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THE INSTITUTE OF CETACEAN RESEARCH

# PRELIMINARY REPORT ON THE GEOGRAPHICAL DISTRIBUTION OF THE BRYDE'S WHALE IN THE NORTH PACIFIC WITH SPECIAL REFERENCE TO THE STRUCTURE OF FILTERING APPARATUS

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## ABSTRACT

Some external characters of the Bryde's whales caught during the summer of 1975 in the waters off Sanriku, northwest Pacific were studied. Although no prominent external characters which may suggest an intraspecific variation in distinguishing the differenciation of possible races were found among the fourteen animals examined, one animal, Sy7518 (12.5 m, male, see Table 6 and Appendix III) showed considerably distinct characters which make the animal be distinguished clearly from the others. It is, however, still obscure whether or not the animal could be said as allopatric forms since no reproductive conditions were examined. It was suggested that one of the most important external characters should be examined for the North Pacific Bryde's whale was the overall morphological characters for the filtering apparatus such as the length of baleen series, whole shape of the apparatus, nature of bristles and the filter area. There found at least two types of Bryde's whales in the regions concerned: the first one is quite less in the number of ventral grooves, lower but broad based in dorsal fin, very coarse and considerably small in its filter area. All of these suggests its closer character to the Bryde's whale proper whereas the second one is almost opposite character to the former in may respects with some intermediate varieties and showed somewhat similarity to sei whale. There seems two more possible populations in the North Pacific Bryde's whales: the first one is largely found in the pelagic waters of the North Pacific, and the other is in the waters off west coast of Kyushu. A possible invasion of the former population into Sanriku, Northwest Pacific is suggested.

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## INTRODUCTION

The North Pacific Bryde's whale is one of two mysticete species to be caught currently by Japanese whaling both in pelagic and coastal waters, and provides an important components among the total catches. Although its taxonomical problem against sei whale in the North Pacific region seems to have been settled by establishing the species which occurs and predominates widely over the warmer waters in the Pacific region (e.g. Omura, 1966a; 1974), little has been studied concerning to its general biological characteristics including the diagnosis for the subspecies or the races. A considerable variations in external appearance for the North Pacific Bryde's whales such as the case known in the South African population (Best, 1970; 1974) have been noticed through the previous studies (Omura *et al.*, 1932; Omura and Fujino, 1954; Omura, 1959, 1962), but the matter was left behind from the further consideration. One of such problem may be found in the intraspecific and morphological variations by occurring localities over the world oceans in large and/or small scale, and the variations are, to some extent, possibly related to the difference by local populations or stocks. It is, therefore, the current problem to elucidate whether any racial defference or allomorphological forms could be found in the North Pacific Bryde's whale. Althouh it has been noticed that there must be some differences in the character of baleen plates taken from the Bryde's whales caught in the North Pacific region, little attention was paid for this matter until we got the knowledge from the South African waters. More recently, however, Masaki (1975) compared the baleen plates of North Pacific Bryde's whales with a hope to distinguish their local populations by examining width-length ratio and some morphology for the bulk of baleen plates collected at many localities over the North Pacific regions along with the recovery data of tagged whales. Masaki (1975) considered that there must be at least two possible subpopulations of Bryde's whales in the North Pacific: the first one is restricted in the waters west of 150°E longitude, while the second one is found in the pelagic region lies between 160°E and 160°W longitudes. However, as far as the figures given by Masaki (1975) are concerned, there seems some difference in the pelagic population which could be separated each other somewhere between 170°E and 180° longitutdes. Under these circumstances, the main purpose of our study was to know and, if it was present, was to find out some critical and well representing external characters showing an intraspecific variation by which the racial difference of Bryde's whale population might be suggested. In the course of examining Bryde's whales at the landstations both in Ayukawa and in Onagawa, northern Japan, we noticed that there were some intraspecific differences in the general structure and the nature of filtering apparatus for the Bryde's whales although the present result should be considered still tentative due to so small number of animals observed. The result is presented briefly in this report along with some considerations.

## MATERIAL AND METHOD

During 24 July to 3 August 1975 following number of whales were caught and examined in Sanriku region:

| Land Stn. | Company | Bryde's | Fin |
|---|---|---|---|
| Ayukawa | Taiyo Gyogyo | 9[1] | 1 |
| Ayukawa | Sanyo Hogei | 4 | — |
| Onagawa | Nippon Suisan | 2[2] | — |

1) No observations for one carcass.
2) Examined only baleen plates for one of two carcasses.

A total catch figure for the Bryde's whale at four land stations during baleen whaling season, May to October 1975, was 116 animals (♂45, ♀71) in all, of which the majority (86.2%) was caught during the months of May to July, so the time when we examined the animals was almost near at the end of Bryde's whaling season. One out of fifteen Bryde's whales landed was not examined. Observed result on a fin whale at Taiyo Gyogyo was not treated in this report except an item for Table 2.

An ordinal biological observations on carcasses were carried out as much as possible for 14 animals. However, the observations on carcasses have had to be done by only one person in the field, no measurements of so-called bodily proportions were made except several measurements for minor part of body for the later convenience (Appendix I). In this survey we focussed our observations especially on measuring the structure of filtering apparatus in general since it was supposed that the differenciation of intraspecific variation as an external character in Bryde's whale would likely be well resulted both in feeding habits and in the form or the character of filtering apparatus through the cetacean evolution.

As for counting the number of so-called baleen plates we followed to the suggested definition by Williamson (1973), that is, when the width of baleen plate has three or more times of its thickness at gum level, we counted it as the 'real baleen plates'. Diameter of baleen bristles was measured at three points, tip, middle and base, under the microscope with a aid of micrometer mounted in the eyepiece. To calculate the whole area of filtering apparatus we measured the overall length of baleen series along gum level and also the length from the base of palatal ridge to the tip of baleen plates section by section so as to be figured out the unfold shape of filtering apparatus on the sectioned paper. By this treatment the filter area was calculated by counting the number of unit squares encircled by the figure. Another minor ways of observations and measurements were described elsewhere in the text where it was thought to be necessary.

## RESULT

### (1) *General descriptions*

The Bryde's whales examined were consisted of 8 male and 6 female with the body length of ranging 10.1–12.7 m (Av. 11.78 m) in the former and 10.8–14.2 m (Av. 12.93 m) in the latter. All these animals were caught in the whaling ground formed some 140–280 nautical miles east off the coast of Sanriku region where relatively high surface sea temperature of above 23°C prevails during mid summer (Figs. 1-a, 1-b). Shift in the location of Bryde's whaling ground was not found when it was compared with the locations occupied in 1953 operations (Omura and Nemoto, 1955). One female of 14.2 meter (Sy7519 animal) carried a well burried steel tag (No. 0789, Fishery Agency Japan) in the midst of her right side back between blow-holes and dorsal fin. The tag had been shot at 26°08′N, 143°00′E on 8 May 1950 and has been reported as sei whale of 38 feet (11.6 m). Thickness of the blubber ranged 4.0–5.5 cm in six measured animals, and that of mammary gland in two animals was 1.5 cm (Sy7519) and 3.0 cm (Ty7544) respectively. No lactating animals were found. Since carcasses are largely cut opened at their ventral cavity to keep the meat more fresh, the stomach contents, reproduction organs and foetus are washed off and lost very

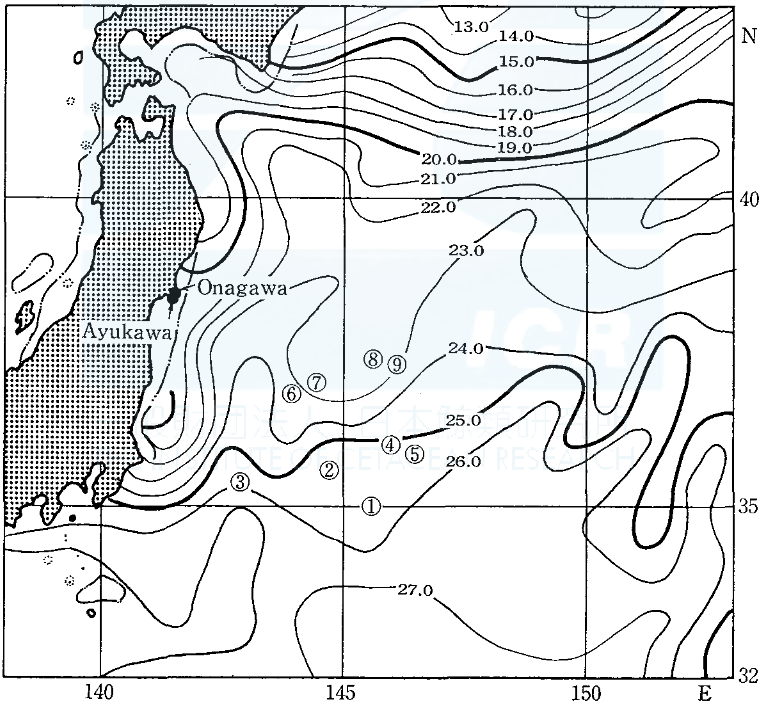

Fig. 1-a. Distribution of surface sea temperature (Japan Meteolological Agency, 1975) and the location of catch in the late July, 1975. (1) Sy7518, (2) Ty7544, (3) Ty7541, (4) Sy 7519, (5) Ty7543, (6) Ns7564, (7) Ns7563, (8) Ty7546, (9) Sy7520.

often while the animal was on the way towing back to the land station. Neither foetuses nor the condition of reproductive organ for female were observed, and consequently the data on the reproductive condition are unavailable in this study. Contrary, weight of testis was obtained from three animals; it was 1.2, 2.1 (Sy7518); 0.4, 0.3 (Ns7563): and 0.2, 0.1 (Ns7564) (Kg) respectively. Comparing these figures with those found in South African waters (Best, 1974), the above animals were adolescence of sexually immature.

Number of ventral grooves was counted at the anterior insertion of flipper on the visible half of body and the number was doubled. The obtained number varied from 50 grooves to 70 (Av. 62) through four animals. It is note worthy that one animal (Sy7518) showed only 50 grooves while another three were over 62.

Abundance of white scar on the epidermis varied considerably by each animals. Number of scar counted in most animals was found somewhere between 15–40 scars on the visible half side of abdomen, and it gave an appearance of moderate state in scarring except two animals which were quite heavily scarred with an appearance of like a newly galvanized iron or zinc plate. One animal (Sy7518), however, was exceptionally smooth in its epidermis with very little number of white scars and, still more, the open pit was completely absent from

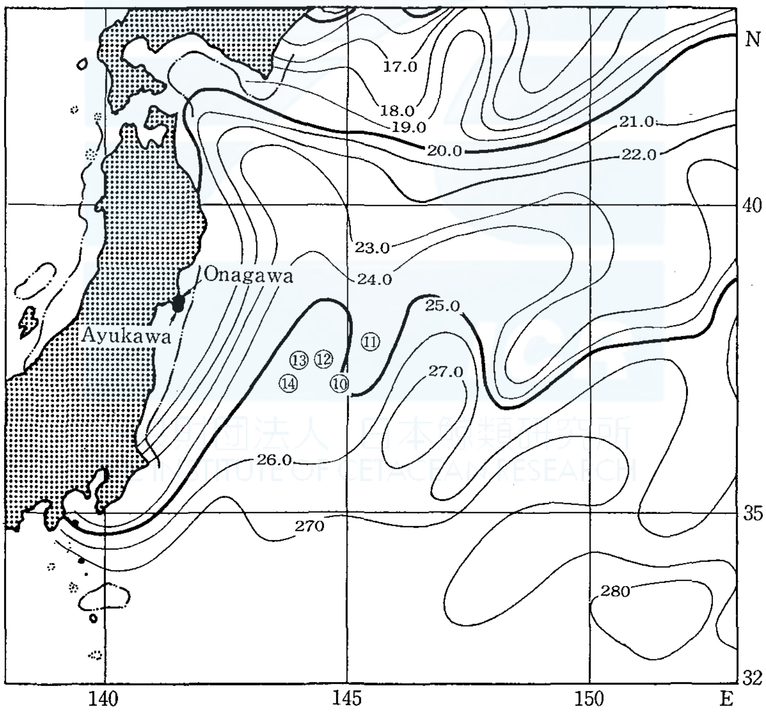

Fig. 1-b. Distribution of surface sea temperature (Japan Meteolological Agency, 1975) and the location of catch in the early August, 1975. (10) Ty7541, (11) Ty7548, (12) Ty7550 (13) Ty7549, (14) Sy7521.

its surface. Usually 1–4 of oval shaped open pits was found in lumber part, flipper and in the upper surface of the rostrum. The measured dimensions of open pit was 8.0×4.5 cm and 3.9×6.7cm or thereabouts, and these sizes for open pits are likely to represent through the animals examined. It is unknown whether the scratched scars were on the under surface of tail flukes.

There found at least three kinds of ectoparasites in some animals though they were not infected altogether on a definite carcass. The parasitic organisms found were *Xenobalanus*, *Pennella* and stalked barnacles, but both juvenile and adult forms of *Balaenophylus* sp. were found on the surface of larger sized baleen plates in every animals.

Very few of stomach contents were observed, since it was, as mentioned before, also cut open while towed back to the land station. However, four animals had luckily kept some amount of stomach contents. The kind of foodstuff was consisted of young pacific mackerel, *Pneumotophorus japonicus japonicus* of about 13.5–15.6 cm in fork length in three animals. *P. japonicus japonicus* occurs very abundantly over the Sanriku region toward considerable pelagic region (Kawamura, 1973) during northern summer, and even migrates into the Ayukawa harbour. The another one was said to have kept euphausiids. Although no specimen of this euphausiids was collected, it might considered probably be *Euphausia pacifica*, since the bulk of this species occurs in the whaling ground off Sanriku region (Komaki, 1967) and also having been found in the stomach of blue, fin, sei (including Bryde's) and humpback whales (Nemoto, 1959).

Collected ear plug and female reproduction organ are usually sent to the Far Seas Fisheries Research Laboratory, Fisheries Agency, when the whaling season was closed, and the age of whales concerned is not yet known to the authors as of March 1976.

In the observations on the general external appearance of Bryde's whales examined, there found no distinct characteristics which may enable to distinguish from one another. However, as it was suggested before, one animal of 12.5 m female (Sy7518) was found to be rather different in its external characters, viz. so small number of ventral grooves along with smooth and little scarred good looking epidermis. This coasely grooved throat well corresponds to that of 'sei whale' caught in the Bonin Islands whaling ground (Omura *et al.* 1952).

### 2) *Proportions*

It does not seem to enable in obtaining any conclusive different characters from the present data on body proportions since only several minor measurements were made sporadically (Appendix I). However, some measurements would be worth to be mentioned in connection with the results on the filtering apparatus. To show rather distinct difference in some animals from the rest, we extracted some figures from the overall data and summerized in Table 1.

Measurements other than Table 1 showed very well coincidence with all

TABLE 1. PERCENT FIGURES FOR SEVERAL NUMBER OF MEASUREMENTS AGAINST BODY LENGTH SHOWING THE ANIMAL WHICH LARGELY DIFFERED FROM THE OTHERS.

| Measurements | No. of animal measured | Average (%) | Figures for prominent difference from the average (%) | Animal |
|---|---|---|---|---|
| Length of a row of baleen plates along the gum level | 8 | 21.85 | 19.20<br>17.59 | Sy7518<br>Sy7521 |
| Length of ridge on the head | 11 | 11.20 | 6.80<br>9.27 | Sy7518<br>Ty7546 |
| Distance between Yakobson's organ and the tip of snout | 12 | 0.76 | 1.43<br>1.31 | Ty7543<br>Sy7519 |
| Dorsal fin: (a) anterior edge | 8 | 5.10 | 6.56 | Sy7518 |
| (b) width | 9 | 4.24 | 5.84<br>3.14 | Sy7518<br>Ty7550 |
| (c) Height | 12 | 2.47 | 1.93<br>2.04 | Ty7546<br>Ty7550 |
| Flipper: (a) anterior edge | 12 | 12.60 | 14.29<br>14.38 | Ty7547<br>Ty7550 |
| (b) width | 12 | 2.44 | 1.69 | Ty7548 |

animals examined, and could be discarded from the considerations. As far as Table 1 is concerned, several animals which showed different proportions could be picked up. Among those animals enlisted in Table 1, Sy7518 animal which was very coarsely grooved and smoothly skinned animal, showed significantly different proportions from the others especially in the length of rostrum, palatal ridge, baleen series, and dorsal fin, giving highest frequency in the number of deviated measurements. Proportions for dorsal fin in Sy7518 animal showed very low and broad triangle which was quite characteristic from the others. The dorsal fin of like this shape had been also known in the 'sei whale' of southern type which occurs in the Bonin Islands waters (Omura *et al.* 1952). This animal as going to be metioned later was also different at two most important measurements while majority of the rest were only distinct at more less important ones. Best (1974) suggested the difficulty to distinguish both inshore and offshore forms of Bryde's whales only by a morphometric examinations due to so frequent occurrence of intermediate forms. From the overall results already mentioned, however, it might be considered that there seems to be at least two or three unusual animals which could be distinguished at several measurements on the external characters.

### 3) *Filtering apparatus*

Filtering apparatus in baleen whales would be one of the most important external characters should be examined closely for the consideration of intraspecific variation or racial problem of whale population until we will have got more biological, physiological, and ecological knowledge on the species concerned. Results obtained are summerized and given in Appendix II.

a) Row of baleen plates

Both the length of a row of baleen plates along gum level and that along palatal ridge are indispensable agents for calculating the area of filtering apparatus. For those animals which had not measured those length above mentioned, it was able to estimate reasonably by drawing the actual unfolded shape of filtering apparatus with the aid of measurements for inside of the filter obtained section by section at every 30 to 50 cm intervals.

The overall length along gum level varied for 190.0–314.0 cm through ten examined animals while the length along palatel ridge was 190.0–285.0 cm. As it was given in Appendix I and Table 1, proportional figures for the length along gum level was small in Sy7518 and Sy7521 animals. Fig. 2 demonstrates

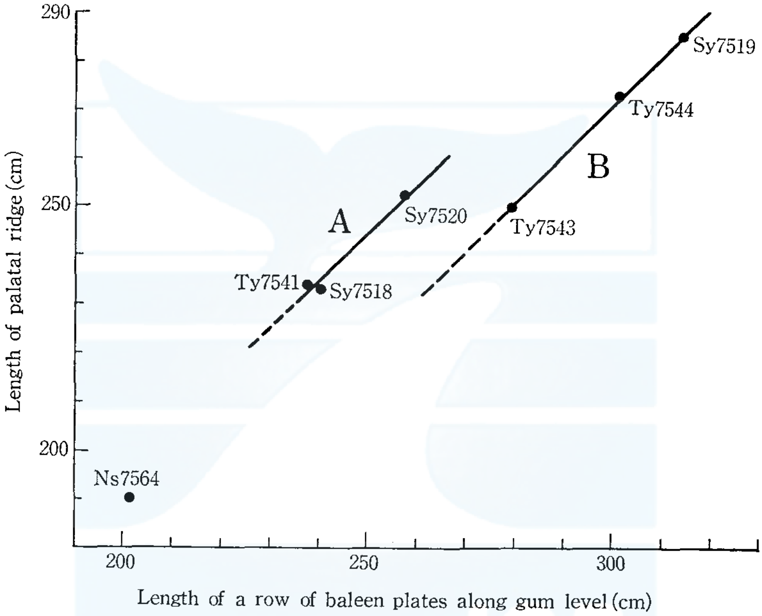

Fig. 2. Length both for a row of baleen plates and for the palatal ridge.

TABLE 2. RATIO FOR THE TRANSVERSE LENGTH OF FILTERING APPARATUS(A) AGAINST ITS MAXIMUM SPREAD ALONG BALEEN SERIES(B).

| | Body length (m) | Animal | B/A |
|---|---|---|---|
| Male | 10.1 | Ns7564 | 0.35 |
| | 12.5 | Sy7518 | 0.37 |
| | 12.6 | Ty7543 | 0.45 |
| | 12.7 | Sy7520 | 0.42 |
| Female | 13.7 | Ty7544 | 0.44 |
| | 14.2 | Sy7519 | 0.40 |
| | 15.3 (Fin) | Ty7542 | 0.42 |

the relationship between both above mentioned lengths. From this figures it is observed that there are two different characters in the general structure of filtering apparatus, that is, rather slender shaped apparatus as shown by the line A in Fig. 2 and more oval shaped one which belongs to the line B. This relationships are more well represented in Table 2. The calculated ratio for the maximum spread connecting tip to tip of both sides of baleen plates against the length of palatal ridge showed that there are two kinds of clearly different figures which are comparable with Fig. 2. Both Ns7564 and Sy7518 animals showed considerable slender shape in their filtering apparatus, but they must be considered separately as being different each other since the former seems to be possibly resulted from its younger age, while the figures for Sy7518 animal, must be noted along with the large enough body length. Although those two different figures are found among male animals, the difference would not be due to the sex.

b) Number of baleen plates and hairs

A total number of so-called baleen plates in a series of baleen plates was counted. The figures as given in Appendix II varied between 254 and 325 plates through eleven animals with 283.5 plates as an approximately averaged number. By comparing these figures with those by Omura *et al.* (1952), majority of the number of baleen plates in the present study was less than 290 plates, and well agrees to that known in the southern type of 'sei whales' from Bonin Islands waters except Ty7541 and possibly Ty7544 animals both of which showed somewhat more ordinal sei-whale-like characteristics. However, the overall variation between each animal seems to be still within an allowable range as Bryde's whale species, and the data provided by Best (1974) for the Bryde's whales of both South African and Chilean waters also suggest variable in that character, though the number of baleen plates of somewhere between 270 and 290 may be a reasonable figures for the Bryde's whales over the many localities.

Quite insufficient data are available for the number of creamy white hairs and plates arranged on the distal end of baleen series as it has been known in fin, minke and some sei whales. As far as the available data are concerned, there was found no clear difference or tendency between animals and also between both right and left baleen series in the amount of creamy white hairs and plates. Intraspecific variation is unlikely to be figured out from this kind of character although there found some noteworthy difference between both right and left sides in Sy7518, Sy7519 and Sy7520 animals. It is, however, still unknown whether those difference or variation are significantly responsible to such a extent as to show a difference of races or allopatric forms.

c) Baleen plates

The shape of cross sectioned beak at cranial to blow-holes was reported as relating agent at least to the morphological difference in both sei and Bryde's whales (Omura, 1962). In connection with this relative angle ($\theta$) which is formed by the outer edge of baleen plate against vertical axis was measured (Table 3). To measure the angle actually, the gum line was adopted as one of two angle

TABLE 3. RELATIVE ANGLE FORMED BY THE LINE AT GUM LEVEL AND THE OUTER EDGE OF BALEEN PLATES.

| | Animal | Body Length (m) | Angle ($\theta$) |
|---|---|---|---|
| Male | Ns7564 | 10.1 | 50.4 |
| | Ns7563 | 11.1 | 53.6 |
| | Ty7547 | 11.2 | 48.5 |
| | Ty7541 | 11.5 | 53.1 |
| | Sy7518 | 12.5 | 49.2 |
| | Ty7549 | 12.5 | 53.6 |
| | Ty7543 | 12.6 | 52.1 |
| | Sy7520 | 12.7 | 49.8 |
| Female | Sy7521 | 10.8 | 47.4 |
| | Ty7548 | 11.2 | 43.6 |
| | Ty7550 | 13.7 | 50.0 |
| | Ty7544 | 13.7 | 53.4 |
| | Ty7546 | 14.0 | 48.8 |
| | Sy7519 | 14.2 | 56.3 |

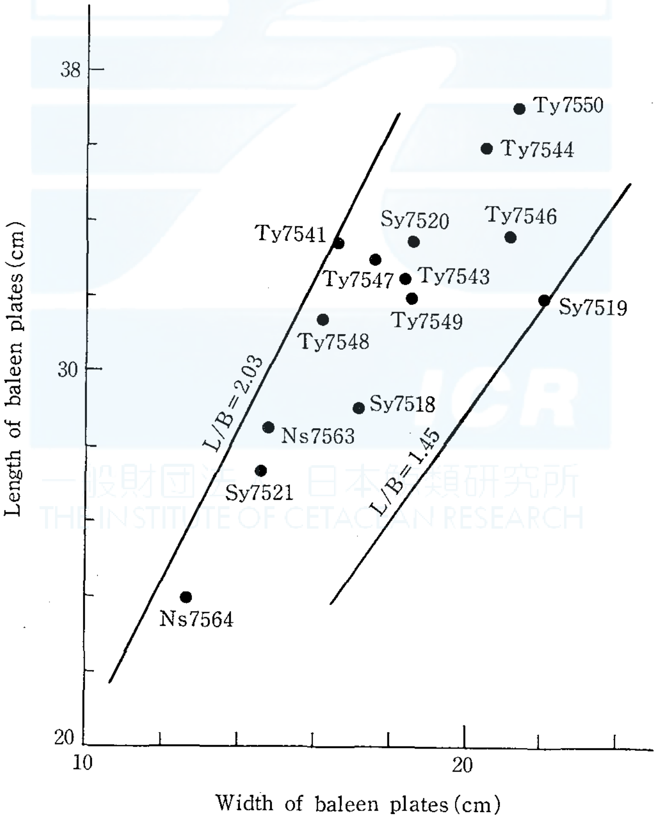

Fig. 3. Width and length of largest baleen plates.

forming basal lines. Consequently, it means that the larger in this angle the more well the baleen plates hanged vertically. The upper and lower extremes for this angle were 56.3° and 43.6° respectively. The general trends in the frequency of this angle seem to change proportionally with the increase or decrease in body length, and this tendency could be considered along with the whole shape of filtering apparatus, viz. length-spread ratios in a series of baleen plates (see Table 2). Some animal showed well horizontally spreading baleen series while another were not. The angle varied so randomly over the examined animals and no significant relationship for the better understanding of an intraspecific variation was found among this characters.

