	0.5	0.9	0.4	—	0.02	0.4	1.6
S. coeruleoalba	0.72	0.85	1.69	1.67	0.50	0.12	0.026	0.70	2.16
	(0.53-1.01)	(0.62-1.15)	(1.26-2.35)	(1.22-2.94)	(0.31-0.74)	(0.067-0.16)	(0.009-0.048)	(0.62-0.94)	(1.56-2.69

Figures in parentheses indicate range.

Table 5 shows the mean weight of blubber, muscle, bone and viscera in some cetaceans expressed as a percentage of body weight. The value of *S. coeruleoalba* was calculated as the mean of organs at the attainment of plateau. The proportional weight of blubber in the striped dolphins is remarkably lower than in the sperm whale and baleen whales. In case of muscle, the striped dolphin shows higher value than the sperm whale and baleen whales except for *Balaenoptera borealis.* The value of bone or viscera for *S. coeruleoalba* is distributed within the interspecies variation of five species.

The mean weight of brain and 8 visceral organs in some cetaceans expressed as a percentage of body weight is shown in Table 6. The values of the striped dolphins were obtained from the animals whose organ ratio attained plateau. The proportional values of brain for Delphinidae are considerably higher than those of the sperm whale and baleen whales. The values of eight visceral organs (stomach, intestine, liver, pancreas, lungs, kidney, spleen and heart) of the striped dolphin fall in the range of the corresponding values of eight species shown in Table 6. The values of liver or lungs on 4 species of Delphinidae are higher than the corresponding values of the sperm whale and baleen whales.

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APPENDIX TABLE 1. ORGAN WEIGHTS OF

Date of kill	Field no.	Body length (cm)	(1) Body weight (g)	Sex	Life stage or Reproductive condition	Age**	Brain (g) (%)
19 XII '78	23	19	114	♂	Fetus		2.8 (2.5)
19 XII '78	24	22	202	♂	Fetus		4.8 (2.4)
19 XII '78	25	25	164	♂	Fetus		2.7 (1.6)
19 XII '78	26	32	453	♂	Fetus		18 (4.0)
19 XII '78	21	44	1030	♀	Fetus		32 (3.1)
19 XII '78	22	53	2000	♀	Fetus		75 (3.8)
15 XII '78	5	64	3700	♀	Fetus		146 (4.0)
6 XII '79	14	77	6860	♀	Fetus		290 (4.2)
6 XII '79	11	79	6780	♂	Fetus		310 (4.6)
6 XII '79	12	85	8550	♀	Fetus		336 (3.9)
19 XII '78	27	91	7940	♂	Fetus		335 (4.2)
6 XII '79	13	97	10150	♀	Fetus		393 (3.9)
19 XII '78	28	97	9800	♂	Fetus		376 (3.8)
19 XII '78	29	100	11000	♂	Fetus		466 (4.2)
19 XII '78	12	123	26000	♂	Immature	0.21	640 (2.5)
6 XII '79	3	124	23000	♂	Immature	0.22	579 (2.5)
19 XII '78	13	135	26700	♂	Immature	0.33	700 (2.6)
19 XII '78	14	215	106300	♂	Mature	8.5	1020 (1.0)
19 XII '78	15	223	116000	♂	Mature	11.5	880 (0.8)
19 XII '78	16	225	145000	♂	Mature	16.5	920 (0.6)
19 XII '78	17	227	131500	♂	Mature	11.5	1030 (0.8)
19 XII '78	18	230	159700	♂	Mature	17.5	990 (0.6)
19 XII '78	19	238	160500	♂	Mature	16.5	960 (0.6)
19 XII '78	20	239	164800	♂	Mature	36.5	890 (0.5)
6 XII '79	1	105.5	16100	♀	Immature	0.05	471 (2.9)
6 XII '79	2	117	18700	♀	Immature	0.16	798 (4.3)
6 XII '79	4	133	29400	♀	Immature	0.31	674 (2.3)
6 XII '79	6	166	49100	♀	Immature	1.0	849 (1.7)
19 XII '78	2	177	60000	♀	Immature	1.75	710 (1.2)
19 XII '78	3	203	96300	♀	Immature	5.5	860 (0.9)
19 XII '78	4	204	87000	♀	Immature	7.5	880 (1.0)
19 XII '78	5	212	109500	♀	Lactating	17.5	1090 (1.0)
19 XII '78	6	218	122000	♀	Resting	15.5	790 (0.7)
19 XII '78	7	218	130800	♀	Lactating	34.5	890 (0.7)
6 XII '79	7	221	138200*	♀	Pregnant	9.5	942 (0.7)
6 XII '79	8	222	140250*	♀	Pregnant	19.5	851 (0.6)
19 XII '78	8	223	128000*	♀	Pregnant	17.5	1010 (0.8)
6 XII '79	9	223	144700*	♀	Pregnant	20.5	1100 (0.8)
19 XII '78	9	228	136800*	♀	Pregnant	18.5	730 (0.5)
6 XII '79	10	229	153340*	♀	Pregnant	16.5	876 (0.6)
19 XII '78	10	232	153200*	♀	Pregnant	25.5	980 (0.6)
19 XII '78	11	236	140000	♀	Resting	18.5	920 (0.7)

* excluding fetus weight.

** determined from body length in the young animals of 177 cm or less, and from the number of den-

*** including eyes, larynx, tongue, bladder and so on.

42 SPECIMENS OF *STENELLA COERULEOALBA*

(2) Viscera (g) (%)	(3) Muscle (g) (%)	(4) Blubber (g) (%)	(5) Bone (g) (%)	(6)*** Others (g) (%)	$\frac{(2)+(3)+(4)+(5)+(6)}{(1)}\times 100$
8.7 (7.6)	20.2 (17.7)	10.3 (9.0)	61.1 (53.4)	1.1 (1.0)	91.2
19.8 (9.8)	25.7 (12.7)	20.6 (10.2)	108 (53.4)	1.7 (0.8)	89.3
19.4 (11.8)	26.0 (15.9)	15.4 (9.4)	90 (54.9)	1.2 (0.7)	94.3
57.8 (12.8)	(—225.3 (49.7)—)		104 (23.0)	6.2 (1.4)	90.9
107 (10.4)	187 (18.2)	176 (17.1)	456 (44.3)	4.5 (0.5)	93.6
307 (15.4)	335 (16.8)	309 (15.5)	860 (43.0)	15 (0.8)	95.3
551 (14.9)	975 (26.4)	694 (18.8)	632 (17.1)	178 (4.8)	85.9
883 (12.9)	2320 (33.8)	1820 (26.5)	1200 (17.5)	99 (1.4)	96.4
1180 (17.4)	1990 (29.4)	1720 (26.4)	1390 (20.5)	70 (1.0)	99.3
1390 (16.3)	2260 (26.4)	2430 (28.4)	1850 (21.6)	71 (0.8)	97.5
1194 (15.0)	1817 (22.9)	2504 (31.5)	1903 (24.0)	106 (1.3)	98.9
1890 (18.6)	2320 (22.9)	3320 (32.7)	1910 (18.8)	102 (1.0)	97.9
1368 (14.0)	2232 (22.8)	2720 (27.8)	2534 (25.9)	121 (1.2)	95.5
1225 (11.1)	2823 (25.7)	3213 (29.2)	2340 (21.3)	289 (2.6)	94.1
3030 (11.7)	9670 (37.2)	5910 (22.7)	5200 (20.0)	590 (2.3)	96.4
3260 (14.2)	9780 (42.5)	5530 (24.0)	2540 (11.0)	180 (0.8)	95.0
2700 (10.1)	8890 (33.3)	6680 (25.0)	6140 (23.0)	740 (2.8)	96.8
10960 (10.3)	57560 (54.1)	17400 (16.4)	16600 (15.6)	1550 (1.5)	97.9
11960 (10.3)	63890 (55.1)	19030 (16.4)	17300 (14.9)	1480 (1.3)	98.8
11300 (7.8)	78460 (54.1)	25810 (17.8)	19650 (13.6)	5790 (4.0)	97.9
11700 (8.9)	67940 (51.7)	25260 (19.2)	18200 (13.8)	4170 (3.2)	97.6
15560 (9.7)	90430 (56.6)	29510 (18.5)	17900 (11.2)	2970 (1.9)	98.5
14180 (8.8)	89180 (55.6)	27600 (17.2)	18910 (11.8)	7400 (4.6)	98.6
14350 (8.7)	91430 (55.5)	31390 (19.0)	18020 (10.9)	5170 (3.1)	97.7
1760 (10.9)	7050 (43.8)	3920 (24.3)	2010 (12.5)	115 (0.7)	95.1
2410 (12.9)	7770 (41.6)	4290 (22.9)	2780 (14.9)	176 (0.9)	97.5
4250 (14.5)	13800 (46.9)	6050 (20.6)	4230 (14.4)	427 (1.5)	100
5580 (11.4)	24100 (49.1)	11200 (22.8)	6120 (12.5)	935 (1.9)	99.4
6480 (10.8)	29930 (49.9)	10300 (17.2)	8520 (14.2)	1640 (2.7)	96.0
10400 (10.8)	47970 (49.8)	16560 (17.2)	13520 (14.0)	4330 (4.5)	97.2
8550 (9.8)	44540 (51.2)	15000 (17.2)	11670 (13.4)	3410 (3.9)	96.5
11680 (10.7)	58910 (53.8)	17090 (15.6)	14320 (13.1)	2360 (2.2)	96.4
11120 (9.1)	72910 (59.8)	19550 (16.0)	14100 (11.6)	1740 (1.4)	98.6
17180 (13.1)	68830 (52.6)	23590 (18.0)	15500 (11.9)	2110 (1.6)	98.0
18700 (13.5)	78300 (56.7)	24800 (17.9)	9800 (7.1)	3390 (2.5)	98.4
19800 (14.1)	77000 (54.9)	26500 (18.9)	11300 (8.1)	3010 (2.1)	98.7
14540 (11.4)	69580 (54.4)	19160 (15.0)	16500 (12.9)	3790 (3.0)	97.5
19800 (13.7)	78800 (54.5)	26100 (18.0)	12700 (8.8)	4470 (3.1)	98.9
12700 (9.3)	71600 (52.3)	19200 (14.0)	16600 (12.1)	10130 (7.4)	95.6
23400 (15.3)	85000 (55.4)	28200 (18.4)	12400 (8.1)	2730 (1.8)	99.6
15300 (10.0)	86000 (56.1)	27100 (17.7)	14800 (9.7)	7060 (4.6)	98.7
13490 (9.6)	77610 (55.4)	24480 (17.5)	16800 (12.0)	4290 (3.1)	98.3

tinal and/or cemental layers in the animals of 185 cm or more.

APPENDIX TABLE 2. BODY LENGTH, BODY WEIGHT AND ORGAN

Date of kill	Field no.	Body length (cm)	Body weight (kg)	Sex	Life stage or Reproductive condition	Age**			
							Heart	Lungs	Liver
19 XII '78	23	19	0.114	♂	Fetus	—	1.0	6.0	—
19 XII '78	24	22	0.202	♂	Fetus	—	1.5	9.0	3.8
19 XII '78	25	25	0.164	♂	Fetus	—	2.2	9.7	5.1
19 XII '78	26	32	0.453	♂	Fetus	—	3.2	24	12
19 XII '78	21	44	1.03	♀	Fetus	—	8.3	44	22
19 XII '78	22	53	2.00	♀	Fetus	—	16.0	103	60
15 XII '79	5	64	3.70	♀	Fetus	—	28.2	194.5	86.8
21 X '70	214	73	—	♂	Fetus	—	44	250	158
6 XII '79	14	77	6.86	♀	Fetus[e]	—	55	334	145
6 XII '79	11	79	6.78	♂	Fetus[a]	—	117	268	180
19 XII '78	31	79.5	4.63	♂	Fetus[c]	—	44	276	128
21 X '70	181	80	—	♀	Fetus	—	63	390	116
21 X '70	219	81	7.10	♂	Fetus	—	68	476	240
6 XII '79	12	85	8.55	♀	Fetus[b]	—	126	432	311
19 XII '78	27	91	7.94	♂	Fetus	—	224	558	140
19 XII '79	30	96	10.0	♀	Fetus[f]	—	105	466	193
6 XII '79	13	97	10.15	♀	Fetus[d]	—	69.5	692	197
19 XII '78	28	97	9.8	♂	Fetus	—	169	507	202
19 XII '78	29	100	11.0	♂	Fetus	—	127	482	219
19 XII '78	12	123	26.0	♂	Immature	0.21	314	917	487
6 XII '79	3	124	23.0	♂	Immature	0.22	237	876	542
19 XII '78	13	135	26.7	♂	Immature	0.33	236	706	369
2 XII '70	614	141.5	31.0	♂	Immature	0.38	210	586	410
13 X '70	E 2	190	—	♂	Immature	—	—	1300	1150
14 XII '71	110	190	—	♂	Immature	3.5	480	1000	1250
25 XI '70	342	192	—	♂	Immature	—	435	1300	1050
14 XII '71	107	195	—	♂	Immature	3.5	600	1550	1500
13 X '70	131	196	—	♂	Immature	—	600	1500	1850
14 XII '71	29	197	—	♂	Immature	4.5	600	1300	1300
14 XII '71	111	197	—	♂	Immature	4.5	550	1200	1400
14 XII '71	3	197	—	♂	Immature	3.5	700	1550	1500
13 X '70	E 5	198	—	♂	Immature	—	—	1600	1300
14 XII '71	1	198	—	♂	Immature	4.5	620	1620	1420
14 XII '71	47	198	—	♂	Immature	5.5	600	1400	1600
14 XII '71	114	200	—	♂	Immature	5.5	700	1500	1750
14 XII '71	112	204	—	♂	Immature	5.5	550	1150	1600
14 XII '71	28	206	—	♂	Immature	3.5	620	1150	1250
14 XII '71	113	208	—	♂	Immature	4.5	680	1650	2050
13 X '70	E 4	212	—	♂	Immature	—	650	1800	2100
14 XII '71	116	214	—	♂	Immature	6.5	600	1750	1850
19 XII '78	14	215	106.3	♂	Mature	8.5	1000	2180	1750
24 X '70	222	216	—	♂	Mature	—	—	2100	1900
19 XII '78	15	223	116	♂	Mature	11.5	1160	2106	1700
19 XII '78	16	225	145	♂	Mature	16.5	1050	1936	2350
19 XII '78	17	227	133.5	♂	Mature	11.5	1060	2058	1600

WEIGHTS OF 82 SPECIMENS OF *STENELLA COERULEOALBA*

Weights of internal organs (g)

Kidney		Pan-creas	Stomach				Intes-tine	Spleen	Brain (g)	Intestine length (cm)
left	right		I	II	III	IV				
0.4	0.3	—	—	—	—	—	—	—	2.8	—
1.8	1.3	—	0.3	0.2	—	—	1.9	—	4.8	—
0.5	0.6	—	—	—	—	—	1.2	—	2.7	—
2.6	2.8	—	(——1.9——)				4.3	—	18	—
5.1	5.1	—	1.4	1.8	—	—	11	0.4	32	—
13	13	—	4.1	3.0	—	—	23	—	75	—
26.4	27.2	5.4	7.0	4.5	2.4	0.9	45.9	0.7	145.7	397
40	40	—	8.7	6.3	(—6.0—)		116	1.8	310	—
28.7	29.8	—	12.5	8.5	3.1	2.6	112	2.8	289.7	580
37.8	35.2	10.3	12.0	7.5	2.4	1.1	131	1.9	309.9	595
32	34	3.2	9.2	7.3	2.7	0.6	73	2.2	—	425
30	32	5.0	11.8	11.0	(—3.2—)		160	5.0	280	—
45	44	6.0	12.2	9.4	(—2.4—)		194	8.0	355	—
37.3	37.6	18.9	15.5	8.5	3.2	2.6	159	2.5	335.9	603
30	30	1.8	13	8.1	3.9	2.1	122	5.3	335	—
43	45	17	17	12	7.4	3.0	195	8.0	—	780
40.3	39.5	—	16.6	14.2	3.4	2.7	233	2.3	393.2	835
34	34	—	13	15	3.4	1.6	210	5.5	376	—
40	39	5.3	12	11	6.0	1.7	—	3.8	466	—
53	59	2.9	33	34	20	6.9	475	25	643	—
54.9	52.1	49.4	29.3	31.2	9.3	8.8	485	12.3	579.4	1190
57	62	24	144	132	121	11	623	30	699	—
65	65	28.6	60	50	42	13.3	850	19.2	—	1200
250	250	300	(——500——)				2200	150	—	—
—	—	98.3	226.5	156.7	86	27	2200	—	—	—
145	140	85	225	140	43.3	29	1750	42.5	—	1310
—	—	112.3	267.6	190.9	61.9	41.9	2950	21.4	—	—
180	—	150	(——650——)				2900	60	—	—
164.6	174.1	116	281.8	192.7	76.7	45.8	2800	25.2	—	—
250	250	131.7	400	250	85.8	25.5	3100	28.0	—	—
191.4	198.2	155.2	343.4	190.7	80	35.4	2150	43	—	—
—	—	158	(——700——)				2600	54	—	—
201.6	217.0	148.5	286.6	190.6	87.4	35.5	2950	34.2	—	—
247.3	217.3	163.8	413.1	201	69	33.3	2900	35.5	—	—
250	250	128.7	500	300	69.7	32.4	2650	26.0	—	—
250	250	105.2	350	250	48.8	17	2750	21.6	—	—
161.3	163.5	88.6	285.4	186.8	93.2	33.3	2500	31.5	—	—
269.1	279.4	155.8	358.4	234.6	71	35	3050	30.8	—	—
302	298	300	(——950——)				3100	44	—	—
—	—	168.8	437.2	220.8	55.8	34.8	2850	55.4	—	—
235	250	143	466	282	57	47	2720	43	1024	—
—	—	180	600	250	120	70	2820	110	—	1835
447	408	151	458	310	56	38	2360	12	881	—
331	317	106	571	220	120	23	2260	37	922	—
309	303	205	580	282	70	62	2870	36	1031	1900

Continued . . .

APPENDIX TABLE 2.

Date of kill	Field no.	Body length (cm)	Body weight (kg)	Sex	Life stage or Reproductive condition	Age**	Heart	Lungs	Liver
13 X '70	130	228	—	♂	Mature	—	850	2100	1600
13 X '70	135	230	—	♂	Mature	—	800	2150	2500
19 XII '78	18	230	159.7	♂	Mature	17.5	1380	2920	2150
19 XII '78	19	238	160.5	♂	Mature	16.5	1280	2800	2000
19 XII '78	20	239	164.8	♂	Mature	36.5	1580	2081	2050
6 XII '79	1	105.5	16.1	♀	Immature	0.05	130	491	260
6 XII '79	2	117	18.7	♀	Immature	0.16	208	715	463
2 XII '70	613	125.5	23.0	♀	Immature	0.24	165	470	330
6 XII '79	4	133	29.4	♀	Immature	0.31	302	1304	809
25 XI '70	344	162	—	♀	Immature	0.68	325	1050	780
6 XII '79	6	166	49.1	♀	Immature	1.0	410	790	667
19 XII '78	1	175	57.0	♀	Immature	1.58	340	1153	852
19 XII '78	2	177	60.0	♀	Immature	1.75	627	877	1010
14 XI '71	2	185	64.0	♀	Immature	3.5	520	1150	1580
25 XI '70	339	188	66.0	♀	Immature	—	420	1100	1250
25 XI '70	340	190	77.0	♀	Immature	—	725	1800	1750
13 X '70	E 3	197	—	♀	Immature	—	—	1200	1700
10 XII '70	616	199	77.9	♀	Immature	—	430	2350	1750
19 XII '78	3	203	96.3	♀	Immature	5.5	732	1489	1530
19 XII '78	4	204	87.0	♀	Immature	7.5	734	1443	1500
13 X '70	E 1	205	—	♀	Immature	—	—	2400	1500
2 XII '70	651	210	95.0	♀	Immature	—	610	1330	1430
19 XII '78	5	212	109.5	♀	Lactating	17.5	683	1902	1650
19 XII '78	7	218	130.8	♀	Lactating	34.5	1500	3070	2900
19 XII '78	6	218	122	♀	Resting	15.5	778	2030	1670
6 XII '79	7	221	138.2*	♀	Pregnant[a]	9.5	2050	3600	2940
6 XII '79	8	222	140.2*	♀	Pregnant[b]	19.5	1970	4060	2760
19 XII '78	8	223	128.4*	♀	Pregnant[c]	17.5	1310	2460	2170
6 XII '79	9	223	144.7*	♀	Pregnant[d]	20.5	2100	3910	2950
25 XI '70	345	226	119.8*	♀	Pregnant	—	650	2500	2150
25 XI '70	343	228	116.2*	♀	Pregnant	—	615	3200	1950
19 XII '78	9	228	136.8*	♀	Pregnant	18.5	934	1722	1900
6 XII '79	10	229	153.3*	♀	Pregnant[e]	16.5	2330	4680	4510
25 XI '70	346	230	114.9*	♀	Pregnant	—	910	2200	2050
19 XII '78	10	232	153.2*	♀	Pregnant[f]	25.5	1020	2148	2130
25 XI '70	341	232	126.4	♀	Mature	—	760	2000	2250
19 XII '78	11	236	140	♀	Resting	18.5	1350	2750	2400

Fetuses a, b, c, d, e, f were obtained from pregnant females a, b, c, d, e, f respectively.

* excluding fetus weight.

Continued.

Weights of internal organs (g)									Brain (g)	Intestine length (cm)
Kidney		Pan-creas	Stomach				Intes-tine	Spleen		
left	right		I	II	III	IV				
308	—	190	(——1000——)				3000	50	—	—
312	358	177	(——800——)				3500	58	—	—
348	356	132	650	314	179	54	3200	35	992	2110
419	402	165	685	302	142	63	3100	70	962	—
464	396	195	813	375	126	50	2900	76	866	—
37.8	41.1	20.7	18.4	26.4	10.8	5.8	347	13.5	471.2	941
44.1	44.3	26.4	33.6	30.1	13.0	9.1	408	9.4	797.5	1015
52.4	50.4	16.6	28.2	27.7	22.9	4.1	470	12.1	—	—
66.2	67.2	88.7	50.6	46.4	14.4	10.3	758	9.7	673.7	1200
100	—	65	118	90	33.2	33	1200	28.2	—	1254
94.1	93.1	144	148	99.1	69.3	57.1	1680	9.3	848.6	1492
115	118	40	156	123	48	27	—	17	784	—
203	135	66	200	112	44	28	1900	37	709	—
220	220	99.7	288.1	159.5	53.9	30.4	2550	30.2	—	—
125	150	80	235	115	45	31.2	1750	32.2	—	1487
—	—	115	410	210	75	40.4	2600	41.9	—	1890
134	158	160	(——600——)				2200	40	—	—
210	200	120	550	165	48	40	2650	21.4	—	—
212	234	126	405	210	70	64	3000	26	856	1787
174	159	104	363	176	49	33	2000	8.2	884	1580
205	194	108	(——600——)				2500	31	—	—
225	240	110	—	—	—	—	2155	17	—	1988
271	264	163	534	251	90	40	2950	13	1086	1900
471	465	164	703	310	74	51	3200	29	887	1900
216	155	164	491	246	74	48	2620	26	788	1820
372	344	—	551	264	86.6	145	2910	28	942.1	1952
417	413	—	595	306	194	96.6	3690	20.6	851	1687
307	321	168	578	355	85	60	2020	28	1005	2017
387	415	—	744	323	181	107	3010	69.8	1099	1900
250	240	160	490	250	70	37.3	2650	17.8	—	2212
—	—	82	355	260	65	42	2200	29	—	1692
291	287	166	531	319	84	92	2950	33.7	731	2325
475	502	—	709	354	98.9	116	4040	53.2	875.7	2302
240	250	115	525	240	52	37.8	2400	35.4	—	2150
348	313	102	549	264	87	47	3200	33	977	2300
250	265	180	540	318	95	50	3050	30.9	—	2208
326	391	200	704	291	98	81	3200	24	917	—

** determined from body length in the young animals of 177 cm or less, and from the number of dentinal and/or cemental layers in the animals of 185 cm or more.