The width-length ratio (=quotient) for the largest baleen plates has been one of the most well examined characters in many previous studies. This figure as given in Appendix II and as demonstrated in Fig. 3 varied between 1.45 and 2.03 with an average of 1.79. From Table 3 and Figs. 4 and 5 which were given by Omura *et al.* (1952), it can be said that the lower the value in this ratio the more closer character is seen as orignally known Bryde's whale itself. In this point of view, following three animals, Sy7518, Sy7519 and Ty7546 showed relatively small width-length ratio than the rest and, consequently, they should be considered to keep somewhat distinguishable character in their baleen shape than the others. Only in Ty7541 animal exceeded in the ratio. Although all the figure obtained was in the range which had been found in Bonin Islands population (Omura and Fujino, 1954) when Fig. 3 is compared with the result as demonstrated by Best (1974), it might be said that the majority of animals in this study carried a similar character with that known in offshore form of the South African waters while those above mentioned three animals were more closer character to one of two forms found in Brasilian waters.

In Bryde's whale, however, there found no only one or two most prominent size of baleen plates but they are found for a section of baleen series consisting of several tenth number of baleen plates to be the same size while their width varies as shown by the function of width-length ratio among them for about 0.5 (Fig. 4). This suggests that it would be very hard to consider and/or try to find out the variations only by means of the width-length ratio of baleen plates unless one gets larger enough difference in that figures.

d) Number of minor baleen plates

Small brush-like baleen plates (=minor plates) are furnished between the inner most end of main plates and the base of palatal ridge (see Williamson, 1973, Fig. 8). The minor baleen plates form also an important filtering meshes on the ceiling of upper jaw. The number of minor plates including a very tiny stump of hairs varied along with both the position of main baleen plates and animals within 5 to 13 plates with three exceptions. Usually the number did not vary much within an animal and may not be so significant character for the purpose of this study (Fig. 5).

e) Baleen bristles

The character of hair-like bristles (=fringes) which finally form straining

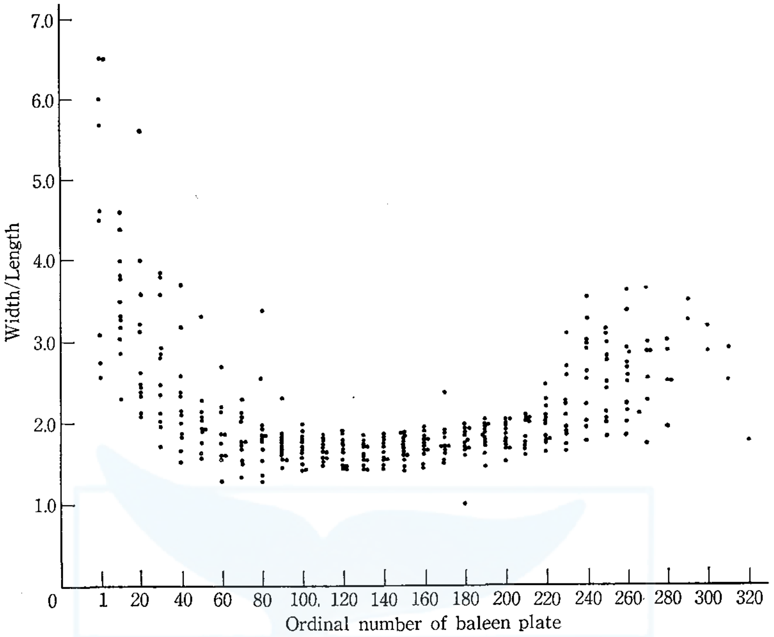

Fig. 4. Variation in the width-length ratio by the part of baleen series.

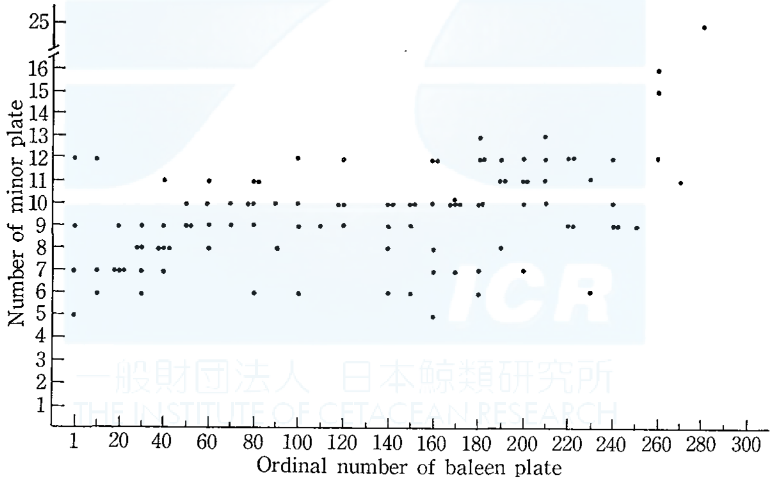

Fig. 5. Variation in the number of minor plates.

meshes of filtering apparatus are considered as to be one of the most important agents should be examined more closely. Since baleen bristles are easily damaged through the sampling and examining process on baleen plates, no measurements on their length were made but examined and measured only their thickness in terms of diameter and the number of bristles per unit length of inner margin of baleen plates.

As it is noticed in the figures on Plate II there were found two kinds of bristles which can be easily distinguished by their appearance: the first one is very long and thick structured in its diameter and streches out straight. This bristles obviously form the main body or structure of the fringe of baleen plates. The second one, on the other hand, is very thinly structured bristles with a trace or an appearance of folding in zigzag shape at one or more angles. This kind of bristles make the filtering apparatus to be more finer netting by entangling with both kind of another bristles from several neighboring baleen plates to result a role as a sort of 'connecting tissue' throughout the baleen series. This thin and zigzagged bristles are very fragile at their angled corners where the bristles are rather flattened like a ribbon string, and are easily damaged by the angles.

By distinguishing above two kinds of baleen bristles, one of author (A. K.) counted their number per unit length of inner edge of baleen plates to give a density which may show the extent of coarseness of netting in filtering apparatus. The determination of density in baleen bristles was made approximately at the halfway of inner margin of the largest baleen plates by sampling all bristles within 2.0 cm length since 1.0 cm as a sampling unit length was considered to be too small for this purpose. The number combined both kinds of bristles varied for 39–85 per 2.0 cm unit length with an average of 60.9 bristles per 2.0 cm. To see the overall result most animal carried the straight and thick bristles of about 1/3 to 1/4 of the number of zigzagged ones. On closer examination, however, it can be noticed that these proportional balance in the number of both kinds of bristles are deformed in both Ty7541 and Sy7518 animals. The former completely lacks the zigzagged bristles and the latter was very little in the number of slightly zigzagged bristles which can be considered almost straight appearance (Fig. 6). The latter was very similar to those found in the animals from Bonin Islands waters previously. In Fig. 6 some additional data which were obtained from another baleen plates of Bryde's whales from various localities were plotted. The result make the authors complicated at their considerations: that is, the all results obtained from our previous collections showed almost or complete lack in the number of zigzagged baleen bristles. They were very similar to the character found in Sy7518 animal. Some of them undoubtedly must have been damaged to result bearing no thin and zigzagged bristles. However, the number of straight bristles as demonstrated in the figure suggests that the animals of previous collection were well luxuriously furnished with straight bristles than the majority of animals in the present study, and only Sy7518 animal corresponds to those figures from the preserved materials. Besides, Ty7541 animal showed also an exceptional character in the number of straight bristles. As far as Fig. 6 is concerned, it can be said that most animals in the present study showed a character of more sei-whale-like Bryde's whales. In Fig. 6 the position where the Bryde's whales from the pelagic waters of the North Pacific or those from the coastal waters off western Kyushu would be placed may be an another interests. This will

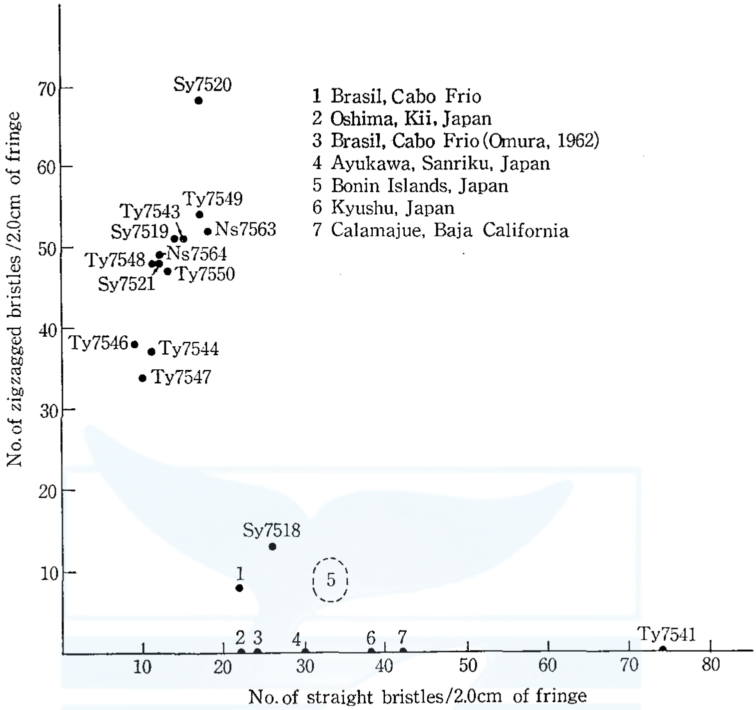

Fig. 6. Density of the two kinds of baleen bristles by the animals from various localities.

TABLE 4. PROVISIONAL CLASSIFICATION FOR THE TYPES OF BALEEN PLATES BASED ON THE MEAN DENSITY OF BRISTLES (NO./2.0 cm).

| Type | Kind of bristles | | Total | Corresponding animal |
|---|---|---|---|---|
| | Straight | Zigzag | | |
| I | 50 | 6.5 | 67 | Ty7541, Sy7518 |
| II | 10 | 36.3 | 43.3 | Ty7547, 7544, 7546 |
| III | 13 | 49 | 62 | Ty7543, 7548, 7550<br>Ns7564, Sy7519, 7521 |
| IV | 17.3 | 58+ | 76 | Ty7549, Sy7520<br>Ns7563 |

be mentioned later in *Addendum* and demonstrated in Fig. 12. The result seems very important external character for the better understanding of an intraspecific variations though the matter needs still more accumulation of further evidences. In connection with this the present data concerning to the character in the density of baleen bristles can be summerized by distinguishing the four provisional types of characteristics in the netting of filtering apparatus (Table 4).

Thickness of straight bristles was observed under the micrometer by

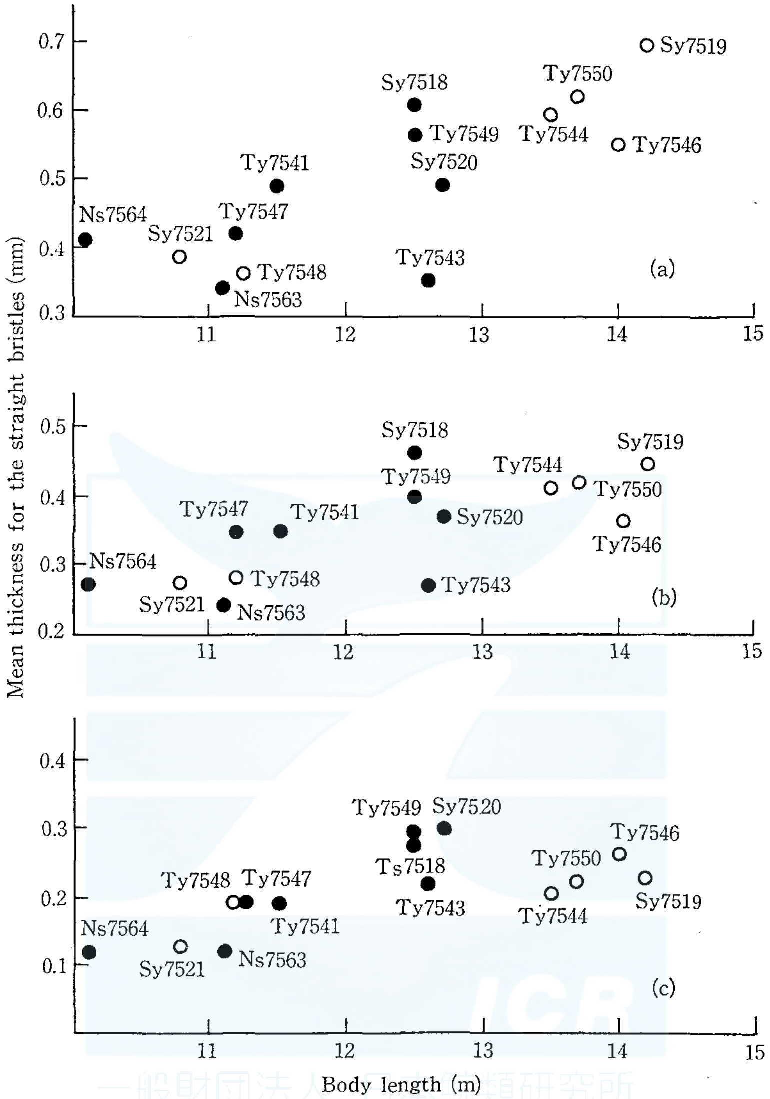

Fig. 7. Thickness of straight baleen bristles at the base (a), middle (b), and at the tip (c) for 14 animals. Shaded circles are males and open ones are females.

measuring their diameter on five pieces of the bristles per animal at their base, middle, and at the tip, and each measurements were averaged. Measurements at the base may give the most reliable figures since those bristles, mere or less, might have possibly been damaged. The straight bristles are tapered toward the tip, and grow thicker with an increase in body length (Fig. 7). Each measurement distributes within some reasonable ranges in many animals with varying trends with their body length. However, as clearly shown in Fig. 7, diameter at the base for Sy7518, Ty7541 and Ns7564 animals were rather unusually thicker than the rest while Ty7543 animal was quite thin in the diameter. The former two are note worthy for their corresponding figure to the type I of baleen plates which almost or completely lack the zigzagged bristles (see Table 4). Comparing the figures at the base with those at the middle and tip, the latter two animals, Ty7543 and Ns7564, both are considered to be rather normally charactered in the nature of their bristles. No difference by sexes was observed. As far as the Fig. 7 is concerned, the Bryde's whales which bear on no zigzagged bristles are furnished with robust and thicker baleen bristles to give a typical character of general qualities of baleen plates having been known in the 'southern type' of sei whales (Omura and Fujino, 1954). Table 5 shows averaged diameter of bristles, and Table 6 does similar data obtained in the animals from various localities. By comparing those figures, it might be suggested that there were at least two forms of bristles. The first one is very thick bristles of more than 0.5–0.6 mm in diameter at the base, and the second one is more thin bristles less than about 0.5 mm. In connection with the South African animals (Best, 1974), the occurrence of Bryde's whale similar to those offshore form in Japanese waters is evident. Although the details about animals from various localities are not known well, all data suggest similar character to those obtained in present study. Some animals, however, clearly showed their more prominent character with finer netting which can be distinguished easily from the another extremes.

In addition to morphometrical difference, coloration of the bristles was distinct in Sy7518 animal: in this respect the bristles of this animal showed completely creamy white even at the base of bristles while the others showed rather greyish white with brownish coloration at the base.

f) Area of filtering apparatus

The row of baleen plates was measured section by section at both its length from the gum level to the tip of baleen plates and from the base of palatal ridge where the arrangement of minor baleen plates ends to the tip of main plates. Using this two series of measurement, filter areas which are formed by both outer surface of a row of baleen plates (expressed by *So* in Appendix II) and inner surface (expressed by *Si* in Appendix II) were calculated on eleven animals. The filter area for inner surface possibly effects on substantial ability of animals to straining out the foodstuff engulfed, and consequently, it gives much larger figures than that formed by the outer surface. The averaged filter area through examined animals was 1.14 squaremeters for the outer surface while it was 1.82 squares meters for the inner surface respectively. As we can see in the column of *Si/So* in Appendix II, the area for the inner surface keeps 1.46 to 1.76 (Av. 1.61) times larger figures than that for the outer surface. Fig. 8 demonstrates the type of whales by the schema which may be classified by the relationship of the filter area between both outer and inner surfaces. In the schema the ratio for *Si/So* in right whale, for instance, may possibly show close to 1.00 and give a regression of an angle of about 45 degree. When the schema is introduced to the case in Bryde's whale, then the figures can be expressed

TABLE 5. AVERAGED THICKNESS OF BALEEN BRISTLES.

| Animal | Base | | Midst | | Tip | |
|---|---|---|---|---|---|---|
| | Str. | Zig. | Str. | Zig. | Str. | Zig. |
| Ty7541 | 0.49 | 0.45 | 0.35 | 0.30 | 0.19 | 0.22 |
| Ty7543 | 0.35 | 0.28 | 0.27 | 0.25 | 0.22 | 0.18 |
| Ty7544 | 0.59 | 0.48 | 0.41 | 0.32 | 0.21 | 0.18 |
| Ty7546 | 0.54 | 0.41 | 0.38 | 0.32 | 0.26 | 0.21 |
| Ty7547 | 0.42 | 0.27 | 0.35 | 0.26 | 0.19 | 0.19 |
| Ty7548 | 0.36 | 0.30 | 0.28 | 0.22 | 0.19 | 0.16 |
| Ty7549 | 0.56 | 0.35 | 0.40 | 0.29 | 0.29 | 0.22 |
| Ty7550 | 0.62 | 0.45 | 0.42 | 0.28 | 0.22 | 0.20 |
| Sy7518 | 0.60 | 0.44 | 0.46 | 0.32 | 0.28 | 0.32 |
| Sy7519 | 0.69 | 0.37 | 0.45 | 0.26 | 0.23 | 0.17 |
| Sy7520 | 0.49 | 0.28 | 0.37 | 0.26 | 0.20 | 0.19 |
| Sy7521 | 0.39 | 0.27 | 0.27 | 0.20 | 0.13 | 0.14 |
| Ns7563 | 0.32 | 0.23 | 0.24 | — | 0.12 | — |
| Ns7564 | 0.41 | 0.37 | 0.27 | 0.19 | 0.12 | 0.14 |
| Av. | 0.4879 | | | | | |

TABLE 6. THICKNESS OF STRAIGHT BALEEN BRISTLES IN BRYDE'S WHALES FROM VARIOUS LOCALITIES.

| Body length (m) | Sex | Thickness of bristles (mm) | | | Locality |
|---|---|---|---|---|---|
| | | Base | Midst | Tip | |
| — | — | 0.43 | 0.38 | 0.29 | Baja California[1] |
| 12.5 | M | 0.58 | 0.32 | 0.24 | Cabo Frio, Brasil[2] |
| 12.2 | F | 0.55 | 0.48 | 0.27 | Oshima, Kii, Japan |
| 13.1 | F | 0.67 | 0.46 | 0.31 | Bonin Islands |
| 13.1 | M | 0.64 | 0.40 | 0.29 | Cabo Frio, Brasil |
| — | — | 0.35 | 0.24 | 0.18 | Kyushu, Japan |
| 13.4 | F | 0.59 | 0.33 | 0.23 | Ayukawa, Japan |
| — | — | 0.46 (0.19～0.84) | | | South Africa, inshore[3] |
| — | — | 0.49 (0.22～1.11) | | | " " offshore[3] |

1) Collected by Dr. R.L. Brownell Jr. Baleen plate was possibly not from the largest part, and no details about the animal are known.
2) For further details, see Omura (1962b).
3) Best (1974).

as given in Fig. 8. As far as the Fig. 8 is concerned, there seems to exist two slightly different groups among the examined Bryde's whales: one shows more closer character to sei whale (suggested by line I) and the other does more likely to Bryde's whale proper (II). One of another data for the filter area in Bryde's whales is available (Nemoto, 1970). By quoting Nemoto's data, Kawamura (1974) figured the filter area of slightly less than 1.7 square meters in

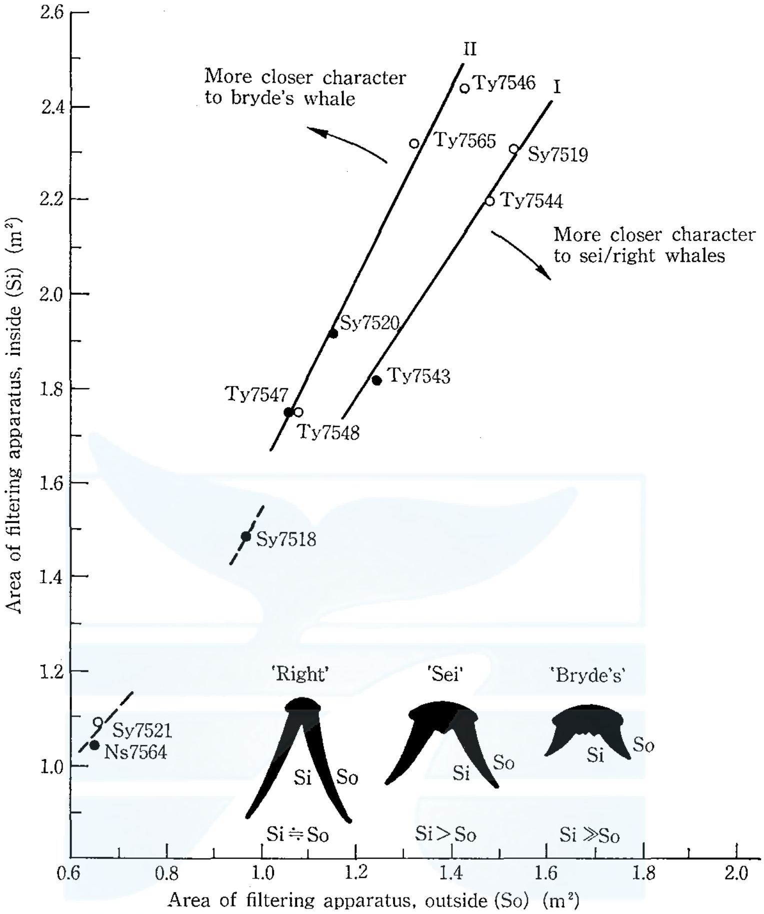

Fig. 8. Filter areas for both outside and inside surfaces along with the schema of showing area size relationships.

15 meter Bryde's whale. This relative figure well corresponds with the area found in Sy7518 animal. If we extraporate this size of whale into the regression as given in Fig. 9, then we will obtain about 2.5 square meters of filter area (see also Kawamura, 1974, Fig. 8-6). What the above mentioned suggests is that there might present at least two different types of Bryde's whales both of which are presumably distinguishable by comparing their filter area. It is still unknown whether above mentioned grouping is valid for distinguishing the intraspecific variation in the North Pacific population of Bryde's whales, those figures for filter area strongly suggest a validity for this purpose of study by accumulating more amount of data.

Fig. 9 demonstrates the relationship between the areas of filtering apparatus for both inner and outer surfaces and their corresponding body length. To see the figure it may be noticed that there are two important characters among

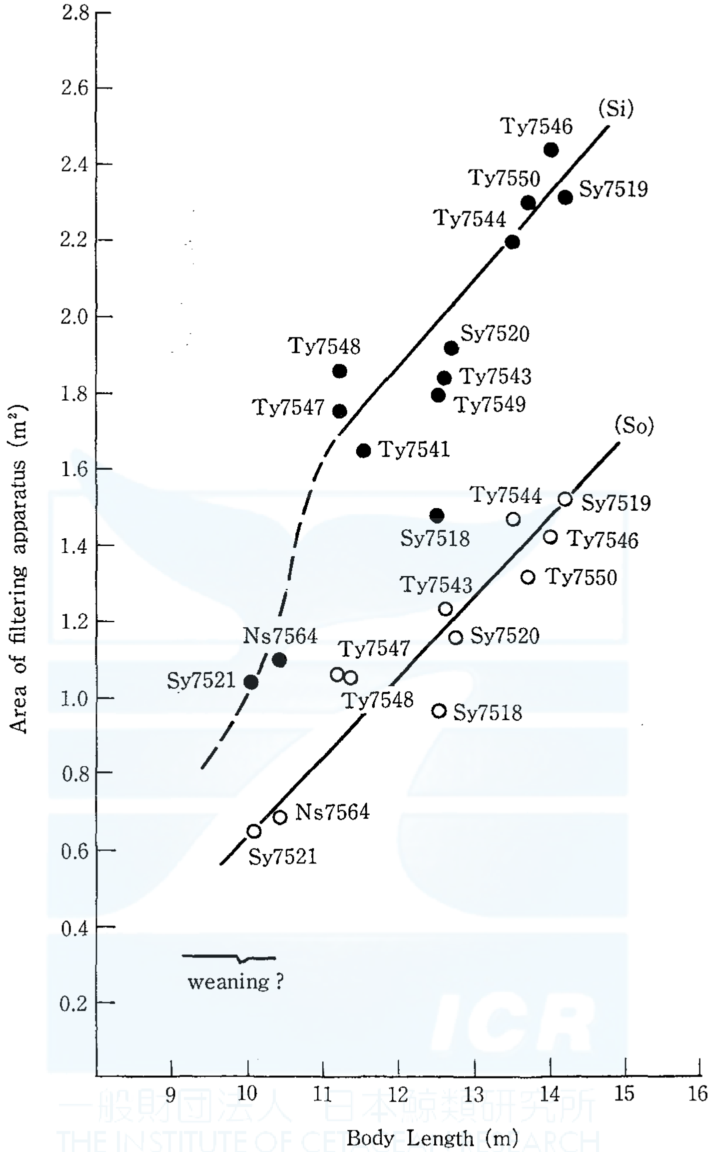

Fig. 9. Area of filtering apparatus against body length. Black spot and (Si) indicate the filter area for inside surface, and open circle and (So) indicate the filter area for outside one.

the examined animals. The first is found in relatively small filter areas compared with body length such as Sy7518 animal. The second one is found in both Sy7521 and Ns7564 animals. It should be noted, however, that these latter two animals do not differ from the relationship shown by the majority at their outer surface area (*So*), but agree well to the regression in general. By consulting also with the data given in Table 2, the filter area for the inner surface in two above mentioned animals would be on the half way of quite rapid development by growing their width of skull or a corresponding structure at somewhere around 10–11 meters in body length while the filter area of outer surface remains unchanged so much. That is, the smaller animals in their body length are narrower in their skull or head dimensions than the larger animals. Relative increase in the size of head region with growth is a well known evidence through several species of baleen whales (e. g. Mackintosh and Wheeler, 1929; Matthews, 1937, 1938) and, similarly, growth in width of skull could be also considered.