APPENDIX TABLE 3. BODY LENGTH, BODY WEIGHT AND ORGAN

Date of kill	Field no.	Body length (cm)	Body weight (kg)	Sex	Life stage or Reproductive condition	Heart	Lungs	Liver
10 XI '70	362	114	15.6	♂	Immature	—	310	410
6 XI '70	167	115	—	♂	Immature	86	320	297
10 XI '70	360	117	16.0	♂	Immature	75	335	630
10 XI '70	359	119	15.6	♂	Immature	105	390	375
10 XI '70	364	123	15.8	♂	Immature	100	400	570
10 XI '70	355	122	17.2	♂	Immature	115	440	660
6 XI '70	170	128	—	♂	Immature	106	400	500
10 XI '70	368	149	24.8	♂	Immature	160	550	540
10 XI '70	393	151	34.7	♂	Immature	170	660	1125
10 XI '70	347	165	39.8	♂	Immature	245	900	920
10 XI '70	48	165	—	♂	Immature	220	1300	1220
10 XI '70	352	167	54.0	♂	Immature	350	1300	1320
6 XI '70	171	173	—	♂	Immature	235	1200	1230
10 XI '70	244	184	—	♂	Immature	300	1500	1270
22 X '70	2	193	75.7	♂	Mature	390	1370	1780
10 XI '70	389	198	80.3	♂	Mature	340	1120	1150
10 XI '70	228	209	—	♂	Mature	340	—	—
22 X '70	33	116	—	♀	Immature	80	320	450
10 XI '70	361	117	12.6	♀	Immature	100	340	510
22 X '70	32	118	—	♀	Immature	170	730	1040
22 X '70	47	120	—	♀	Immature	100	420	380
10 XI '70	354	123	17.1	♀	Immature	100	370	515
10 XI '70	358	123	14.8	♀	Immature	90	300	500
10 XI '70	357	130	16.9	♀	Immature	100	440	435
22 X '70	42	130	19.6	♀	Immature	110	500	560
22 X '70	34	155	—	♀	Immature	200	200	1030
10 XI '70	232	164	—	♀	Immature	192	660	840
10 XI '70	312	165	35.0	♀	Immature	220	1000	820
10 XI '70	509	167	36.6	♀	Immature	205	980	950
6 XI '70	169	168	—	♀	Immature	269	930	1250
10 XI '70	370	178	50.9	♀	Immature	350	1350	1630
10 XI '70	236	179	—	♀	Immature	250	1280	1000
10 XI '70	280	181	53.8	♀	Immature	300	1200	1300
22 X '70	65	184	53.0*	♀	Pregnant	280	950	1190
10 XI '70	242	188	—	♀	Mature	320	1200	1650
10 XI '70	282	189	70.1	♀	Mature	—	1550	1700
10 XI '70	245	190	53.2	♀	Mature	280	970	850
22 X '70	25	190	57.1	♀	Lactating	310	1060	1370
6 XI '70	165	193	—	♀	Mature	300	1150	1650
10 XI '70	250	193	61.8	♀	Mature	400	1250	1300
10 XI '70	234	194	—	♀	Mature	360	1050	1750
22 X '70	18	195	62.1	♀	Lactating	290	960	1460
10 XI '70	350	195	67.8	♀	Mature	350	580	1500
10 XI '70	349	195	56.3	♀	Mature	400	1200	1300
10 XI '70	309	195	68.4	♀	Mature	—	1400	1250

WEIGHTS OF 55 SPECIMENS OF *STENELLA ATTENUATA*

Weights of internal organs (g)

Kidney		Pancreas	Stomach				Intestine	Spleen	Intestine length (cm)
left	right		I	II	III	IV			
—	45	12.4	32.7	36.1	12.4	11.3	410	13.8	—
46	56	—	34.6	45.8	9.2	6.2	370	12	700
72	50	26.8	55	40	10.1	9	445	14	820
—	—	25.5	37.6	36.2	12.6	—	465	18.3	775
—	—	25	38.8	39.2	8.6	6.4	410	9.4	845
50	—	25.3	37.8	42	16.2	—	595	18.4	930
—	—	27	40.3	45.8	16.3	6.5	500	18	826
75	75	41.2	130	60	26	—	790	20.4	975
—	—	56.3	130	85	19.5	—	980	26.9	888
150	135	100	200	160	40.4	23.6	1650	17.2	1329
—	—	90	210	80	30	30	1340	17	1453
—	—	—	—	—	—	—	1750	—	—
176	170	117	(——1700——)				1700	51	1330
160	—	72	270	170	40	29.5	1600	32.8	1280
—	—	150	460	200	60	40	1660	65	1486
—	240	—	625	180	50	34	1720	33.2	1117
205	240	95	480	225	55	28.6	—	19.7	—
60	60	20.5	29	19	6	4	320	6	900
48	50	21.2	28	28.6	8.4	7.0	270	10	688
60	60	70	29	19	6	4	420	38	900
—	—	34.5	49.5	41.8	13.5	6.8	550	20	1161
40	60	33.7	54.6	41.2	19.1	—	580	17.3	880
—	—	29.5	44.2	32.8	14.0	—	575	11.1	820
—	60	17	50	50	11.1	10.1	480	20.8	778
—	—	25	40	40	10	10	460	10	790
—	—	70	130	90	38.2	23	1270	18.9	1235
95	90	60	120	98	70	13.3	1000	32	1020
—	—	70	200	110	36.1	21.1	1300	17.2	—
135	135	80	205	110	25.7	21	1300	58	895
160	155	80	(——700——)				1800	21	1240
—	—	—	—	—	—	—	1350	—	—
165	168	105	288	150	26.8	31.4	1400	8	1117
—	—	—	—	—	—	—	1700	—	—
210	190	110	300	140	39.4	31.6	1600	12.8	—
—	—	100	490	180	50	40	1920	23	1232
—	—	—	—	—	—	—	2400	—	—
—	200	100	320	170	44.8	28.8	1180	12.3	1350
—	—	87	340	200	43.3	31	1640	13.8	1593
—	—	160	(——1000——)				—	6	—
—	—	—	—	—	—	—	1750	—	—
245	255	120	475	215	55	24.9	1700	23.7	1422
260	310	120	390	210	40	30	1960	29	1418
245	255	120	457	215	55	24.9	1750	23.7	1337
—	—	—	—	—	—	—	1880	—	—
220	235	100	410	200	65	36.2	1850	11.4	1145

Continued...

APPENDIX TABLE 3.

Date of kill	Field no.	Body length (cm)	Body weight (kg)	Sex	Life stage or Reproductive condition	Heart	Lungs	Liver
10 XI '70	279	197	67.8	♀	Mature	385	1250	1400
6 XI '70	166	198	—	♀	Pregnant	295	950	1800
10 XI '70	391	199	71.0	♀	Mature	365	1200	1580
10 XI '70	348	200	61.5	♀	Mature	—	1020	1450
6 XI '70	163	203	—	♀	Mature	370	1100	2000
10 XI '70	507	207	56.3	♀	Mature	300	1000	1450
10 XI '70	508	208	72.0	♀	Mature	360	1150	1780
6 XI '70	164	210	—	♀	Pregnant	362	1400	1700
6 XI '70	168	210	—	♀	Pregnant	302	1300	1300
6 XI '70	172	210	—	♀	Mature	—	1500	1900

* excluding fetus weight.

Continued.

Weights of internal organs (g)										Intestine length (cm)
Kidney		Pancreas	Stomach				Intestine	Spleen		
left	right		I	II	III	IV				
245	225	215	390	190	41.4	43.4	1950	20.9		1548
—	—	—	—	—	—	—	2700	—		1290
245	250	110	445	240	75	37	1850	25.3		1466
—	—	—	—	—	—	—	1600	—		—
—	196	140	(———850———)				2750	47		1665
210	190	115	325	200	50	34.9	1900	19.2		1200
—	225	145	390	200	—	10.4	1750	62		1586
—	—	—	495	275	50	24	2750	20		1000
—	—	136	(———700———)				1850	26		1118
316	280	128	(———1000———)				2650	29		1450

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THE STOMACH OF THE BOUTU, *INIA GEOFFRENSIS*: COMPARISON WITH THOSE OF OTHER PLATANISTIDS

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ABSTRACT

The stomach of the Boutu, *Inia geoffrensis*, was examined macro- and light microscopically, and was compared with those of the three other species of Platanistidae as well as with those of some sea dolphins. The stomach of the *Inia* consisted of a forestomach, main stomach, connecting channel, and pyloric stomach. The esophagus was more straightly continuous with the main stomach than with the forestomach, and the opening to the main stomach was larger than that to the forestomach. The biflucating manner of the esophagus of two species of Platanistidae, *Inia* and *Platanista*, was different from that of sea dolphins, in which the esophagus leads directly to the forestomach. The forestomach of the *Inia*, lined with stratified squamous epithelium, was relatively smaller than that of the *Platanista*, and those of sea dolphins. The main stomach of the *Inia* was a large thick-walled musclar sac, rather resembling that of *Pontoporia*, without any partitions as seen in the *Platanisata* and *Lipotes*. It was lined with a plicated glandular mucous membrane possessing mucous, parietal, and chief cells. A narrow zone of cardiac glands existed only adjacent to the esophagus. The main stomach communicated with the pyloric stomach by a crooked, narrow connecting channel, which lay in the caudo-dexter part of the main stomach. The channel was similar to that of the *Pontoporia* in its location and shape. The elongated tubular pyloric stomach lay in the dorso-dexter part of the connecting channel, and was smaller than the globular pyloric stomach of *Platanista* and the J-shaped one of the *Pontoporia*. The mucosae of the channel and pyloric stomach were similar and contained pyloric glands. The histological nature of each part of the stomach observed in the three species of Platanistidae and in other sea dolphins was fundamentally the same. A distinct sphincter could be seen between the end of the pyloric stomach and the duodenal ampulla as in other dolphins.

INTRODUCTION

A number of morphological studies of the stomach in several species of sea dolphins have been made by several investigators. Those done on the stomach of the fresh water dolphins, Platanistidae (in which four genera, *Pontoporia*, *Platanista*, *Lipotes*, *Inia* are included), however, seem to be very small in number, probably due to this family's special distribution. Burmeister (1867, 1869) and Anderson (1879) reported upon the anatomy of the Franciscana, *Pontoporia blainvillei*, and the Susu, *Platanista gangetica*, respectively, the structures of the stomachs of which were described briefly. We also made macro- and light microscopical observations of the stomachs of *Platanista* (Yamasaki and Takahashi, 1971) and *Pontoporia* (Yamasaki *et al.*, 1974). Hinton and Pycraft (1922) made a preliminary note on the morphology of the Baiji, *Lipotes vexillifer*, including a very brief description of the morphology of the stomach. Recently, anatomical reports on the stomach of *Lipotes* have appeared from Chen and Chen (1975), and Zhou *et al.* (1978, 1979ab). Since among the stomachs of Platanistidae the morphology of that of *Inia* has not yet been reported upon, the structure of the stomach of this dolphin will be reported upon here and will be compared with those of the three other species of Platanistidae and some sea dolphins which have been described.

MATERIAL AND METHODS

The specimen of the stomach of the Boutu (Amazon dolphin), *Inia geoffrensis*, (body length 204 cm, female) used for this study was provided by the Kamogawa Sea World, Chiba, Japan, after death from unidentified disease. Owing to contraction due to fixation, and deformity caused by transportation to our laboratory, the external features of the stomach seemed to vary considerably from the natural state. The organ was preserved in 10% formalin solution and small pieces were taken for light microscopy. Paraffin sections from these were stained with hematoxylin-eosin, Azan, PAS and Alcian blue for histological examinations.

The stomachs of *Platanista* and *Pontoporia* already reported upon by us and of *Stenella coerureoalba* were reexamined for comparision.

OBSERVATIONS

Although the stomach may vary in size and the appearance of the exterior or the interior may depend on whether the stomach is in a fixed or unfixed state as well as on the amount of its contents, an empty *Inia* stomach fixed was examined and the following features were obtained. The stomach of the *Inia* consisted of three compartments; fore, main, and pyloric stomachs. A narrow compartment or channel connected the main stomach with the pyloric stomach. The first part of the duodenum immediately distal to the pyloric stomach was dilated and formed the duodenal ampulla. External grooves, which might have been visible between compartments in good condition, could not be clearly distinguished owing to considerable deformity. The thick-walled esophagus, which had distinct longitudinal folds with many fine transverse folds in its interior, was more straightly continuous with the main stomach than with the forestomach, and its thick mucous folds generally continued toward those of the main stomach.

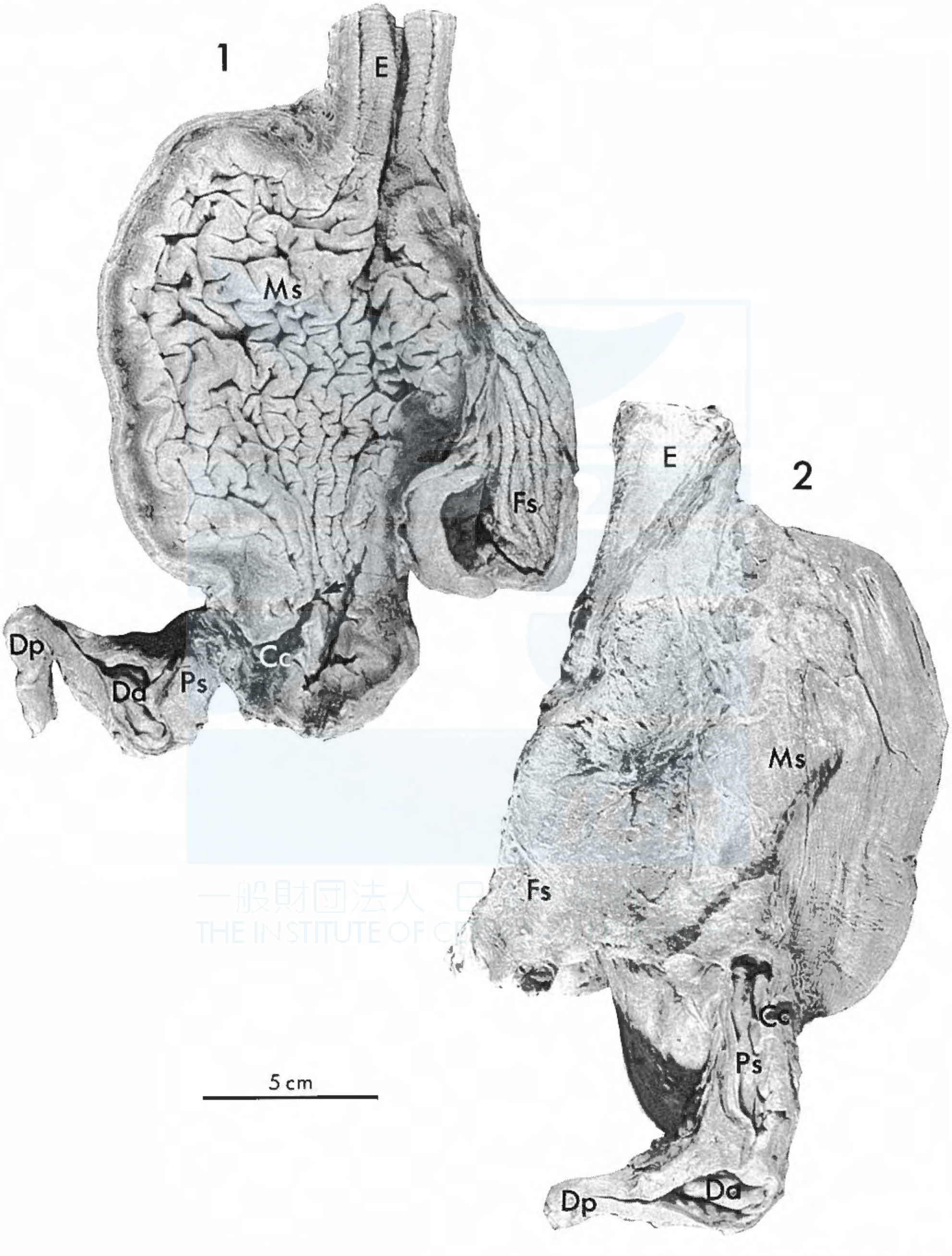
Forestomach The forestomach was located in the dorsal and slightly left side of the mainstomach and was a pear-shaped muscular sac (Fig. 1). The cranial two-thirds of its ventro-dexter wall adhered to the dorsal wall of the main stomach.

The depth of the forestomach, from the biflucation between the fore- and main stomach to the bottom of the forestomach, was approximately 12 cm and its width was about 4 cm at the lower widest part. The interior of the forestomach had firm, mainly longitudinal folds. Several folds were continuous with those in the esophagus but were far thinner. There were also occasional transverse folds. The wall of the forestomach was far thinner than that of the esophagus, and was about 5 mm in thickness at the dorso-sinister wall, becoming thick, about 7 mm or more, at the bottom and at the wall facing the main stomach. There was no definable sphincter at the opening.

The mucosa of the forestomach was non-glandular, consisting of stratified squamous epithelium continuing from the esophagus (Fig. 3). Its thickness, however, was about half or less than that of the esophagus, measuring from 0.3 to 0.4 mm in thickness. The superficial cells of the epithelium appeared to have lost their nuclei and undergone cornification. The connective tissue papillae occupied about 80% of the total thickness of the epithelium. The tunica musclaris was far thinner than that of the esophagus, consisting of inner circular and outer longitudinal smooth muscle layers, about 0.5 mm thick in all near the bottom of the forestomach, with the former being roughly twice the thickness of the latter. No glands were seen within the forestomach.

Main stomach This was a firm, thick-walled muscular sac and was the largest compartment (Fig. 1). It was somewhat pear-shaped and measured about 18 cm in depth, and 11 cm across at the upper widest part. The entrance was approximately 1.5 cm in diameter and no definable sphincter existed. The main stomach was lined with a thick, mucous membrane thrown into numerous thick folds giving the whole a labyrinthine appearance. In the lower part, however, the folds were somewhat longitudinal in arrangement. An abrupt change at the entrance from the stratified squamous epithelium of the esophagus to the glandular epithelium of the main stomach was exhibited by the mucous membrane (Fig. 4). This epitheliar border obliquely ran from the cranio-dexter to the caudo-sinister reaching about 2 cm lower than the septum between the main and forestomachs. There was an opening, about 3 mm in diameter, that led into the next compartment, a connecting channel, at the ventro-dexter wall of the main stomach, about 2 cm from the caudal end of the main stomach. The wall, which seemed to be considerably contracted by fixation, was very thick, from 1 to 2.5 cm.

Light microscopically, tubroalveolar glands composed of light cells of one kind could be seen only along the narrow zone, about 1 mm in breadth, adjacent to the border between the esophagus and the main stomach (Fig. 4). Although the material was in poor condition, these glands were clearly distinguishable from the remaining glands of the main stomach and were surely cardiac glands. The glands covering the remainder of the main stomach were seen to be of the same structure. They were simple and tubular, with little evidence of branching, and measured from 2 to 2.5 mm in length (Fig. 5). The glandular mucosa, with surface mucous cells which were stained with PAS, were continuous with the epithelial lining of the gastric pits, measuring about one eighth of the length of the glands. Although post-mortem degeneration of the gland cells prevented an exact histological examination, chief and parietal cells could be seen along the cripts. Staining with PAS and Alcian blue revealed no evidence of mucous neck cells. Parietal cells were numerous, being uniformly distributed down to the base of the gland. Chief cells were not so basophilic in dyeing in our specimen. The approximate ratio of



the parietal cells to the chief cells was 1: 3 or less. Musclaris mucosa did not form a conspicuous compact layer. Several relatively well developed smooth muscle layers, from 0.5 to 1 cm in thickness mainly arranged circularly, could be seen in the loose connective tissue of the very thick tela submucosa. There were many relatively thick blood vessels and few thin nerve fiber bundles in the submucosa. The muscular coat consisted of two complete layers (inner circular and outer longitudinal). The former was about twice as thick as the latter, with both together measuring about 1.5 mm.

Connecting channel The channel was situated on the right near the caudal end of the main stomach and, on the whole, was roughly in a sagittal plane (Fig. 1). The course of the channel was rather dorsad in direction for approximately 1 cm, then dextro-caudad for about 2 cm. Thereafter it curved upwards for about 2 cm, reaching almost to the dorsal side of the main stomach. It then curved to the right for a short distance, after which it entered the pyloric stomach. The diameter of the channel was about 8 mm throughout its whole course, with there being no sphincteric structures along the channel, though its entrance become slightly narrower. The inner surface of the channel exhibited some low longitudinal folds. The caudo-ventral wall of the channel of the mid-part was thin, about 5 mm thick, with the remainder being far thicker.

The mucosa of the connecting channel was composed of tubular glands of a mucous type (Fig. 6). The thickness of the mucosa was from 0.5 to 1 mm. The pits extended about halfway the length of the glands. The glands were not tightly packed and were separated by a relatively well developed lamina propria. Muscularis mucosa was inconspicuous. The submucosa was about half the thickness of that of the main stomach and was relatively vascularized. The muscularis consisted of two layers and measured approximately 1 mm or more in all at the ventral wall. The muscle on the dorso-sinister side of the channel was continuous with that surrounding the main stomach.

Pyloric stomach The pyloric stomach was an elongated tubular compartment, with its cranio-ventral part closely abuting the dorso-dexter wall of the main stomach (Fig. 2). It was situated in a cranio-sinister to caudo-dexter position, lying roughly in a frontal plane. The pyloric stomach was approximately 6 cm in length and about 1.5 cm or more in diameter. The opening from the connecting channel was present on the ventral wall and was about 1.5 cm away from the cranial end of the pyloric stomach. The pyloric sphincter, containing muscle and with an opening

←Fig. 1. The inner aspect of the stomach and the initial part of the duodenum of *Inia geoffrensis*, which is cut off along the lesser and greater curvatures. The esophagus is more straightly continuous to the main stomach than to the forestomach. Note the differences of thickness in the wall, and the appearance of the mucosa of the forestomach and of the main stomach. E-esophagus; Fs-forestomach; Ms-main stomach; Cc-connecting channel; Ps-pyloric stomach; Da-duodenal ampulla; Dp-duodenum proper. An arrow indicates the entrance of the connecting channel.