Apart from the main purpose of the present study, it is also suggested by the unusual figure in those above mentioned two animals that they might had been under a quite rapid development in their feeding apparatus. A rapid development in the structure relating to more active feeding, which is said to occur in coincidence with the weaning of animal, has been known both in some dolphins such as *Stenella* (e. g. Perrin 1975a, b) and in baleen whales (Mackintosh and Wheeler, 1929). According to Mackintosh and Wheeler (1929), the southern blue whale weans at 16 m, and relative size of its head increase from 15.3% (13.5 m in body length) to 21.2% (26.5 m). Similarly, mean curve for the growth of baleen plates in fin whale changes steeply pointing upward at 12.0–14.5 m of body length (Mackintosh and Wheeler, 1929).

More recently, Best (1974) reported that a stranded female Bryde's whale of 8.5 m (28 ft) was found to be a calf under suckling with only remains of milk in her stomach. By considering these facts along with the result obtained in this study, it seems then that both Sy7521 and Ns7564 animals might have weaned slightly before of the current season, and supposed to be under a physiological condition between nursing and adolesecence. Their weaning might took place at somewhere around 8–9 meters in body length. From these considerations the difference in the areas of filtering apparatus in both Sy7521 and Ns7564 animals could be supposed quite normal. In summerizing the data concerning to the filter area only one animal, Sy7518 showed a quite small filter area against its body length and it may be one of significant external characters which make the animal be distinguished almost completely from the others.

## DISCUSSION

As it has been mentioned in the previous sections, the Bryde's whale which occurs in the Sanriku region during mid summer shows to some extent the morphological variations by each animal in its external characters; some showed quite different external characteristics from the others in a measurement or a nature over the general appearance of body while the matter was completely different from each other in another respect of observations. As to the purpose of this study, which aims to find out some valid external characters for distinguishing the difference of animals by localities the matter seems, therefore, to go into fairly complexities when the animal is examined more closely.

To make the matter more clear the results which have been mentioned elsewhere in the previous sections were summerized in Table 7. From this table, it may be obvious that an animal, Sy7518 was quite distinct in its external characters in many observed respects which enable the animal be distinguished well from the rest. Another two animals, Sy7519 and Ty7541, will come to the next but more less characteristic than the former. The another six animals differed to some extent only in one or two items of observations and/or measurements. When we consider about those results or evidences, it can be said in general that an actually important morphological variation could be found in the difference of the character of filtering apparatus and relating functions or structures such as the number of ventral grooves and filter area.

TABLE 7. DISTINCT EXTERNAL CHARACTERS FOUND IN NINE BRYDE'S WHALES. CONCRETE DETAILS FOR THE PARTICULARS ON THE LEFT COLUMN ARE FOUND IN APPENDICES, TABLE, AND FIGURES GIVEN ELSEWHERE IN THE TEXT.

| | Sy 7518 | Ty 7543 | Sy 7519 | Sy 7521 | Sy 7520 | Ty 7546 | Ty 7541 | Ty 7547 | Ty 7544 | Ns 7564 |
|---|---|---|---|---|---|---|---|---|---|---|
| Scarring | + | | | | | | | | | |
| No. of ventral grooves | + | | | | | | | | | |
| Proportion | + | + | + | | | | | | | + |
| Creamy white baleen series | + | | + | | + | | | | | |
| Length of baleen series | + | | | + | | | | | | |
| Shape of baleen series | + | | | | | | | | | |
| No. of baleen plates | | | | | | | + | + | + | |
| Breadth-length ratio for the largest baleen plate | + | | + | | | + | | | | |
| Density of baleen bristles | + | | | | | | + | | | |
| Thickness of baleen bristles | + | | | | | | + | | | |
| Area for filtering apparatus | + | | | | | | | | | |

As it was shown in Table 4 and Fig. 5, the difference in the density and general appearance of baleen bristles in addition to the filter area may be one of the most important characters which are valid for distinguishing the intraspecific variations at least in the North Pacific Bryde's whales. Unfortunately we have had no occasion to examine the baleen plates and the bristles of both inshore and offshore forms of Bryde's whales in South African waters (Best, 1970; 1974), and it is still unknown whether or not all animals examined in this study belongs to those offshore form. However, as far as the descriptions by Best (1970; 1974) are concerned, the Bryde's whales examined in this study should belong to the offshore form without any exceptions as stated previously by Omura (1959). Since those more sei-whale-like Bryde's whale in the shape of baleen plates have not been known at present from the North Pacific region,[*] it may be possible that the animals other than Sy7518 and possibly Ty7541 could be considered as rather an inshore like type of character among the North Pacific Bryde's whales although the habitat for both types of whales, as far as the catch location is concerned, does not seem different from each other.

The recovery of whale tags suggests that most of Bryde's whales occur during winter in the waters of Bonin Islands head directly to Sanriku region in the following northbound migrations but some of them also head to both Kii and Kyushu regions although some animals headed to Kii region may enter finally into the Sanriku region (Omura, 1974). Recent tag recovery suggests that one of Bryde's whales in the south-western of the North Pacific, which was tagged at 02°20′N, 135°26′E, on 4 February 1975 was found to be relating to the so-called North Pacific pelagic stock by recoverying the tag at 29°20′N, 175°20′E on 19 July 1975. The baleen plates which were collected previously in the Bonin Islands waters, as examined and classified by four types in this study (see Table 4), do not include such character of more finer netting with many zigzagged bristles.

According to Omura (pers. comm.) all baleen plates of Bryde's whales examined at Bonin Islands were those robust nature ones with coarse and thicker bristles (see Plate III, figs. 1–2). These characters are considered very similar to those found in Sy7518 animal which is, at present, supposed to be very scarce among the Bryde's whales caught throughout the whaling season in Sanriku region (it occupies the share of only about 7.0 percent of total catch in this study). When we consider this along with whale movements by the recovered tags, there might occur some changes such as niche shifts among Bryde's whale populations that make northward migrations close to the northern Japan. When we assume that majority of Bryde's whales in the Bonin Islands waters migrate up to Sanriku region, then the question arises where those more sei-whale-like Bryde's whales come close to that region and/or whether any possibilities to occur these whales too in the Bonin Islands waters.

## CONCLUSION

Although no decisive conclusion was drawn in this study, it may be said that there occurs at least two types of Bryde's whales in the waters off Sanriku region. It is still unknown whether or not they could be called as allopatric

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[*] There is only one baleen plates which suggests the occurrence of inshore form of Bryde's whale in Japanese waters (see Best, 1974, fig. 4). We examined the same baleen plate again and found that the specimen lacks some inner most part by damage (Breadth: 14.0 cm, Length: 35.0 cm). The bristles of baleen plate were really finer than the ordinal ones (see Table 5 in the text). However, the position from where the specimen was collected is unknown. As it was shown in Fig. 4 in the text the width-length ratio for baleen plates varies much with the position in baleen series, the treatment for this specimen seems better to be held for the time being.

forms untill we will have more information on their reproductive conditions. One of them, however, clearly shows analogous characters with the animals known in Bonin Islands waters, but it occurs with less prominent among the number of migrating animals head to Sanriku region. The external characters which make both types of Bryde's whales be distinguished from each other are very slight, and could not be distinguished by an overall treatment of the data since those chracteristics in external characters might be greatly reduced by dilution through the analysial process.

*Addendum*

In the course of finishing the manuscript there was an opportunity to examine the baleen plates of Bryde's whales caught in both Kyushu and pelagic region of the northern North Pacific through the courtesy of the Far Seas Fisheries Research Laboratory, Fisheries Agency. The obtained result seems to contain some indispensable evidence and worth to be presented here for the further comparison and considerations of concerning to those racial problem in the North Pacific population the Bryde's whales.

One of present authors (A. K.) made the baleen plate measurements on thirty-eight animals from the catch in Kyushu region and thirteen animals from the pelagic waters of the northern North Pacific. As to the thickness and the density of baleen bristles, 17 out of 51 materials were counted and measured their diameter at the base by following similar procedure as having been described in the previous section. Although the number of animals and materials above mentioned consists only a part of total catch figures for both regions, animals to be examined were selected randomly from the bulk of material kept at the above mentioned laboratory, and the result can be considered to represent the whole.

In regard to the relationships between width and length in largest baleen plates, it was clearly shown that the length of baleen plate against its width in the animals from pelagic region of northern North Pacific was undoubtedly larger enough to be distinguished from the majority being found in the animals from the waters off the west coast of Kyushu except one instance (Fig. 10; Plates VI, VII). In the material from Kyushu, there found no such slim shaped baleen plate as mentioned before, and each baleen plate was rather small but furnished with more thicker bristles than the former and robust nature in general. It should be noted that there were no baleen plates which exceeded 31cm or more in their overall length in the materials from Kyushu, and also there were no overlapping figures of baleen plate dimensions between the populations of both the pelagic waters of the North Pacific and the coastal waters off Kyushu. In comparison with the results found in Sanriku region, figures for width-length relationships were shown by encircling them with broken line (Fig. 10 and, see also Fig. 3). With this figure the isolated plots for both North Pacific pelagic and Kyushu are completely filled up by overlapping each other, and make Fig. 10 be completed as to present a series of variation in the shape

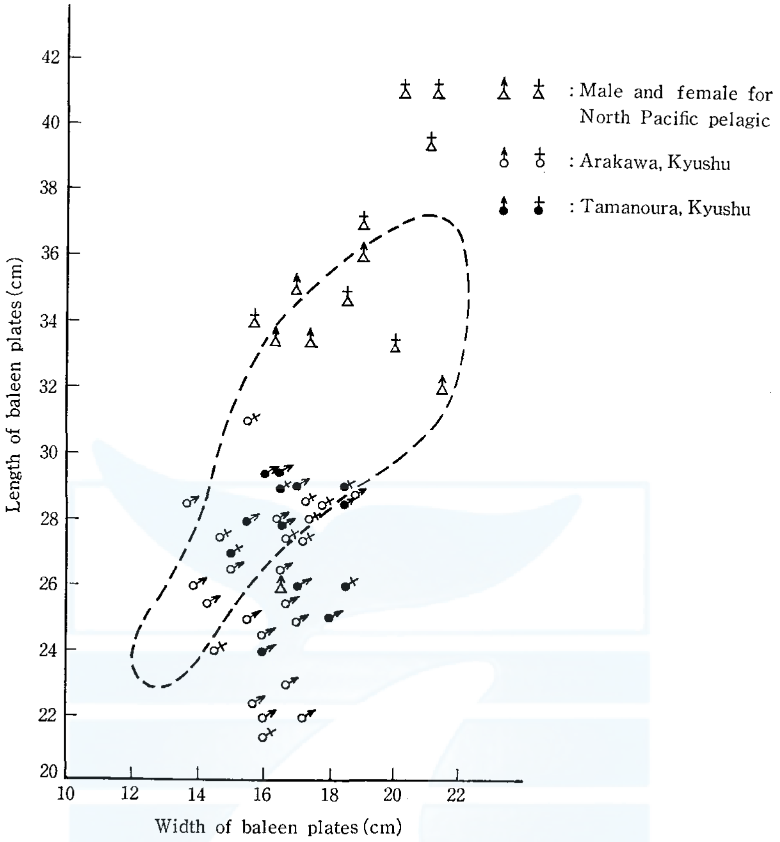

Fig. 10. Width and length relationships of largest baleen plates for the animals caught in the North Pacific pelagic and in the coastal waters off western Kyushu.

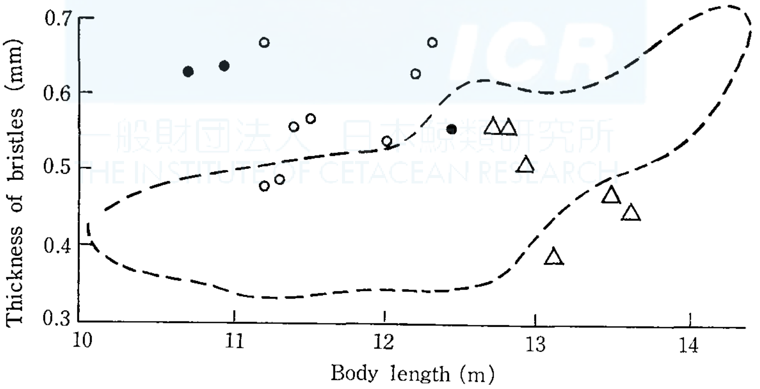

Fig. 11. Thickness of straight baleen bristles at the base for the animals both Kyushu and North Pacific pelagic. Plot distribution for Sanriku region is indicated by an encircle. Shaded circles indicate the animal from Tamanoura, open ones from Arakawa, and triangles are from the North Pacific pelagic.

TABLE 8. THICKNESS AND DENSITY OF BALEEN BRISTLES OF BRYDE'S WHALES BOTH FOR KYUSHU AND FOR THE NORTH PACIFIC PELAGIC REGIONS.

| No. of animal examined | Range of thickness for straight bristles (mm) | No. of straight bristles measured | Averaged thickness (mm) | Averaged no. of bristles/2.0 cm of fringe | | Remarks |
|---|---|---|---|---|---|---|
| | | | | straight | zigzag | |
| 3 | 0.244-0.647 | 44 | 0.437 | 15.0 | 38.0+ | NPP-3N, 1972[1] |
| 3 | 0.388-0.734 | 22 | 0.545 | 8.0 | 32.0 | NPP-3K, 1974[2] |
| 6 | 0.316-0.691 | 66 | 0.491 | 11.5 | 35.0 | Av. for both NPP-3N & NPP-3K |
| 4 | 0.496-0.766 | 30 | 0.635 | 16.25 | 12.25 | JCAK, 1973[3] |
| 4 | 0.334-0.637 | 50 | 0.523 | 16.0 | 20.5 | JCAK, 1974 |
| 3 | 0.453-0.710 | 24 | 0.609 | 9.0 | 20.7 | JCTK, 1974[4] |
| 11 | 0.428-0.704 | 104 | 0.589 | 13.75 | 17.82 | Av. for both JCAK & JCTK |

1) North Pacific, pelagic, Nisshin Maru No. 3.
2) North Pacific, pelagic, Kyokuyo Maru No. 3.
3) Japan, coastal, Arakawa land-station, Kyushu.
4) Japan, coastal, Tamanoura land-station, Kyushu.

of baleen plates from northern to southern regions.

The thickness for straight appearance of baleen bristles and the density of bristles are given in Table 8. The averaged thickness for the pelagic population of the northern North Pacific was 0.491 mm while that for the Kyushu region was 0.589 mm. When these figures along with their body length were compared with those in Sanriku region (Av. 0.488 mm, Table 5), it can be said that the baleen bristles for Kyushu are distinctly thick enough to be separated from those in another regions (Fig. 11), and overall figures for the Sanriku population make complete the thickness distribution for both the North Pacific and Kyushu populations as it was seen in the width-length relationships for baleen plates.

Density of baleen bristles in terms of the number of straight and zigzag shaped bristles per 2.0 cm of baleen fringe differed much between two above mentioned regions: the density for zigzagged bristles in the North Pacific pelagic animals was 35.0 bristles/2.0 cm on average whereas it was only 17.82 bristles/2.0 cm in Kyushu animals. The former seems to correspond to some of types II to IV of baleen plates (Table 4) and the latter would possibly be to type I. An important character in the density of bristles is not the absolute number or abundance of bristles but relative dominancy between straight and zigzagged shape of bristles since baleen fringe is apt to be damaged through many occasions prior to examination. When the number of straight baleen bristles is plotted against that of zigzagged ones, it is clearly noticed that very little number of zigzagged bristles are found in the animals from Kyushu, while they are more prominent in the animals from the pelagic waters of the northern North Pacific. The latter shows well coincidence with the character of baleen bristles found in the animals from Sanriku region (Fig. 12).

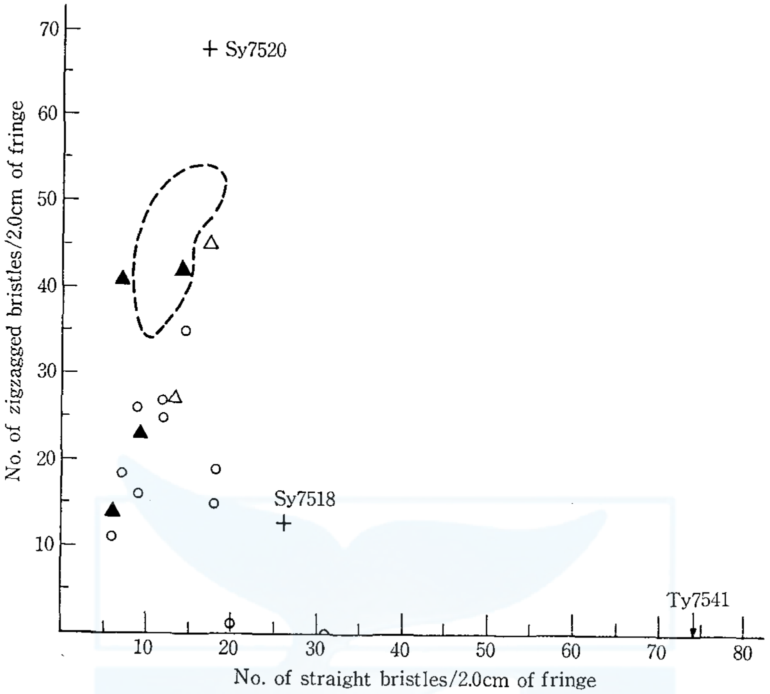

Fig. 12. Density of the two kinds of baleen bristles for the animals from Kyushu and North Pacific pelagic. Corresponding distribution for Sanriku region is indicated by an encircle and cross marks. Open circles indicate the animal from Kyushu and triangles indicate that from the North Pacific pelagic.

TABLE 9. STOMACH CONDITION FOR FIFTY-ONE BRYDE'S WHALES WHICH BALEEN PLATES WERE ADDITIONALLY EXAMINED FOR THE COMPARISON OF PRESENT STUDY.

| | | Sardine | Mackerel | Fish | Unknown[1] | Unknown[2] | Euphausiid | Empty |
|---|---|---|---|---|---|---|---|---|
| Arakawa[3] | May | 1 | | | | | | |
| | June | | 2 | | | | | |
| | July | | 4 | 3 | | 9 | | |
| | August | | 1 | 1 | | 3 | | |
| | September | | | | | 1 | | |
| Tamanoura | June | | 1 | | | 1 | | 1 |
| | July | | 1 | | | | | 1 |
| | August | | 1 | | 1 | 5 | | 1 |
| North Pacific pelagic[4] | July | | | 1 | | | | 2 |
| | August | | | | | | 8 | 2 |

1) Unknown kind of stomach contents.
2) Unknown whether there were any food or not.
3) Data for both 1973 and 1974 are combined.
4) Data for both 1972 and 1974 are combined.

The result which was found by treating the materials under grouping each individuals suggests that the filtering apparatus in the animals of the North Pacific pelagic region is structured more finer in its netting than those of Kyushu region, and that the animals in Sanriku region shows an intermediate character as a whole. However, it must be remembered that there were so much variations in the latter animals. To support this tendency the stomach condition for the animals of both North Pacific pelagic and Kyushu is given in Table 9. The kind of food organisms in Kyushu region is represented by mackerel, sardine and some small fishes, which are somewhat similar to that found in Sanriku region, while euphausiids predonimated in the animals caught in pelagic region of the northern North Pacific.

To summerize the result presented as *addendum*, it may be said and speculated to some extent that there must be two possible different populations of Bryde's whales in the northwestern North Pacific region: the first one is characterized by relatively longer and finer netting of baleen bristles, and is found in the pelagic waters of the northern North Pacific where they prey on the euphausiids and small swarming fishes. The second one, on the other hand, is found widely over the waters off western Kyushu, which sometimes extend even to the midst of the Yellow Sea. Animals found there carry very small but more coarse netting in filtering apparatus, which is possibly similar character to that has been found in Sy7518 animals in the Sanriku region. The Bryde's whale population off west Kyushu is possibly consisted of the animals both from southern waters of the western Pacific and of an endemic populations possibly from the Yellow Sea and the East China Sea regions. The animals caught in the Sanriku region show an intermediate external character in an overall treatment by dilution but each animal can be distinguished as to be placed in one of both above mentioned extremes. This suggest a possible mingling of different populations in that region. The Bryde's whales in Bonin Islands keep migratory relationships to Sanriku region, but it is still unknown whether or not they show a similar external characters to those have had been known previously in that region. If there were no niche shifts and Bonin Islands population has been remained unchanged in those region, then a considerable invasion of the North Pacific pelagic population into the Sanriku region must be considered so as to give an intermediate characters for the population in Sanriku region.

## ACKNOWLEDGMENTS

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to compare the result on the animals in Sanriku region with that both in Kyushu and in the pelagic region of the northern North Pacific. Personally, we are indebted to Dr. Seiji Ohsumi of above mentioned laboratory for permitting of our sampling the baleen bristles, and also Mr. Siro Wada of the same laboratory for prepering and assisting our laboratory work in Shimuzu. Without their kind help no data were available for the animals both in Kyushu and in the northern North Pacific, and these circumstances are greatly appreciated.