←Fig. 2. Dorsal view of the stomach and the initial part of the duodenum of the *Inia*. A portion of the interior of the anal part of the connecting channel, the pyloric stomach, and the duodenal ampulla are seen. for abbreviations see Fig. 1.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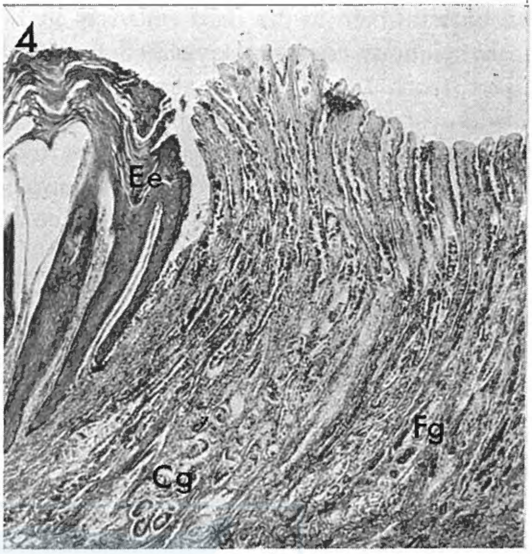
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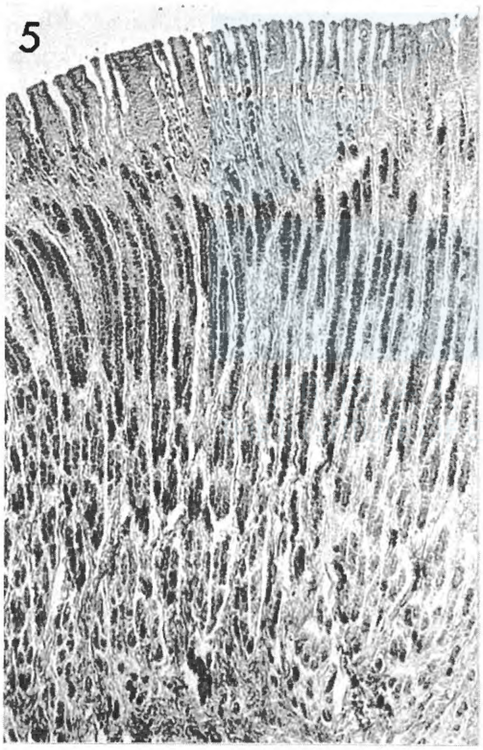
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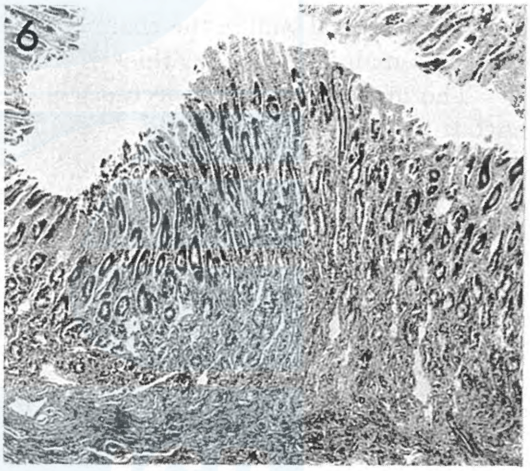
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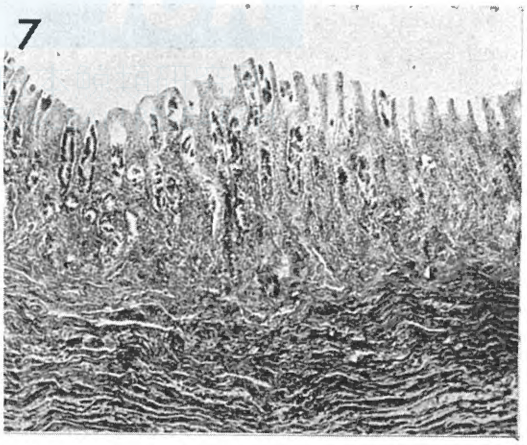
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about 2 mm in diameter, lay at the distal end of the pyloric stomach. The opening led into the duodenal ampulla which was about 2.5 cm in diameter (Figs 1 and 2). The wall of the pyloric stomach was approximately 5 mm in thickness. Its inner surface exhibited several folds arranged longitudinally which might be obliterated in the living state.

The histological structure of the pyloric mucosa was fundamentally similar to that of the connecting channel (Fig. 7). The mucosa was about 0.6 mm thick. The lamina propria contained some lymphatic nodules in places. The appearance of the musclaris mucosa, submucosa, and muscularis also resembled those of the connecting channel.

COMPARATIVE CONCLUSIONS AND DISCUSSION

As shown in Figure 8, there are considerable interspecific morphological differences in the stomach of Platanistidae. One notable difference is the presence or absence of the forestomach, which is an esophageal diverticulum existing in most cetaceans and which is sometimes referred to as the first or esophageal stomach. That is, the forestomach exists in *Platanista** (Anderson, 1879; Yamasaki and Takahashi, 1971) and *Inia***, but not in *Pontoporia* (Burmeister, 1867, 1869; Brownell and Ness, 1970; Yamasaki *et al.*, 1974) and *Lipotes* (Hinton and Pycraft, 1922; Chen and Chen, 1975; Zhou *et al.*, 1978, 1979ab).

The esophagus of the *Inia* seems to be more straightly continuous with the main stomach than with the forestomach, and the opening of the forestomach is rather smaller than that of the main stomach. In *Platanista* the esophagus leads to the forestomach and main stomach with roughly the same diameter through the biflucation which Anderson (1879) described as the " common opening ". In the case of sea dolphins (Gihr and Pilleri, 1969; Harrison *et al.*, 1970; Smith, 1972; our observation) the esophagus leads to the forestomach directly. The opening of

←Fig. 3. A photomicrograph of the forestomach wall. Stratified squamous epithelium and the tunica musclaris are thin compared with those of the esophagus. No glands are seen within the forestomach. H-E stain. ×25

←Fig. 4. A photomicrograph of the epithelial transition between the esophagus and the main stomach. Cardiac glands are found at a narrow zone between the esophageal mucosa and the fundic glands. Ee-esophageal epithelium; Cg-cardiac glands; Fg-fundic glands. H-E stain. ×40

←Figs 5, 6 and 7. Same magnification photomicrographs of the mucosa of the main stomach (Fig. 5), the connecting channel (Fig. 6), and the pyloric stomach (Fig. 7). Note the differences in the glandular nature and thickness of each mucosa. H-E stain. ×40

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* Anderson (1879) and Yamasaki and Takahashi (1971) referred to the forestomach as the " first cavity " and the " first compartment ", respectively.

** We mentioned the presence of the forestomach of the *Inia* in the description of the digestive tract of *Pontoporia* (Yamasaki *et al.*, 1974).

the forestomach from the esophagus, which usually projects rather like a nozzle into the forestomach, is far larger than that of the main stomach. These specific fea-

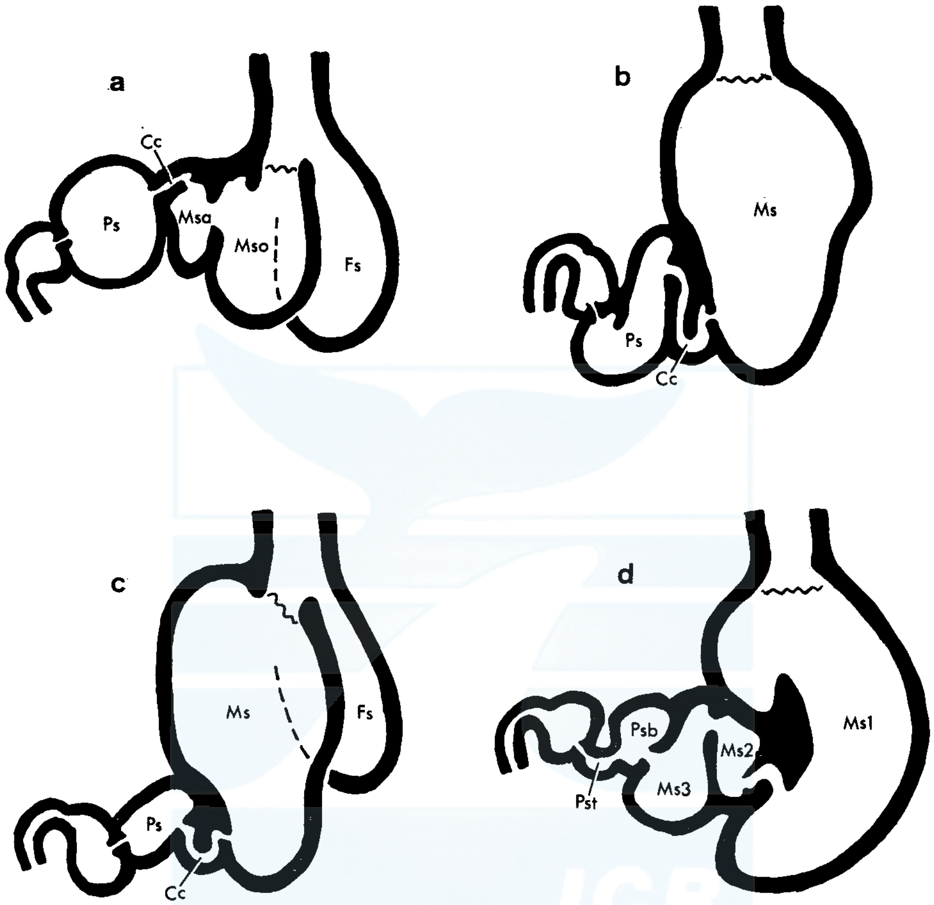

Fig. 8. Diagramatic representation of four stomachs of Platanistidae: a-*Platanista*, b-*Pontoporia*, c-*Inia*, and d-*Lipotes* (modified after Zhou *et al.*, 1979b). Note the relationships of the position, proportion, and communication of each compartment. Fs-forestomach; Ms-main stomach; Mso and Msa-oral and anal parts of the *Platanista* stomach; Ms1, Ms2 and Ms3-first, second and third parts of the *Lipotes* main stomach; Cc-connecting channel; Ps-pyloric stomach; Psb and Pst-bulbous and tubular parts of the *Lipotes* pyloric stomach.

tures in *Inia* and *Platanista* suggest that swallowed food may enter the forestomach and main stomach at the same time or the main stomach first, while in sea dolphins swallowed food may enter the forestomach directly.

The forestomach of the *Inia* observed was a pear-shaped muscular sac, and was considerably small compared with the main stomach. It was also relatively smaller than that of the *Platanista*. In observed cases of sea dolphins, it has been bigger (Jungklaus, 1898; Gihr and Pilleri, 1969; Harrison *et al.*, 1970; our observation), or smaller (Smith, 1972) than the main stomach. The forestomachs of the observed *Inia* and *Platanista*, however, were relatively small in depth and width when compared with those of sea dolphins.

Harrison *et al.* (1970) suggested that sea dolphins take as many fish as possible when the opportunity arises. The forestomach in adult dolphins is therefore considered to act as a place for the storage and breaking down of foods. In unweaned cetacean calves the forestomach is much smaller than in adults (Slijper, 1962; Smith, 1972), and in Mysticeti, which feed on small plankton, the forestomach is smaller than the main stomach (Slijper, 1962). In addition, *Hyperoodon* and *Ziphius* have no forestomach (Weber, 1886; Slijper, 1962). It is also said that these animals, which feed exclusively on soft food such as squid, could easily dispense with the forestomach. However, comparing the stomachs of the four species of Platanistidae with their food habits, provides some indication that there may be no direct relationship between the presence or absence of the forestomach and food habits, since dolphins having no forestomach are known to not always feed only on soft food*. In addition, since the muscular layer of the forestomach of the *Inia* and *Platanista* seems to be comparatively thinner than that of sea dolphins, it could be said that such a function, storage and breaking down of foods, in the forestomach of the *Inia* and *Platanista* is inferior to that in sea dolphins. According to Smith (1972), it is thought by several investigators that despite the non-glandular nature of the forestomach of sea dolphins some chemical activity takes place there involving gastric juice from the main stomach. If this usually occurs in the cetacean forestomach, it may be assumed that gastric juice may flow far more easily in *Inia* and *Platnista* than in other dolphins.

Hinton and Pycraft (1922) stated that the stomach of *Lipotes* was very primitive in form, the ventriculus (probably indicating the forestomach) being widely confluent with the second compartment (=main stomach) in *Platanista* and other dolphins. Although further developmental studies may be expected to clarify whether this deficiency in the forestomach of *Pontoporia* and *Lipotes* is the result of regression or confluence with the main stomach or is a case of original lack of development, it is of interest to consider the biological meanings that may be attached to this problem of the forestomach of Platanistidae.

The border line between the esophagus and the main stomach is quite clearly indicated by the abrupt change in lining, from stratified squamous epithelium to a glandular mucosa in all species of Platanistidae, while the line of the *Inia* runs almost transversely, or at a right angle to the long axis of the main stomach (Fig. 8c).

As shown in Figure 8, the main stomach of the *Inia* is rather a simple sac, with its shape resembling that of the *Pontoporia*. On the other hand, the main stomach

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* See for food habits: Burmeister, 1869; Brownell and Ness, 1970; Fitch and Brownell, 1971; Pilleri, 1971; Brownell and Herald, 1971; Pilleri, 1972; Chen and Chen, 1975; Zhou *et al.*, 1977; Chen *et al.*, 1980.

of *Platanista** and *Lipotes*** is divided into two and three parts respectively: the oral and anal compartments in the former (Yamasaki and Takahashi, 1971), and the first, second, and third compartments in the latter (Zhou *et al.*, 1978; Zhou *et al.*, 1979ab). The partitioning of the anal part of the main stomach of the *Lipotes* can be seen to be more complicated than that of the *Platanista.* Although it is difficult to compare the relative sizes of the main stomachs of the species of Platanistidae with one another, in species lacking a forestomach the main stomach seems to be bigger in proportion than that of species having a forestomach. If one includes the anal two compartments as part of the main stomach the volume of the main stomach of the *Lipotes* may be considered to be rather large. This may be a compensation for the absence of the forestomach for the storage of food.

The cardiac glands, which were found for the first time in the cetacean stomach by Hosokawa and Kamiya in 1971 in a blue whale, exist at the narrow zone adjacent to the esophageal mucosa in the *Inia* as well as in *Platanista* (Yamasaki and Takahashi, 1971) and *Pontoporia* (Yamasaki *et al.*, 1974). In a *Lipotes* described by Zhou *et al.* (1978) the cardiac gland zone was more well developed than those in the *Platanista* and *Pontoporia* we reported. Although Smith (1972) stated that no cardiac glands existed in the *Phocoena phocoena*, the glands may usually be found in other cetacean stomachs when all parts of this region are examined. All of the mucosa of the main stomach consist of glands of the same type, except for a narrow zone of cardiac glands. Superficial mucous cells, chief cells, and parietal cells have been detected in gastric epithelium in the *Inia*, *Platanista*, and *Pontoporia* we observed. Mucous neck cells have not been detected in these dolphins, possibly due to post-mortem changes. The numerical ratio of parietal cells to chief cells was approximately 1: 3 or less in all three species observed. This is in good accordance with the results of Harrison *et al.* (1970) and Smith (1972) in several sea dolphins, and of Hosokawa and Kamiya (1971) in baleen whales. It is interesting that this ratio of dolphins living in fresh water is almost the same as that for those living in the sea. Zhou *et al.* (1978; 1979b) found the mucous glands intermingled with fundic glands of the main stomach of the *Lipotes*, and stated that this was a characteristic feature of this dolphin.

The chief functions of the main stomach and forestomach of cetaceans are, respectively, chemical and mechanical digestion. Sand and small stones are often found in the cetacean forestomach and may play some part in mechanical digestion along with the highly muscular wall (Slijper, 1962). In *Lipotes*, dozens of stones, 3 cm in maximum diameter, were reported in the main stomach by Zhou *et al.*

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* Anderson (1879) and Yamasaki and Takahashi (1971) referred to the main stomach as the " second cavity " and the " second compartment ", respectively. Anderson did not consider the second cavity as two separate chambers.

** Hinton and Pycraft (1922) observed that the stomach of the *Lipotes* was less completely segmented proximally than in most other genera and found that towards the pylorus several small compartments were shut off as usual. Chen and Chen (1975) indicated that the stomach consisted of four chambers, two large proximal compartments separated by a rudimentary septum, and two anal ones communicating by small openings with each other and with the second compartment.

(1977), suggesting the possibility of the employment of stones in mechanical digestion.

The connecting channel of the *Inia* observed was situated in the ventro-dexter region near the caudal end of the main stomach and was rather similar to that of the *Pontoporia* in its location and shape (Figs 8b and 8c). In *Platanista* the channel* is located at the cranio-dexter region of the anal part of the main stomach (Fig. 8a). The entrance of the channel of the *Inia* and *Pontoporia* is located near the caudal end of the main stomach, while in *Platanista* it is found at the cranial wall of the anal compartment of the main stomach. According to Zhou *et al.* (1978; 1979b) no connecting channel exists in *Lipotes* (Fig. 8d). In the case of sea dolphins (*Stenella, Delphinus, Tursiops* observed by Harraison *et al.*, 1970), the connecting channel is located near the cranial end of the main stomach. However, in *Tursiops* shown by Slijper (1962), in *P. phocoena* observed by Smith (1972), and in *Stenella* in our observation the connecting channel was located consistently towards the caudal end of the main stomach. Its entrance was placed nearly at the midpart of the ventro-dexter wall of the main stomach in our specimen. Although Gihr and Pilleri (1969) did not mention the connecting channel in *Stenella* and *Delphinus*, they observed in their communication two different alternatives between the second and third stomachs (which may correspond to the main stomach and the connecting channel, respectively) in Odontoceti; the opening of the third stomach may be situated in the middle of the second stomach or in a more proximal position. They stated that the junction in the *Stenella styx* was placed well to the proximal end, so that this led to the conclusion that the stomach of this dolphin was highly differentiated. If this conclusion is acceptable, the Platanistidae stomach may be of an undifferentiated type. The connecting channel of Platanistidae is longest in *Pontoporia* (about 8 cm), shortest in *Platanista* (2 cm), and intermediate in *Inia* (4 cm). *Platanista*'s seems to be noticeably shorter than those in sea dolphins. Although the entrance and exit of the channel of the observed Platanistidae became slightly narrow, no marked sphincteric structures or constrictions existed along its course. The channel, except for that in the *Lipotes*, however, at least may as a whole perform a valvular or sphincteric function. In Platanistidae there may be a tendency for a long channel to exist in species having a stomach with a simple main stomach (e.g. *Pontoporia* and *Inia*), and for a short channel (*Platanista*) or the absence (*Lipotes*) of a channel in species with complicated partitions of the main stomach. Septal structures seen in the anal part of the main stomach in *Platanista* and *Lipotes* may have some sphincteric functions. Harrison *et al.* (1970) have made several suggestions on the biological significance of the connecting channel of sea dolphins. Even taking these suggestions into consideration, it is difficult to explain the relationship between the developmental degree and the functions of each kind of channel of Platanistidae. The histological nature of the connecting channel is identical with the pyloric stomach, and is fundamentaly the same in three species of Platanistidae and also in sea dolphins described by former authors (Har-

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* This was called the " passage " by Anderson (1879) and Yamasaki and Takahashi (1971).

rison *et al.*, 1970; Smith, 1972). The channels of all dolphins should be considered as a part of the pyloric stomach.

Although the pyloric stomach of the *Inia*, which in tubular in shape (Fig. 8c), is situated at the caudo-dexter part of the main stomach is a similar manner to that of the *Pontoporia* (Fig. 8b), it is considerably smaller than that of the *Pontoporia*. While those of the *Platanista** and of *Lipotes*, (Figs 8a and 8d), are globular in shape, that of the latter is rather small, with its anal part becoming a narrow tube (Zhou *et al.*, 1978; Zhou *et al.*, 1979b). The pyloric stomach of sea dolphins (Harrison *et al.*, 1970; Smith, 1972; our observation) is an elongated tubular structure and far bigger than those of Platanistidae. A distinct sphincteric structure exists at the distal end of the pyloric stomach in all species of Platanistidae as well as in other dolphins. In Platanistidae this structure is obviously the one which can be considered as a sphincter of the stomach, which may regulate the neutralization of stomach contents by the backflow of duodenal contents.

When comparing the stomachs of four species of Platanistidae with one another, considerable interspecific differences can be found as mentioned above. The digestive tract distal to the stomach of each species of this family also varies considerably from species to species: for example at the macroscopic level, the whole length of the intestine is 55, 50, 15, and 10 times longer in proportion to body length in *Pontoporia* (Yamasaki *et al.*, 1975), Inia (unpublished), *Lipotes* (Chen and Chen, 1975), and *Platanista* (Takahashi and Yamasaki, 1972), respectively. *Platanista*'s intestine is very unique among Platanistidae; there being a marked caecum as observed in some baleen whales. The structure of the stomach ought to be closely related to that of the whole digestive tract and closely concerned with food habits. It is assumed that the modifications of the digestive tract seen in each species of Platanistidae do not always show a characteristic feature that results from adapting to living only in fresh water, since *Pontoporia* is actually found only in coastal sea water. Although sufficient consideration could not be taken concerning the biological significance of the modifications of the stomach in this study, further morphological observations of the stomach of all species of Platanistidae will be useful to the study of the morphology and function of general cetacean stomachs.

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* This was called the "third gastric cavity" and the "third compartment" by Anderson (1879) and Yamasaki and Takahashi (1971), respectively.

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ACTIVITIES AND UNDERWATER SOUNDS OF FIN WHALES*

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ABSTRACT

Routine activities observed in fin whales (*Balaenoptera physalus*) were correlated with their underwater sounds. The acoustic and behavioral observations throughout 23 years were from a variety of geographical areas, but were more frequent in waters of the western North Atlantic around Cape Cod, Massachusetts, USA. Shipboard and aerial observations using arrays of hydrophones with low-frequency capability and radio tracking of tagged whales provided confirmation of both acoustics and behaviors. Routine activities were described including blowing, short dives (apparently a search behavior), long dives (often feeding), near-surface slow swimming (resting), rapid travel, and surface feeding. Underwater sounds included higher frequency sounds (under about 100 Hz), 20-Hz pulses (both single pulses and patterned sequences), ragged broadband low frequency pulses and low-frequency rumbles, as well as non-vocal sharp implusive sounds. Occurrence of the sounds, typical levels, responses, seasonality, and relationship to behavior suggested that the sounds were used in specific ways: the higher frequency sounds appeared to be for communication with nearby finbacks, the 20-Hz single pulses seemed to be used for both local and longer distance communication, the patterned seasonal 20-Hz pulses appeared to be courtship displays, the low-frequency rumble seemed to have surprise or agonistic significance, and the non-vocal impulsive sounds apparently were adventitious and related to surface feeding. Other sounds and behaviors were not as well defined or repeated enough for such analysis. Mechanisms of sound production, the effect of the environment on the low frequency sounds, the propagation of these sounds, and the relationship of the sounds from similar whale species is discussed.

INTRODUCTION

Finback whales, *Balaenoptera physalus* (Linné, 1758), are seen world wide and their behaviors at the surface of the sea are often observed, but very little is known of their activity underwater. In this paper an attempt is made to correlate our observations to provide an interpretation of some behaviors and to relate these to the underwater sounds of finback whales. Emphasized is the population that we have studied most—the whales of the western North Atlantic, and particularly those that come close to the shores of Cape Cod, Massachusetts.

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Impressions of finback activity usually are based on the behaviors that are seen at the surface of the sea. This includes only a small portion of the whales' behavior because they are at the surface for very short periods. Behavioral interpretations, therefore, have had to be based mainly on this visible surface activity even though it may not be related directly to the whales' underwater behavior. Blows, for example, probably have little relationship to underwater feeding, resting, and social activity.

In order to reach below the surface and try to assess the behaviors of submerged whales, we utilized underwater sound. The underwater sounds produced by finbacks have been studied (since 1958) during different behaviors and in different geographical areas and seasons. Multiple hydrophones were used to separate sound arrival times in order to locate and track the sound sources and to distinguish the whale sounds from other sounds in the sea. Special techniques and equipment were required to record and study the very low frequencies (as low as 18 Hz) and the very wide dynamic ranges in the finback sounds.