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## APPENDIX I. BODY PROPORTIONS OF THE BRYDE'S WHALES

| Serial No.<br>Sex | Ns7564<br>Male | Ty7547<br>Male |
|---|---|---|
| Body Length (m) | 10.1 | 11.2 |
| Length, row of baleen plates along gum level | — | — |
| Length, anterior end to largest baleen plates in baleen series | — | 10.8 |
| Length, largest baleen plate | — | — |
| Length, palatal ridge | 18.81 | — |
| Spread of filtering apparatus across both sides (maximum) | 6.53 | 8.75 |
| Width, palatal ridge close to anterior end | 0.84 | 1.07 |
| Ratio, item 6/item 5 | 0.35 | — |
| Spread of arch across both lower jawbones (maximum) | 8.61 | 10.09 |
| Length, side ridges on the head | 12.27 | 13.30 |
| Distance between right and left side ridges at their anterior end | 1.98 | 1.12 |
| Distance between right and left side ridges at their posterior end | 5.34 | — |
| Distance, tip of snout to anterior end of side ridges | — | — |
| Distance between both depressions of Yabobson's organ | 0.12 | 0.09 |
| Distance, tip of snout to Yakobson's organ | 0.64 | 0.67 |
| Distance, Yakobson's organ to anterior end of baleen series | — | — |
| Length, dorsal fin (anterior insertion to tip) | — | 5.00 |
| Length, dorsal fin at base | 3.86 | 3.80 |
| Height, dorsal fin (fin tip to base) | 2.77 | 2.41 |
| Concavity, dorsal fin (deepest part of posterior border to line between fin tip and posterior base) | — | 1.07 |
| Length, flipper (posterior insertion to tip) | 8.81 | 10.09 |
| Length, flipper (anterior insertion to tip) | 11.58 | 14.29 |
| Width, flipper (maximum) | 2.37 | 2.50 |
| Length, fluke (notch to tip) | 11.88 | 12.86 |
| Length, fluke (anterior insertion to tip) | — | 13.93 |
| Width, fluke (shortest distance between anterior border of flukes and notch) | 6.13 | 6.34 |

CAUGHT OFF SANRIKU, NORTHWESTERN PACIFIC IN 1975.

| Ty7541 Male | Sy7518 Male | Ty7549 Male | Ty7543 Male | Sy7520 Male | Sy7521 Female | Ty7548 Female | Ty7550 Female | Ty7544 Female | Ty7546 Female | Sy7519 Female |
|---|---|---|---|---|---|---|---|---|---|---|
| 11.5 | 12.5 | 12.5 | 12.6 | 12.7 | 10.8 | 11.2 | 13.7 | 13.7 | 14.0 | 14.2 |
| 28.69 | 19.20 | — | 22.14 | — | 17.59 | 21.25 | — | 21.97 | 21.86 | 22.11 |
| 9.91 | 12.96 | — | — | — | 10.83 | 11.88 | — | — | — | — |
| 2.56 | — | — | — | — | — | — | — | — | 4.50 | — |
| 20.35 | 18.64 | — | 19.84 | 19.84 | — | — | — | 19.93 | — | 20.07 |
| — | 6.96 | — | 8.88 | 8.27 | — | 8.57 | — | 8.76 | 8.29 | 8.02 |
| 1.13 | 0.88 | — | 1.03 | 0.94 | 1.11 | 0.76 | 1.02 | 0.88 | 0.93 | 0.94 |
| — | 0.37 | — | 0.45 | 0.42 | — | — | — | 0.44 | — | 0.40 |
| 10.26 | — | 10.96 | — | 9.84 | 11.76 | 9.82 | 10.73 | 9.92 | 10.00 | — |
| 12.69 | 6.80 | — | 11.66 | 11.26 | — | 11.30 | 11.61 | 12.07 | 9.27 | 10.98 |
| — | — | 0.56 | — | 0.39 | — | 1.12 | 1.53 | — | — | 3.09 |
| — | — | — | — | — | — | 3.57 | 2.34 | — | — | — |
| — | 1.36 | — | 1.34 | — | — | — | — | — | — | — |
| 0.13 | 0.16 | 0.10 | 0.91 | 0.12 | — | — | 0.10 | 0.09 | 0.09 | 0.09 |
| 0.65 | 0.52 | 0.76 | 1.43 | 0.59 | — | 0.54 | 0.73 | 0.66 | 0.64 | 1.31 |
| 0.17 | — | — | — | — | — | — | — | — | — | — |
| 5.04 | 6.56 | — | 4.32 | 4.88 | — | 5.58 | — | 4.82 | 4.57 | — |
| 5.04 | 5.84 | — | 3.41 | — | 4.91 | 3.57 | 3.14 | 4.60 | — | — |
| 2.69 | 2.88 | 2.48 | 2.26 | 2.52 | 2.41 | 2.59 | 2.04 | 2.63 | 1.93 | — |
| — | 1.28 | 1.08 | 0.67 | 1.10 | 0.74 | 0.85 | 0.37 | 1.09 | 0.34 | — |
| 8.95 | 8.24 | 9.04 | 8.49 | 9.61 | 7.96 | 8.66 | 10.07 | 8.76 | 8.71 | — |
| 12.08 | 11.52 | 12.72 | 12.14 | 11.57 | 11.85 | 13.26 | 14.38 | 13.14 | 12.79 | — |
| 2.60 | 2.60 | 2.48 | 2.53 | 2.76 | 2.32 | 1.69 | 2.70 | 2.26 | 2.46 | — |
| 12.43 | — | 13.12 | 12.14 | 12.13 | 12.22 | 12.14 | 12.70 | 12.66 | 12.57 | — |
| 12.43 | — | 13.84 | — | 12.91 | 13.15 | 12.95 | 13.14 | — | — | — |
| — | — | 6.24 | 6.26 | 6.46 | 6.20 | 6.25 | 6.35 | 6.22 | 6.07 | — |

## APPENDIX II. MEASUREMENT ON THE FILTERING APPARATUS OF BRYDE'S

| Measurement | | Ns7564 | Sy7521 | Ns7563 |
|---|---|---|---|---|
| Length, total (m) | | 10.1 | 10.8 | 11.1 |
| Length, row of baleen plates along gum level (cm) | | 201.5 | 190.0 | — |
| Length, row of baleen plates along palatal ridge (cm) | | 190.0 | — | — |
| Maximum spread of filtering apparatus across both sides (cm) | | 66.0 | — | — |
| Largest baleen plate | Length: *L* | 24.0 | 27.5 | 28.5 |
| | With: *W* | 12.6 | 14.5 | 14.7 |
| | *L*/*W* | 1.90 | 1.90 | 1.94 |
| Number of baleen plates (total)[1] | | 261 | 282 | — |
| Number of creamy white hairs and plates (number/length) | Right | — | 15/10.5 | — |
| | Left | — | — | — |
| Number of hair of stump of hairs in baleen series | Anterior | ? | 19 | — |
| | Posterior | 19 | 19 | — |
| Number of minor plates at largest baleen plates[2] | | $10+\alpha_4$ | 12 | — |
| Number of bristles on largest baleen plate (number/2.0 cm)[3] | Straight | 10 | 12 | 18 |
| | Zigzag | 49 | 48 | 52 |
| | Total | 61 | 60 | 70 |
| Averaged thickness of straight baleen bristles (diam. mm) at | Base | 0.41 | 0.39 | 0.34 |
| | Middle | 0.27 | 0.27 | 0.24 |
| | Tip | 0.12 | 0.13 | 0.12 |
| Areas for filtering apparatus ($m^2$) | Outside: *So* | 0.65 | 0.67 | — |
| | Inside: *Si* | 1.04 | 1.10 | — |
| | *Si*/*So* | 1.59 | 1.65 | — |

1) Definition for so-called baleen plates was based on that by Williamson (1973)
2) Number of small brush-like plates which are arranged between main row of blaeen plates and the palatal ridge
3) Length of bristles was not measured due to poor condition of preserved materials for this purpose

WHALES CAUGHT OFF SANRIKU, NORTHWESTERN PACIFIC IN 1975.

| Serial No. of animal | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Ty7547 | Ty7548 | Ty7541 | Ty7518 | Ty7549 | Ty7543 | Sy7520 | Ty7550 | Ty7544 | Ty7546 | Sy7519 |
| 11.2 | 11.2 | 11.5 | 12.5 | 12.5 | 12.6 | 12.7 | 13.7 | 13.7 | 14.0 | 14.2 |
| — | 238.0 | 237.0 | 240.0 | — | 279.0 | 252+ | — | 301.0 | 298.0 | 314.0 |
| — | — | 234.0 | 233.0 | — | 250.0 | 252.0 | — | 273.0 | — | 285.0 |
| 98.0 | 96.0 | — | 87.0 | — | 112.0 | 105.0 | — | 120.0 | 116.0 | 114.0 |
| 33.0 | 31.5 | 33.5 | 29.0 | 32.0 | 32.5 | 33.5 | 37.0 | 36.0 | 33.7 | 32.0 |
| 17.5 | 16.1 | 16.5 | 17.2 | 18.5 | 18.3 | 18.5 | 21.2 | 20.5 | 21.0 | 22.0 |
| 1.89 | 1.96 | 2.03 | 1.69 | 1.73 | 1.78 | 1.81 | 1.75 | 1.75 | 1.60 | 1.45 |
| 254 | $260+\alpha_1$ | 325 | $267+\alpha_2$ | — | 286 | 266 | — | $311+\alpha_3$ | 293 | 273 or 283 |
| 45/27.0 | 15/8.5 | — | —/57.0 | — | ?/39.0 | —/39.0 | — | 50/22.0 | 24/— | 27/17.0 |
| 38/19.0 | 20/11.0 | 9/2.7 | 27∼28/8.0 | — | — | —/19.0 | — | —/26.0 | 23/6.7 | 53/38.0 |
| 18 | 23 | 18 | 22 | — | 23 | 21 | — | 10 | 12 | 17 |
| 21 | — | 14 | — | — | 13 | 21 | $25+\alpha$ | 17 | $30+\alpha$ | 21 |
| 7 | 10 | 6 | 12 | — | 7 | 11 | 11 | 13 | $11+\alpha_4$ | 11 |
| 10 | 12 | 14+59[4] | 26 | 17 | 15 | 17 | 13 | 11 | 9 | 14 |
| 34 | 48 | — | 13[5] | 54 | 51 | ca. 68 | 47[5] | 37[5] | 38 | 51 |
| 44 | 60 | 74 | 39 | 73 | 66 | 85 | 60 | 48 | 47 | 65 |
| 0.42 | 0.36 | 0.49 | 0.60 | 0.56 | 0.35 | 0.49 | 0.62 | 0.59 | 0.54 | 0.69 |
| 0.35 | 0.28 | 0.35 | 0.46 | 0.40 | 0.27 | 0.37 | 0.42 | 0.41 | 0.38 | 0.45 |
| 0.19 | 0.19 | 0.19 | 0.28 | 0.29 | 0.22 | 0.20 | 0.22 | 0.21 | 0.26 | 0.23 |
| 1.06 | 1.06 | — | 0.97 | — | 1.24 | 1.16 | 1.32 | 1.48 | 1.43 | 1.53 |
| 1.75 | 1.76 | 1.65 | 1.50 | 1.81 | 1.82 | 1.92 | 2.32 | 2.20 | 2.44 | 2.31 |
| 1.65 | 1.65 | — | 1.53 | — | 1.46 | 1.66 | 1.76 | 1.49 | 1.71 | 1.51 |

[4] 15 thick long bristles and 59 slender ones of straight features

[5] Not heavily zigzagged features of almost straight.

Possible number for alpha letter:

$\alpha$=unknown, $\alpha_1=10\text{-}15$, $\alpha_2=20$, $\alpha_3=1\text{-}2$, $\alpha_4=1$, respectively

## EXPLANATION OF PLATES

### PLATE I

Fig. 1. Baleen plate of type I (see Table 4 in the text): Sy7518 animal of 12.5 m, male caught at 34-56N, 145-37E on 24 July, 1975. Ayukawa, Sanriku, Japan.

Fig. 2. Baleen bristles of the above animal.

Fig. 3. Baleen plate of type II: Ty7547 animal of 11.2 m, male caught at 37-16N, 144-58E on 1 August 1975. Ayukawa, Sanriku, Japan.

Fig. 4. Baleen bristles of the above animal.

### PLATE II

Fig. 1. Baleen plate of type III: Sy7519 animal of 14.2 m, female caught at 36-00N, 146-12E on 27 July, 1975. Ayukawa, Sanriku, Japan.

Fig. 2. Baleen bristles of the above animal.

Fig. 3. Baleen plate of type IV: Sy7520 animal of 12.7 m, male caught at 37-16N, 146-10E on 30 July, 1975. Ayukawa, Sanriku, Japan.

Fig. 4. Baleen bristles of the above animal.

### PLATE III

Fig. 1. Baleen plate of No. 134 animal of 13.08 m, female caught in the waters of Bonin Islands on 15 May, 1950.

Fig. 2. Baleen bristles of the above animal.

Fig. 3. Baleen plate of Bryde's whale from Kyushu, southwestern Japan. No details about the animal is known.

Fig. 4. Baleen bristles of the above animal.

### PLATE IV

Fig. 1. Baleen plate of No. 16 animal of 12.19 m, female caught at 33-35N, 136-25E on 31 May, 1952. Ohshima, Kii, Japan.

Fig. 2. Baleen bristles of the above animal.

Fig. 3. Baleen plate of No. 19 animal of 13.41 m, female caught at 37-07N, 141-20E on 4 July, 1953. Ayukawa, Sanriku, Japan.

Fig. 4. Baleen bristles of the above animal.

### PLATE V

Fig. 1. Baleen plate of 13.11 m (43 ft), male animal caught at 23-13S, 41-53W on 14 September, 1961. Cabo Frio, Brasil (see also Table 2 in Omura, 1962 for body proportions of this animal).

Fig. 2. Baleen bristles of the above animal.

Fig. 3. Baleen plate of 12.5m, male animal caught at 22-56S, 41-52W on 27 September, 1960. Cabo Frio, Brasil (see also Omura, 1962). Note completely different shape and character of this specimen from the above shown one.

Fig. 4. Baleen bristles of the above animal.

### PLATE VI

Fig. 1. Baleen plate of 10.9 m, male animal caught at 32-36N, 128-05E on 10 August, 1974, Tamanoura, Kyushu, Japan.

Fig. 2. Baleen bristles of the above animal.

Fig. 3. Baleen plate of 11.2 m, male animal caught at 31-42N, 128-51E, on 13 June, 1973, Arakawa, Kyushu, Japan.

Fig. 4. Baleen bristles of the above animal.

## PLATE VII

Fig. 1. Baleen plate of 13.1 m, female animal caught at 37-41N, 167-05E on 9 July, 1972, pelagic region of the northern North Pacific.

Fig. 2. Baleen bristles of the above animal.

Fig. 3. Baleen plate of 13.6 m, female animal caught at 37-07N, 168-41E on 9 July, 1972, pelagic region of the northern North Pacific.

Fig. 4. Baleen bristles of the above animal.

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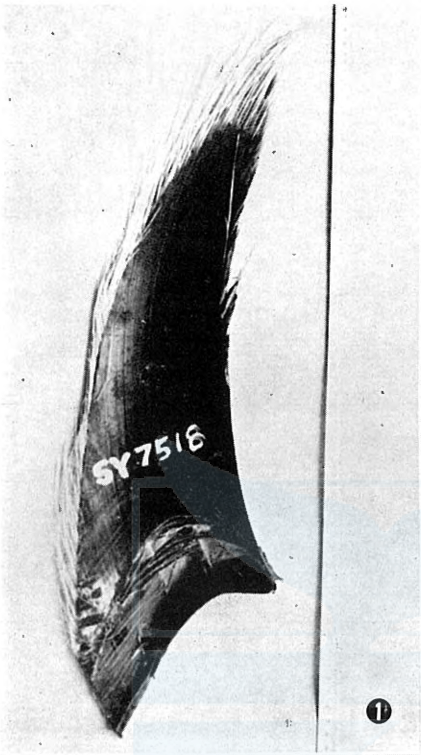

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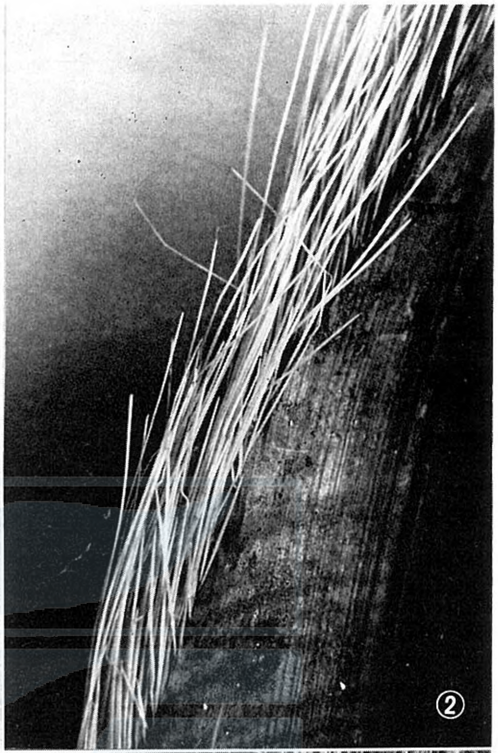

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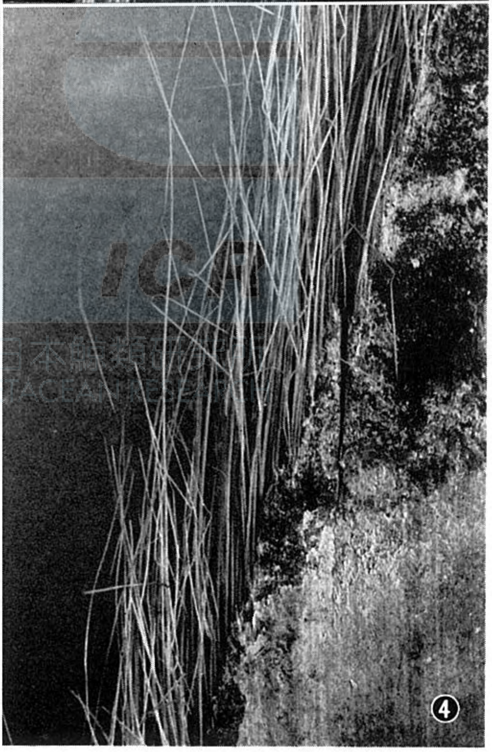

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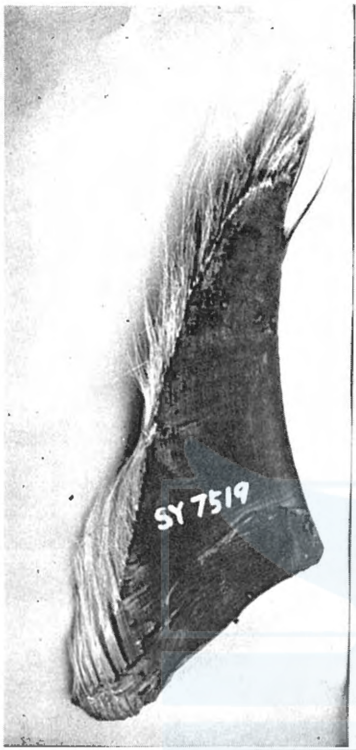

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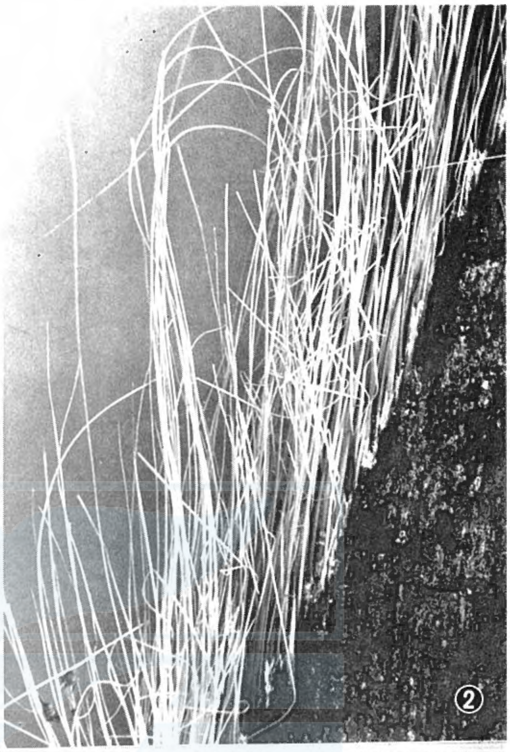

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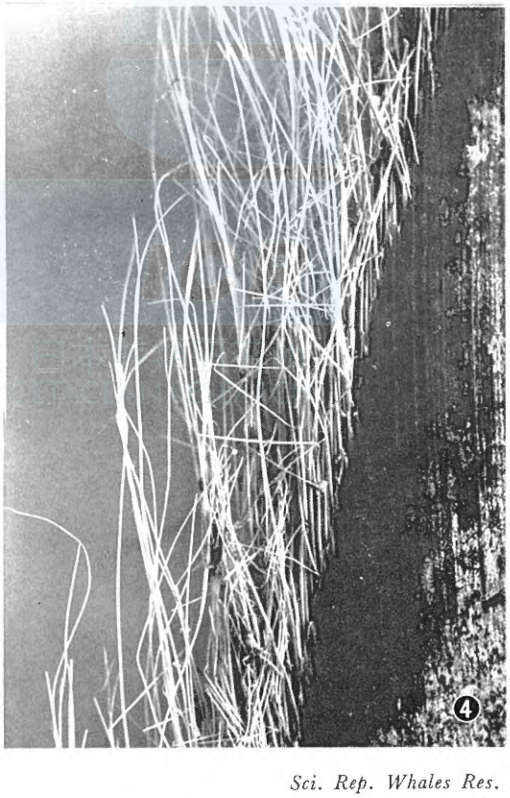

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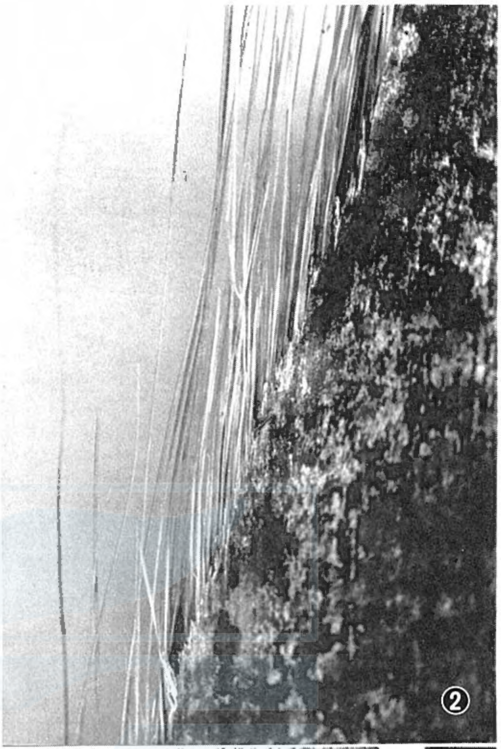

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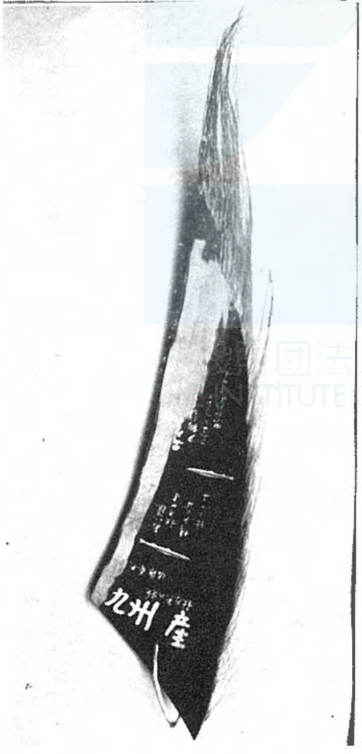

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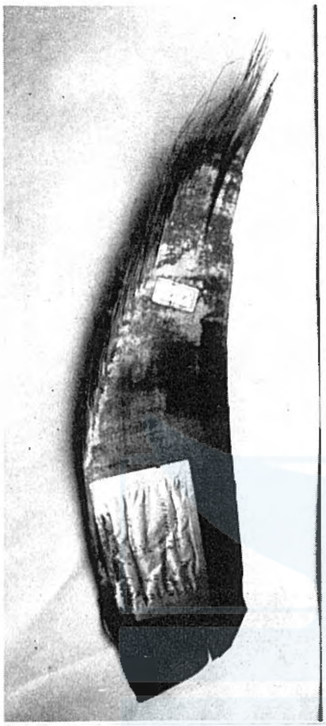

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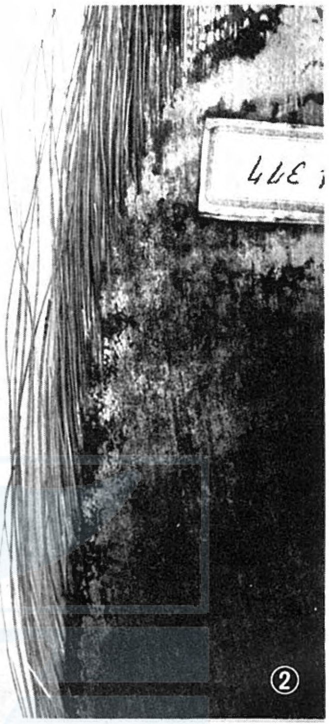

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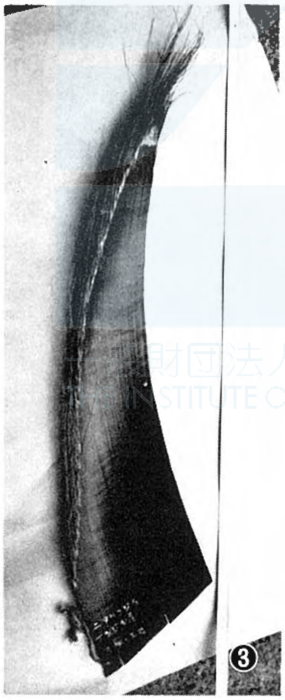

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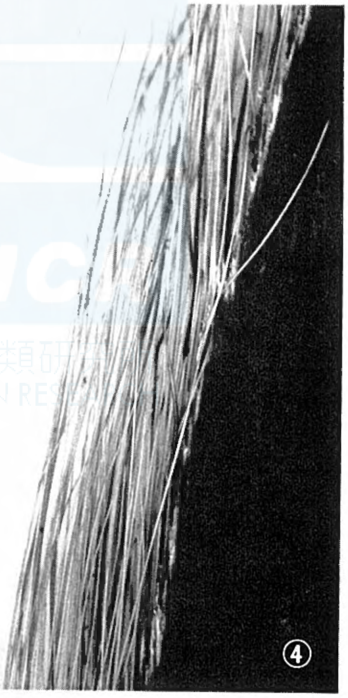

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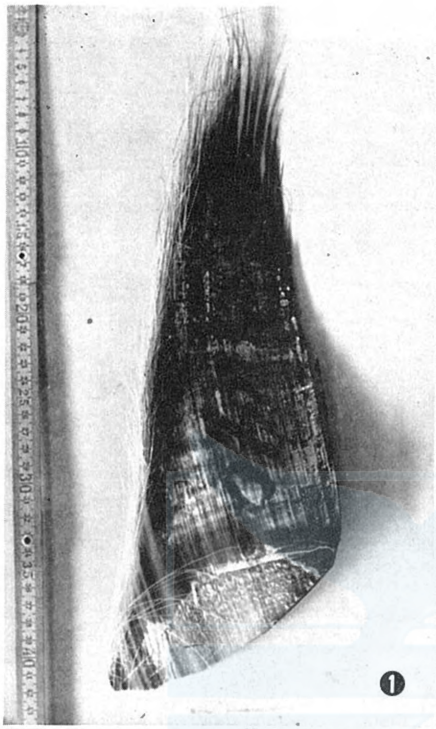

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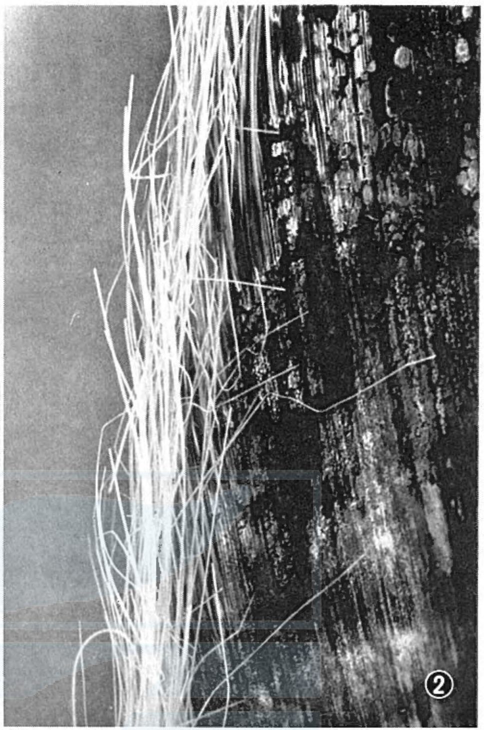

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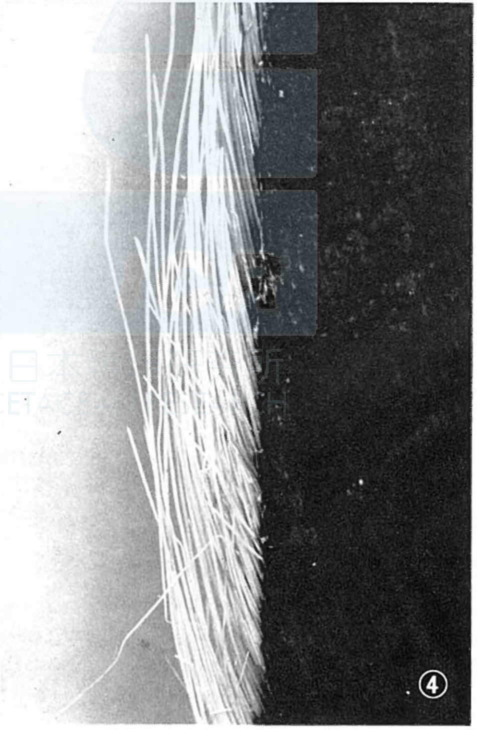

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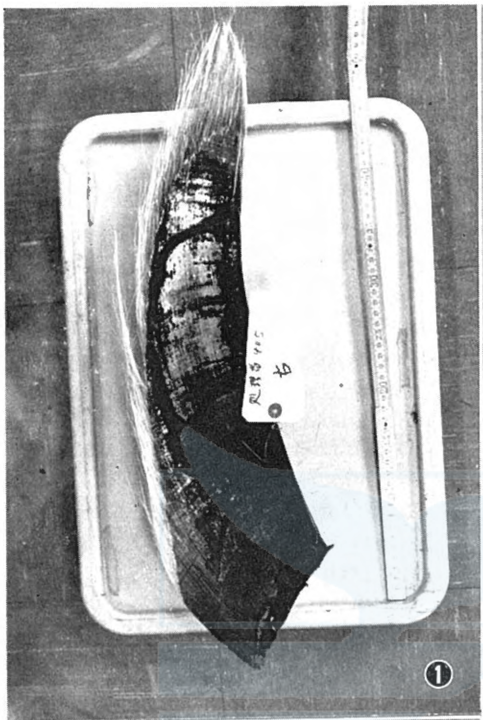

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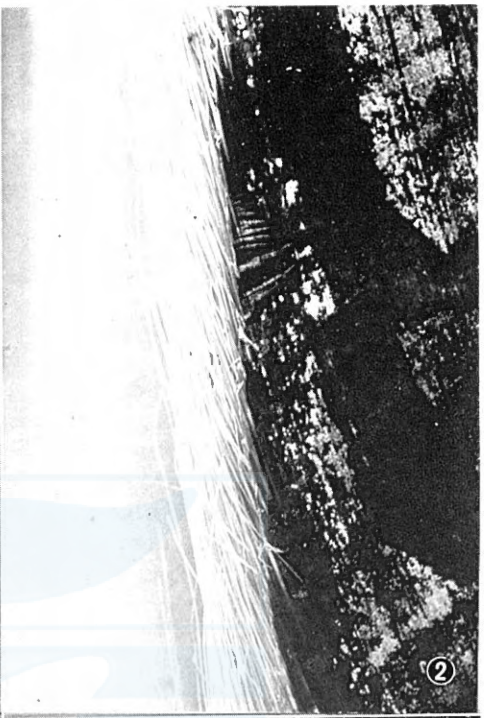

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# A MATHEMATICAL CONSIDERATION ON THE FUNCTION OF BALEEN PLATES AND THEIR FRINGES

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## ABSTRACT

Many have suggested that baleen fringes are adapted to the food that is caught and strained by baleen whales. A study reported here suggests that the situation is slightly more complicated.

In balaenopterid whales, the baleen is arranged so that when the jaws are opened more than about 15 degrees, the mouth becomes open all the way to the rear of the mouth, making filtration impossible, but allowing freedom of movement in the jaws when the whale is making large gulps. The baleen plates are curved, which makes them rigid in the center of the baleen row, while making them flexible around the margin, which is interpreted as producing a sealing zone that prevents openings from developing in the baleen while the whale is straining his food.

The fringes, of taxonomic interest, vary in characteristics in the same whale. There are actually at least 2 different kinds in the fin whale—a large kind and a small kind. The fringes give the baleen plate an internal structure that is grainy, like wood. This brings about a striking phenomenon—the more acutely the plate's edge cuts across this grain, the fewer fringes can be produced by the plate in this region. Therefore, where the plate edge is very steep, as in the right whales, the diameter of the fringe must be very small to make up for this shortcoming. A sei whale was found where the angle was zero degrees between the edge and the grain, and correspondingly, no fringes at all were on the plate at this level.

A mathematical formula was developed that relates fringe characteristics with baleen plate characteristics. Several shortcomings to this formula are mentioned.

## INTRODUCTION

As is fairly well known, the whalebone whales have a specialized feeding structure involving hardened, keratinized palatal rugosities[*] (Barge, 1936, p. 43)

[*] There has been some doubts expressed in the literature as to what constitutes the true mammalian palate in the whalebone whales, with Cuvier and a number of authors believing that the baleen stands upon the regular mammalian palate, while Eschricht believed that the regular palate took in only that surface exposed within the area covered by the baleen, the latter area being thus a new addition to the mammalian palate. The matter was last considered by Freund in 1912, who decided that the baleen were to be considered what Cuvier had held them to be—palatal rugosities standing upon the regular mammalian palate.

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*No. 28, 1976, 37–55.*

extended into the form of a series of transversely arranged plates on each side of the upper jaw (Tomilin, 1957, p. 6). Teeth are only present during a transient embryonic stage (Ridewood, 1922). The palatal plates, also known as baleen or whalebone, and popularly called "gills" or "strainers" by those involved in the whale fishery, are more related to hair in structure and composition than to bone, which the term whalebone deceptively implies. Whalebone is composed of a large number of hairlike tubules arranged in parallel and cemented together by a matrix or marrow which becomes broken up on the internal edge of the

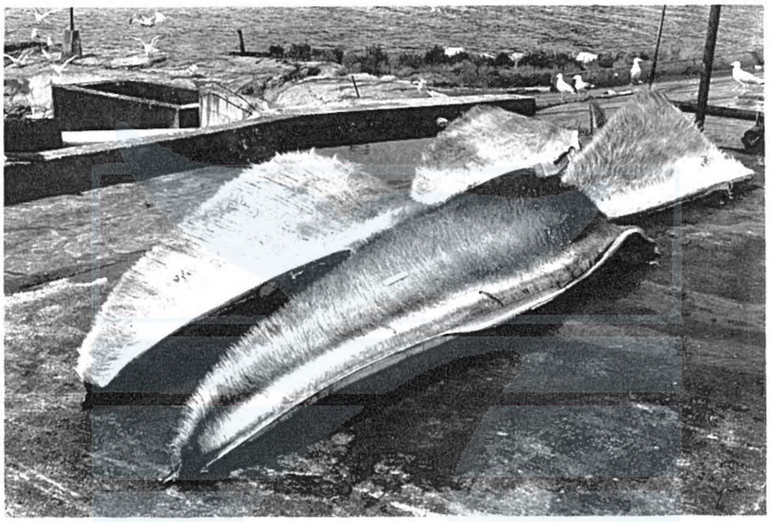

Fig. 1. The left baleen rows of a fin whale (in front) and of several sei whales (to the left and behind).

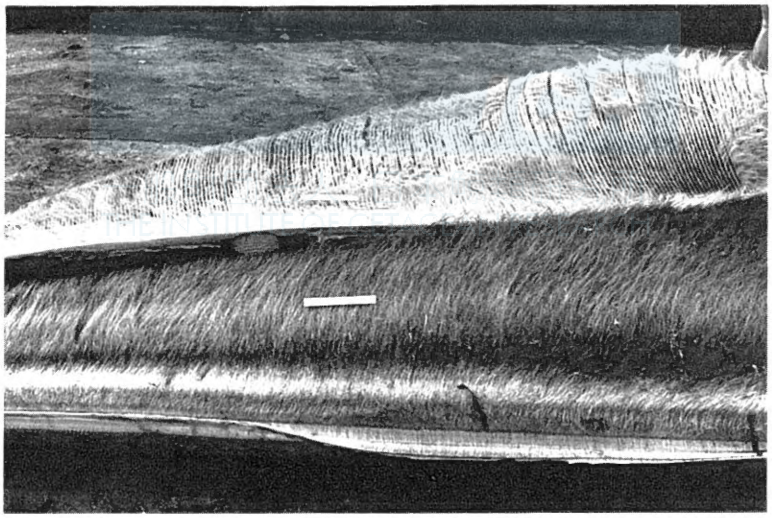

Fig. 2. The fringes and baleen of a fin whale (in front) and a sei whale (behind).

plate by friction against the tongue which releases the tubules, that then form a tangled fringe along the border of the plate (Turner, 1873; Tullberg, 1833; Tomilin, 1957 (1967)). These freed tubules are usually referred to as bristles or fringes. Since the term "bristle" is also used for the sensory hair fibers or vibrissae found on the surface of the head and jaws in whalebone whales, as well as for the bristle-like anterior serial homologs for the baleen plates in the front of the palate, the term "fringe" is used here. The fringes obstruct the slitlike spaces between the palatal plates, and form a layer or screen on the internal margin of the plates, typically concealing the latter from view from within the mouth (Figs. 1 and 2). The baleen plates and fringes are known to differ in several ways from species to species, so that they have taxonomic value, while it has also been suggested that the characteristics of the palatal plates and the fringes are adapted to the nature of the food taken by each species, depending on whether the food is minute, consisting of copepods (right whales and sei whales), or krill, a Euphausid crustacean (blue whale), or fish (fin whale, minke whale, humpback whale) (Tomilin, 1957; Nemoto, 1959; and personal observations made on northwest Atlantic whales). It is generally held that finer fringes are necessary for trapping finer sizes of plankton, and that coarser fringes are needed for imprisoning fish and krill (Nemoto, 1959, p. 155). Nemoto believes further that it is the fringe fineness and not the fringe density that influences or is correlated with food preferences.

## WHALEBONE FORM AND CONFIGURATION

The whalebone, as already mentioned, is composed of a series of plates that form a uniformly graded series from the front of the mouth, or tip of the snout, to a level somewhat behind the eye, on a greatly enlarged palate. In all baleen whales, the baleen on either side of the mouth is separated at the rear by the median palatine keel, while in front, the baleen is separated by a space in the right whales (Eschricht and Reinhardt, 1861; Nemoto, 1959), while they are joined by a series of coarsely bristle-like serial homologs to the palatal plates in the balaenopterid whales or rorquals, the latter term being understood to include the genus *Megaptera*. This crossband is called among other things the *Zwischenband* by Freund in his studies of the cetacean palate (loc. cit.). The zwischenband has been presumed to have a functional significance, although this function is not yet known. In bulk, it is only a tiny fraction of the entire structure of baleen on the palate, so that its consequences would seem to be minimal. It is probably a secondary condition, for it is absent in the gray whale as well as in right whales.

The skull has a long, flattened rostrum to support this straining apparatus which is entirely confined to the oral cavity. The absence of a cheek, in which place there lies exposed a spacious vestibulum oris s. pariacoel in front of the angle of the mouth, permits the angle of the mouth to lie very far posteriorly, behind the eye, giving the head a reptilian appearance that has been recognized by others (von Schulte, 1916). The cheek's absence is correlated with the absence of cheek teeth and any form of mastication. The enormous palate is supported by specialized processes of the maxillary bone that reach backward, and which have been described by G. S. Miller (1923) as a part of the telescoping of the cetacean skull.

Transversely, the baleen is separated into a single dominating large triangular plate, that tends *en masse* to close the oral cavity on each side from above, and a number of ribbonlike medial platelets, of variable form, that are short and occupy a linear zone between the main lateral plates externally and the smooth median palatal crest or keel that forms a prominent longitudinal arch along the middle of the roof of the mouth. The terminology for these variable features of the baleen has been discussed by Williamson (1973). In the fin whales of the northwest Atlantic, the medial platelets are coalesced into a small triangular platelet that sometimes even fuses with the main lateral plate. The baleen closes the entire side of the mouth, except for an oval opening in front, when the jaws are opened on the order of 10 to 15 degrees. It is interesting to note that an opening of the mouth greater than this quickly or abruptly opens the mouth cavity all the way to the rear, and thus completely frees the lower jaw from the whalebone on the upper jaw. The lower jaw, thus freed, is allowed to adopt any number of configurations permitted by an intramandibular kinesis, to which it is known to be adapted (Lillie, 1910, p. 99). These facts have led to two contrasting hypotheses related to feeding in the rorquals; the first is continuous feeding supposed while the jaws are open on the order of 10 to 15 degrees, and the second is the supposition of intermittant "gulping" or engulfment of dense swarms of the prey. The smallness of the forward aperture in the rorquals when the jaws are open 10 to 15 degrees argues against the continuous mode of feeding in the rorquals, for filter-feeding vertebrates have a clearcut tendency to develop large mouths that are closed on the side. Nearly all the anatomical structures that are here described and elsewhere during this study all suggest that the rorquals feed by the engulfment of swarms of prey, rather than by true filter-feeding, which seems to be confined to the bowhead and the right whales, where there is also a large opening formed in the front of the mouth.

The main lateral plate of the rorqual palate approximates a right triangle whose short base is lodged within a matrix on the ventral surface of the palate, and whose other edge stands externally, so that the hypotenuse sweeps along the internal face of the plate and produces and supports the fringes that line the internal border of the baleen (Fig. 3). The triangle has a curve along its length, causing the apex of the plate, which projects downward into the oral cavity, to be situated further laterally than the lateral edge of the plate's base secured to the rostrum. This character of the baleen plates in the rorquals forces a complication upon the jaw kinetics which has not been generally recognized; namely, the mandibular rami must rotate around the baleen during opening and closing of the mouth. This rotation may be seen in whales brought

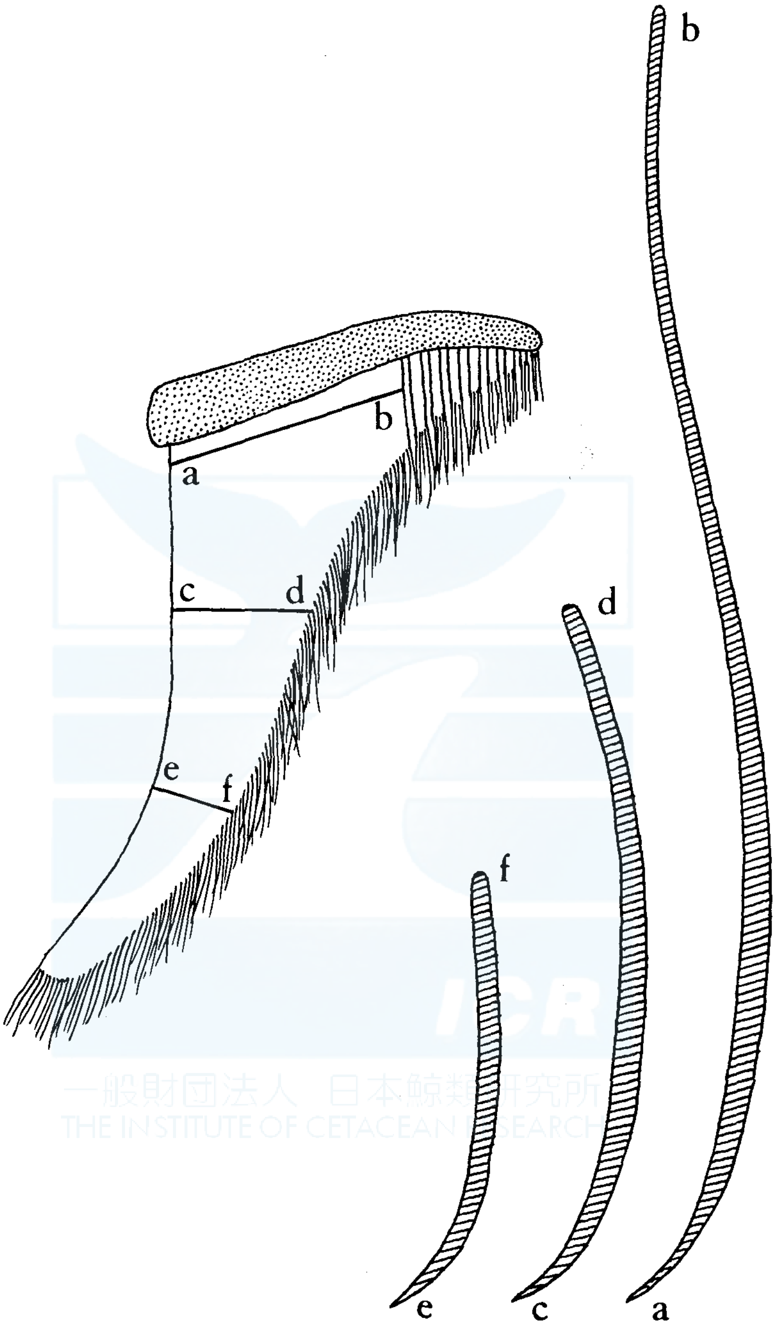

Fig. 3. A sei whale baleen plate and its curvatures, diagrammatically shown.

up and processed during flensing, and is controlled by the adducter jaw musculature, as was demonstrated by Lillie (loc. cit. p. 99). This complication is not indicated in the classical diagrams demonstrating the feeding mechanism of balaenopterid whales, where the outward sweep of the whalebone is usually not indicated. This is by and large due to the fact that these diagrams were based on foetal material, where the outward sweep of the adult stage had yet to appear. The baleen appears relatively late in embryonic life, so that its general configuration can only be seen in postnatal specimens.

In cross-section, the plates show another bend or curve, that was earliest recognized by Scoresby in the bowhead (1810, p. 579). In the rorquals the plates are concave posteriorly and convex anteriorly, giving a sinuous course to the slitlike spaces that pass between consecutive plates (Fig. 3). This curve has been found to give rigidity to each plate, and at least makes them resist deformation in the central area of the baleen when considerable pressure is brought to bear on them. This circumstance must be considered as applicable only to the rorquals, for the extremely flexible plates of balaenid whales suggests an entirely different situation, as has been recognized by Nemoto (loc. cit. p. 154) and Tomilin (1957). In the rorquals, the lateral edge of each plate terminates as a thin blade with a sharp edge, which on the other hand is relatively flexible and yielding, and curved rather sharply to the rear. When the mouth closes to less than 15 degrees, these edges are apparently pressed together, closing or reducing the spaces between the plates. When the mouth is slightly open, the spaces are apparently closed ventrally and left open dorsally to convey exiting water away from the cavity of the mouth, especially through the spacious vestibulum oris lying immediately in front of the angle of the mouth posteriorly.

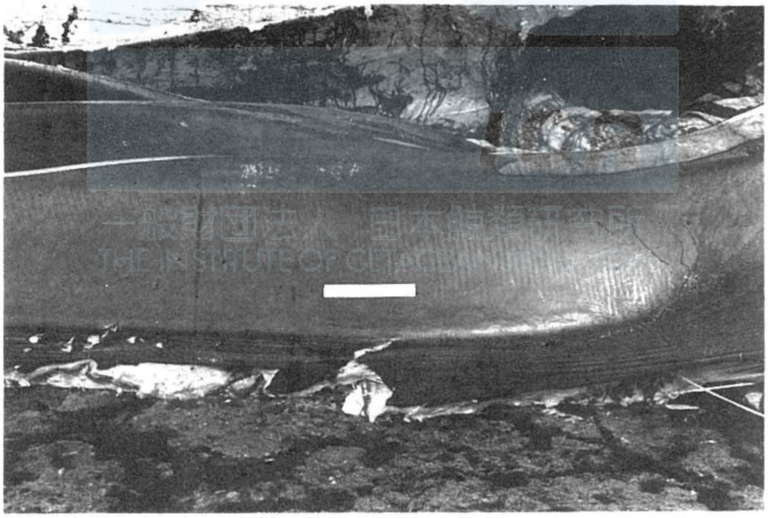

Fig. 4. A closeup view of the ridged surface contours on the medial face of a fin whale mandible. The ruled marker is 6 inches or approximately 15 centimeters.

In this way an effective seal can be made between the baleen and the lower jaw while food is being strained out of the water. These relations are fairly plain when one examines the baleen *in situ* on fresh specimens. The close or intimate relation indicated above between the palatal plates and the lower jaw can be further demonstrated by the typical presence of furrows and ridges impressed upon the medial face of the lower jaw, which matches the pattern and spacing of the baleen plates, and suggests considerable pressures brought to bear between the lower jaw and the distal region of the whalebone in balaenopterid whales (Fig. 4). These furrows and ridges on the mandible are not a post mortem artifact of towing the whale in for processing, as this produces patches of freshly exposed dermis next to zones where the baleen is shredded into long ribbons along its grain.

Whereas the palatal plates of the balaenopterids are relatively short, sturdy, and apparently subjected to considerable stresses, the whalebone plates of the right whales are very long, narrow, and straplike, and extremely flexible, even in dried specimens. What flexibility the rorqual baleen has is lost when preserved as a dry specimen.

## CHARACTERISTICS OF THE FRINGES

The fringes are formed by abrasion of the tongue against the edges of the palatal plates. In life they are limp, extremely flexible, and elastic, capable of being stretched a good fraction of their length without breaking. This is not the case in dried study specimens. The fringes lie freely against the baleen in any direction, according to the current conditions that might dominate in their vicinity of the mouth. A randomly-woven net or mat thus has a tendency to form over a large portion of the plates, where intricate entanglement forces the fringes to stay close to the margins of the plates for much of the fringes' length. This tangling tends to vanish along the distal apex of the baleen, and along the medial margin, where the small medial platelets stand adjacent to the exposed palatine crest.

The fringes vary in characteristics along the edge of the palatal plates, and may actually be classified into different sorts (Figs. 5 and 6), which produces a complication that must eventually be reckoned with when quantitative relationships or taxonomic criteria are developed for more detailed comparison of fringes and fringe density between whale species.*

The fringes along the apex or distal tip of the baleen are stiff and coarse, and do not become tangled. The whalebone matrix may be slow to erode away from the fringes here, or else a process of splitting in the plate takes place here, to help bring about making larger and stiffer filaments, which helps give the ventral margin of the baleen the appearance of a brush along its length (Figs. 1 and 2). As already remarked, this portion of the baleen is apparently trapped

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* Rund (1940, p. 6, figs. 2 and 3) illustrates these two sizes of fringe for a fin whale.

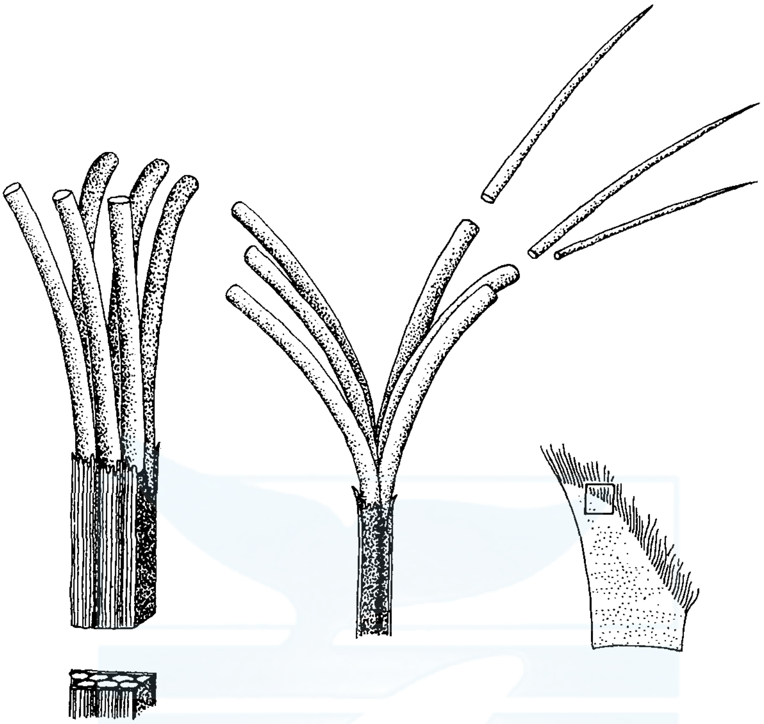

Fig. 5. The characteristics of the fringes from the distal region of the baleen plates of a fin whale. Only one large type of fringe is present.