New techniques often had to be developed for specific studies including the design and fabrication of special hydrophones, amplifiers, recorders and analytic equipment, quiet boat propulsion, and tagging and tracking gear. Methods were devised for study of these animals at sea—for surface and aerial photography, for broadband (including very low frequency) acoustic recording and signal analysis, for acoustic tracking underwater, and for radio tagging and tracking. The sounds from finback whales (Schevill, Watkins, and Backus, 1964) provided the stimulus for much of the early progress in design of equipment and techniques for the acoustic observations at sea.

Although the behavioral and acoustic observations in this report are largely unpublished findings, emphasis is not on detailed descriptions of events or sounds. Instead, correlations of behavior with underwater sound are made to try to outline finback acoustic behavior. The limitations of our data are recognized—the small sample sizes, the sometimes incomplete observations, the lack of supporting secondary information—but perhaps the extrapolations and the correlations that are made will provide impetus for further work and greater understanding of finback activity.

METHODS

Observation techniques

Observations and recordings of finbacks were made in a wide variety of geographical locations, worldwide, and recordings made on bottom-mounted hydrophone systems by other researchers have been studied (including recent recordings by Peggy Edds, 1980). Our own sampling of finback acoustic behavior since 1958 has included approximately 4,000 hours of hydrophone listening and observations at sea, including the deep ocean at several locations in both the Atlantic and the Pacific as well as shallow water observations off the eastern and western coasts of the USA, in the Gulf of St. Lawrence, and off Greenland and Alaska. The Cape Cod, Massachusetts area with finbacks available year round has provided consistent opportunities for repetitive study and has allowed comparisons with these other observations. Replications of the observations of behavior with comparable underwater acoustic recordings have allowed confidence in the analyses.

A wide variety of observation platforms were utilized for study of finback activity including vessels of 15 to 75 meters (m) for pelagic work. The quieter boats consistently have been the most successful, so that we have several times used sailing ships for work with finbacks.

Aerial observations were used extensively to watch the near-surface behavior of finbacks, particularly in coastal waters around Cape Cod (cf. Watkins and Schevill, 1979). Depending on the transparency of the water and sometimes the color of the bottom in shallow water, whales have been followed visually to depths of about 30 m. The quieter, slow flying aircraft have been the most useful, flying at an altitude of 300 m for spotting and then dropping to 50 or 100 m for photography and closer inspection. Keeping the aircraft off to the side and down-wind of the animals has reduced disturbance from engine noise. Flying so that the shadow of the aircraft remained a short distance from the whales has avoided their reaction to it; the shadow often was used to measure the whales.

In protected areas near shore, small boats were particularly useful for close approaches to finback whales. Small boats with motor, sail, and oars have been used, including small 2.5-m dinghys, for taking hydrophones very near a whale. Finbacks often seemed to make closer approaches to the smaller quieter vessels than they did to larger ones.

Shore-based observations were useful for monitoring near-shore whales, and bottom-mounted hydrophones even at some distance from shore provided good information about the patterns of sound from whales in those areas. The separation of deep hydrophones from surface wave-noise, and the more advantageous sound-paths provided by deeper hydrophones often have permitted hearing sounds from greater distances. Moored hydrophones (both deep and near the surface) also recorded good sounds apparently without disturbing the whales. Although such systems did not allow direct observation, they have been useful for monitoring the occurrence of particular sounds or patterns. For example, we were able to examine in detail the continuous recording (since 1958) of low frequencies from offshore bottom-mounted hydrophones at the Bermuda Sofar station to trace the seasonal occurrence of finback sounds (cf. Patterson and Hamilton, 1964).

Comparisons of our acoustic observations of finbacks were made with those of other species in the same waters and under the same conditions. This has provided means of checking the characteristics of the sounds in relation to the effects of the environment (relative levels, sound path variations, noise backgrounds) and it has allowed assessments of the reactions of different species in a variety of behaviors. Our experience with the underwater sounds of more than 60 species of marine mammals has provided a good base for comparison. Ten or more species of cetaceans are available in local Cape Cod waters. Most often seen are *Balaenoptera physalus*, *B. acutorostrata*, *Megaptera novaeangliae*, *Eubalaena glacialis*, *Lagenorhynchus albirostris*, *Lagenorhynchus acutus*, *Phocoena phocoena*, and less often *Balaenoptera borealis*, *Globicephala melaena* and *Orcinus orca*. The effects of different seasons and environments have been noted, and when possible, we have tried to trace the movement of populations and individuals.

Near-surface activity of the whales was documented by photography whenever possible. From ships, a close scrutiny of behaviors often was possible, but because of low angle reflection off the surface, usually only the portions of the animals above water were visible or able to be photographed (Fig. 1). Correlation of acoustic data with the visible surface activity was attempted from the ship observations. Aerial observation usually allowed a better (higher angle) view of the whales underwater, and polarizing filters on the camera lenses often were used to reduce the effect of surface reflections. We tried to combine surface and aerial glimpses (sometimes from simultaneous observations) to provide a coherent picture of finback whale behavior.

Fig. 1. A finback whale (*Balaenoptera physalus*) moves slowly past, all but its fin below the surface of the water. Note that although the whale is very close, nothing of the submerged whale is visible because of low angle reflection off the surface of the water—typical of ship observations. Photo by Karen E. Moore, 26 April 1977. Cape Cod Bay.

Sound systems

Because of the potential of reaching below the surface with sound to learn more about the animals, we have emphasized acoustics and developed sound systems especially for work with finbacks.

(a) Hydrophones were developed for receiving the very low-frequency sounds associated with these whales. Broadband systems (to 200 kHz) also were designed to make sure that we were able to record the entire spectrum of their underwater sounds. Wide dynamic ranges were required to avoid overload distortion from the relatively loud sounds, as well as to receive low-level vocalizations. Many different systems were successfully utilized including large rochelle-salt crystal units, magnetostrictive hydrophones, variable-reluctance plate and moving coil detectors, and small ceramic sensors (barium titanate, lead zirconate titanate, lithium sulphate monohydrate).

(b) Cables of different lengths allowed the hydrophones to be floated away from the ship to separate the sensors from the noise of waves against the vessel, and to be suspended deep enough to reduce noise from the sea surface above the hydrophones (Watkins, 1966). To keep wave noise low and to allow for drift compensation, long cables often were paid out to keep the hydrophones stationary in the water as the ship drifted. Cables as long as 1 kilometer (km) or more sometimes were used. Impedances of the cables, therefore, had to be sufficient to allow for the variety of lengths so that both good low frequency and good high frequency response could be maintained. Motion of the cables and hydrophones was damped by a variety of methods, such as by using floats to support the cables in self-damping catenaries.

(c) Amplifiers for boosting signals to proper recording levels were chosen according to the requirements of the hydrophone system (bandwidth, gain, and dynamic range). Low-noise and low-distortion systems were emphasized. Impedance-matching and cable-driving amplifiers were located as close to the hydrophone sensors as possible.

(d) Recorders were designed to register the important sounds that were received, and they were made portable so that work from small boats was always possible. High quality recording equipment was used in calibrated systems to be sure of consistent, repeatable sound recordings. Bandwidth and distortion adjustments were made to achieve the best recorded spectrum for the sounds (often a different adjustment for the low-frequency finback vocalizations than for broadband sounds). Mechanical stability and constant tape speed were maintained in the recording systems for faithful reproduction of low-frequency sounds. Practical power-supply systems used rechargeable battery packs, not dependent on ship's power.

(e) Monitors that provided good quality sound reproduction were used to check on recording excellence. These were power amplifiers with speakers or headphones that allowed good response to broadband signals and visual monitors that provided accurate indications of relative signal levels over the recording spectrum. Signals out of the range of our (human) audible spectrum, as were many of the finback sounds, were monitored with special systems (oscilloscope, pen recorder, heterodyne converter). Signals were assessed immediately after recording (separate recordings and playback systems) so that the recorded sounds could be compared realistically with sounds as heard before they passed through the recorder.

A practical arrangement of this sea-going listening system worked well with finback sounds from a ship (Watkins, 1966; Watkins and Schevill, 1971). The hydrophone, connected to a long cable, was suspended from a visible buoy at the surface. The cable was supported by floats at intervals adjusted to allow maximum distance from the ship and reduction of wave motion on the hydrophone. The depth of the hydrophones was kept shallow enough (7 to 30 m, often 15 m) to try to restrict the listening range to only local animals. This was possible because in warm weather the surface waters of the open sea during daylight often had downward refraction of sound.

A typical sequence of events at sea during observations of finback whales and the recording of their underwater sounds usually included the following: (a) Whales were located. (b) Their surface behavior was observed. (c) The ship was maneuvered, with as little underwater noise as possible, to be near the whales, to drift past them or to be in their path. (d) The ship was silenced—all machinery stopped. (e) Hydrophones and cables were put out quietly. (f) Observations were correlated by time and running commentary on tape. (g) Patterns of underwater sounds and surface behavior were followed as long as possible. (h) As the whales moved out of acoustic and visual range, the hydrophones were pulled in and the ship moved as unobtrusively as possible to a more favorable position to resume the observations. Sequences of four hours or more have been possible.

Array of hydrophones

Arrays of hydrophones were used successfully to locate and track whales producing sounds underwater. A three-dimensional track of successive sounds was provided by means of a floating 4-hydrophone arrangement (Watkins and Schevill, 1972). Each hydrophone was recorded on a separate tape channel, and relative hydrophone positions were calculated from pinger sounds in the water. Sound arrival-time differences at each hydrophone were used to calculate the locations of the hydrophones as well as for the underwater sound sources. When the sound sources were nearby, accurate three-dimensional underwater positions were possible, but at a distance only direction and depth vectors were available from the array analysis.

Linear towed arrays of hydrophones also were used effectively to locate finbacks with only two hydrophones separated by 100 m or more. By maneuvering the ship, thereby changing the orientation of the array, relative direction to the sound source could be determined. Two or more hydrophones also were useful in distinguishing these low-frequency finback signals from noise. Local wave noises usually registered on each hydrophone separately, while whale sounds were heard on all hydrophones, delayed according to relative direction and sound-path differences.

All of our recordings were made broadband at sea, with as wide a recording spectrum as possible. Then, in the laboratory, the sounds were analyzed for their component parts. Filters to reduce wave-noise interference during field recording were not used because of the potential modification of higher-frequency signal components by the lower-frequency filtering. To study relative time patterns and amplitude relationships of finback sounds, oscillographic and continuous spectrographic analyses, and computer time-series analyses were used. Frequency patterns and spectra of sounds were assessed by sound spectrographs, computer Fourier transform and power spectra analyses, and frequency analyzers.

During our acoustic observations of finbacks, the whales generally have not appeared to react negatively to our presence as long as we utilized relatively silent, unobtrusive arrangements. We have therefore carefully tried to keep our ship quiet during listening sequences with as little splashing as possible and no engine or machinery noise. We have also tried to reduce the visual effect of our underwater equipment with blackened housings and dark lines to avoid light reflections. During close approaches by finbacks to our ship or cables, the animals have reacted when they suddenly appeared to notice the objects and turned away sharply or suddenly stopped their activity and left the area. The degree of their avoidances has seemed to depend on the whales' previous behavior. When the whales were active socially or feeding, they seemed to take little notice of our presence. When not obviously preoccupied, they generally could not be approached closely and would move cautiously away from even a silent drifting ship.

Radio tracking

Radio tagging and tracking of whales (Watkins and Schevill, 1977b; Watkins, Wartzok, Martin, and Maiefski, 1980) has given good confirmation of behaviors noted in other ways, as well as providing much new information about finbacks. Tagging has been particularly needed for finback whales since it is difficult to distinguish individuals of this species. The radio tags provided positive individual identification that was not dependent on visibility or weather. The tags were remotely implanted in the blubber so that they remained in place for several weeks. The whales did not react negatively to the tag implantation, but they sometimes reacted to the sounds of the tagging boat (Watkins, in press). Tagged finbacks returned to " normal " behavior within a short time after tagging, and they appeared not to notice the tags or the tracking boats as long as the boats did not come close. Finbacks were tagged and tracked in protected waters of the St. Lawrence River, Canada (Ray, Mitchell, Wartzok, Kozicki, and Maiefski, 1978) and in Prince William Sound, Alaska (Watkins, Johnson, and Wartzok, 1978; Watkins, Moore, Wartzok, and Johnson, 1981), and in the open sea between Iceland and Greenland (Watkins, 1981). The longest sequence of radio tracking one finback whale was 28 days, in Alaska (Fig. 2). The greatest distance covered in one track was 2.095 km during 10 days in the Atlantic (Fig. 3). Throughout these tracks, behavioral changes seemed to depend on the whale's activity, participation with

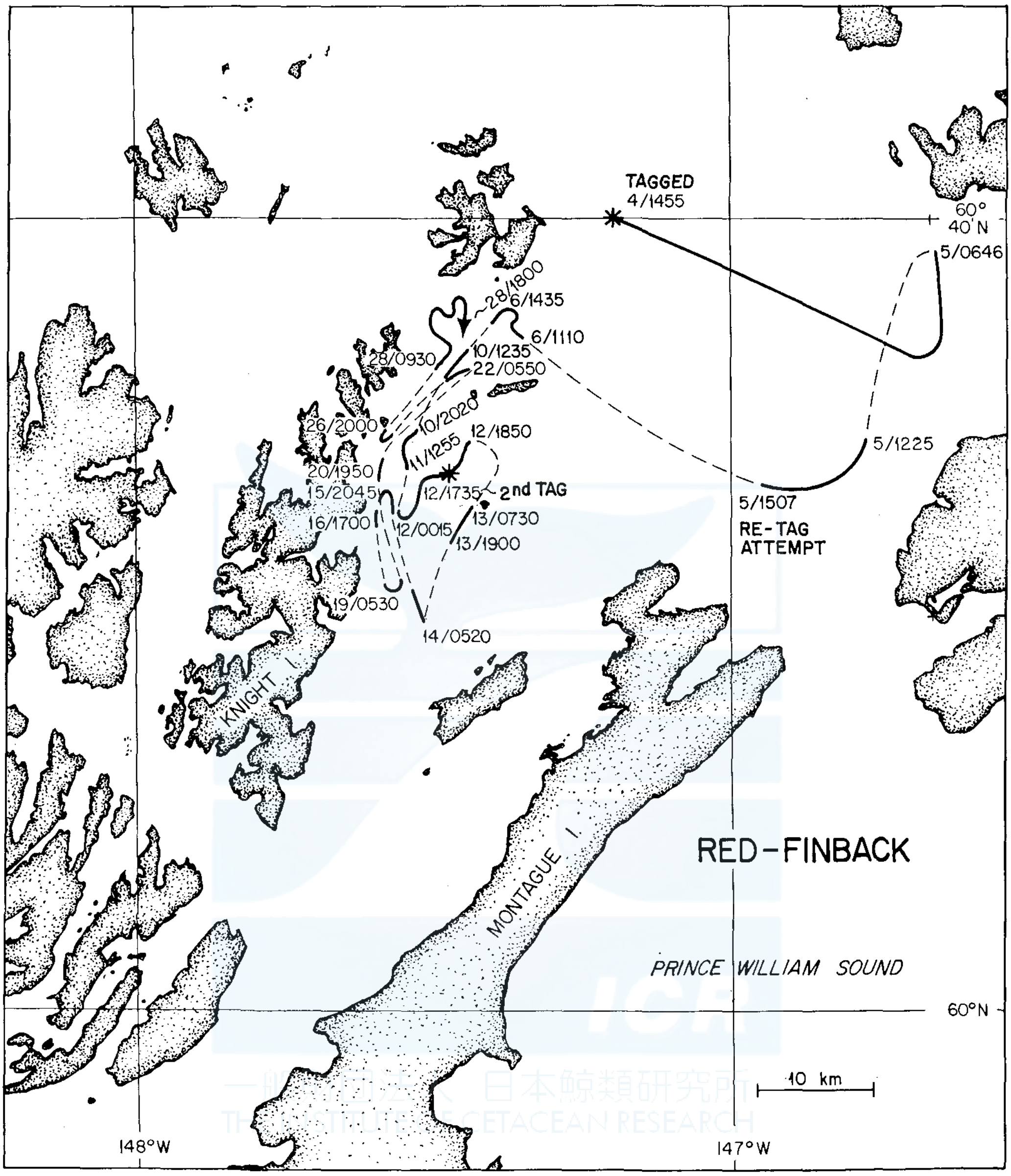

Fig. 2. The track of a radio-tagged finback whale in Prince William Sound, Alaska, June 1978, demonstrated this whale's preference for one particular part of the Sound for 28 days. This whale was not tracked continuously, but the radio signals indicated long dive routines (11 to 12 min) during much of the day and a change at dark to near-surface behavior (Fig. 2 in Watkins, Moore, Wartzok, and Johnson, 1981, courtesy of Deep-Sea Research). Solid lines indicate periods of continuous tracking. " Red " refers to the color of the streamer on the tag.

TRACK OF RADIO-TAGGED FINBACK WHALE
25 JUNE - 5 JULY 1980

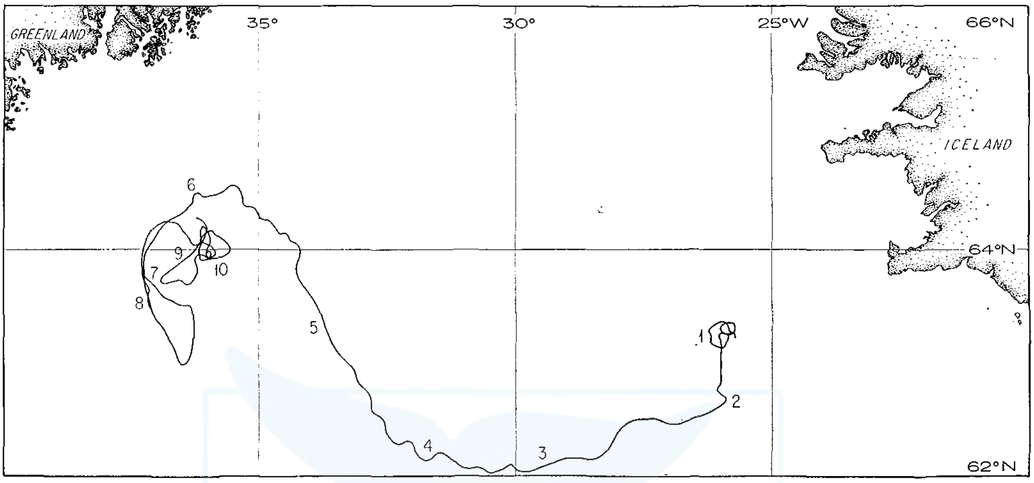

Fig. 3. A finback whale that was radio-tagged off Iceland was tracked continuously for ten days, June-July 1980. The whale travelled 2095 km during this period, and as much as 292 km in one day, 1 July. The tagged whale was with one to seven other finbacks for most of the time, and behavior varied throughout the track. The whales fed on krill off Iceland, then left that area and fed on schooled small fish off Greenland during the last four days of the track off Greenland (Fig. 6 in Watkins, 1981).

other whales, and the activity of their prey. During some behaviors the finbacks were easily identifiable at the sea surface, but during others not enough of the whales' bodies was visble (for hours) to permit recognition (the presence of any whales) without confirmation from the radio-tag signal.

Our observations of finback whales have not been systematic in any locality, but they have been more frequent in waters around Cape Cod. Generally, these whales were noted and observed as they were encountered during cruises that often were designed for other work. However, we have consistently prepared acoustic equipment that could record finback sounds well on all cruises. Most observations have been in waters of less than 200-m depth within 25 km of shore. Although some authors have considered that finbacks are mostly an offshore species (Nishiwaki, 1972, p. 22) their occurrence nearshore often has been noted (c.f. Allen, 1916). Our observations from aircraft have mostly been during the spring, and generally in relatively good weather. Our few opportunities to observe these whales in bad weather have indicated that the whales take little notice of the sea conditions so that their behaviors have remained about the same as in calmer water. The locations for the observations of finback behavior noted below are in the Cape Cod Bay and Massachusetts Bay area (roughly bounded by 41°40′ to 42°40′ N, and 69°30′ to 70°40′ W); otherwise specific positions are given.

Correlation of observations

The descriptions of behavior and sounds below are generalized to focus on the apparent correlations, both negative and positive. In each activity, there was a wide spectrum of variation—the broader our opportunity for observation, the larger the apparent variability. By noting the norms, we hope that the basic patterns of underwater sound and activity will be seen.

To put the observations in perspective, some of the general conditions of sound production by finbacks are given, then routine behaviors and associated sounds are identified, and the sounds are related to behavior. As more is understood of the underwater activity of finbacks, more behavioral and acoustic patterns can probably be recognized.

RESULTS

General observations

The obvious activities of these whales fell into a few routine behaviors and there were some specific underwater vocalizations. Definite associations of the underwater sounds (both positive and negative correlations) could be made with specific activities.

Finback activity is categorized below in a few of the most obvious behaviors: (1) Blowing at the surface was the most visible behavior. (2) Short (2–6 min) dive routines generally were the most common activity. (3) Long (6–14 min) dive routines were apparently related to feeding underwater. (4) Near-surface slow swimming seemed to be a " resting behavior ". (5) Rapid travel near the surface was characteristic of whales in transit. (6) Surface feeding on schooled fish was easily visible. Other behaviors were less frequent or less identifiable. There was a continuous gradient between types of behavior, of course, but the categories listed here appear to be representative, and they occupied the whales for long enough to be apparently distinct.

Underwater sounds from finback whales also are categorized for reference: (1) " Higher frequency sounds " included a variety of vocalizations from approximately 100 Hz to 30 Hz, most sweeping downward in frequency. (2) The " 20-Hz pulses " produced both as single pulses and patterns of repeated pulses also mostly had downward sweeping frequency, near 20 Hz and often quite stereotyped. (3) " Ragged low-frequency pules " were short, broadband pulses often with low frequency emphases. (4) " Low-frequency rumbles " were longer duration, broadband sounds below about 30 Hz. (5) Sharp impulsive sounds did not appear to be vocalizations but were characteristic of certain behaviors.

When finback whales were found completely alone, separated apparently by 20 km or more from any other finback, no vocalizations were heard. On the other hand, when underwater sounds were heard from a finback, other finbacks have always been found within a few km. Even in company with other finbacks, however, these whales were silent much of the time. The underwater vocalizations of finbacks appeared to be produced voluntarily, and sometimes could be correlated with specific behaviors. These sounds seemed to be noticed by other finback whales.

Finback whale activity

Blowing at the surface during respiration was the most visible activity of finbacks. A general description of the surface behavior of finbacks was given by Andrews (1909) and Mackintosh and Wheeler (1929), including blow series. The whales seldom appeared at the surface without blowing 1 to 20 or more times. During respiration, the whales generally lifted the blowhole well out of water. Sometimes, however, only a small portion of the whale was visible during respiration, with only the prominence around the blowhole out of water, as seen in the radio tracking experiment off Iceland, (Watkins, 1981). During some activities the radio

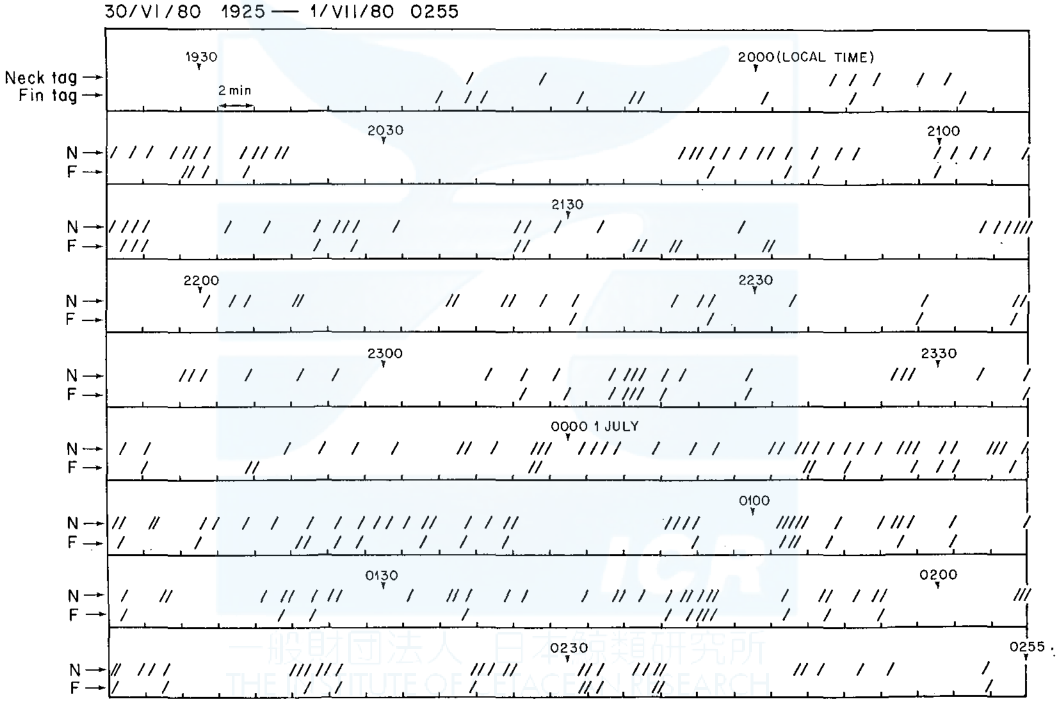

Fig. 4. Signals from the two radio tags on a finback whale are plotted from 1930, 30 June to 0255, 1 July 1980 during the continuous track from Iceland to Greenland (Fig. 3). Signals from the tag at the base of the fin (F) are shown as the bottom line of each row and those from the tag on the whale's neck (N) are shown above. Each slanted line represents a set of signals during one surfacing, 0.5 to 2 sec or longer. The back (neck) tag was exposed much more often than the fin tag, and these signals correlated somewhat with breathing. During this period, the whale averaged one exposure of the back tag in 1.85 min (233 signals/430 min). Sometimes the whale blew without exposing the tag, and occasionally signals were received although the whale did not breathe (Fig. 7 in Watkins, 1981).

tagged whale and its one to seven companions exhaled underwater and then only inhaled when they surfaced, producing no visible blows.

The time between blows in a series was variable, with intervals of 5 sec to 2 min or longer, apparently depending on the whale's exertion and interest in other behaviors. Often the first few and sometimes the last few blows of a series were separated by the least time.

Over periods of a few hours, finbacks generally have averaged about one blow for 1 to 2 min of dive-cycle (total dive time plus surface time). Radio tagging experiments have provided long enough observations of identified whales to be able to follow their respiration patterns (Fig. 4; Ray, Mitchell, Wartzok, Kozicki, and Maiefski, 1979; Watkins, 1981; Watkins, Moore, Wartzok, and Johnson, 1981). Blow sequences for individual whales sometimes were consistent, apparently varying with the level of exertion. Individual whales often had slightly different respiration rates and differences in blow characteristics though participating together in the same activities. The apparent effort connected with finback blows also varied. The first blow of a series, especially after a longer dive, often was more intense than the following blows, louder in air, with a more " explosive " beginning and a higher visible plume. Later blows in a series seemed to be much more relaxed.

Finback whales usually swam forward while blowing, and generally the back was lifted well out of water during each blow. In still water, sometimes only the raised area around the blowhole was brought above the surface so that the forward motion of the whale directed the water flow around and away from the open blowholes. When combined with other near-surface activities, the whale's surfacing, the attendant forward motion, and the blow-all often weve accomplished very rapidly. In finbacks, the exhalation generally has lasted about one sec, slightly longer than the subsequent inhalation, and the blowholes were opened less widely during exhalation, producing more sound in air (turbulence). Inhalation with very widely opened blowholes has consistently been almost inaudible. Just before a dive, particularly before longer or more hurried dives, the finbacks usually have " rounded-out ", and raised their backs high as they began a dive.

During " normal " blowing, there generally was little water disturbance or splashing as finback whales surfaced to blow and then submerged. The whale's surfacing and submergence usually has been slow and smooth, even in rough water. The tip of the whale's rostrum usually remained below the water and their flukes seldom appeared at the surface.

It was not surprising, therefore, that very little underwater sound was ever heard during respiration. Neither the movement of the whale's body at the surface nor the whale's blows produced much sound underwater. The slight splashing sounds of the whale's body moving at the surface usually were less than the sounds of local wavelets. Occasionally a whale produced a cough-like sound in air from the blowhole or restricted the lips of the blowhole to form more prolonged air turbulence during exhalation. This was more audible both in air and underwater than the sounds of normal blowing. In finbacks, these sounds have not appeared to be produced purposefully, in contrast to other species, such as humpbacks (*Megaptera novaeangliae*) that produced apparently purposeful blowhole sounds used for underwater signalling (Andrews, 1909; Watkins, 1967).

Dive routines (whale submerged between blow series) were of two types distinguishable as separate, somewhat stereotyped behaviors-short dive of 2 to about 5 or 6 min and longer dive of 6 or 7 to about 14 min. The separation of these routines at 6 min is artificial but at about 5 to 7 min the behaviors usually changed character as the whale shifted from one dive routine to the other. Generally, several whales in an area participated in the same dive routines for prolonged periods (hours) at a time. Some of the intermediate length dives (5 to 7 min) and short dives of less than 2 min were not characteristic of the short or long dive routines, but often appeared to be indicative of transitional behaviors.

Short dive routines of approximately 2 to 6 min were the most common activity noted in finback whales. During short dive routines the whales blew only a few (2 to 8) times between dives and often these blows appeared to be quite unhurried. Between blows of a series, the whales generally moved slowly near the surface. During short dive routines the whales appeared to travel underwater for only short distances, usually only 100 to 500 m during each dive. There was little observable pattern to locations of successive surfacings, although surfacings sometimes were along a line of bathymetric features. Generally, even though all the finback whales visible in an area participated in the same short dive routines, their surfacings normally were not synchronized. Whales were separated by 200 m or more as they moved slowly across an area, often all making some progress in the same direction, but on seemingly random courses. Thus, over several hours, during short dive routines a group of two or more finbacks would progressively cover a wide area.

Both the higher frequency sounds and a few 20-Hz pulses (described below) were heard occasionally from finbacks during short dive routines, but there was no particular sound sequence that characterized this behavior. The calls heard during these times were no different from sounds heard during most other behaviors. The higher frequency calls were the most common, usually without obvious response from another finback. They occurred irregularly, averaging about one sound per half-hour recording. In addition, occasional 20-Hz single pulses and ragged 20-Hz pulses sometimes were heard. Few vocalizations (often none) were heard during short dive routines.

Whales participating in short dive routines in an area appeared to be in contact with each other since changes in behavior were observed as shifts in the activities of all the whales. A group of finbacks usually remained within 1 to 3 km of each other, although moving about apparently quite independently.

Long dive routines were dives of 6 to 14 min or longer. Because the dives were longer, they appeared to require more exertion than the shorter ones, evidenced by the greater intensity of the blows that followed long dives (c.f. Andrews, 1909). During long dive routines finback whales usually blew 6 to 14 or more times in a series with the first blows relatively intense (see above) and separated by short intervals. Sometimes at the whale's surfacing, their mouths were seen to be slightly open with water flowing out through the sides of baleen (nomenclature after Williamson, 1973). Occasionally after a long dive, their throats were enlarged with ventral grooves expanded indicating that the whales had been feeding (Watkins and Schevill, 1979). After the last blow of a series, the whales rounded-out quite high and dove steeply to begin another long dive. This was usually accompanied by prominent fluke disturbances on the surface of the water (" foot-prints " made by the upward thrust of the flukes) as if the whale were in a hurry to get back down (cf. Gunther, 1949). From aerial observations, this could be seen clearly. Although several whales were diving in the same area, they usually surfaced seprately after long dives.

Underwater vocalizations of both the higher frequency calls and occasional 20 Hz pulses were heard from finbacks more often during long dive routines than during the short dives. As in the shorter dive routines, there were no particular sound sequences that characterized this behavior. Although both types of calls were heard, the higher frequency sounds were the more common. Compared to the blows following short dive routines, the vigorous intense blow after long dive routines produced slightly more sound underwater and the water splashes also were more audible as the whale moved more rapidly at the surface.

When several whales dove together in long dive routines near each other, there were likely to be underwater vocalizations, particularly those of higher frequency, sometimes in sequences of 5 to 10 sounds, and produced by more than one whale (different sweep rates). Consistently, when two or more whales were in a long dive routine near each other, the occurrence of underwater sounds was likely.

Near-surface slow swimming behavior of finback whales (less than 1 km/hr), was often within only 10 to 20 m of the surface and was especially visible from the air. In this activity, finbacks blew at irregular intervals of one to four min often with only one or two blows per surfacing, usually with very little of the body visible above water. The whales swam slowly and travelled along a meandering track. Sometimes two or more whales were seen to move slowly in this near-surface behavior, often 100 m or more apart but sometimes within 15 m of each other. There was no obvious interaction with their companions, and they seemed to ignore passing boat traffic that probably would have disrupted many other behaviors. This slow swimming activity continued for periods of 10 to 30 min or longer, and did not occur at regular intervals. Underwater vocalizations were not heard from finbacks during this near-surface slow swimming behavior.

Rapid travel near the surface was typical of finbacks in transit. Often they moved along relatively straight courses and at relatively constant speeds (10 to 16 km/hr) for prolonged periods. The radio tracked whale between Iceland and Greenland (1980) continued this behavior for most of four days. Sustained speeds of 20 km/hr or more have been observed for at least 20 minutes (from the air three whales were followed for 7 km, 1 May 1975). Blows during rapid travel were sometimes at quite regular intervals, especially in calm seas, of 30 sec to 4 min or longer. In rough seas, the whales seemed to blow as they had opportunity in deeper troughs between seas. Finbacks travelling rapidly often rose relatively high out of water when blowing, sometimes cutting the surface of the water with the forward part of the jaw (chin) and rising high enough so that ventral grooves were visible. Once from an aircraft we saw a large finback travelling very rapidly whose body arched completely out of water in a " porpoising " leap as it blew (Cape Cod Bay, 26 April 1974).

Up to six finback whales have been seen swimming rapidly together, spaced at least 15 m apart and blowing within a short time of each other. One such group was observed (1 May 1975, 35 km N. Cape Cod) swimming 12 to 15 km/hr. They were continuously visible from the air as they swam at 5 to 10-m depths heading toward a large group of feeding finbacks 10 km away (Watkins and Schevill, 1979).

Underwater sounds of rapid swimming were noticeable only during calm sea conditions and consisted mainly of splashing sounds at the surface. Low-frequency rumble vocalizations (see below) also were heard occasionally when travelling whales passed very close to our ship (Fig. 5). The rumble was a vocalization and not a hydrodynamic sound.

Near-surface feeding behavior on schooled fish (Nemoto, 1970, Tomilin, 1957; Watkins and Schevill, 1979) had distinctive components that varied with the finback whale's prey, but the behaviors included the common elements noted below.

Fig. 5. A finback whale approaches to dive and pass beneath our boat while producing a low-frequency rumble sound (as in Fig. 11). Photograph by Karen E. Moore, 12 June 1980, Cape Cod Bay.

Near-surface feeding sometimes followed a period of short diving but did not appear to be related to long dives or to near-surface slow swimming activities. The schooled fish were chased in the surface waters by the whale. Often it was possible to watch this behavior for long periods from an aircraft. Typically, after reaching its prey, the whale moved through the schooled fish, mouth opening and closing to engulf prey and water. The whale opened its mouth as it reached the fish school and reduced its swimming speed as it closed its mouth. The ventral grooves of the finback were expanded with the large mouthful (Fig. 6) (Ingebrigtsen, 1929; Gaskin, 1976; Watkins and Schevill, 1979). When at the surface, water could be seen to flow through the sides of baleen as the throat region shrank in size. Most passes by feeding finbacks through fish schools were with the body parallel to the surface so that little of this behavior was visible from ships. Usually only a portion of the whale's back and fin and sometimes part of the head were visible above the surface. Occasionally, as the whale turned sharply onto its side in pursuing the fish school, a fluke and flipper were visible above water as well (Gunther, 1949, p. 124).

All of the whale's orientations during feeding—on the side, upside down, or

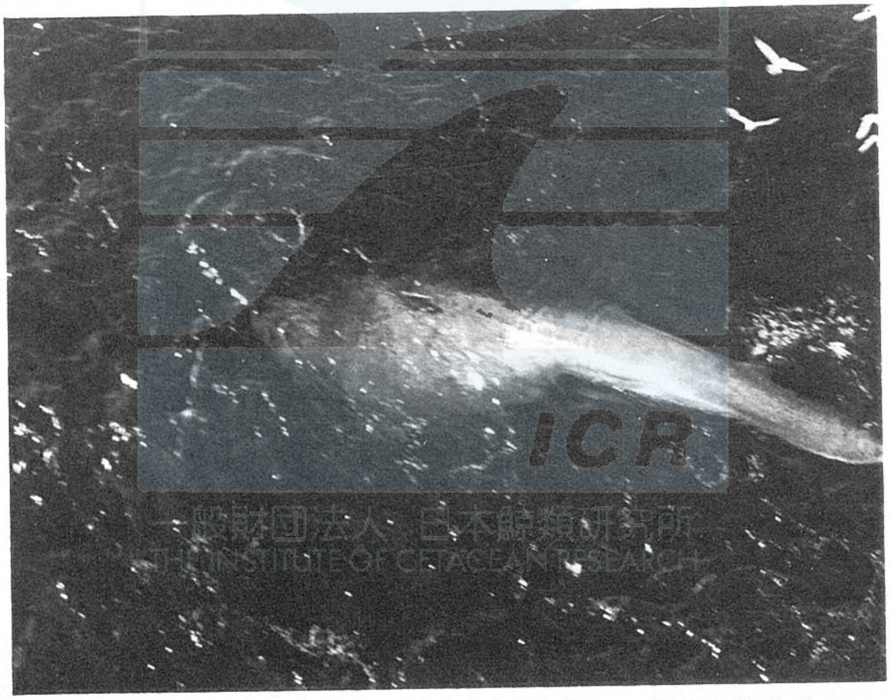

Fig. 6. A finback whale is photographed during feeding on schooled fish (perhaps *Clupea harengus*). Although feeding usually is with the back uppermost, the whales sometimes turn on either side in order to chase active prey. The whale seems to be able to change direction more rapidly by turning onto its side. Note the expanded ventral grooves allowing the whale to swell to about twice its diameter (Fig. 1 in Watkins and Schevill, 1979, Courtesy of Journal of Mammalogy) Photo by Watkins, 29 April 1976, 10 km north of Cape Cod.

even vertical—were related to the mobility of the prey. From long-term aerial observations, it was obvious that the whales chased schooled fish and followed the school in all directions. Side swimming seemed to allow the whale to turn rapidly in either direction by strong horizontal fluke movements. The whales often turned on their sides at the end of a feeding pass as they rapidly changed course. Whales were seen swimming on either their left or right sides, and sometimes they followed a fish school down and back up so that the whales were inverted with ventral grooves uppermost as they opened their mouths. Side swimming during feeding sometimes was visible at depths greater than 20 m and obviously was not related to feeding near the surface. Against a light colored bottom, we have watched from the air as finbacks dove and twisted and turned, apparently chasing schooled fish near the bottom in water depths to 30 m. Feeding activity that included side swimming at the surface often was conspicuous from the ship observations because of the splashing of flukes and flippers (noted by many authors, cf. Andrews, 1909; Tomilin, 1957), while the usual feeding passes with the whale's rostrum parallel to the surface generally was not identifiable except by aerial observations (Watkins and Schevill, 1979).

With some highly mobile prey, finbacks dashed at the surface of the water to catch a fish school. During this behavior the finbacks burst through the surface of the water at low 20 to 30-degree angles, often with considerable splashing. Sometimes the mouth was opened so that the sides of baleen cut the water as the whale moved forward at the surface. Sometimes also, during hard chases, a small (30 to 50 cm) disturbance like a gas bubble appeared behind the whale as it surfaced.

No vocalizations that could be related to hunting, chasing, or feeding were heard from finback whales. Frequencies to 500 kHz have been monitored and no vocalizations have been found during feeding. Nothing resembling echolocation signals was ever heard. During feeding at the surface on schooled fish, however, the sequence of splash sounds were characteristic of that behavior. In addition, there often was a sharp impulsive sound that coincided with the opening of the whale's mouth just at the surface of the water. Prior to the arrival of the whale at the surface, occasionally there also was a loud impulsive sound that preceeded the appearance of the bubble at the surface. Although these sounds apparently were not vocal, the combination of sounds connected with such surface feeding provided distinguishing acoustic indications of the whale's behavior.

Other finback behaviors also were partially visible at or near the surface. Such activity included social behavior, possible courtship routines, cow-calf behavior, and relatively short diving activity. These were variable, transient behaviors that were sometimes mixed with the more stereotyped activities, particularly the shallow dive routine. Although these were mostly activities involving interaction between individuals, very few sounds were heard from these whales. So far, we have not been able to relate any of the finback vocalizations to these behaviors.

Finback Vocalizations

The higher frequency sounds produced by finback whales (Fig. 7) generally were down-

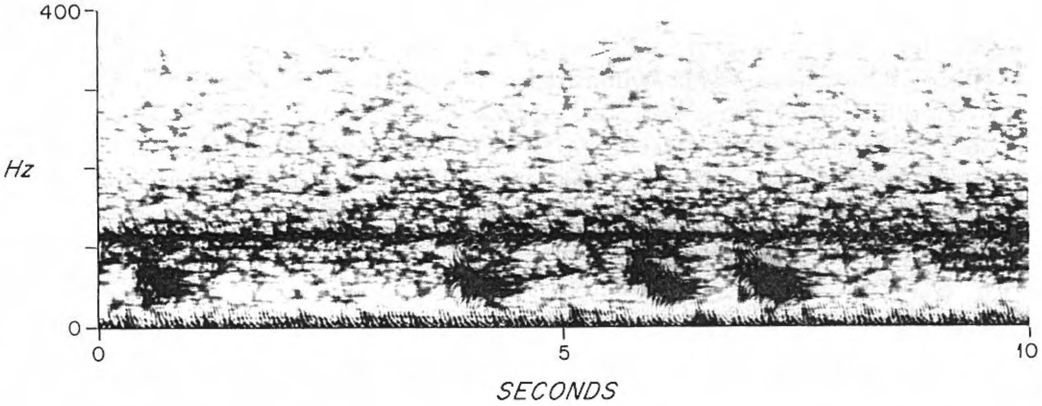

Fig. 7. A sound spectrogram of "higher frequency" finback sounds shows 75 to 40-Hz downward sweeping frequency in these sounds, generally without harmonics. The line at 120 Hz is the ship's generator. The sounds are from at least three whales and were recorded 12 September 1961, about 25 km east of Cape Cod. The filter bandwidth of the analysis was 13 Hz (Schevill and Watkins, 1962, Fig. 35).

ward sweeping pulses, many with frequencies from about 75 Hz to 40 Hz (Schevill and Watkins, 1962). To distinguish these sounds from the lower frequency "20-Hz" pulses also from finbacks (see below), we originally called them "40-Hz" sounds because the two could be separated by octave filters. The two sounds were not harmonically related. The "40-Hz", higher frequency sounds often were composed of about 20 cycles of the sweeping frequency with durations of about 0.3 sec. The level of the higher fequency sounds varied but was maximum at 55 to 60 dB (re 1 dyne/cm^2). The waveform of the sweeping frequency usually was sine-wave when recorded from nearby whales in deep water; there were no prominent harmonics. Successive pulses from individual whales had variable source levels though the sweeping frequency spectra of the sounds remained relatively constant. The received sounds were variable in duration, amplitude, and beginning and ending frequencies which were all potentially affected by multipath differences. Therefore, our descriptions are based on analyses of sounds from nearby whales in deep water.

The higher frequency sounds were the calls most often heard from finbacks during the summer season and they were heard occasionally from all sizes of adult whales (13–20 m long). These sounds were heard both as single relatively isolated calls and as repeated calls, repeated two to five or more times apparently by the same whale. When two or more whales were vocalizing, the sounds of individuals were separable by slight differences in the characteristic frequency sweep of those sounds as well as by directional differences to the sound sources. The higher frequency sounds were never repeated, unlike the 20-Hz pulse patterns (below).

Higher frequency finback sounds have been recorded during most our summer listening sessions. Our most recent recordings were in June 1980.

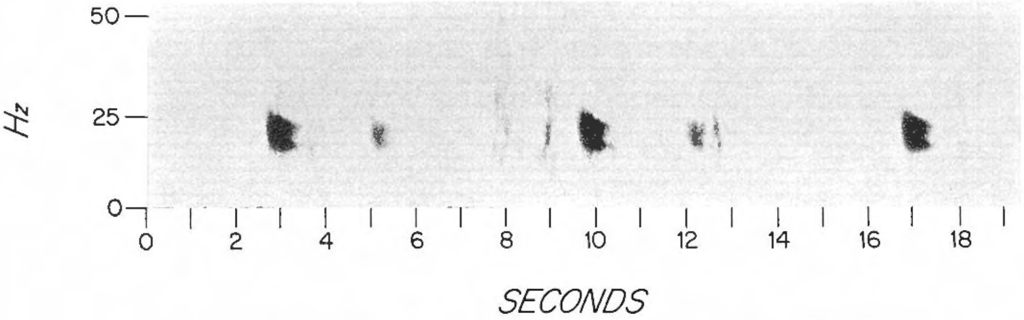

Fig. 8. A spectrogram of 20-Hz pulses from a finback shows the characteristic downward sweep in frequency, approximately 23 to 18 Hz. These sounds were in a patterned sequence of repeated pulses from one whale (at 3, 10, and 17 sec) with a 7-sec repetition rate. A second whale that was more distant also was pulsing at the same rate, and its sounds may be seen in the spectrogram (at 5 and 12 sec). The sounds were recorded 10 km north of Provincetown, Cape Cod, on 11 October 1978. The filter bandwidth of the analysis was 6.5 Hz.

The *20-Hz pulses* (Fig. 8) heard from finbacks (Schevill, Watkins, and Backus, 1964) were similar in composition to their higher frequency (" 40 Hz ") sounds, described above. The 20-Hz pulses swept downward in frequency usually from about 23 Hz to 18 Hz, and they were composed of approximately 20 cycles of the sweeping frequency with a duration of about 1 sec. The 20-Hz pulses generally were louder (than the higher frequency sounds) with maximum source levels of 75 to 80 dB, occasionally higher. The waveform of the pulses was sine-wave when recorded from nearby animals in deep water (without interference from reflections or other sound paths), and they usually had no prominent harmonics or higher frequency components. The pulses usually increased smoothly in amplitude over the first third of the sound, remained relatively constant in level during the middle third, then decreased in amplitude over the final third of the pulse. Successive pulses in a series had variable source levels although the location and orientation of the whales producing the sounds were not changing (demonstrated particularly by multiple hydrophone recordings, 11 October 1978).