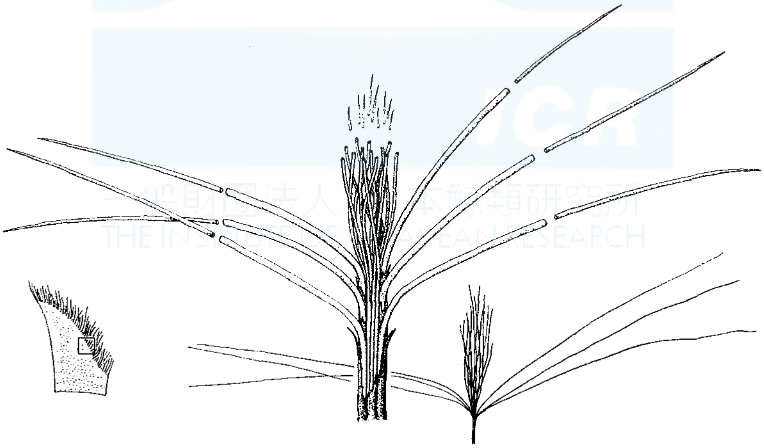

Fig. 6. The characteristics of the fringes from a more proximal portion of a baleen plate from a fin whale. The fringes are arranged into two kinds in three series, a smaller kind of fringe being intercalated between the two outer rows of large fringes.

between the floor of the mouth and the tongue medially and the lower jaw laterally during feeding, effectively sealing the opening between the lower jaw below and the palatal plates above with an extremely dense set of stiff coarse fringes. Toward the median line, coarse fringes persist somewhat in the fin whale, as two layers, adjacent to each face of the plate, giving the face a grained, grooved appearance to its surface. These fringes gradually become finer as the medial side of the plate is reached. Between these two layers of long and coarse fringes there appears a finer, shorter type of fringe, which the rest of the thickness of the plate supplies, so that the thicker the plate is locally, the more of these finer fringes are accommodated (Fig. 6). They may be as short as one centimeter or even less, in contrast with the coarser variety, that often reaches 20 centimeters in length. The finer fringes come to dominate in number medially, giving the baleen of the fin whale a fine white silky appearance (occasionally with black patches of pigmentation that interrupt this texture with a darker shade of fringes). The most medial fringes are supported weakly by rows of medial platelets, in such a manner that slight pressure applied to the layer of fringes here, as produced by the palm of one's hand, causes the collapse of the ribbons or platelets of whalebone underlying the fringes. This region of the baleen also appears to be relatively densely fringed, although it has yet to be demonstrated objectively. It may also be interpreted as a zone of sealing, where the complex of fringes and whalebone platelets collapses during the feeding cycle to form a mildly water-resistant barrier that prevents openings from developing and enlarging into the thinner screen supported by the main lateral plates. By various means the fringes also appear to increase in density toward the front of the mouth (by the closer approximation of plates) and posteriorly (both by closer approximation of plates and change in plate configuration). In this way the whalebone appears to be completely surrounded by a region that prevents the development of openings in its margin while filtration is taking place (see also below). It is here suggested that not the entire screen surface of the baleen takes part in the actual act of filtration, but only a semiovoid area in the central and rearward portion of the whalebone. At any rate, the marginal area takes on a second function, if it does filtration as well, of acting as an intermediate sealing area that prevents openings from appearing and growing while the food is being strained from the water. This consideration would prevent a simple relation from appearing when a comparison is attempted between the total screen areas of different species of mysticete whales for the purpose of attempting to determine relative feeding efficiencies between species, unless the filtering, active portion of the baleen is proportionate throughout all the rorqual species.

In a relationship with water isomorphic or similar to Ohm's law for electric currents, water is determined to flow along the path of least resistance, and so would seem to be mostly confined to the central region of the whalebone series, where the fringe density appears to be minimum (see also below), and where the plates are most rigid and most widely separated, so that closure between plates during stress cannot ordinarily take place. The relative contributions of these two factors, first the plates themselves locally closing around the margins to shut out a water current, and second the relative different densities of fringes around the baleen, has yet to be determined. In the event that the second factor should prove to be relatively significant, methods of determining or calculating fringe density would be needed to establish the part that the fringes play during the feeding cycle. That a current regime is set up within the mouth that involves water flowing along the path of least resistance, which can be structurally controlled to some degree, has previously been suggested in relation to the function of the gill slits and gill rakers of fishes (Galbraith, 1967).

Certain of the relations between the fringes and the palatal plates are demonstrated in Table 1, where fringe counts were made along with other measurements, of three consecutive plates taken from approximately the middle of the row of a 56-foot male fin whale taken by the Atlantic Whaling Co. at Williamsport, Newfoundland, in 1972. Each plate was divided horizontally, or perpendicular to its grain, or the course of the tubules within its substance, into 3 centimeter ribbonlike units. For each such unit, the number of fringes it contributed along the plate edge was counted. This was converted into a density per transverse centimeter. Secondly, it is important to note that the inner edge of the plate cuts the grain of the tubules at an angle, so that the fringes, relatively dense when considered per transverse or horizontal distance, are thinned out by having to be spread along a longer edge than this, over a variable length. This relationship holds for all whalebone whales, and has notable consequences for the narrow plates of the right whales.

Thus, as the table shows for the first fin whale plate, in the ribbonlike unit between 12 and 15 centimeters from the medial edge of the plate, a total of 285 fringes, or 95.1 per transverse centimeter, both of the coarse and fine variety, pass to the edge of the plate. Since, however, the edge of the plate makes an angle of only about 11.5 degrees with the tubule grain at this location, the edge of the plate corresponding to this portion of the baleen is 15.2 centimeters long, to produce a density of only 18.8 fringes per direct centimeter of edge. The sine of 11.5 degrees is approximately .197, and, correspondingly, 3 cm./15.2 cms. is .197, and .197×95.1 fringes per transverse centimeter yields the observed 18.8 fringes per direct edge centimeter. Thus the steeper the edge of the plate, and the more acutely it cuts the angle of the plate's grain, the more thinned out are the fringes. Thus, as can be seen in the table, the thinnest densities tend to occur along the middle of the edge of the plate, where the plate is steepest, notwithstanding the fact that it is also relatively thick in cross-section here as well, and so relatively densely fringed when considered by transverse or horizontal units of distance. Local irregularities in plate form, which commonly occur, prevent a perfectly smooth trend in fringe densities as taken along the plate's edge. The tables somewhat weakly suggest an increase in density distally, but this emerges from the increased fringe size that predominates here. Likewise, the increase in density is only weakly suggested medially. Here the

TABLE 1. FRINGE AND PLATE PARAMETERS MEASURED FOR THREE CONSECUTIVE BALEEN PLATES TAKEN FROM THE MIDDLE OF THE BALEEN ROW OF A 56-FEET MALE FIN WHALE TAKEN IN NEWFOUNDLAND, 1972. FOR FURTHER EXPLANATION OF THE PARAMETERS SET FORTH IN THIS TABLE, SEE THE TEXT.

| | Position of plate portion counted | Number of fringes in 3 transverse or horizodtal cms. | Number of fringes in 1 transverse centimeter | Length along edge corresponding to the 3 cm counted | Number of fringes per cm. of direct edge | Plate thickness in mm. | Sin $\theta$ |
|---|---|---|---|---|---|---|---|
| baleen plate no. 1 | 0- 3 | 102 | 34. 1 | 3. 9 | 26. 2 | 1. 35 | . 769 |
| | 3- 6 | 124 | 41. 3 | 7. 1 | 33. 8 | 1. 95 | . 423 |
| | 6- 9 | 170 | 56. 7 | 9. 3 | 18. 3 | 2. 75 | . 323 |
| | 9-12 | 194 | 64. 6 | 10. 3 | 18. 8 | 3. 23 | . 291 |
| | 12-15 | 285 | 95. 1 | 15. 2 | 18. 8 | 3. 70 | . 197 |
| | 15-18 | 264 | 88. 0 | 14. 1 | 18. 7 | 3. 75 | . 213 |
| | 18-21 | 211 | 70. 3 | 8. 1 | 26. 1 | 3. 49 | . 371 |
| | 21-24 | 135 | 45. 0 | 8. 1 | 16. 8 | 3. 02 | . 371 |
| | 24-27 | 85 | 28. 4 | 3. 7 | 26. 6 | 2. 80 | . 937 |
| baleen plate no. 2 | 0- 3 | 118 | 39. 4 | 4. 0 | 45. 0 | 1. 69 | . 750 |
| | 3- 6 | 137 | 45. 7 | 7. 5 | 18. 3 | 1. 94 | . 400 |
| | 6- 9 | 187 | 62. 3 | 9. 6 | 19. 5 | 2. 03 | . 312 |
| | 9-12 | 234 | 77. 9 | 11. 0 | 21. 3 | 2. 42 | . 273 |
| | 12-15 | 314 | 104. 5 | 14. 6 | 21. 5 | 3. 52 | . 206 |
| | 15-18 | 305 | 101. 5 | 14. 6 | 20. 9 | 3. 89 | . 206 |
| | 18-21 | 213 | 71. 0 | 8. 0 | 26. 6 | 3. 54 | . 375 |
| | 21-24 | 157 | 52. 4 | 8. 2 | 19. 2 | 2. 80 | . 366 |
| | 24-27 | 79 | 22. 3 | 3. 0 | 26. 3 | 2. 47 | 1. 000 |
| | 27-30 | 22 | 7. 3 | 3. 0 | 7. 4 | 1. 11 | 1. 000 |
| baleen plate no. 3 | 0- 3 | 124 | 41. 3 | 4. 2 | 29. 5 | 1. 40 | . 714 |
| | 3- 6 | 134 | 44. 7 | 7. 6 | 17. 6 | 2. 00 | . 395 |
| | 6- 9 | 184 | 61. 4 | 9. 1 | 20. 2 | 2. 20 | . 329 |
| | 9-12 | 229 | 76. 3 | 10. 6 | 21. 6 | 3. 05 | . 283 |
| | 12-15 | 308 | 102. 8 | 13. 6 | 22. 7 | 3. 20 | . 220 |
| | 15-18 | 294 | 97. 9 | 14. 1 | 20. 9 | 3. 52 | . 213 |
| | 18-21 | 204 | 71. 3 | 8. 7 | 23. 5 | 3. 49 | . 345 |
| | 21-24 | 146 | 48. 6 | 8. 6 | 17. 0 | 2. 68 | . 349 |
| | 24-27 | 88 | 29. 3 | 3. 6 | 24. 5 | 2. 58 | . 833 |

plates are relatively more numerous than their counterpart main lateral plates, and so provide a surplus of fringes in the medial palatal zone.

It will also be found that plate thickness is positively correlated with the number of fringes per transverse or horizontal centimeter of plate for these three fin whale plates. This correlation is only weakly developed for the fin whale, however, due to the presence of two different kinds of fringes. There is one linear regression from the lateral edge of the plate to its center, where the large fringes dominate and the plate is relatively thicker to support them, and another regression from the center to the medial edge, where the finer fringes dominate. A stronger correlation may perhaps be found in other whales, if there is not the same strong distinction between two different classes of fringes.

## QUANTITATIVE CONSIDERATIONS

The fringes of the whalebone are the functional portion of the baleen, that actually take part in capturing or imprisoning the food. The mechanism apparently varies with the food item. Copepods and other minute plankton may be strained out of the water somewhat inefficiently by sang mechanisms, while larger krill and fish are more easily and effectively retained by being too large to pass between the fringe filaments and are thus imprisoned within the oral cavity, much as the food of many fish is impounded in the branchial chamber by the gill rakers. If the fringes were absent, most of this food, including fish, could probably escape between the palatal plates, that are more to be considered a structural support for the layer of fringes which permits at the same time an exit for water passing through the screen. This "fishproof" filter is comparable in design with that of the whale shark, *Rhineodon typus*, which was described and figured by Gudger in 1941. This filter may be contrasted with that of the basking shark, *Cetorhinus maximus*, the latter depending in part on the aid of mucus secretion to help snag food out of the water. That mucus often figures in filter feeding indicates the innate inefficiencies that are usually present in true filter feeding mechanisms. Kawamura (1974) has presented evidence indicating a similar inefficiency probably being present in the straining mechanism of the sei whale. The whale shark, with its "fishproof" filter is known to prey on fish schools (Gudger, 1915), while the basking shark is confined to feed on more relatively inert plankton (Schnakenbeck, 1955), since its filter apparatus is not particularly effective in restraining fish, as is also the case with the filter-feeding Mississippi paddlefish, *Polyodon spathula*, (Imms, 1904). Due to the effect of a boundary layer in moving fluids, snagging mechanisms in filtration apparatuses are likely to be inefficient (for a reference to boundary layer phenomena, cf. Schlichting, 1968).

The denser the layer of fringes, the more effectively it retains food, but the harder it is to pass water through it and out between the plates, so that fringe density has a minimum and maximum level between which there must lie an optimum condition. This optimum condition will have a certain degree of inefficiency, depending upon the type of food. The density of fringes covering the baleen palatal plates seems to be controlled by a number of factors, no one of which necessarily may stand out from species to species, according to the preliminary observations so far made on various whalebone whales. That fringe density is apparently correlated with the hydrodynamics of the whale's feeding mechanism implies what Nemoto (loc. cit.) suggested, that fringe density is not primarily correlated with food type (p. 155).

Fringe density can be formulated in several different ways: either as the total surface area of fringes per unit of screen surface, or as the total fringe volume per unit of screen area. It may also be conceived as a total length of fringes confined to each unit of area. Comparison between right whales and sei whales with such balaenopterid species as the fin whale shows that fringe radius plays an important role in affecting the density. This excludes the density parameter expressed as the total length of fringes confined to each unit of area from consideration. The fact that fringe filaments can be approximated as narrow circular cylinders allows the implication that volume is kept at a minimum while fringe surface area is made large. Volume density would indicate the quantity of material obstructing the passage of food out through the baleen plates, and could also be correlated perhaps with another potentially useful parameter, porosity. Surface area density on the other hand would indicate the physical interaction possible between the fringes and the water passing through them. Doubling the volume by doubling fringe length doubles the surface area as well. Doubling fringe radius on the other hand quadruples the volume while only doubling the surface area, thus making the volume version of the parameter more sensitive to variations in fringe size. This quadrupled fringe volume density can be easily appreciated in comparing the baleen of the sei whale with that of the fin whale (Figs 1 and 2). Note that the denser and more coarsely fringed surface of the baleen in the fin whale quite effectively conceals the plates lying underneath. This effect is best brought out by considering fringe density as the total volume of fringe filaments per unit of screen surface area. At any rate, the expressions for fringe volume and fringe surface area differ simply by a factor of r, the fringe radius, when expressed as proportionalities.

We thus define the density as being proportional to the average volume, V, of a fringe, and the number of fringes, n, present:

$$d \propto Vn\,. \qquad (1).$$

The average volume of a fringe, approximated as a circular cylinder, is proportional to the square of fringe radius, r, and the average fringe length, l:

$$V \propto r^2 l\,. \qquad (2).$$

The number of fringes per unit of area is dependent upon several factors, which are as follows:

$n \propto l/w$, where w is the space between plates. Other factors being fixed, doubling the width between plate halves the remaining finge density.

$n \propto b$, where b is the width of the palatal plate's edge. Other factors being fixed, twice the plate edge thickness is assumed to acommodate twice the number of fringes provided by the plate. This can only be approximate, however, for as shown for the fin whale discussed above, there are 2 kinds of fringes involved, and doubling the thickness would affect only 1 of the 2 kinds involved, or both to different proportions.

$n \propto p$, where p is the density of fringe tubules per unit of transverse or horizontal section area of the plate (see also the discussion above, regarding Table 1). Doubling p doubles the number of fringes per unit area. This seems to be achieved in life by usually decreasing the average fringe radius, so that there is a tendency for p to be in part a variable dependent on r, and vice versa, which complicates this analysis, since it involves finding a formula for fringe density based on independent variables.

$n \propto \sin\theta$, where $\theta$ is the angle that the plate's margin forms with the vertical. (See also the discussion above regarding Table 1) Doubling $\sin\theta$ doubles the quantity of plate supporting a given surface area of the screen, and thus doubles the number of fringes arising in that area.

Combining these four proportionalities yields

$$n \propto p\frac{b}{w}\sin\theta\,. \tag{3}$$

Substituting (2) and (3) into (1) yields

$$d \propto r^2 l p \frac{b}{w}\sin\theta$$

or

$$d = k r^2 l p \frac{b}{w}\sin\theta \tag{4}$$

for some unknown constant of proportionality, k. Dimensional analysis of (4) shows that k has no physical dimensions.

Of the factors appearing in formula (4), several seem to be less variable than the remaining ones, although this is based on preliminary observations. In particular, w, the width between plates seems liable to least variation from one species to the next, although in any one individual, it tends to decrease by about half its value toward the front of the mouth and to the extreme rear. When too narrow, the space prevents easy flow of water through the baleen, whereas when too wide, it cannot satisfactorily support the fringes. In the latter case, the fringes are prone to disentangle and wash between the plates, opening up gaps among them. This has been observed to happen post mortem in several sei whales, which seem especially prone to show this variably developed, and in a fin whale (Fig. 8).

There is next to be considered the possibility of a web of interrelationships which would complicate the significance of formula (4), which is based in form on the ideal that all factors on the right-hand side are all independent variables. Placing these 6 variables on which fringe density depends into the simplest scheme, Figure 7, there emerges a set of ten possible complicating interrelationships, of which three seem at present to exist.

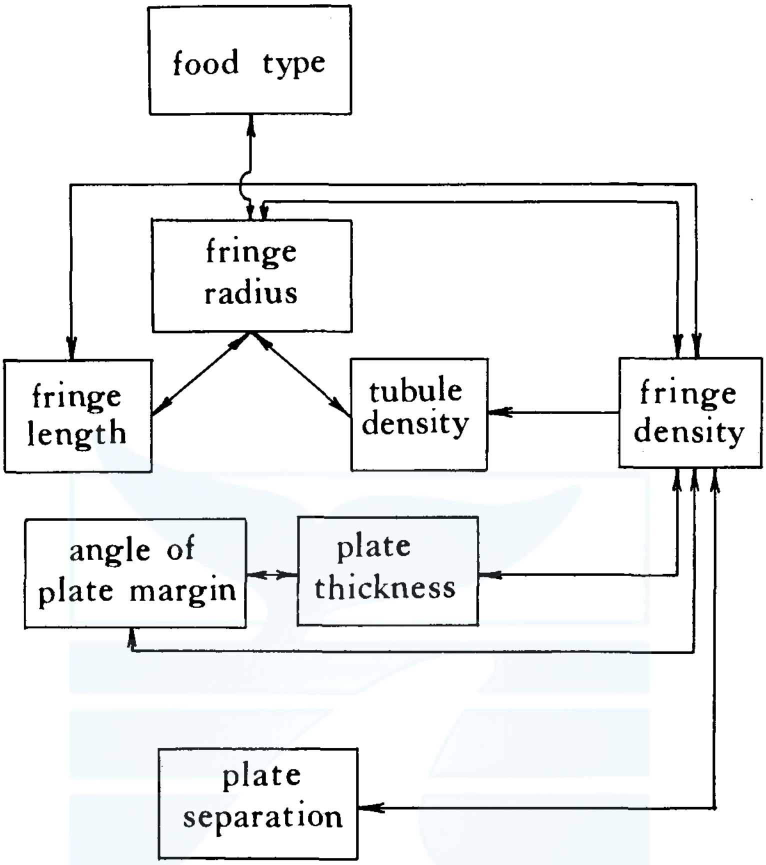

Fig. 7. The simplest scheme of interrelationships observed up to now in the characteristics of baleen plate form and configuration and fringe characteristics. For discussion, see text.

(1) Fringe radius-fringe length. It seems probable that increasing fringe radius entails an increase in fringe length, by virtue of making the fringe stronger and more resistant to wear. Graphing as a histogram the fringes of a fin whale yields a somewhat bimodal distribution of lengths, one mode long, for the fringes of larger radius, and another mode, among the shorter fringes, for those of smaller radius.

(2) Plate thickness-angle of plate margin. In balaenopterid whales, there appears to be valid grounds for believing that plate thickness increases with the angle of the plate's margin, first as an artifact of wear, and secondly as an element of design, an effect that strengthens the plate in that portion of the baleen where rigidity is necessary to keep the screen of the whalebone functional.

(3) Fringe radius-tubule density. In right whales especially, where there is a very steep plate angle less than 10 degrees, the tubule density of the plate

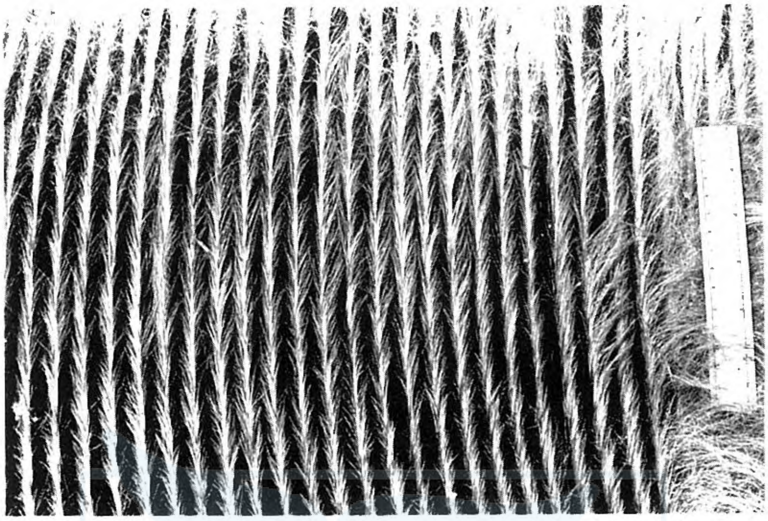

Fig. 8. Sei whale baleen, showing the manner in which the fringes may on occasion wash between the plates, which could result in feeding inefficiencies if of common occurrence. Such regions are extensively present in the sei whale baleen shown in fig. 2.

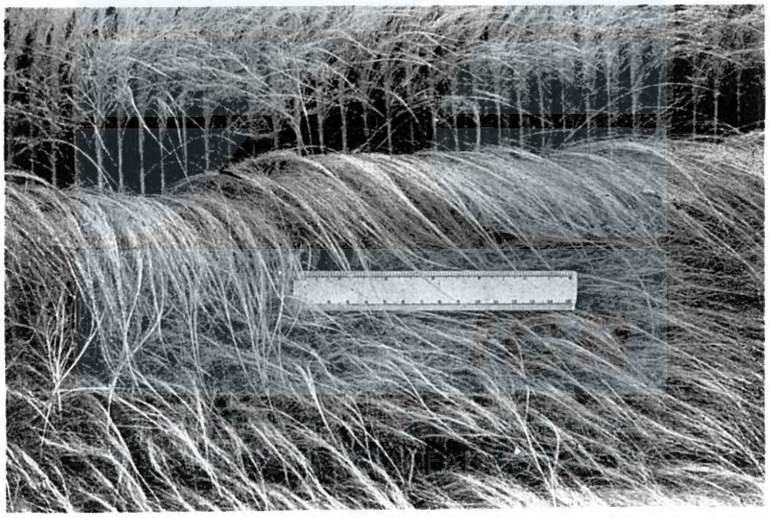

Fig. 9. A growth pace in a sei whale, from which no fringes arise. This zone is due to a weak development of the tubule matrix during that year's growth. The angle of the plate is here so steep that it is actually parallel to the grain of the plate.

must increase sharply to provide enough fringes to accommodate the long and very steep border of the plate. This has been made possible by a sharp reduction in the fringe radius, which is thus related to the increase in tubule density. On the other hand, if fringe diameter is the primary variable of concern, where it must be small to function well with the food concerned, then the plate must apparently have a steep angle to prevent the density of fringe filaments from exceeding an optimum level. In all events the fineness of the fringes of the right whale are correlated with the very narrow plate shape, whether or not they are truly correlated with the prey taken.

Formula (4) conveniently summarizes several of the phenomena that have been above noted in the baleen studied of the various species. One more instance is worth noting, regarding the sei whale. An individual was taken at Blandford, Nova Scotia, which shows the extreme consequences of the " right whale effect", where steepness of the plate's margin makes it difficult to develop a satisfactory supply of fringes along the border. By formula (4), an angle of zero degrees, which has a sine value of zero, implies that fringes disappear from that area entirely. Such regions have in fact been found in the steeper regions of the sei whale baleen, where, for one exceptional pace of growth, no fringes arise from the plate at all. This is matched more proximally with a bluntly-angled " step", where, by the formula, and as is evident in the photograph of Fig. 9, a proportionally greater density of fringes arises.

## CONCLUSIONS

1. There exist the following variables associated with the parameter of fringe density in whalebone whales:
   a. fringe radius
   b. fringe length
   c. tubule density of the plate
   d. palatal plate thickness
   e. angle of plate margin
   f. separation between plates.
2. These six variables may be combined to produce a formula expressing fringe density as volume per unit of surface area. The use of this formula is made complicated by at least 3 relations observed between the following variables:
   a. fringe radius—fringe length
   b. plate thickness—angle of plate margin
   c. fringe radius—tubule density.
3. In particular, the plate form is correlated with fringe characteristics by the presence of a trigonometric relation between the angle of the plate's margin and fringe density, and by plate thickness and fringe density.
4. The fineness of fringes is a sensitive variable that is correlated with plate shape. If fringe fineness is truly correlated with the food taken, it is also correlated with the angle of the baleen plate's inner margin, and thus with plate form.
5. The lateral edge of the baleen plate in rorqual whales follows a curve that sweeps outward, and which is everywhere closely related with the medial

face of the mandible when the mouth is closed. This relation is substantiated by the presence of furrows and ridges on the inner face of the mandibles (fin whale), which closely correspond to the configuration of the baleen.

6. The baleen plates are thickened and arched in several planes, and this provides a rigidity that resists closure of the plates by collapse in the central area of the baleen. This rigidity is in contrast strikingly absent around the margins of the baleen screen, which suggests the presence of a sealing zone that prevents gaps from developing during the feeding cycle.

## ACKNOWLEDGMENTS

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# ADDITIONAL INFORMATION ON SKELETON OF THE MINKE WHALE FROM THE ANTARCTIC

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## ABSTRACT

A skull and postcranial bones of the minke whale from the Antarctic, kept at the Irako Natural History Museum, were studied comparing with two other specimens reported previously by one of the present authors. In general the present specimen supported the observations made earlier, but the form of the pelvic bone is different and more study is needed in future in this respect.