Unlike the higher frequency sounds, the 20-Hz pulses were heard throughout the year but particularly in the summer as single pulses and in short series of two to five pulses. In the winter season (late October to early May) the 20-Hz pulses (Fig. 9) were heard in repeated stereotyped patterns with relatively fixed intervals between pulses. Pulse intervals in the repetitive patterns varied from 6 to at least 37 seconds (6, 7/11, 8, 9, 12, 15, 10/18 were common regular pulse intervals). Sometimes the patterns were in doublet form (such as the 7 sec/11 sec and 10 sec/18 sec sequences). The stereotyped patterns of 20-Hz pulses, apparently from the same individual, could be heard for hours, with silent periods of two to four min between pulse series lasting two to 20 min. Two or more pulse patterns have been observed to be produced alternately by the same whale.

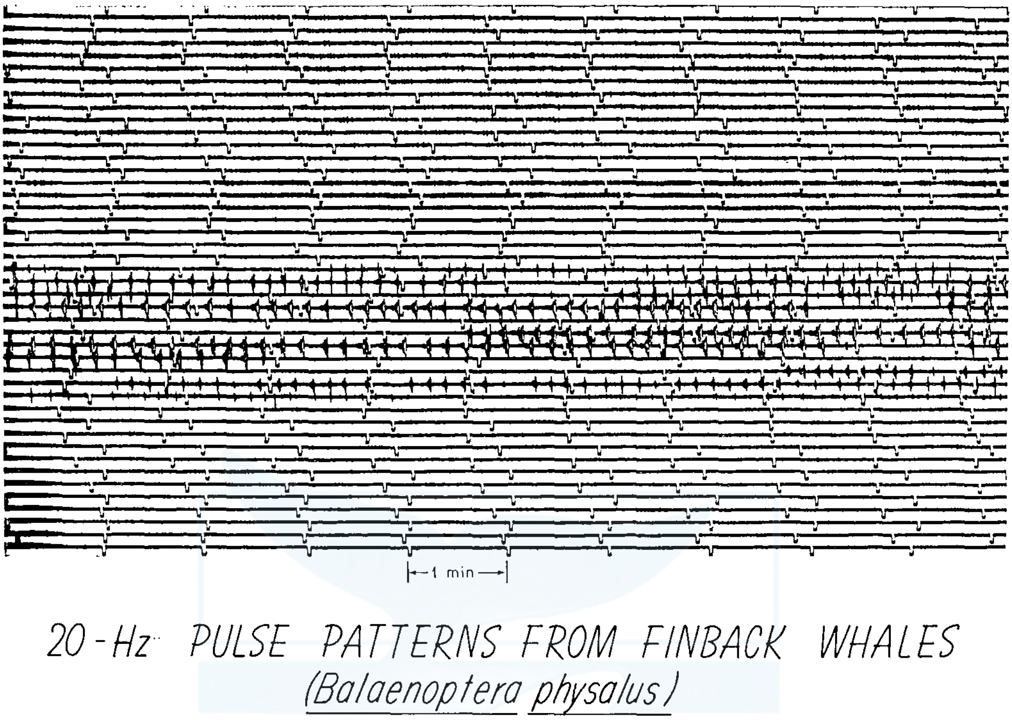

Fig. 9. A portion of a continuous drum oscillograph record shows patterned 20-Hz finback sounds recorded near Berrmuda. The sounds were from a bottom-mounted hydrophone, 12 December 1979 (courtesy of the Sofar Station, St. Davids, Bermuda). The signal was filtered 40 Hz, low pass. Markers on the record are at one min intervals. The record was continuous, three lines to one hour, so this sequence lasted approximately two and three-quarter hours. Note the periodic short break in the pattern of about two min, typical of the patterned 20-Hz pulse series. The breaks in the pattern do not necessarily coincide with breathing.

The 20-Hz single pulses and 20-Hz pulse patterns have been recorded at sea from ships since 1958, and arrays of hydrophones were used to locate the pulsing whales (our latest opportunity was 11 October 1978, in Cape Cod Bay). In addition, aerial observations were correlated with bottom hydrophone recordings to relate sound sequences with the occurrence of finback whales (as in tests off Halifiax, Nova Scotia 1961; Schevill, Watkins and Backus, 1964). Analyses of long-term records from bottom-mounted hydrophones such as the Bermuda Sofar recordings (1958–1980) have confirmed pattern variations. Comparison of recordings from other bottom systems at a variety of locations have shown the seasonality and geographic distributions of the pulse patterns from finbacks (including our own work off Maine and California; that of Walker, 1963, off Massachusetts; the southern Norwegian Sea by Weston and Black, 1965; New Zealand by Kibblewhite, Denham, and Barnes, 1967; the central Pacific by Northrop, Cummings, and Thompson, 1968; and Northrop, Cummings and Morrison, 1971).

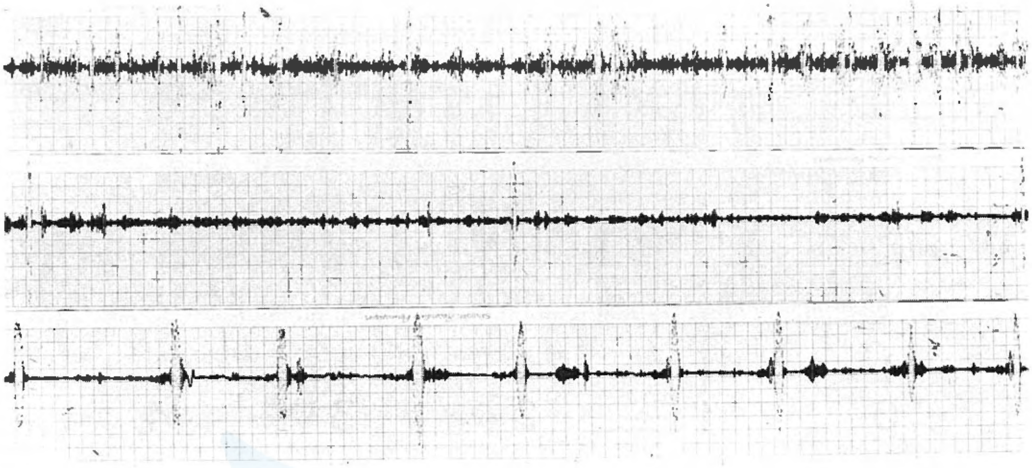

Fig. 10. Three types of 20-Hz pulses are compared in the oscillographs; pulse pattern (top), single pulse (middle), and ragged pulses (bottom). All three were recorded within one hour from the same group of whales on 14 September 1961, north of Race Point, Cape Cod. The regular pattern (top) is at an 8-sec rate within a pair (doublet) of pulses and 10 to 12 sec between pairs. The three " single " pulses (middle) are 39 sec and 37 sec apart. There apparently were several whales producing the ragged pulses (bottom), while the patterned and single pulse series were each from one whale.

Ragged low-frequency pulses also were heard from finbacks. These sounds had a relatively broadband spectrum below 30 Hz, somewhat similar to the low-frequency rumble (below), and they also had narrowband components at particular frequencies, often with 20-Hz emphasis. The pulse durations were variable from short bursts of less than 0.1 sec to defined pulses of about 1 sec. The ragged pulse envelopes were highly variable, with maximum level of the sounds about 40 dB (re 1 dyne/cm^2). Because of similarities in spectra, ragged pulses may be short segments of the " low-frequency rumble ". The ragged pulses appeared to be easily masked by wave noise. These finback pulses are compared in Fig. 10.

The ragged low-frequency pulses were recorded during many encounters with finbacks, but were particularly noticeable in the winter season, often before or after a patterned series of 20 Hz pulses. The ragged pulses were recorded from within 1 m of a finback trapped by low water near Brewster Mass., 27 May 1963 (Schevill, Watkins, and Backus, 1964).

The *low-frequency rumble* is hard to describe because it often was partly masked by local wave noise. The sound was a broadband noise sequence with energies concentrated below 30 Hz, much like the ragged pulses mentioned above. Amplitude peaks in the sound were distributed somewhat randomly throughout the sound (Fig. 11), which lasted from 2 to 8 sec, sometimes longer. The 20-Hz components of the sound sometimes were prominent.

Low frequency rumble sounds have been recorded during many close approaches by finback whales to our ship or our hydrophone cables. The sound was

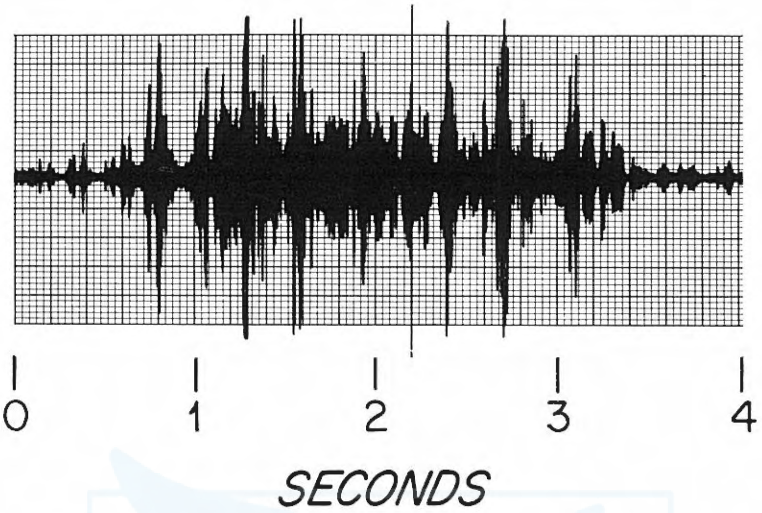

Fig. 11. The low-frequency rumble sound is heard during close approaches by finback whales. The frequency spectrum is mostly below 30 Hz with a very ragged amplitude envelope. The sequence in this oscillograph is about 3.5 sec long, and was made by one whale passing under our boat (as in Fig. 5). This sound was recorded 11 August 1961 and was one of the first rumble sounds that we noticed from finbacks, recorded at 40°27′N, 70°57′W, South of Cape Cod.

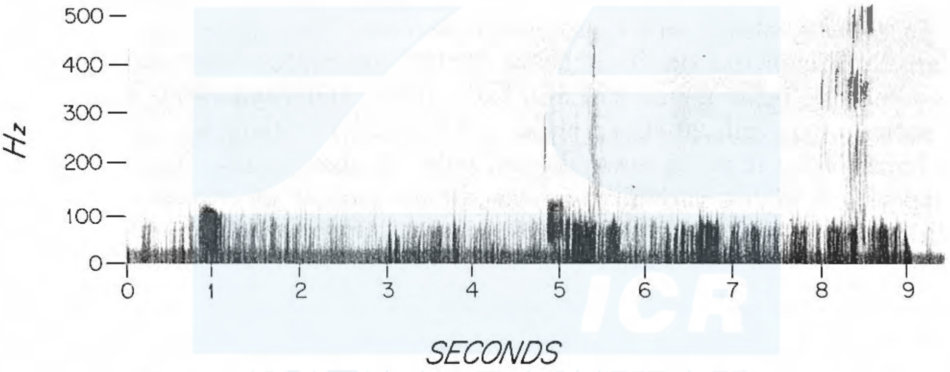

Fig. 12. Non-vocal, broadband, impulsive sounds associated with surface feeding by two finback whales are shown in the middle and to the right of this spectrogram. A " higher frequency " vocalization is seen at the left. The whales were feeding on *Ammodytes americanus* schooled near the surface, and they were recorded 23 May 1980 in Cape Cod Bay. The filter bandwidth of the analysis was 65 Hz.

first noticed during recordings at 40°30′N, 71°W on 11 August 1961, and our most recent recording of a rumble was from a finback that passed 3 m under our boat 12 June 1980 (6 km N. Race Point, Cape Cod).

The sharp *impulsive sounds* heard particularly in connection with some surface feeding behaviors did not appear to have been purposeful vocalizations. The sounds were composed of short broadband pulses with sharp rise-times, energy to at least 10 kHz and exponential decay over the 0.1 sec or less duration of individual pulses. Pulse levels were estimated sometimes as high as 80 dB or above (re 1 dyne/cm^2), but most were less. These and other impulsive sounds from finbacks have been recorded for years, but only recently have we been able to relate the sound sequences (Fig. 12) specifically to surface feeding activities (lastest recordings were June 1980, off Provincetown, Cape Cod).

None of the finback vocalizations was directional; the propagation pattern of all of these underwater sounds appeared to be omnidirectional. In addition, they did not appear to be affected by the depth of the whale producing the sounds or by the size of the whale—the same range of sounds was made by large and small whales. The sounds were not heard at the same time as a blow.

Association of Underwater Sounds with Behavior

The higher frequency sounds apparently were used as signalling between finback whales, and were heard most often during group activity. The sounds from one group were sometimes answered by similar sounds from other finbacks, sometimes at distances estimated up to 5 km. The sounds were produced by whales both at the surface and by whales diving to at least 200 m (from hydrophone array data) with no obvious differences that could be related to depth of the vocalizing whales. The higher frequency sounds were recorded in both daylight and darkness, though our night-time observations have been too limited for good comparisons. The higher frequency sounds were more prevalent in the summer, and were heard particularly when several whales were near each other and participating in long dive routines or surface feeding activities. Individuals were often silent for long periods even during group activity. Few of these higher sounds were heard during other activities, including occasional near-surface social or apparent courtship behavior.

The higher frequency sounds were not heard from whales that were apparently alone, that is, no other finbacks found within a 15 to 20 km radius. None of these sounds were heard from whales feeding by themselves near the surface, or in long dives by themselves. As noted earlier, lone finbacks usually were silent.

Similar correlations also could be made for the single 20-Hz pulses, indicating that they too were used in signalling between whales. Single pulses and short series of 20-Hz pulses apparently were utilized in many of the same situations as were the higher frequency sounds. When we were able to remain with the same group of whales for long periods it was evident that 20-Hz pulses occurred less often than the higher sounds. Like the higher sounds, the 20-Hz pulses sometimes were heard in response to similar pulses from both nearby and distant whales. We noted also that pulses from finbacks could be stimulated occasionally by the sudden introduction of a loud low frequency sound in the water, such as the starting of a ship's engine.

The patterns of repeated 20-Hz pulses were heard mostly in the winter season, and they were produced by only one finback whale in a group. With multiple hydrophones (Fig. 13) the vocalizing whale often could be located, and in every

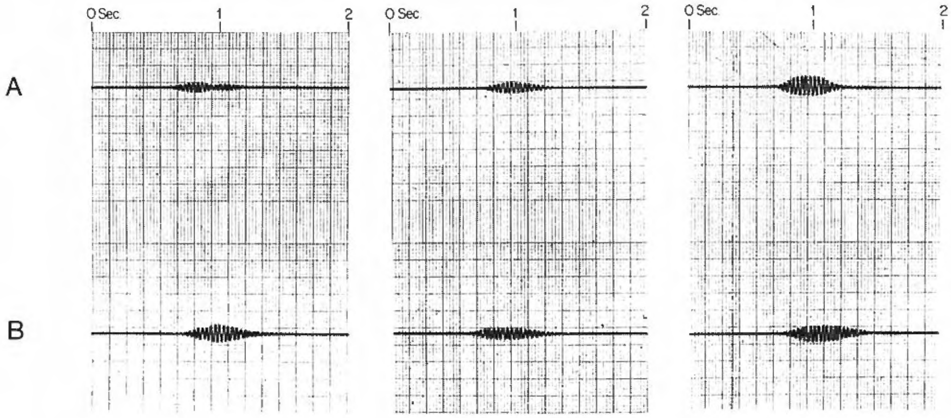

Fig. 13. A sequence of patterned 20-Hz finback whale sounds is shown in these oscillographs. The sounds were recorded on two hydrophones, A and B, separated by about 240 m. The relative position of the whale over a 20-min period is at first off the end of the array beyond hydrophone A (left), and then off the other end beyond hydrophone B (middle), and finally back nearer the first position (right). During analysis, levels were adjusted for approximately equal signal amplitudes from both hydrophones. The 20-Hz pulse pattern was continuous throughout this 20-min recording while the group of four whales appeared to be in a short dive routine. The recording was made 12 September 1961, about 50 km east of Cape Cod.

case, this was not one of the largest whales of the group. When more than one whale in an area was producing the stereotyped pulse patterns, the pulsing whales were always separated by at least 1 km. A pulsing finback was sometimes in a group of whales and sometimes was separated by a few km from other finbacks. Pulsing whales appeared to participate in shallow dive routines with other whales and the sounds continued sometimes throughout blow sequences—although a blow never actually coincided with a 20-Hz pulse. The 20-Hz pulse patterns (sequences of pulse-to-pulse intervals) from all pulsing whales within a local area sometimes were remarkably alike.

Ragged low frequency pulses often with 20-Hz emphasis also were heard from groups of whales, most often during the winter season. None of these pulses were heard from finbacks that were separated by more than a few km from other finbacks. During the winter season, the ragged sounds were heard only when there was no established pulse pattern. Although several whales in a group were heard producing these ragged pulses, the sounds usually stopped when a regular 20-Hz pulse pattern started, with little overlapping of sound types. Thus there appeared to be several sources in a group of whales for the ragged pulses and only one source in a group for the 20-Hz pulse pattern. The whales always appeared to be near the surface when the ragged pulses were heard.

We termed the low-frequency rumble a " proximity burst " on our field tapes because it usually was heard during very close approaches by a finback whale to our silent ship or a drifting hydrophone cable. The rumble appeared to be a response to the whales' unexpected encounter with these objects. The rumble also has been heard when whales passed close to each other. As with the ragged pulses, the whales were always near the surface when these rumble sounds were produced (see Figs 5 and 11).

The impulsive sounds were associated only with near-surface feeding, and when we were close enough, we sometimes saw the bubble-like disturbance break at the surface shortly after the sound occurred. This initial sound with accompanying " bubble " only occurred during very rapid, high exertion maneuvering in connection with feeding on fish schools such as herring (*Clupea harengus*) and occasionally sand lance (*Ammodytes americanus*).

Attribution of Low Frequency Pulsed Sounds to Finbacks

The association of these low frequency underwater sounds with finback whales was by means of a long series of studies. The sounds could not be positively identified with any whales until improved listening capability at low frequencies was developed. The sounds then could be tracked to finback sources, and the behaviors of the whales were monitored for correlation with these vocalizations.

Some of these low-frequency sequences were noted originally on deep hydrophone lowerings (depths to 1,000 m and more) made by Henry Johnson from Woods Hole Oceanographic Institution ships in 1950–51, during geophysical studies, but the sounds were not heard near the surface. We realized later that this was largely because of masking at the same frequencies by local wave noise. Specialized equipment was needed to work with the low frequencies (see Methods section), and experience was required to separate these signals from background noise, so that our data now constitute most of the ship recordings to date of finback sounds.

The 20-Hz sound work began with the attention given by military listening systems to the pulse patterns. The relative precision of pulse repetition, the sine-wave character of the sounds and the long repetitive patterns, all seemed to indicate man-made signals. A wide variety of other possible sources also were suggested (Walker, 1963, 1964; Patterson and Hamilton, 1964). Recordings were made in different localities, and we collected information from experimental bottom-mounted hydrophones operated by other workers. With more sampling, the signals were seen to be less precise and the variability typical of biological systems became more obvious. Efforts to record the sounds from ships at sea were expanded and we began to be successful in hearing the sounds at the surface. Aircraft surveillance of animals in the listening areas was used to identify animal species that were present. The 20-Hz sounds were associated increasingly with the presence of finback whales. The list of these early identifications had six entries, but all linked the sounds with finbacks (Schevill, Watkins, and Backus, 1964, p. 149). To test the correlation, a listening site off Halifax, Nova Scotia was occupied, with continuous aerial observation of the hydrophone area. When the 20-Hz pulses were heard underwater, finback whales were found near the hydrophones. Next, extensive acoustic surveys were made by ship, and the 20-Hz signals were associated only with finbacks, never with other species. Arrays of two and four hydrophones were used to track the 20-Hz pulses underwater, and in each case the tracks led to finback whales. Also, as indicated above, we recorded the ragged sounds having 20-Hz emphasis from a trapped finback barely covered with water (Brewster, Mass., 27 May 1963). In the years since, all of these sounds have continued to correlate only with finbacks.

Useful distances for finback sounds

Because the finback sounds travel well through water over relatively long distances, an understanding of the possible utility of the sounds to the whales required an assessment of the useful intensities and distances for hearing the sounds. Although maximum source levels of the 20-Hz sounds were 80 dB or higher (re 1 dyne cm^2), most of the sounds, including the 20-Hz sounds, were seldom that high, often not more than 40 to 60 dB. There was a wide variability in the level of the same type of calls from the same whale. Finback sounds, therefore, were seldom produced at their loudest. Nearby whales obviously were not " shouting ", and responses from other whales mostly were at relatively low levels. Sometimes successive pulses in a series had 20 to 30 dB level differences. Whales occasionally responded loudly to distant pulses. The levels of the sounds apparently were controlled by the whales.

Most finbacks were observed to be in small groups (2–5), but they occasionally moved about alone. This was true both in the summer and winter seasons. When underwater sounds were heard from finbacks, the whales producing the sounds generally were not far from another finback, usually less than 1 km and within at least 15 km. The need for loud calling, therefore, was not evident, and in fact, the whales seldom produced high level calls, especially in the summer season. In the winter season, the patterns of 20-Hz pulses sometimes were quite loud, although these signals, too, often were produced at relatively low source levels, less than 40 dB (re 1 dyne/cm^2). The proximity of other whales did not seem to relate to the level of the pulse patterns.

The distance at which sounds can be heard underwater is a function of the environment (see texts like Urick, 1967). At sea, within 500 m of the surface, the usual day-time arrangement of temperature layers produces downward bending sound paths. In shallow water, the sound paths are more complicated because of signal interaction with bottom and surface reflections, as well as temperature stratification and tidal currents. Thus, in our experience the distance at which a whale could be heard was as much a function of the environment as of the intensity of their calls. The low frequencies of finback calls generally allowed their reception at greater distance than for other whale sounds, but practical distances for receiving the sounds on hydrophones within 50 m of the surface usually was limited in shallow water to 8 to 10 km, sometimes to as much as 25 km. In deeper water the downward sound paths generally also were limiting, so we often found that our listening limit was 12 to 15 km (demonstrated by locating the vocalizing whale).

These sound-producing whales apparently did not go deeper than about 500 m, because the ranges could have been greater if the whales were deep.

The pulse patterns from finbacks often were heard continuously enough so that the vocalizing whales could be located by acoustic tracking. From more distant, deeper whales, the signals sometimes were not receivable when the whales rose to the surface to breathe, due to the downward bending sound paths. During very stable sea conditions, sound path estimates from bathythermographic measurements could be used to judge distances to vocalizing whales (confirmable by finding the pulsing whales). We were able to track the sources of the 20-Hz pulse patterns sometimes by intensity differences alone—moving our ship in the direction of increasing pulse amplitude. At other times, the levels of sequential pulses in a pattern varied too much for such tracking, but towed hydrophone arrays, usually with only two hydrophones 100 to 300 m apart, could be used to obtain relative bearings to the sound source (ship stopped during listening). Tracking of the winter season pulse patterns consistently led us to vocalizing finbacks.