## INTRODUCTION

Omura (1975) studied two skulls and postcranial bones of the minke whale from the Antarctic and found several characters which differ from the minke whale in the northern hemisphere. Since then we were informed that an another sample of bones is being kept at the Irako Natural History Museum in Aichi prefecture. These bones were taken by a request of the museum for display on 4 December 1973 on the Kyokusei Maru, a minke whaling factory ship which operated in the 1973–74 Antarctic season. Noon position of the ship of this day is 63°33′S and 120°16′E. A total of 36 minke whales were processed on this day, and from which a complete set of skeleton was collected, but there is no assurance that all of the bones were taken from single animal.

These bones were transported to Japan in April the following year and had been burried in sand nearby the museum for extraction of oil until January 1976. We were permited by the museum to investigate these bones after dug out from sand and prior to mounting for display. In this paper bones of this whale or the Irako specimen are compared with the two specimens (71J2793 and 71J2883) reported by Omura (1975).

## SKULL

The skull is comparatively large and its length is 2,266 mm. Size of this skull is compared with other two specimens in Table 1. As seen in this Table the skull of the Irako specimen is larger than that of 71J2793 but smaller than in

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*No. 28, 1976, 57–68.*

TABLE I. COMPARISON OF SKULL OF THREE SPECIMENS OF THE MINKE WHALE FROM THE ANTARCTIC

| | Irako | 71J2793* | 71J2883* |
|---|---|---|---|
| Condylo-premaxillary length (mm) | 2,266 | 2,115 | 2,350 |
| Breadth of skull, squamosal (mm) | 1,177 | 1,075 | 1,256 |
| Sex, Body length (m) | ? | M. 8.5 | F. 9.8 |
| Age | ? | Ad. 25 years | Ad. 39 years |

* Cited from Omura (1975).

71J2883, suggesting that this skull was obtained from a whale of about 9 m in length.

Omura (1975) found several distinctions which separate minke whales from the Antarctic from those in the northern hemisphere. In the form of the skull these are: 1. the rostrum is more rounded in dorsal view and flat in profile, 2. anterior margin of nasals is concave and no groove is present on inferior surface, 3. no triangle region is formed by frontal and parietal (or interparietal) at vertex, 4. hamular process of pterygoid is short and broad, and 5. lachrymal is large and rectangular. The present specimen of Irako agrees in general in all characters listed above. In Figs. 1 and 2 are shown the profile of the skull and form of pterygoid separetely, on which no further explanation would be needed.

In the region of vertex (Fig. 3), however, the shape of the frontal is somewhat different from the other two specimens. In the Irako specimen there are two thin projections of frontal towards nasals and they cover partly posterior ends of nasals and premaxillaries. At a glance the photograph shown in Fig. 3 resembles in some extent to that of the Matsushima specimen from the North Pacific (Fig. 4 of Omura, 1975), but the most important point is that in the Irako specimen no trace of parietal is appearing on the upper surface of the vertex and the nasals are situated very close to the supraoccipital bone, whereas in the Matsushima specimen the parietal present at the center of the vertex and nasals are at more anterior position. The form of nasals of the Irako specimen is quite similar to the other two specimens and their anterior margin is concave.

The shape of the lachrymal is similar in general, but shorter and broader than in the two specimens. Measurements of malar and lachrymal are given in Table 2.

Measurements of the skull are shown in Table 3. The percentage figures of measurements against skull length are also compared with two other specimens in the table. All measurements for the Irako specimen are very close to those of the two other specimens, excepting the measuremet no. 28 (tip of premaxillary to anterior end of vomer) in which the Irako specimen shows somewhat greater value. This means, however, a comparatively shorter vomer and which is thought to be subject to individual or age difference. In any case the specimens other than the Irako specimen are full grown animal of high

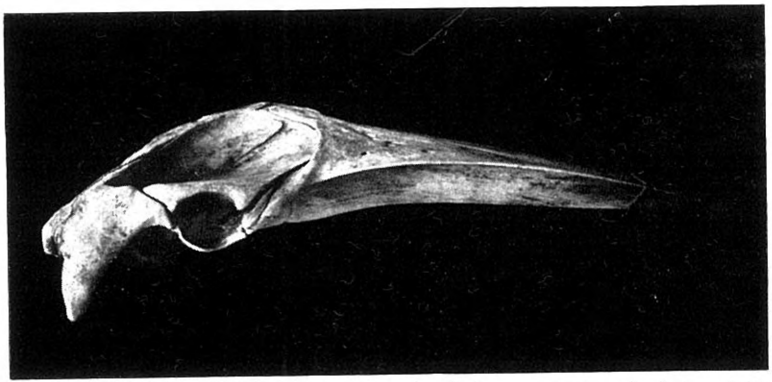

Fig. 1. Lateral view of the skull of the Irako specimen of minke whale from the Antarctic.

Fig. 2. Inferior view of the skull of the Irako specimen of minke whale from the Antarctic, showing the form of the pterygoid.

Fig. 3. Superior view of the skull of the Irako specimen of minke whale from the Antarctic, showing the vertex.

TABLE 2. MEASUREMENTS OF MALARS AND LACHRYMALS OF THE IRAKO SPECIMEN OF MINKE WHALE FROM THE ANTARCTIC (in mm)

| | Length, greatest | | Breadth at middle | |
|---|---|---|---|---|
| | Right | Left | Right | Left |
| Malar | 246 | 250 | 38 | 38 |
| Lachrymal | 348 | 229 | 105 | 106 |

age, but the age of this specimen is not known.

In the skull measurements Omura (1975) noted several distinctions among minke whale populations from the Antarctic, North Atlantic, and North Pacific. These are in the Antarctic specimen: 1. breadth of skull is narrower than in those from the other two oceans, 2. rostrum is longer than those from the North Pacific, 3. breadth of rostrum at base is narrower than those from the other two oceans, and 4, breadth at middle of rostrum is narrower than those from the North Atlantic. In these characters the figures for the Irako specimen (measurements nos. 10, 11, 12, and 16) are all within the ranges of the other two specimens as seen in Table 3, and no change of observation is needed. In conclusion the skull of the Irako specimen agrees well in general with the other two specimens from the Antarctic.

## VERTEBRAE

The character which separates minke whales from the Antarctic from those in the northern hemisphere in vertebrae is in the 7th cervical (Omura, 1975). In minke whales in the northern hemisphere the 7th cervical has parapophysis though it reduced to a tubercle, whereas the two specimens from the Antarctic were lacking parapophyses and no sign of tubercle was noted. Also in the Irako specimen parapophysis is lacking as seen in Fig. 4, but in this specimen there is very low elevation of bone on the surface of body or a sign of tubercle, though it is not clearly shown in the photograph. In this specimen the 2nd and 3rd cervicals are united at lateral margins of the spinous processes.

In total 48 vertebrae were preserved in the Irako specimen. These are 7 cervicals, 11 dorsals, 12 lumbars, and 18 caudals (Fig. 5), but the size of the 18th caudal is much larger than the expected size of the last, comparing with those of the other two specimens. It is possible, therefore, that the last caudal was missed when sampled and the vertebral formula of the Irako specimen should be C 7, D 11, L 12, Ca 19, total 49. This total number of 49 is in close agreement with the other two specimens which numbered 49 and 50 respectively.

In the Irako specimen the vertebral epiphyses are not all fused to their centra. Posterior epiphyses of the vertebrae from 3rd dorsal to and inclusive 2nd lumbar are not fused and in the 6th dorsal also anterior one is not fused. In all of the above vertebrae linea epiphysialis is quite visible even in those

## TABLE 3. SKULL MEASUREMENTS OF THE IRAKO SPECIMEN OF MINKE WHALE FROM THE ANTARCTIC, COMPARED WITH OTHER SPECIMENS

| | Measurements | Irako specimen | | 71J2793 and |
|---|---|---|---|---|
| | | in mm | % | 71J2883 (%) |
| 1. | Condylo-premaxillary length | 2,266 | 100 | 100* |
| 2. | Length of premaxillary, right | 1,600 | 70.6 | 70.4 - 72.8 |
| 3. | „ „ „ , left | 1,633 | 72.1 | 71.4 - 72.6 |
| 4. | „ „ maxillary, superior, right | 1,566 | 69.1 | 68.6 - 70.0 |
| 5. | „ „ „ „ , left | 1,586 | 70.0 | 70.0 |
| 6. | Tip of premaxillary to vertex | 1,668 | 73.6 | 71.9 - 72.8 |
| 7. | „ „ „ „ nasals | 1.445 | 63.8 | 64.5 - 66.0 |
| 8. | Length of nasals, median | 183 | 8.1 | 6.3 - 7.2 |
| 9. | Breadth of nasals, anterior | 118 | 5.2 | 4.6 - 5.8 |
| 10. | Length of rostrum | 1,502 | 66.3 | 64.0 - 69.4 |
| 11. | Breadth of rostrum at middle | 462 | 20.4 | 18.9 - 22.7 |
| 12. | Breadth of rostrum at base | 727 | 32.1 | 29.8 - 32.8 |
| 13. | Breadth across maxillaries at vertex | 236 | 10.4 | 8.8 - 10.1 |
| 14. | Breadth of frontal across nasals | 250 | 11.0 | 10.9 - 11.1 |
| 16. | Breadth of skull, squamosal | 1,177 | 51.9 | 50.8 - 53.4 |
| 17. | „ „ „ , frontal | 1,149 | 50.7 | 49.5 - 51.9 |
| 18. | „ „ „ , maxillaries | 1,113 | 49.1 | 46.9 - 48.7 |
| 19. | Length of orbit, frontal, right | 191 | 8.4 | 8.9 - 8.8 |
| 20. | „ „ „ „ , left | 192 | 8.5 | 8.8 - 9.0 |
| 21. | Breadth of occipital bone | 906 | 40.0 | 35.9 - 37.7 |
| 22. | Breadth across occipital condyles | 209 | 9.2 | 9.6 - 9.7 |
| 23. | Height of occipital condyle, right | 126 | 5.6 | 6.2 |
| 24. | „ „ „ „ , left | 123 | 5.4 | 5.9 - 6.0 |
| 25. | Breadth of foramen magnum | 72 | 3.2 | 3.3 - 3.4 |
| 26. | Height of foramen magnum | 100 | 4.4 | 4.6 - 5.4 |
| 27. | Length from foramen magnum to vertex | 628 | 27.7 | 27.7 - 28.6 |
| 28. | Tip of premax. to anterior end of vomer, median | 422 | 18.6 | 12.2 - 12.3 |
| 29. | „ „ „ „ „ „ „ palatine, median | 1,591 | 70.2 | 69.9 - 71.2 |
| 30. | „ „ „ „ posterior „ „ „ „ | 1,966 | 86.8 | 84.3 - 87.4 |
| 31. | „ „ „ „ „ „ „ pterygoid | 2,087 | 92.1 | 91.5 |
| 32. | Breadth across hamular processes of pterygoid | 234 | 10.3 | 9.9 - 10.0 |
| 33. | Length of mandible, straight, right | 2,186 | 96.5 | 97.2 - 97.5 |
| 34. | „ „ „ „ , left | 2,185 | 96.4 | 96.4 - 98.1 |
| 35. | „ „ „ , curved, right | 2,340 | 103.3 | 104.4-106.2 |
| 36. | „ „ „ „ , left | 2,330 | 102.8 | 104.0-106.9 |
| 37. | Height of mandible at coronoid, right | 267 | 11.8 | 13.2 - 14.3 |
| 38. | „ „ „ „ „ , left | 283 | 12.5 | 13.4 - 14.3 |
| 39. | „ „ „ „ condyle, right | 200 | 8.8 | 9.4 - 9.5 |
| 40. | „ „ „ „ „ , left | 208 | 9.2 | 9.6 - 9.9 |

* Actual length of skull is shown in Table 1.

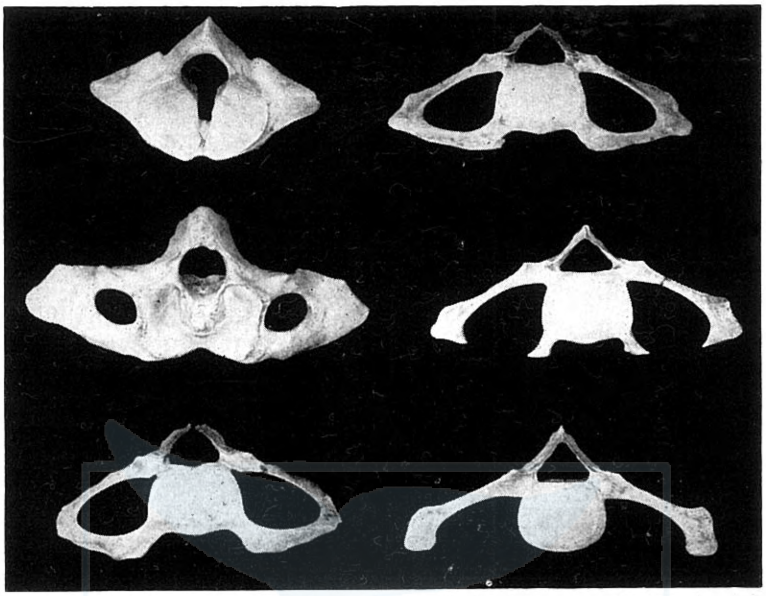

Fig. 4. Anterior view of the cervical vertebrae of the Irako specimen of minke whale from the Antarctic. Left side: 1st, 2-3 combined, and 4th; Right side: 5th, 6th, and 7th from top to bottom.

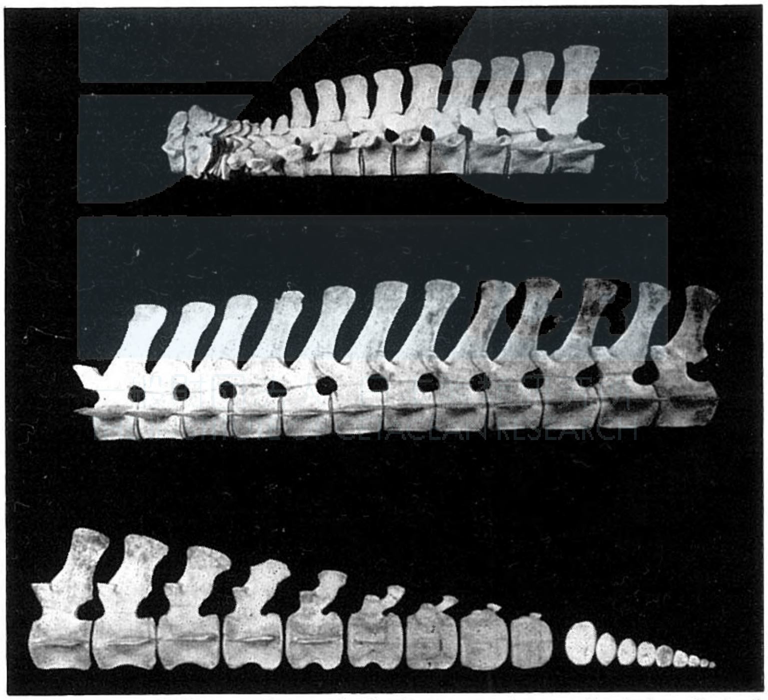

Fig. 5. Lateral view of the vertebrae of the Irako specimen of minke whale from the Antarctic. Upper: Cervical and dorsal vertebrae. Center: Lumbar vertebrae. Lower: Caudal vertebrae.

already fused. The posterior epiphyses of the 4th and 5th dorsals were not recovered when dug out of the sands.

All of the vertebrae of the Irako specimen are thought to have been collected from single whale, but it is not certain whether or not the skull and vertebrae were collected from the same individual. Measurements of vertebrae are appended this report, but these are of limited value. The aggregated length of vertebrae is 6,305 mm. The corresponding figures of the full grown specimens (71J2793 and 71J2883) are 5,872 and 6,741 mm respectively. The body length of the Irako specimen would, therefore, be between those of the two adult specimens or about 9 m, though it has not attained physical maturity.

The chevron bones (Fig. 6) are 9 in number, but possibly the first and the last were missed when sampling. In general they resemble in form and size to those of the specimen 71J2773. In the second chevron of the present specimen, right and left laminae are not fused together as in the case of the other specimen. Measurements of chevron bones are shown in Table 4.

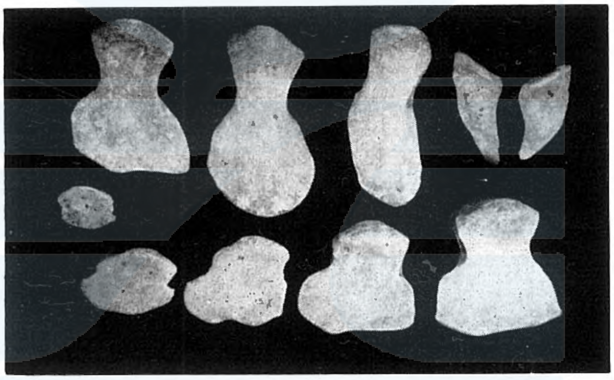

Fig. 6. Chevron bones of the Irako specimen of minke whale from the Antarctic. From right to left. Upper: 2nd (separated), 3rd, 4th, and 5th. Lower: 6th, 7th, 8th, 9th, and 10th.

TABLE 4. MEASUREMENTS OF CHEVRON BONES OF THE IRAKO SPECIMEN OF MINKE WHALE FROM THE ANTARCTIC (in mm)

| No. | | Length | Height | No. | Length | Height |
|---|---|---|---|---|---|---|
| 2* | R. | 80 | 138 | 6 | 168 | 178 |
| | L. | 79 | 160 | 7 | 154 | 141 |
| 3 | | 93 | 233 | 8 | 133+ | 116 |
| 4 | | 145 | 247 | 9 | 124 | 87 |
| 5 | | 159 | 198 | 10 | 73 | 51 |

* Not united.

## RIBS AND STERNUM

There are 11 pairs of ribs, but possibly the left 3rd and the right 9th bones were substituted by bones of other individual, presumably due to breakage. Heads of these two ribs are not coincide with others. All bones, except right 7th whose head was broken partly, are all perfect. In Fig. 7 are shown proximal parts of ribs, excluding those of dubious origin. Measurements of ribs

Fig. 7. Proximal parts of ribs of the Irako specimen of minke whale from the Antarctic.

TABLE 5. STRAIGHT LENGTH OF RIBS OF THE IRAKO SPECIMEN OF MINKE WHALE FROM THE ANTARCTIC (in mm)

| No. | Length | | No. | Length | |
|---|---|---|---|---|---|
| | Right | Left | | Right | Left |
| 1 | 744 | 714 | 7 | 1,197+ | 1,215 |
| 2 | 1,078 | 1,177 | 8 | 1,157 | 1,154 |
| 3 | 1,272 | ? | 9 | ? | 1,098 |
| 4 | 1,310 | 1,302 | 10 | 1,012 | 1,042 |
| 5 | 1,300 | 1,289 | 11 | 1,125 | 1,099 |
| 6 | 1,243 | 1,262 | | | |

are shown in Table 5. In general they are larger than those of the 71J2793, but smaller than in the 71J2883.

The sternum is roughly T shaped rather than cruciform (Fig. 8), and its breadth is 379 mm and the height is 411mm. This sizs is greater than in the other two specimens from the Antarctic.

Fig. 8. Sternum of the Irako specimen of minke whale from the Antarctic.

## SCAPULA AND FLIPPER BONES

Scapula (Fig. 9) of the Irako specimen resembles in general to that of the other two specimens, but it is narrower and higher than the latter. The ratio of breadth against its height of the right and left scapullae are 1.65 and 1.63 respectively, whereas this ratio is 1.76-1.81 in the specimens 71J2793 and 71J2883. Measurements of scapullae of the Irako specimen are shown in Table 6.

Measurements of the humerus, radius, and ulna are shown in Table 7. The distal epiphyses of the radius and ulna are not fused in both sides.

Fig. 9. Right scapula of the Irako specimen of minke whale from the Antarctic.

TABLE 6. MEASUREMENTS OF SCAPULA OF THE IRAKO SPECIMEN OF MINKE WHALE FROM THE ANTARCTIC (in mm)

| | Right | Left |
|---|---|---|
| Greatest breadth | 789 | 774 |
| Greatest height | 478 | 474 |
| Length of acromion, inferior | 218 | 228 |
| Breadth of acromion, distal end | 61 | 66 |
| Length of coracoid, inferior | 121 | 127 |
| Breadth of coracoid, distal end | 51 | 48 |
| Length of glenoid fossa | 154 | 154 |
| Breadth of glenoid fossa | 117 | 116 |
| Ratio of breadth against height | 1.65 | 1.63 |

TABLE 7. MEASUREMENTS OF HUMERUS, RADIUS, AND ULNA OF THE IRAKO SPECIMEN OF MINKE WHALE FROM THE ANTARCTIC (in mm)

| | Humerus | | Radius | | Ulna | |
|---|---|---|---|---|---|---|
| | Right | Left | Right | Left | Right | Left |
| Length* | 305 | 307 | 492 | 489 | 534 | 532 |
| Breadth* | 148 | 150 | 68 | 69 | 105 | 104 |

* Measured at middle.

TABLE 8. LENGTH OF PHALANGES OF THE IRAKO SPECIMEN OF MINKE WHALE FROM THE ANTARCTIC (in mm)

| Phalanx | Right | | | | Left | | | |
|---|---|---|---|---|---|---|---|---|
| | I | II | III | IV | I | II | III | IV |
| 1 | 86 | 85 | 95 | 58 | 83 | 97 | 85 | 60 |
| 2 | 85 | 95 | 101 | 62 | 86 | 103 | 94 | 64 |
| 3 | 75 | 77 | 77 | 64 | 74 | 77 | 78 | 64 |
| 4 | 57 | 57 | 55 | 40 | 58 | 53 | 57 | 39 |
| 5 | 21 | 38 | 37 | — | 33 | 35 | 40 | — |
| 6 | — | 25 | 23 | — | — | 24 | 26 | — |
| 7 | — | 14 | — | — | — | 15 | 16 | — |

The phalangeal formula of the Irako specimen is $I_5$, $II_7$, $III_{6-7}$, $IV_4$, but probably some small distal bones were missed at the time of sampling. Measurements of phalanges are shown in Table 8.

## HYOID AND PELVIC BONES

Hyoid bone of the Irako specimen is of no special feature and resembles to those of other specimens reported by Satake and Omura (1974). Its transverse breadth is 445 mm, height at middle is 102 mm, and the depth between two forward promontories is 34 mm. Length of right and left stylophyals are 310 and 305 mm respectively.

Pelvic bone of the Irako specimen (Fig. 10) is of some interest. This bone was taken possibly from a male, but it differs in form from that of the specimen 71J2793 from the Antarctic as well as from that of a specimen from the North Pacific (compare with Figs. 12 and 13 of Omura, 1975). Length and width of the pelvic bone of the Irako specimen are 205 and 44 mm in the right bone and 202 and 44 mm in the left bone respectively. These figures are very close to those of the specimen 71J2793, but the form is different. In the Irako specimen bones are a little slender and curving inwards. Further the tubercle or tuberculum laterale is not situated towards the middle of the bone, differing from that of the specimen 71J2793. Omura (1975) listed the pelvic bone in Fig. 14 of his paper as one of the characters which separate the minke whale population from the Antarctic from that from the northern hemisphere, but this needs further examination in the light of the present knowledge. Rather a wide individual variation in the form is expected.

Fig. 10. Pelvic bones of the Irako specimen of minke whale from the Antarctic.

## ACKNOWLEDGMENTS

Our sincere thanks are due to the staff of the Irako Natural History Museum. They not only permited us to investigate the bones, but also helped us greatly during our work at the museum. The photographs shown in Figs. 2 and 3 were taken by the staff.

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APPENDIX. MEASUREMENTS OF VERTEBRAE OF THE IRAKO SPECIMEN OF MINKE WHALE FROM THE ANTARCTIC (in mm)

| Serial no. | Vertebral no. | Greatest breadth | Greatest height | Centrum | | |
|---|---|---|---|---|---|---|
| | | | | Breadth | Height | Length |
| 1 | C 1 | 387 | 237 | 211 | R. 128, L. 126 | 66 |
| 2 | 2 | 539 | 246 | 206 | 136 | 35 |
| 3 | 3 | 511 | 197 | 161* | 110* | 26 |
| 4 | 4 | 488 | 190 | 156 | 110 | 30 |
| 5 | 5 | 519 | 194 | 152 | 117 | 34 |
| 6 | 6 | 510 | 205 | 150 | 117 | 37 |
| 7 | 7 | 511 | 210 | 148 | 118 | 42 |
| 8 | D 1 | 522 | 230 | 153 | 119 | 52 |
| 9 | 2 | 523 | 294 | 163 | 121 | 66 |
| 10 | 3 | 492 | 340 | 163 | 121 | 83 |
| 11 | 4 | 520 | 374 | 164 | 123 | 98+ |
| 12 | 5 | 570 | 395 | 163 | 125 | 106+ |
| 13 | 6 | 636 | 412 | 163 | 127 | 119 |
| 14 | 7 | 684 | 432 | 167 | 127 | 131 |
| 15 | 8 | 703 | 453 | 165 | 125 | 144 |
| 16 | 9 | 715 | 452 | 171 | 123 | 147 |
| 17 | 10 | 703 | 476 | 176 | 125 | 151 |
| 18 | 11 | 709 | 493 | 175 | 124 | 156 |
| 19 | L 1 | 667 | 521 | 174 | 137 | 162 |
| 20 | 2 | 665 | 528 | 178 | 141 | 166 |
| 21 | 3 | 674 | 544 | 177 | 144 | 173 |
| 22 | 4 | 669 | 569 | 180 | 145 | 178 |
| 23 | 5 | 659 | 576 | 182 | 148 | 187 |
| 24 | 6 | 650 | 594 | 184 | 156 | 188 |
| 25 | 7 | 629 | 599 | 186 | 156 | 195 |
| 26 | 8 | 636 | 588 | 191 | 155 | 200 |
| 27 | 9 | 625 | 589 | 194 | 154 | 207 |
| 28 | 10 | 598 | 596 | 203 | 161 | 214 |
| 29 | 11 | 594 | 572 | 205 | 171 | 221 |
| 30 | 12 | 504 | 562 | 209 | 169 | 228 |
| 31 | Ca 1 | 458 | 528 | 210 | 171 | 232 |
| 32 | 2 | 419 | 505 | 210 | 178 | 236 |
| 33 | 3 | 366 | 453 | 209 | 189 | 234 |
| 34 | 4 | 303 | 410 | 213 | 196 | 232 |
| 35 | 5 | 237 | 364 | 222 | 201 | 226 |
| 36 | 6 | T.P. disappear | 309 | 217 | 202 | 218 |
| 37 | 7 | — | 271 | 198 | 200 | 206 |
| 38 | 8 | — | 239 | 170 | 190 | 189 |
| 39 | 9 | — | 207 | 153 | 184 | 160 |
| 40 | 10 | — | S.P. disappear | 143 | 151 | 112 |
| 41 | 11 | — | — | 131 | 116 | 82 |
| 42 | 12 | — | — | 112 | 97 | 72 |
| 43 | 13 | — | — | 101 | 89 | 68 |
| 44 | 14 | — | — | 88 | 74 | 58 |
| 45 | 15 | — | — | 71 | 59 | 46 |
| 46 | 16 | — | — | 55 | 43 | 37 |
| 47 | 17 | — | — | 39 | 33 | 31 |
| 48 | 18 | — | — | 38 | 23 | 24 |
| 49 | 19 | — | — | ? | ? | ? |

* Measured from posterior side, since 2nd and 3rd are united together.
In other bones all from anterior side.