Day and night differences

Finback activity apparently changed at night. Their diving behavior during daylight has often included dive sequences longer than three or four min (including the dive routines noted above), but the night-time observations have indicated shorter submergence times, few longer than four min. When we were able to get close to these animals at night, they were staying near the surface, and generally were in small groups. Our night-time acoustic observations have been limited since we usually did not know where the whales were during darkness, but there sometimes was an apparent increase in the rate of sound production, both of higher frequency and 20-Hz sounds. If these sounds had a social context, the nocturnal sound increase would be expected as the whales apparently remained in social groups at night. The radio tracking experiments with finbacks as well as with *Megaptera novaeangliae* (Watkins, Johnson and Wartzok, 1978; Watkins, Moore, Wartzok and Johnson, 1981) and on *Balaenoptera edeni* (Watkins, di Sciara, and Moore, 1979) demonstrated generally shorter submergence times during darkness in all of these species.

DISCUSSION

Interpretation of behavior

Our observations of both behavior and underwater sounds present a consistent picture of finback activity. The large number of observations over more than 23 years from many geographic areas in different seasons have provided a general view of the whales' visible activities. The emphasis on long term observation of one local population (Cape Cod) has provided comparative data to balance out the unusual occurrences that could otherwise dominate scattered sampling. Increasing experience, better equipment, and improved techniques have allowed increasingly detailed observations.

Interpretation of the portions of behavior that were observed has required the use of all available observational methods. Certainty of identification of individual whales through radio tagging and tracking over long sequences allowed confidence in our observations. Mixing visual, acoustic, and tracking techniques (radio and hydrophone array) often confirmed interpretations of whale activity.

The differences observed in behaviors, such as the varying blow characteristics and spacing of blows may reflect individual differences and preferences of particular whales. The differences may also have been indicative of other activities, social pressures, levels of exertion, relative health, or previous experience that could not be assessed. The whales' activity at depth probably affected the observable surface behavior which usually centered around respiration.

The shallow dive routines appeared to be a foraging or searching behavior. Whales spread out over several km and often worked back and forth to cover a large area. These whales would be able to alert each other to conditions approrate for feeding, either by vocalizations or by the sounds of their own feeding, especially when the prey was near the surface. It may be significant that the shallow dive routines seemed to be the most common behavior seen in finback whales, and that only a few sounds were heard during this activity, seldom with any response from other whales. This apparently was a search behavior with little vocal communication needed.

The longer dive routines often appeared to be associated with feeding at depth. During the long dives, several whales sometimes dove near each other, and feeding sometimes was indicated by water flowing from partly opened mouths as the whales surfaced, occasionally with throats still enlarged and full. Sea birds were seen sometimes hovering near the surfacing whales and picking up scraps from the water around the whales' mouths. Compared to other behaviors, whales in long dive routines often blew more rapidly and they appeared to be in a hurry to dive again, arching in a high " roundout " as they went down steeply. From an aircraft at such times, finbacks could be seen to stroke hard with their flukes as they dove. All of this seems to correlate the long dives with a deep (not visible from the air) feeding routine. That more vocalizations were heard during this routine may be indicative of several whales close together participating in the same activity. More sounds also were heard when several whales were feeding near each other at the surface. The fact that they were feeding may have been incidental to the occurrence of sounds and the presence of several whales close together may have been the significant ingredient for sound production.

The near-surface slow swimming appears to be a resting behavior, in which whales move slowly a few m below the surface for extended periods. During this behavior we have not heard vocalizations even though there may have been several finback whales together. Because very little of the whale is visible at the surface during this behavior, we may have missed seeing many resting whales. Shifts to such resting sequences from other activities might have been responsible for the occasions in which finback whales seemed suddenly to disappear (noted also in the radio tagged finbacks and humpbacks—Watkins, Moore, Wartzok, and Johnson, 1981).

The surface activity of finbacks does not include much splashing, so that the sounds associated with surface feeding may stand out prominantly. Other whale species often display aerial behaviors such as fluke waving, flipper slapping, lobtailing, and breaching, but finbacks seldom do any of this. Actually, there is little noise produced underwater by the aerial activities of any species, except for lobtailing and flipper slapping, which produce characteristic, recognizable sounds underwater. In our experience, breaching and fluking produce very little underwater sound even at extremely low frequencies. Local wave noise even in relatively calm sea conditions soon masks the loudest breaching sounds from a few hundred m distance.

Interpretation of the underwater sounds

The higher frequency calls seemed to serve as social communication with other finbacks and appeared to be used a little differently from the 20-Hz pulses The higher sounds were heard mostly during interaction of two or more whales, particularly when several whales fed together at the surface and during long dive routines. These sounds perhaps served to alert other whales of the group activity. The fact that the higher frequency finback sounds were never loud would seem to relegate them to communication with nearby whales In contrast, the 20-Hz pulses sometimes were very intense. Individual differences in the rate of the dropping frequency sweep of the calls (both in higher frequency and 20-Hz pulses) provided a means of separating the calls of individuals, which we assume that the whales could also utilize.

The low-frequency rumble often appeared to be a response to surprise, as when a finback passed close (within about a whale length) to a drifting silent ship or floating cable The sound was sometimes accompanied by a sharp turn or a dive to avoid the object. The rumble also has been heard when two finback whales approached each other, so that we have wondered it it could have an agonistic significance as well.

The non-vocal sounds associated with finbacks feeding at the surface were distinctive to that behavior. They did not appear to be produced purposefully, but they were adventitious to that mode of feeding. We have often been alerted by these sounds to the presence of such feeding finbacks, so we assume that the whales also might be alerted by this means.

The vocal sounds of finbacks include wide variations in spectrum and duration of the higher frequency sounds, the single 20-Hz pulses, and the low frequency rumble, but the pulses in the 20-Hz patterns were stereotyped in frequency and duration. All of the vocalizations of finbacks appeared to be controlled voluntarily by the whales, levels varying from " whispers " to " shouts ". This was demonstrated using acoustic location techniques with other cetaceans (Schevill and Watkins, 1966; Watkins and Schevill, 1974; Watkins, 1980) where sound levels varied without changes in the animal's orientation.

The high variability that we and others (Cummings and Thompson, 1977;

Thompson, Winn, and Perkins, 1979; Edds, 1980) have noted in the low frequency finback sounds often may be caused by environmental modification of the sounds. Low-frequency, long wavelength sounds are particularly susceptible to modification in shallow water, when depths are less than a few wavelengths and echo periods allow sound reflections to return within the duration of the sounds. This often is further complicated by multiple sound paths and refraction through distinct temperature layers as well as transmission through bottom material. Therefore, we have avoided detailed descriptions of sounds from shallow water and have based our analyses on deep water observations of nearby whales.

Fundamental frequencies and intervals between pulses were the components of the sounds that were most stable with distance, and therefore probably most important to the whales. Levels varied greatly so that the amplitude modulation, particularly the slighter differences in level, probably were meaningless (also apparently true for sperm whales which emphasized temporal coding, Watkins and Schevill, 1972). In finbacks, the rate of downward sweep in frequency may have been the most important component of the sounds. The sweep rate of one whale was relatively constant, at least for a few hours, and may have provided a means of individual identification. In deep water from nearby whales, the sweep rates often were very precise and repeated in both the higher frequency calls and 20-Hz sounds, as well as the 20-Hz pulse time-patterns.

Single 20-Hz pulses sometimes were used apparently for long distance signalling (up to 25 km). Usually, they were louder (sometimes by 40 dB) than the higher frequency sounds, and we occasionally noted responses from more distant whales. An example of this occurred (9 May 1975, Race Point, Cape Cod) when we were listening near a lone finback that was in a short dive routine near our boat. In the background, we heard five or six barely audible underwater 20-Hz pulses, then the nearby whale responded with two extremely loud 20-Hz pulses and immediately swam away at about 20 km/hr. The whale travelled fast near the surface going toward a group of finbacks identified previously by aircraft 20 to 25 km away. Our boat's speed was 12 km/hr, so we were soon left behind.

Patterned 20-Hz pulses perhaps were used as a reproductive acoustic display. The pulses were heard as established patterns only during the winter reproductive season. The patterns have not been heard from the largest finbacks, which probably are females. In a group of adult whales it was often a slightly smaller whale (therefore possibly a male; Ichihara, 1957; Ohsumi, 1960) that produces the pattern. The 20-Hz pattern may be recognizable at a distance because of the usual regularity of repetition rate of the low frequency signals. In some ways, the finback pulse patterns were similar to the humpback whale " song ", which also appears to serve as a reproductive acoustic display (Payne and McVay, 1971; Winn and Winn, 1978).

Although social and apparent courtship activity involved pairs or groups of whales, it was interesting that few sounds, not even the 20-Hz display patterns, were audible from these whales. In addition, we've not heard sounds that could be attributed to cows and their calves. This is different from our experience with some other whale species in which sounds from cows with calves (humpbacks) were audible and frequent, and groups of socializing whales were vocally active (right whales and humpbacks).

Long ranges unlikely for these sounds

Because of the low frequency and the intensity of at least some of the 20-Hz finback pulses, Payne and Webb (1971) speculated that these sounds could be used for extremely long distance communication, (to several thousands of km), particularly if the whales made use of the deep ocean sound channels (described in Urick, 1967). From our observations of finback behavior, this seems unlikely. The signal would be distorted and lengthened by the many transmission paths of the sound channel over long distances and the sounds would have to be " reconstructed " by the whale to allow recognition of the signal. To use the sound channel effectively, both the whale producing the sounds and the listener would need to be in the sound channel —usually deeper than 1,500 m in the open sea in lower latitudes. This is far deeper than data indicate as normal for finback dives. The utility of such long range communication in these whales does not seem to be evident. Although finbacks occasionally responded to sounds that appeared to be from other whales at distances up to 25 km, most of their responses were to signals from nearby whales. There were few lone finbacks; most were found in groups throughout the year, perhaps lessening the need for long range signalling.

Mechanisms and similarities in sound production

The mechanism of sound production in these whales is not understood. Any sound generating system would have to account for the observed characteristics of these underwater sounds: (1) low-frequency sine-waves, often intense, of one sec or longer duration; (2) sounds that do not change with (pressure) depth; (3) sounds of the same frequency and intensity ranges whether from small or large whales; (4) sounds in which the whale can control level, duration and repetition rate; (5) precise repetition in frequency and time over long periods and throughout a wide variety of activities. There has been a consistent negative correlation of finback vocalization with blowing at the surface, perhaps indicative of the sounds being made with air recycled internally and maybe involving the larynx (Schevill, 1964; Hosakawa, 1950). The similarities in the physical characteristics of the various sounds produced by finback whales suggest a common sound generator although there are two sound categories (narrow and broadband). The different sounds were not heard simultaneously from one finback.

The similarities of sounds from other related species also suggest similar sound generators. Minke whales (*Balaenoptera acutorostrata*) recorded in the waters of the Antarctic, Cape Cod, and the Gulf of St. Lawrence, all produced similar downward sweeping sounds but at higher frequencies, of generally shorter durations and with a wider frequency range (Schevill and Watkins, 1972, and unpublished recordings; Peggy Edds, pers. comm.). The sounds of Bryde's whales (*Balaenoptera edeni*) recorded by Cummings and Thompson (1977), and blue whale sounds (*Balaenoptera* *musculus*) reported by Cummings and Thompson (1971),—all are low-frequency (12 to 150 Hz), sine-waves with little harmonic energy, and often very loud. Our attribution of sounds to sei whales (*Balaenoptera borealis*) is still uncertain since our recordings in the presence of these whales have also included sounds from other *Balaenoptera* species. Patterned sounds similar to those of finbacks have not yet been found in these other species.

Finback whales that have produced sounds within range of our underwater listening systems consistently have produced the sine-wave and restricted bandwidth pulses at low frequencies. Although we have had long experience in listening to the various species of *Balaenoptera*, we have not heard the reported high frequency sounds (*B. physalus*, Perkins, 1966) or the broadband pulses and click-like sounds (*B. acutorostrata*, Beamish and Mitchell, 1973; Winn and Perkins, 1976; *B. musculus*, Beamish and Mitchell, 1971).

SUMMARY

Our observations to date have provided a fragmented though consistent picture of finback underwater acoustic behavior. These distinctive sounds appeared to be communicative. The higher frequency sounds seemed to be used primarily in signalling nearby whales—particularly during activities such as surface feeding and deep dive routines when several whales were together. Single 20-Hz pulses sometimes seemed to be used in longer distance (" shouting ") to whales that were farther away. The repetitive patterns of 20-Hz pulses were seasonal and perhaps were a courtship or reproductive acoustic display. The ragged low-frequency pulses have not been as clearly defined because of the difficulties in distinguishing these from background noise. The longer low-frequency rumble sounds were associated with surprise and perhaps agonistic responses. Surface feeding sounds were characteristic of that activity, although these sounds apparently were adventitious and not vocal.

The behaviors noted here were chosen because they had visible components and were repeated often enough to be identifiable. No specific underwater sounds were found to be characteristic of these behaviors, but instead, the vocalizations appeared to be related to interaction between whales during some of these activities, particularly during the long dive routines and surface feeding, and occasionally during short dive routines. The whales usually were silent during other behaviors: blowing, near-surface slow swimming, fast travel.

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A PYGMY SPERM WHALE STRANDED AT TOKAIMURA, IBARAGI, JAPAN

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It was informed that on 29 September 1979 a pygmy sperm whale was found stranded on beach of Tokaimura, Ibaragi. One of the authors (Y.T.) went there on 2 October 1979 and confirmed that the whale was a young male *Kogia*. The body of the whale was already half-decomposed, but she made measurements of body proportions (Table 1) and brought back the head of that whale for precise identification of the species. The skull of the whale was obtained by boiling the head at WRI and the species was identified as *Kogia breviceps*, based upon the key characters of Handley (1966).

For long years most workers accepted that there was a single but variable species in the genus *Kogia*, while as many as seven species have been described. Following works by Ogawa (1936–37) and Yamada (1954), Handley (1966) established that there are two well-defined species, the pygmy sperm whale *Kogia breviceps* Blainville, 1838 and the dwarf sperm whale, *Kogia simus* Owen, 1866.

Recently Ross (1979) made extensive study of pygmy and dwarf sperm whales, using at least 80 animals recorded on the southern African coast up to the end of 1975. He compared the material of *K. breviceps* and *K. simus* and confirmed Handley's (1966) distinction of the two species based on cranial and external characters, with the exception of the relative height of the foramen magnum and the position of the dorsal fin relative to body length, which should be used with caution in specific identification.

Handley (1966) listed up distinguishing characteristics of *Kogia breviceps* and *K. simus* in his Table 1. The majority of these differences refer to features of the cranium and mandible. According to Ross (1979) the most distinctive cranial characters are the shape of the dorsal sagittal septum near the vertex and the dorsal cranial fossae. In *K. breviceps* the sagittal septum near the vertex is broad, whereas in *K. simus* it is narrow. The shape of the dorsal cranial fossae of the two species is different in that that in *K. breviceps* the left fossa is conspicuously narrower than the right, and each fossa slopes gradually from the dorsal rim of the skull. In *K. simus* dorsal rim of the cranial fossae is sub-spherical, and the posterior wall of each fossa is steep, giving a cupped appearance to the skull.

In the characters listed above the Tokaimura specimen (Figs 1–4) agrees well to those of *K. breviceps*. In the mandible Handley (1966) noted the number of mandibular teeth, 12–16 pairs in *K. breviceps* and 8–11 pairs in *K. simus*. He noted, however, in rare case 10 or 11 pairs in the former and 13 pairs in the latter. The length of mandibular symphysis is longer in *K. breviceps* than in *K. simus*.

The Tokaimura specimen had 24 teeth in all and this was estimated that

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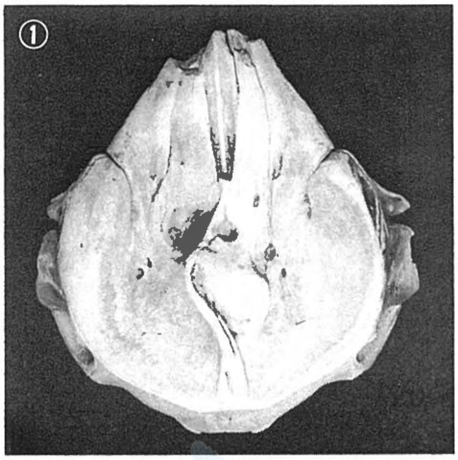

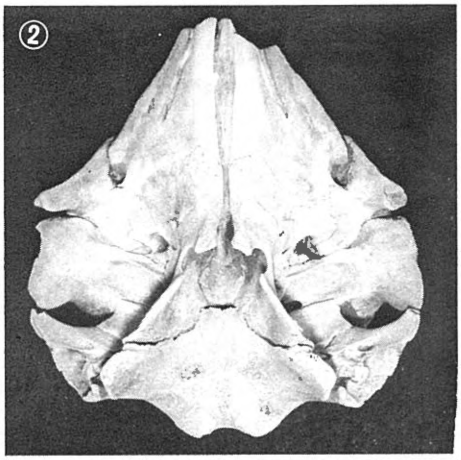

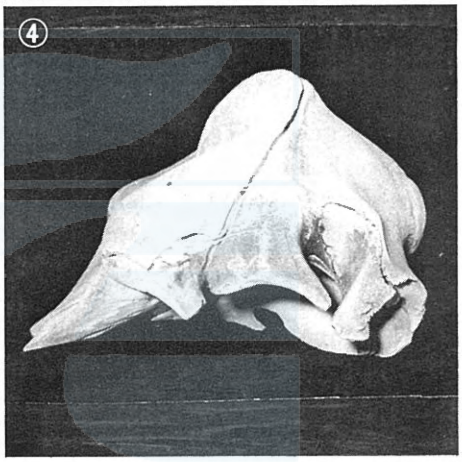

Fig. 1. The skull of the Tokaimura specimen of *Kogia breviceps*. Dorsal view.
Fig. 2. The same skull. Ventral View.
Fig. 3. The same skull. Posterior view.
Fig. 4. The same skull. Lateral view.

originally it had 13 pairs and 2 were missed, judged from the shape of the teeth. One is very small and curved greatly (straight length 9 mm). This agrees with the character of *K. breviceps*. The mandibles of the Tokaimura specimen were broken into small pieces and we can not measure the length of the symphysis. No maxillary tooth was found.

Measurements of the skull of the Tokaimura specimen are shown in Table 2. In this table the measurement numbers are the same to those used by Ross (1979). As seen in this table 20 mm was added for breakage. This figure was carefully decided, but in any case this is an estimate. The result was compared with Table 26 of Ross (1979) and found no special feature. Most of them are within the ranges of his value. Measurements no. 3 (Rostrum, basal width) and no. 12 (Height of ventral border of foramen magnum) are outside his ranges, but very

TABLE 1. BODY PROPORTION OF THE TOKAIMURA SPECIMEN OF *KOGIA BREVICEPS*

	Measurements	in mm	% of Total length
1.	Tip of snout to notch of flukes (Total length)	2,480	100
2.	Tip of snout to center of eye	270	10.9
3.	Tip of snout to blowhole	240	9.7
4.	Tip of snout to ant. insertion of flipper	430	17.3
5.	Tip of snout to ant. insertion of dorsal fin	1,370	55.2
6.	Tip of snout to tip of dorsal fin	1,515	61.1
7.	Length of gape	66	2.7
8.	Length of blowhole	40	1.6
9.	Length of eye	42	1.7
10.	Notch of flukes to umbilicus	1,570	63.3
11.	Notch of flukes to genital slit (male)	1,455	58.7
12.	Notch of flukes to anus	685	27.6
13.	Girth on transverse plane at ant. insertion of dorsal fin	1,960	79.0
14.	Girth on transverse plane at anus	980	39.5
15.	Length flipper, ant. insertion to tip	325	13.1
16.	Length flipper, axilla to tip	260	10.5
17.	Height, dorsal fin	83	3.3
18.	Length, dorsal fin	165	6.7
19.	Width of flukes, tip to tip	580	23.4
20.	Anterior border of flukes to notch	170	6.9
21.	Anterior border of flukes to tip	400	16.1

TABLE 2. CRANIAL MEASUREMENTS OF THE TOKAIMURA SPECIMEN OF *KOGIA BREVICEPS*

	Measurements	in mm	% of Total length
1.	Total (condylobasal) length*	337	100
2.	Rostrum, length**	126	37.4
3.	Rostrum basal width**	158	46.9
4.	Rostrum, width at its middle**	113	33.5
5.	Breadth across pre-orbital angles of supra-orbital processes	277	82.2
6.	Breadth across post-orbital processes	288	85.5
7.	Zygomatic width	278	82.5
8.	Height to vertex	217	64.4
9.	Width of vertex	25	7.4
10.	Width of supra-occipital at narrowest part between posterior margins of temporal fossae	197	58.5
11.	Tip rostrum-left naris	163	48.4
12.	Height of ventral border of foramen magnum	75	22.3
13.	Length maxillary toothgroove-right	64+	
14.	Length maxillary toothgroove-left	52+	
15.	Width outer margins occipital condyles	78	23.1
16.	Tip rostrum-hind margin pterygoids	181	53.7
⋮			
24.	Height dorsal border of foramen magnum to vertex	105	31.2

* 20 mm added for breakage.

** Measured ventrally.

close to his upper ranges.

The cranial measurements of *Kogia*, however, subject to wide ranges of individual variation, judged from figures in Tables 26 and 27 of Ross (1979), and it seems very difficult to separate both species from cranial measurements alone. In some cases, however, condylobasal length of the skull may useful. Handley (1966) gives condylobasal length of adult specimens of *K. breviceps* and *K. simus* as 391–469 mm and 262–302 mm respectively. The condylobasal length of the Tokaimura specimen was estimated 337 mm as shown in Table 2. This length is much larger than those of *K. simus*, but still this whale was judged to be immature and bones of skull are fused loosely. The largest tooth measures 19 mm in length and pulp cavity is not closed. In *K. breviceps*, however, the pulp cavity appears to remain open at the base of tooth throughout life (Ross, 1979).

Body proportion or external measurements of the Tokaimura specimen of *K. breviceps* (Table 1) are compared to Table 3 of Ross (1979) and found slight differences between those, but we can not conclude anything at this moment and further collection of material is needed. According to Table 3 of Ross (1979) no distinct difference was observed between *K. breviceps* and *K. simus*, excepting the height of dorsal fin. This value is 2.3–4.7% of total body length in *K. breviceps* (12 specimens) and 5.4–10.0% in *K. simus* (19 specimens), the latter species having quite taller dorsal fin than the former. This height of dorsal fin of the Tokaimura specimen is 3.3% of the body length and this value is within the ranges of those of *K. breviceps* (Table 1).

Yamada (1954) gives measurements of body proportions of his specimen nos 3, 4, 5 and 6. Among them total length was not measured in nos 5 and 6. We calculated, therefore, percentage figures of the height of the dorsal fin against total body length for his specimen nos 3 and 4, and got the value of 6.7 and 5.9% respectively. These are all within the ranges for *K. simus*.

Further he presents cranial photographs of the specimen nos 1, 2, 4, 5 and 6. Judged from these photographs we assumed that his no. 4 specimen is *K. simus*, being the sagittal septum near the vertex is very narrow and the cranial fossae giving a cupped appearance of the skull.

In this way we can further assume that his specimen no. 1 is probably *K. simus* and nos 2, 5 and 6 to be *K. breviceps*. This can be checked by the length of mandibular symphysis. According to Ross (1979) this length is 13.7–26.3% of the skull length in *K. breviceps*, whereas the corresponding figures in *K. simus* is 11.1–15.8%. We calculated this value for nos 1, 2, 4, 5 and 6 from his Table 3. These are 12.3, 15.2, 11.1, 15.8 and 15.2% of their skull length respectively. Our conclusion is, therefore, Yamada's specimen nos 1, 3 and 4 are probably assigned to *K. simus* and nos 2, 5 and 6 to *K. breviceps*.

From the coast of Japan *Kogia* was first reported by Van Beneden and Gervais (1868–1879). The species of this *Kogia* (du Japon) is judged to be *K. breviceps* from drawings shown in PL. LXI of their report. The left dorsal cranial fossa is much narrower than the right and the posterior wall of each fossa seems to slope gradually from the dorsal rim of the skull. The condylobasal length of the skull is estimated to be 342 mm (measured length from the drawing was multiplied by 3). Width of the vertex was estimated as wide as 18 mm and this is 5.3% of the total length. This value is smaller than that of the Tokaimura specimen (Table 2), but still within the ranges of values given by Ross (1979), or 5.0–11.9% in 22 specimens. Further right mandible has 13 teeth and no maxillary tooth present.

Honda (1928) reported a *Kogia* was stranded on the coast of Tsudanuma, Chiba, on 1 October 1927. This whale had 13 pairs of teeth on mandibles. No maxillary tooth present. Sex was determined as male and he gives general description, external as well as internal, of the whale body. He collected skull and other bones of this whale. The skull was studied later by Ogawa (1936–37) and it is possible that the species is *K. breviceps.*

Hirasaka (1936) reported stranding of a *Cogia* (*Kogia*) *breviceps* at Ishigakijima, Okinawa, on 8 March 1935. He gives a photograph of this whale and reports that the body length was said as 8 shaku (2.4 m), and no further information available. From the photograph shown in his paper it is true that the animal belongs to the genus *Kogia,* but the species can not be identified from this photograph alone.

Hirasaka (1937), however, obtained skull and post-cranial bones of this whale later and identified the species as *Kogia breviceps.* According to him, however, he perceived several characters similar to those of the *simus*-type but there are some others that contradict them, showing the general characteristics of the *breviceps.* His opinion was that the younger individual with a skull of under 300 mm (skull length of his speciemen is 290.5 mm) gradually change to a general type (of *breviceps*) after accomplishing a certain period of growth.

He gives, however, photographs of the skull of his *Kogia.* Judged from these photographs we consider this whale would be a *Kogia simus.* The dorsal rim of the cranial fossae is sub-spherical and the posterior wall of each fossa seems steep, giving a cupped appearance. The dorsal sagittal septum near the vertex is not broad. The number of alveoli in each mandible is 9 and the length of symphysis is 14.8% of the skull length.

Ogawa (1936—1937) studied five skulls and other bones, including those obtained by Honda (1928). He recognized both *K. breviceps* and *K. simus* occur on the coast of Japan. He thought that his specimen nos 2, 3 and 4 whales are *K. breviceps* and nos 1 and 5 whales are *K. simus.* These are supported by his description and photographs in his paper. He was also of opinion that the *Kogia* (du Japon) reported by Van Beneden and Gervais (1868–1879) should be assigned to *K. breviceps.*

Yamada (1954) studied six specimens of *Kogia* taken at Taiji, Wakayama and measured external as well as cranial proportions. His specimens are smaller in length in general and the condylobasal length ranged 276–302 mm. The highest number of teeth on one mandible is eleven and others are 8–10. Maxillary tooth is common in all specimens. His report was preliminary and no definite conclusion was stated as to the distinction between *K. breviceps* and *K. simus.* He stressed, however, a strong opposition against the dominant opinion of recent (then) time that the younger animals of initial resemblance with *K. simus* turn into the general type of *K. breviceps* as they grow. Then his paper was followed by Handley (1966) as stated before. We also commented Yamada's paper (1954) in some extent as stated already. In this case, however, the number of teeth was not a good criterion in separating the two species.

Since then no scientific paper on the genus *Kogia* has been appeared in Japan to our knowledge.

Our sincere thanks are due to Dr A. Okata and his staff of the Ibaragi Prefectural Fisheries Experimental Station. They kindly informed us the stranding of this whale and gave us great help in measuring the body proportions and sampling of the head of this whale for study of the skull.

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SOME ANOMALOUS DISPOSITIONS OF THE JACOBSON'S ORGAN IN THE FIN WHALE

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Since the begining of the current research program at the Spanish whaling factories in 1977, nearly three hundred fin whales have been studied and the Jacobson's organ has been examined in each case because it was included in a program to collect certain basic measurements.

During the 1979 season in the whale factory of Canelinas (La Coruna, Spain) anomalous dispositions of the Stenson's orifices were observed in two occasions. As similar abnormalities in cetaceans have not been reported to our knowledge, we thought it would be interesting to describe them here.

The first observation refers to an adult male of 18.10 m long (no: Z. 79/18). In this whale, while the right orifice presented a completely normal situation the left was situated in the bottom of a fold located among the frontal baleen plates (Fig. 1).

The other whale observed was an adult male of 19 m long (no: Z. 79/24). Stenson's orifices were in the normal situation but they were duplicated and four orifices present in total. Their size was smaller (210 mm) than in other whales of similar body size (360 mm).

We could not observe any other anatomical abnormalities in these two whales. Both animals appeared to be completely healthy.

Although it is usually believed that Stenson's orifices in cetaceans are only a

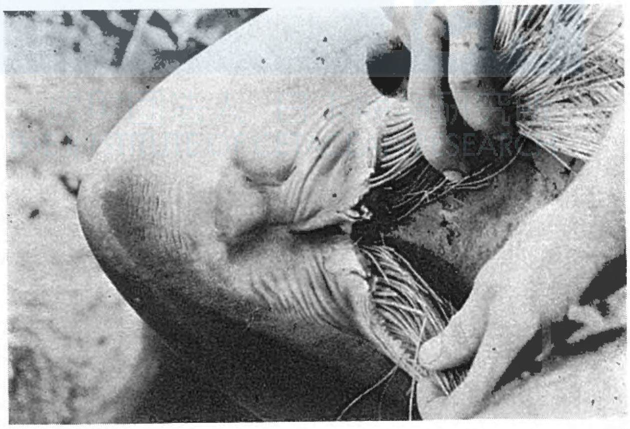

Fig. 1. Tip of the upper jaw of the fin whale (no. Z. 79/18) showing the fold where the left Stenson's duct was allocated.

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vestige of a primitively more developed organ and they seem to have no function at all, but it doesn't appear that this was completely ascertained. For this reason it is impossible to say to what extent these abnormalities affect the normal life of the whales. The blubber thickness measured on the middle point of the animal's body length, at dorsal, lateral and ventral sides were 8, 6.5 and 6 cm in the first specimen and 13.5, 7 and 8 cm in the second respectively; the mean weight of the testis was 8.6 kg and 14 kg respectively. All these values, as well as a series of morphometrical results, were within the normal limits -applying the signification tests- obtained from other whales in the same season.

In conclusion, it is thought that the above mentioned abnormal dispositions of the Jacobson's organ can hardly affect the feeding and hence growth of the animals.

The authors would like to acknowledge the kind collaboration of the staff and personnel of I.B.S.A.

FIRST CASE OF DICEPHALY IN ODONTOCETI

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It is well known that many types of teratological specimens have been found among mammals including man. However, there are few reports of such cases in Cetacea. Kawamura (1969) describes Siamese twins in the sei whale (*Balaenoptera borealis*). These were male bodies measuring 114 and 137 cm in length respectively. They were considered a typical morphological example of complete ventral fusion from the throat to a point just anterior to the navel. There was one umbilical cord only, the fusion between both taking place along their posterior margins. Zemsky and Budylenko (1970) reported an almost identical case of twin female foetuses in the humpback whale (*Megaptera novaeangliae*) with body-lengths 124 and 120 cm respectively.

A double monster of the striped dolphin (*Stenella coeruleoalba*) has been observed by Kawamura and Kashita (1971). That was a malformed embryo with two body-lengths 16.8 and 17.2 cm along a rostro-caudal axis. Kamiya and Miyazaki (1974) also described the early developmental stage in a *Stenella* embryo 9 mm long cranio-caudally, affected with several malformations.

In this note, we wish to report the first known case of *duplicitas anterior* in Odontoceti. The specimen was collected off the Pacific coast of Japan's Kii Peninsula (33°36′N, 135°56′E) on December 14, 1979. It consists of a teratological female foetus taken from the left uterus of a *Stenella coeruleoalba*. The mother's body-length was 221 cm. Its age, as determined from the count of both dentinal and cemental growth, was estimated to be about 14.5 years. There was one corporus luteum and three corpora albicantia in the left ovary and no corpora in the right one, which indicates a yound mother. Pictures of the monster are herewith presented and the following comments can be made.

1) The specimen shows a rostral duplication that affects the front portion of the head. Fusion begins dorsally at the blow-hole level and ends immediately behind the throat. The vertebral column is strongly curved cranio-caudally in a C-shaped line. The cranio-caudal body-length is 85.7 cm on the left side, 85.8 cm on the right side. The total body-weight is 7.0 Kg. 2) In the two well separated beaks, the mandible of the right one lacks a symphysis and its two rami cross near their tips. 3) There is a single brain-case with one brain. No skull cap was formed and therefore only a small and malformed brain mass is protruding on the surface of the head (encephalocoele). The brain-weight is 30 g, which is very light if compared with that of a normal foetus brain at the same stage about

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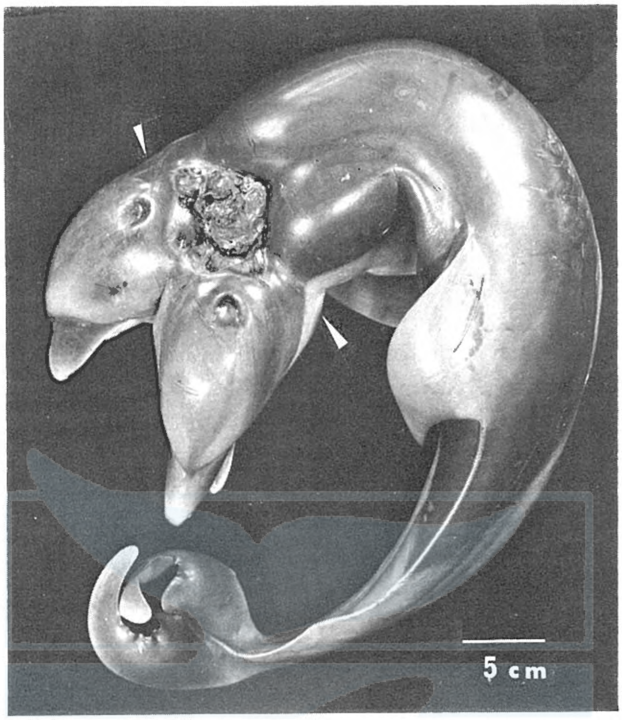

Fig. 1. Dorsal view of the striped dolphin dicephalic foetus. Note the two well-separated beaks and the encephalocoele immediately behind the blow-hole. White arrows show the positions of the eyes on the lateral facies.

250 g. On the abnormal hemispherical surface of the brain, one can see some gyri (Fig. 1). 4) An eye can be seen on the lateral side of each head just behind the oral angle. After dissection along the medial line of fusion, we found two other eye-balls embedded on each head. All those eye-balls show an almost normal size. The specimen thus has four eyes. 5) Fig. 2 shows a dorsal X-ray photograph in which one can see a petrous bone in normal position on each side, paired nasal bones, maxillar bones, one foramen magnum, etc. but no skull-cap as already mentioned. Tooth formation in the upper and lower jaws was progressing well. 6) Other parts of the external structures show no conspicuous differences from a normal foetus in either shape or size. For example, there are a pair of flippers, a tail and an umbilical cord on the abdomen, etc. 7) The visceral organs in the thoraco-abdominal cavities show an almost normal organ formation in comparison with the same stage of a normal foetus, except for some irregular shapes caused by the pressure of the curved vertebral column. In each oral cavity, one finds an abnormal small tongue-like muscular mass.

This teratological specimen can thus be characterized as a dicephaly, diprosopy and tetraophthalmy case in the dolphin. The specimen has not yet been finely dissected. The anatomical details of its internal organs, currently under investigation, will be reported elsewhere in a journal for morphological research.

Fig. 2. An X-ray photograph taken in dorso-ventral direction. Arrows show the petrous bones. It can be noted that the skull-cap is unformed.

We wish sincere thanks to Prof. P. Pirlot, Université de Montréal, for critical reading of the manuscript.

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A THIRTY FOUR YEARS OLD MALE KURIL SEAL FROM SHIRETOKO PEN., HOKKAIDO

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The Kuril seal (*Phoca kurilensis* INUKAI, 1942) is distributed from northern Kuril Islands to the Pacific coast of eastern Hokkaido. The population in the Kuril Is. is estimated at under 2,000–2,500 including those in the Shikotan and Habomai Is. (Belkin, 1964). The Japanese population is limited to nine hauling grounds in the above range, and the number is estimated at 200–250 individuals (Niizuma et al., 1980; Fig. 1). The presence of the species along the Okhotsk coast of Hokkaido is not confirmed at the present.

The present material was shot by Mr. H. Ohki, an expert seal hunter, in the Spring of 1980 on the coast of Kuzurehama at Shiretoko Pen. (Fig. 1). He identified the species by its black coat marked with white ring spots and its large body size. The sex was not recorded by him. The skull was brought to us for detailed analysis, and registered as Protocol Number 1351 of Department of Anatomy, Faculty of Dentistry, Hokkaido University.

The skull shows some of the features of *P. kurilensis* mentioned by Belkin et al. (1969); that is, as compared with harbour seal (*P. vitulina larga*), the posterior margin of the zygomatic bone makes a corner, the inferior surface of the tympanica is flat and the proboscis is massive (plate I). The skull measurements are as follows; condylobasal length 232 mm; zygomatic width 152 mm; mandibular length 161 mm. The condylobasal length of the present specimen is larger than the maximum size (227 mm) of *P. v. larga* reported by Belkin et al. (1969), and come within the range of male *P kurilensis* 226–248 mm. According to the data of Belkin (1964), the range of zygomatic width of the female *P. kurilensis* is 122.4–145 mm and that of the male is 134.5–158.7, and the mandibular length of the female is 141.6–160.2 and the male is 149.2–174.8. All the above measurements on the present specimen exceed the range of the female and come in the range of the male. This strongly suggest the specimen may belong to a male rather than a female.

The preparation of tooth slides for age determination was done as follows. At first step, several longitudinal sections of about 40 μ in thickness were taken from the root of a canine tooth using a fine saw with diamond wafering blades (Kosaka Loboratory Ltd, C1–1). Then, they were decalcified with plank-Rychlo's solution (Plank and Rycholol 1952) for 10–15 min. at room temperature, and stained with Delafield's haematoxylin for 1–30 min. Finally they were mounted with Canadian balsam for permanent preparations.

There were observed 34 stainable layers in the cementum. And the age of the animal was considered to be 34 years old (Plate I). The age determination by Naito and Nishiwaki (1972) on the un-decalcified thin sections of 49 males and

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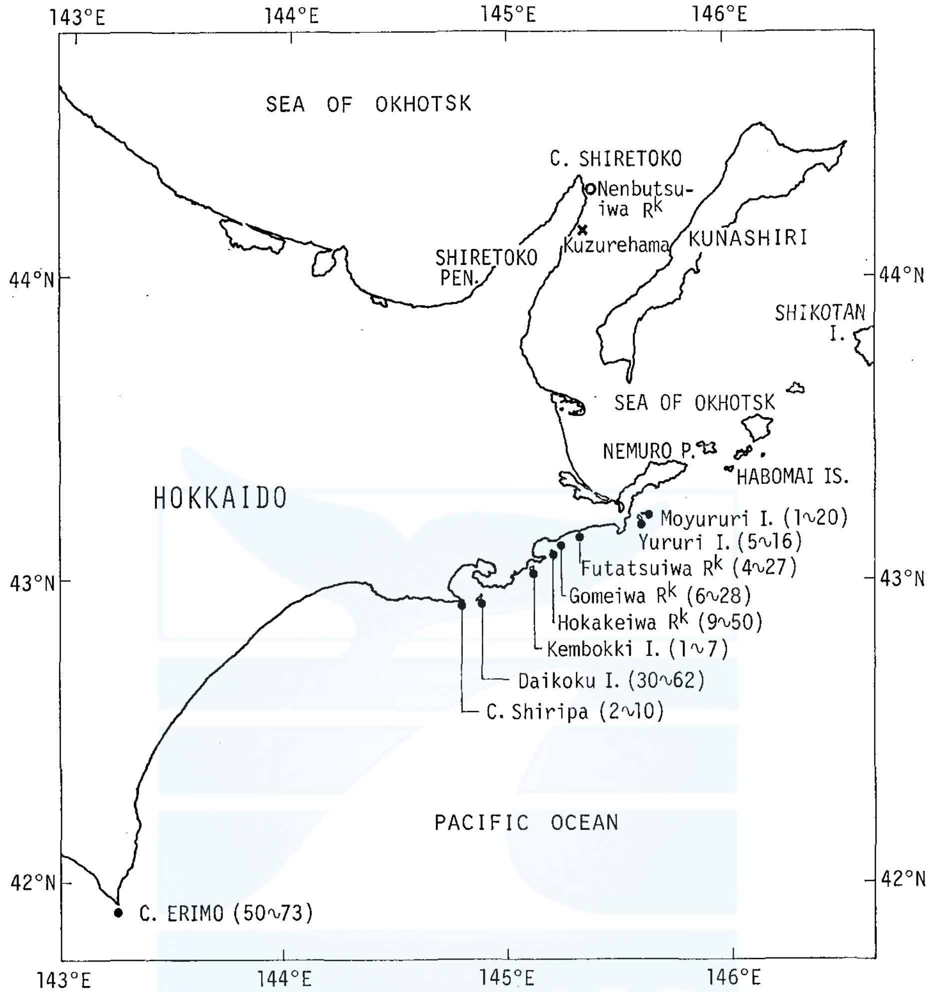

Fig. 1. Geographical distribution of the nine hauling grounds (●) of *P. kurilensis* along the coast of eastern Hokkaido, Japan. Numbers show the result of censuses taken by the Marine Mamm. Res. Group in the middle of June during the years 1974–1981 (From Niizuma et al., 1980 and unpublished data). × indicates the location of present material.

57 females of the same species revealed that 98% of the males were under 10 years and 95% of the females under 18 years, and that the maximum ages of the males and females were 18 and 24 years respectively. According to Naito and Konno (1979), the maximum age of the *P. v. larga* obtained by the same method was 30 years in males and 33 years in females, and the corresponding figures also obtained by the same method (Y. Naito pers. comm.) of the ribbon seal (*P. fasciata*) was 26 years and 21 years respectively. In the subgenus *Pusa* animals of over 40 years have been found by the stained sections and the group is considered to be the most

longevous among the Pinnipedia (Helle, 1980). From the condition on the heavily worn teeth of the present individual (Plate I), the age of 34 years is considered to be close to the maximum age of the species in natural environment, as shown the maximum ecological longevity by Ohtaishi (1978) of this species.

It is thought that the present individual of *P. kurilensis* might be originated from the southern Kuril Is. However, it is also possible to regard it as a survivor of a breeding colony previously existed on the Shiretoko Pen. According to Mr. I. Nedefuji, an old seal hunter, *P. kurilensis* had bred untill about 1959 on the cliffy coast between Kuzurehama and Nenbutsuiwa Rock on the east coast of the Shiretoko Pen. Since the male *P. kurilensis* tends to remain at its birth hauling ground almost around the year (Marine Mammal Research Group, 1978), the latter consideration may be more plausible.

We wish to express our deepest appreciation to Mr. H. Ohki for providing us with the materials, Mr. N. Hachiya of our laboratory, and the members of the Survey Group of the Vertebrate Community, Shiretoko Peninsula and the Marine Mammal Research Group for their help and kind advice.

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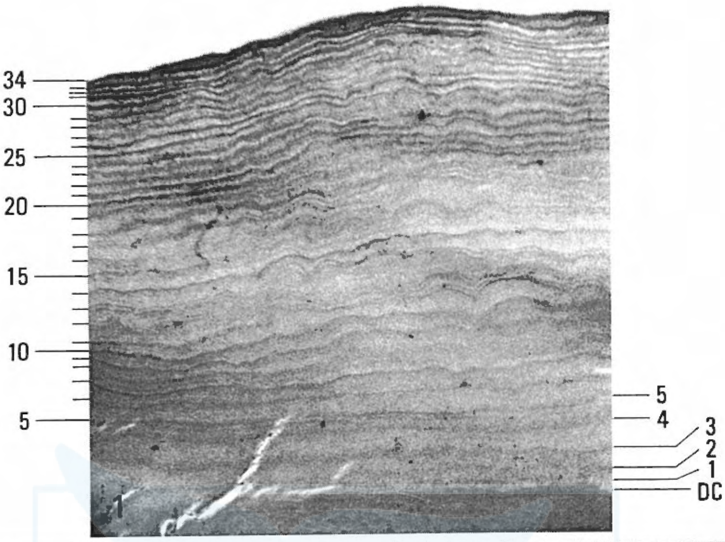
EXPLANATION OF PLATE

PLATE I

Fig. 1. Cementum of the canine teeth. DC shows dentino-cemental junction; the numbers show the age of each layer. Hematoxylin stain. ×22

Fig. 2. Lateral view of skull. Posterior margin of zygomatic bone makes a corner, the inferior surface of tympanica is flat and the proboscis is massive.

Fig. 3. Dorsal view of skull and mandible. The teeth are heavily worn.



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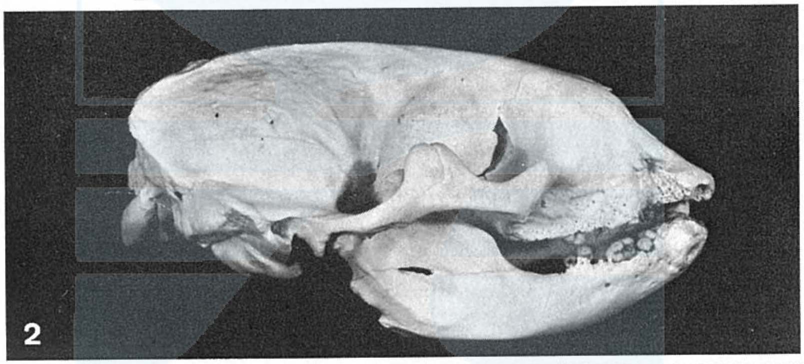

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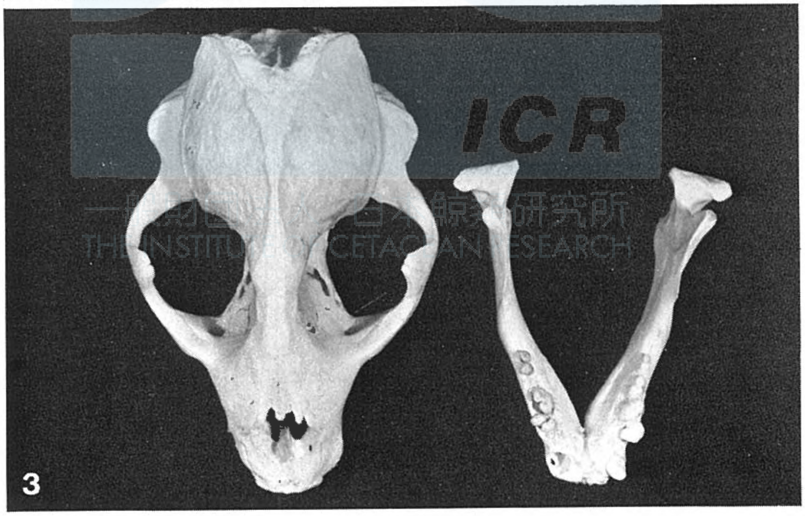

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