# A SKULL OF THE MINKE WHALE DUG OUT FROM OSAKA

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## ABSTRACT

Among collections of bones of whales dug out from Osaka and now being kept at the Osaka Museum of Natural History is included a half-broken skull of the minke whale, *Balaenoptera acutorostrata*. After comparing with known specimens of this species this whale was estimated to be a full grown animal of about 9 m in length.

## INTRODUCTION

During several years in 1960's a number of bones of whales have been dug out from various places in Osaka city while large-scale construction works such as subways, expressways, and buildings were going on (Shindo, 1975). These bones are now being kept at the Osaka Museum of Natural History and I had a chance to observe these bones in December 1975 and found a half-broken skull of the minke whale is included among the collection.

In addition to these, bones of sperm whale were also dug out recently from underground of Higashiosaka city. The species of this whale was identified by Okazaki (1975) by the presence of the characteristic atlas and a tooth among the collection.

At the period of Jomon Transgression (about 7,000–3,000 B. P. [years before present]) a vast area from Uemachi Upland, where Osaka castle is situated, eastwards and including Higashiosaka city to Ikoma mountain had been invaded by sea water, forming a bay called Kawachi-wan. This area is now the Osaka Plain. The development of the Osaka Plain was studied by Kajiyama and Itihara (1972) with reference to the radio-carbon dates. They recognized nine successive stages of the development. In the second or the stage of the Paleo-Kawachi Plain (ca. 9,000 B. P., earliest Jomon age) the sea level was lower than in the present by 20 m or over. Osaka Bay was already in existence, but the Kawachi area was not covered by sea water. In the third or the stage of the Kawachi Bay I (ca. 7,000–6,000 B. P., the first half of early Jomon age) the sea level reached to that of the present and the Paleo-Kawachi Plain was widely covered by sea water. In the fourth or the stage of the Kawachi Bay II (ca. 5,000–4,000 B. P., latest early Jomon to middle Jomon ages) the sea level remained nearly unchanged, but in the next stage of the Kawachi Lagoon (ca. 3,000–2,000 B. P., latest Jomon to the first half of Yayoi ages) due to the development of the sand bar north of the Uemachi Upland, Kawachi Lagoon was formed and the inner part of the bay was filled with

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fresh water. The growth of the sand bar continued and it developed successively into the stages of the Kawachi Lake I and II, Osaka Plain I, and finally to the stage of the Osaka Plain II or the present.

In the 3rd and 4th, and also in the 5th stages too, it is possible that whales came into the Kawachi Bay and some of them stranded ashore or dead afloat and finally sunk. This is the possible explanation why bones of whales dug out from the alluvial deposits in Osaka. It is also possible, therefore, that these bones are of the existing whale species.

## OBSERVATION AND CONCLUSION

(Plates I and II)

This skull (O. M. N. H., F2639) was dug out from 14 m deep while constructing underground railroad at 2-Chome, Oimazato-hommachi, Higashinari-ku, on 11 August 1966. The skull was broken transversely towards middle part of the supraoccipital bone by mishandling during preparation for transportation after discovering. Its posterior portion is remaining in a very good condition, suggesting the skull was a splendid specimen before it was broken. Exo- and basioccipitals, and temporals are nearly perfect, enabling me to measure the breadth at squamosal or the greatest breadth of the skull, as well as other measurements concerning posterior region of the skull precisely. Posterior marginal portion of the vomer is remaining attached, but pterygoids are broken and tympanic bullae are lacking.

Vertex and facial region of the skull are completely broken, but orbital process of the frontal of both sides, part of vomer, 170 cm in length, and some fragments of maxillary and premaxillary are remaining separately. Frontals are broken at their proximal ends and their distal margins or orbits are complete and the orbital length was measurered accordingly.

At a glance this skull can be identified to be a species of balaenopterid whales (Balaenopteridae) and from its comparatively smaller size to be the minke whale. Measurements of the skull are shown in Table 1, comparing with corresponding measurements of other specimens from the North Pacific and Antarctic, cited from Omura (1975). Measurements numbers in the table are the same as used in the previous paper (1975). The breadth of the skull at squamosal of this specimen (F2639) is far greater than in the two specimens from the North Pacific (AY69B, AY69A), and lying between figures for the two specimens from the Antarctic, suggesting the body length of this whale is also between these two specimens, i. e. 8.5–9.8 m and possibly around 9 m. These two whales from the Antarctic are physically matured (Omura, 1975) and since the body length at sexual maturity of minke whales is somewhat smaller in those from the North Pacific than in those from the Antarctic (Ohsumi *et al.*, 1970) this specimen from Osaka was possibly a full grown whale. This is also supported by rigid structure of the skull.

TABLE 1. MEASUREMENTS OF THE SKULL (F2639) COMPARED WITH THE KNOWN SPECIMENS OF THE MINKE WHALE (in mm)

| Measurements | F2639<br>Osaka | AY69B*<br>N. Pacific | AY69A*<br>N. Pacific | 71J2793*<br>Antarctic | 71J2883*<br>Antarctic |
|---|---|---|---|---|---|
| 16. Breadth of skull at squamosal | 1,180 | 708 | 613 | 1,075 | 1,256 |
| 19. Length of orbit, frontal, right | 207 | 156 | 146 | 188 | 207 |
| 20. Length of orbit, frontal, left | 206 | 157 | 146 | 190 | 207 |
| 21. Breadth of occipital bone | 822 | 563 | 473 | 760 | 886 |
| 22. Breadth across occipital condyle | 229 | 157 | 154 | 203 | 228 |
| 23. Height of occipital condyle, right | 124 | 98 | 120 | 131 | 145 |
| 24. Height of occipital condyle, left | 124 | 96 | 100 | 124 | 142 |
| 25. Breadth of foramen magnum | 79 | 83 | 80 | 70 | 79 |
| 26. Height of foramen magnum | 60 | 90 | 85 | 97 | 127 |
| Sex, body length, and age | ? | M. 6.6 m<br>juv. | M. 5.4 m<br>juv. | M. 8.5 m<br>ad. | F. 9.8 m<br>ad. |

* Cited from Omura (1975).

In other measurements figures for this specimen are within the ranges of the values of the two specimens from the Antarctic or very close to them, except the measurement no. 26 (height of foramen magnum), which is thought to be of less importance. From this table it can safely be concluded that this specimen is a skull of the minke whale, *Balaenoptera acutorostrata*. There remains, however, still a taxonomic problem among minke whale populations of the world, i. e. a possibility that the Antarctic minke whale, *B. bonaerensis*, is in fact a different species or subspecies of the minkes in the northern hemisphere, *B. acutorostrata*. But the distinctions so far noted in the skull are in the vertex and facial regions and not concern the posterior portion of the skull (Omura, 1975). Accordingly this problem does not affect the above conclusion.

## ACKNOWLEDGMENTS

My sincere thanks are due to Mr. Hiroyuki Taruno and other members of the Osaka Museum of Natural History. They extended me all possible arrangement and help for the works done at the museum. Mr. H. Taruno also read and commented on draft of the manuscript.

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## EXPLANATION OF PLATES

### PLATE I

Half-broken skull of the minke whale dug out from Osaka and now being kept at the Osaka Museum of Natural History. F2639.

Fig. 1. Posterior view.
Fig. 2. Anterior view.

### PLATE II

The same specimen shown in Plate I.

Fig. 1. Superior view.
Fig. 2. Inferior view.

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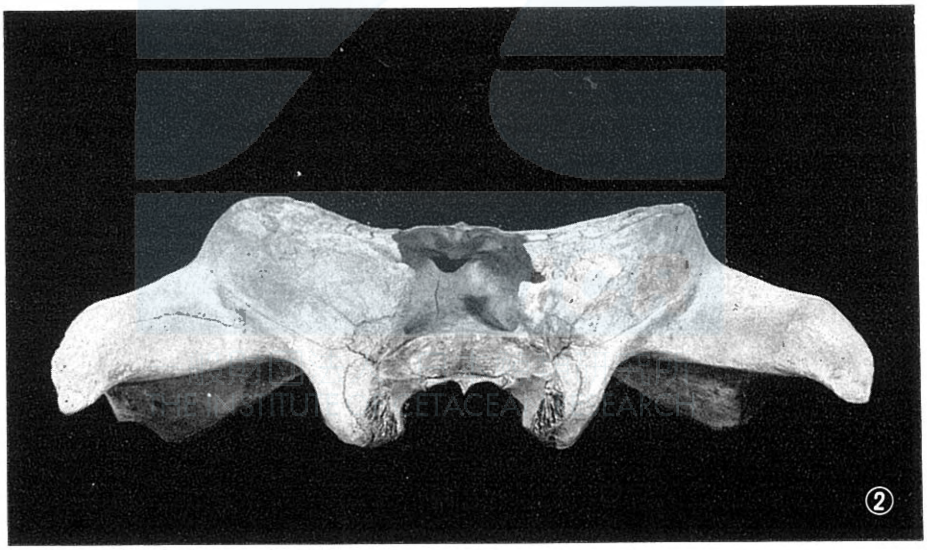

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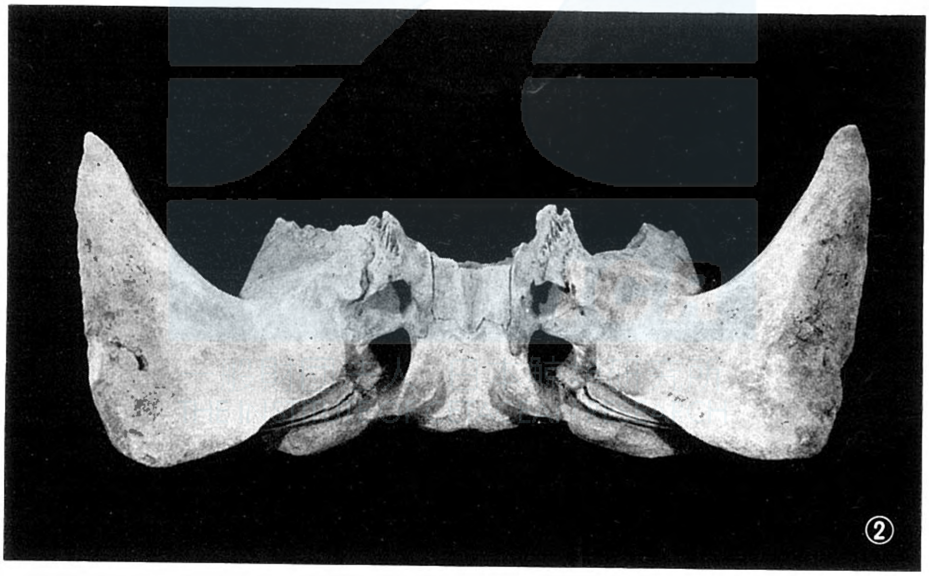

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# RECONSIDERATION OF LIFE HISTORY PARAMETERS OF THE SPOTTED AND STRIPED DOLPHINS BASED ON CEMENTAL LAYERS

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## ABSTRACT

Growth layers are visible in both cementum and dentine of the decalcified and stained teeth of *Stenella attenuata* and *S. coeruleoalba*. Their accumulation is annual in young dolphins, but in older animals only the accumulation of cemental layers are detected. Growth of the dolphin lasts longer than expected from previous studies. The maximum age is more than 45 years and sexual maturity is attained at 9 years in females of both species. Annual natural mortality rate of 7.5% in *S. attenuata* and the total mortality of 11.8% in *S. coeruleoalba* are estimated for adult females. In immature animals the mean mortality is lower, and higher in adult males. Annual ovulation rate is about 0.41 in both species. Reproductive parameters are analysed in relation to the age of animals and the present population level.

## INTRODUCTION

The age determination of delphinids has been made by counting the growth layers in dentine or cementum. The accumulation of layers was shown to be annual in case of *Tursiops truncatus* based on the animals born and died in an aquarium (Sergeant 1959, Sergeant *et al.* 1973). Sergeant (1962), Kasuya (1972), and Kasuya *et al.* (1974) also indicated the possibility of the same accumulation rate for *Globicephala melaena, Stenella coeruleoalba,* and *S. attenuata* respectively based on the materials covering limited seasons, and analysed the life history of those dolphins.

However, through the analysis of life history parameters of an unexploited population of *S. attenuata*, Kasuya *et al.* (1974) concluded that the accumulation of dentinal growth layers ceases in older animals as already indicated by Sergeant (1962) for *G. melaena*. This made it difficult to study the life history of the species, and even if the life history parameters are estimated by other indirect method the accuracy was unsatisfactory.

The present study was undertaken to reconsider the life history parameters of the spotted dolphin, *S. attenuata*, and of the striped dolphin, *S. coeruleoalba*, which were fomerly estimated through the analysis of dentinal growth layers or by other indirect method (Kasuya 1972, Kasuya *et al.* 1974, Kasuya and Miyazaki 1976). Since the cemental layers abandoned in the study by Kasuya

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*et al.* (1974) were found in this study to be readable if the teeth were stained after the decalcification of a thinner ground section.

## MATERIALS AND METHOD

All the materials used in this study were collected from the catch of the drive fishery off the Pacific coast of Japan. Though the samples were collected randomly from the catch, as the species have the tendency to form a separate schools in relation to the sex, growth and reproductive stages (Kasuya 1972, Kasuya *et al.* 1974, and Miyazaki 1975) and also some members of a school will be lost during the drive, the samples are not necessarily an unbiased representative of the population. This bias was considered in the analyses.

As shown in Table 1 all the samples of *S. attenuata* are the same as those used by Kasuya *et al.* (1974) except for 2 schools (nos. 8 and 9), which were examined by Mr. S. Matsui of The Taiji Whale Museum and by myself respectively. The data from these two schools were used only for the estimation of the sex ratio at birth.

TABLE 1. SOURCE OF MATERIALS USED IN THIS STUDY

| School no. | Species | Date of driving | Place of driving | No. dolphins caught | No. dolphins examined | No. dolphins aged males | No. dolphins aged females |
|---|---|---|---|---|---|---|---|
| 1 | *S. attenuata* | 23, Oct., '70 | Kawana | 264 | 131 | 17 | 27 |
| 2 | „ | 10, Nov., '70 | „ | 1381 | 273 | 9 | 15 |
| 3 | „ | 4, Nov., '72 | „ | 189 | 48 | 17 | 13 |
| 4 | „ | 13, Nov., '72 | „ | 192 | 117 | 54 | 54 |
| 5 | „ | 16, Nov., '72 | Futo | 67 | 23 | 7 | 15 |
| 6 | „ | 12, Feb., '73 | Taiji | 146 | 122 | 45 | 67 |
| 7 | „ | 2, Jul., '73 | „ | 60 | 36 | 9 | 9 |
| 8 | „ | 24, Jan., '75 | „ | 102 | 102 | — | — |
| 9 | „ | 16, Jan., '76 | „ | 91 | 44 | — | — |
| 22 | *S. coeruleoalba* | 14, Dec., '71 | Kawana | 903 | 306[1] | 217[2] | 62[2] |
| 38 | „ | 17, Nov., '72 | „ | 411 | 203 | 37 | 68 |
| 43 | „ | 15, Nov., '73 | „ | 414 | 250 | 105 | 65 |
| 44 | „ | 20, Nov., '73 | „ | 1724 | 470 | 78 | 81 |
| 45, 46 | „ | 23, 24, Nov., '75 | „ | 1000 | 399 | — | — |

1) All immature except 7 sexually mature males.

2) Based on dentine layers read by ordinary method.

The materials of *S. coeruleoalba* were collected from the catch of six drives off the Izu coast. The school numbers in Table 1 are the same as those used by Miyazaki (1975). Though the five schools from nos. 38 to 46 in Table 1 were composed of mature and immature animals of both sexes, the school no. 22 was peculiar in the extreme scarcity of mature animals and the higher ratio of the males as indicated in Table 1 and Figs. 18 and 19 showing the age composition.

From school nos. 45 and 46, only the informations on body length, sex, and ratio of reproductive stages of adult females are available.

The growth layers were counted independently by three methods on a longitudinally sectioned tooth. The first is the ordinaly one (Kasuya *et al.* 1974), or to count the opaque dentinal layers under transmitted light with a stereoscopic microscope (×50 to ×80). The thickness of these sections was 50 to 70$\mu$. For the second and the third methods, the tooth slides used for the first method were ground thinner to a thickness between 10 to 20$\mu$, and decalcified in the 5% water solution of formic acid for several hours. Then they were stained with Mayer's haematoxylin solution and mounted with glycerin. By this preparation the dentinal and cemental growth layers are observed clearly as the well stained and poorly stained layers arranged alternatively. For the age determination by the second method, the number of stainable dentinal layers was counted with a microscope (×100). The fetal dentinal layer is not included in the count. The disagreement of repeated count by this method was less than 5%. The counting of cemental layers, the third method of age determination, was made with a microscope (×150) on a same slide used for the second, and at a part of the thickest cemental layer, which usually situates at a position between cervix and the midlength of the root. Though the arrangement of cementoblasts seems to be correlated with the stainable cemental groundsubstance, the counting of the layer was made on the condition of the latter. Three counts were usually made on the best spot of a slide and the middle figure was used as the number of cemental layers. The disagreement of the repeated counts was usually from 5 to 15%. The discrepancy of the repeated counts is larger in older animals. The fetal cemental layer was not usually detected by the above method, and possibly not included in the count.

As one accumulation cycle of the layers consists of a stainable and an unstainable layer, the real number of the cycles of an animal with n dark layers is expected to be between $n-1.5$ and $n+0.5$. Then the average number of the cycles of the animal is considered to be $n-0.5$, if the samples are obtained evenly from all seasons. Though, it is not actually proved if each kind of layer represent the period of 6 months, the figure $n-0.5$ was used tentatively as the approximate age of the animal.

The presence of corpora in the ovaries was used as the indication of the sexual maturity of the female, and their number was counted by the ordinary method (Kasuya *et al.* 1974). Usually the weight of left testis was measured, and the right testis only when the left is not available. The maturity of the male was determined by the testis weight based on the mean weight of single testis at the attainment of sexual maturity 68 g for *S. attenuata* (Kasuya *et al.* 1974) or 16.5 g for *S. coeruleoalba* (Miyazaki 1975, Kasuya and Miyazaki 1976).

## RESULTS

### *Comparison of the methods*

The relationship between the number of dentinal growth lyers counted by ordinary method and that counted on decalcified and stained dentine is shown in Fig. 1. As the stainable dentinal layer seems to correspond approximately with the translucent layer or with the part transitional from opaque to translucent layer of undecalcified dentine, the two counts compared are not indicating the number of same kind of layers. So, the disagreement of only one layer is not significant, and it is suggested that the two methods can give almost same result for the dolphins younger than 8 layers and that after this age the correlation becomes less. The count on undecalcified tooth with more than 12 layers gives, in general, smaller figure than that on decalcified and stained dentine. There is detected no sexual difference in this relationship. The disagreement of the counts of dentinal layers by the two methods will be caused by the difficulty of reading the layers in secondary dentine, or by the difficulty of distinguishing the thin layers of older animals. If so, the count made on decalcified and stained preparation of thinner tooth section can be a better indication of the age, since the layers are more clearly observed by this preparation.

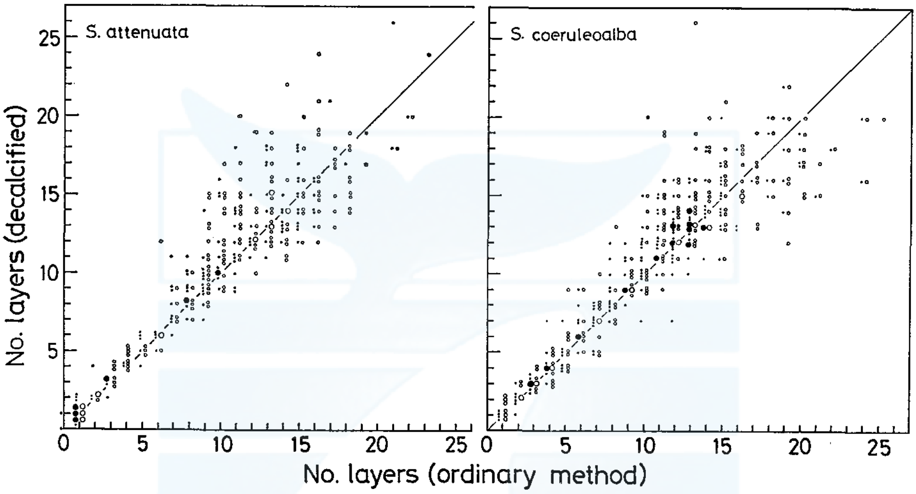

Fig. 1. Comparison of count of dentinal layers made by ordinary method (undecalcified) and that made after decalcification and staining. Open circle indicates female, closed circle male, and solid line the equal accumulation rate. Larger circle indicates five animals, and the smaller one.

However, when the number of dentinal layers in decalcified and stained tooth is compared with that of cemental layers of the same tooth slide, the two coincide extremely well only up to the age of 9 layers in *S. attenuata* or the

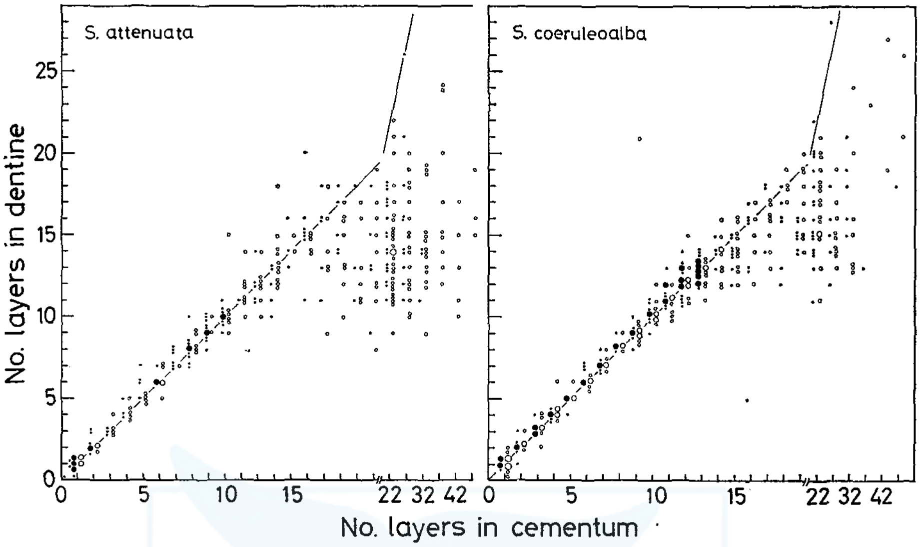

Fig. 2. Comparison of the accumulation rate of dentinal and cemental layers. Layers were counted after decalcification and staining. For other marks see Fig. 1.

age of 11 layers in *S. coeruleoalba* (Fig. 2). After these ages the latter usually gives the higher number, and there is observed almost no correlation between the number of layers in dentine and cementum in teeth with more than 20 cemental layers. This must indicate that the acumulation of the dentinal layers ceases at an large variety of age above 9 layers (*S. attenuata*) or 11 layers (*S. coeruleoalba*), and that the accumulation of cemental layers continues longer as in the case of *G. melaena* (Sergeant 1962). The ages of the oldest animal were 46 cemental layers in *S. attenuata* and 50 in *S. coeruleoalba*. They are about twice as high as those estimated from the dentinal growth layers.

*Accumulation rate of layers*

As the sample of *S. attenuata* covers wider range of seasons, the seasonal change of the dentinal growth layer was analysed for this species, Table 2 shows the condition of the dentinal growth layers being calcified at the time

TABLE 2. CONDITION OF DENTINE BEING CALCIFIED AT THE TIME OF DEATH OF *S. ATTENUATA*

| Dentine* / Date | Stainable layer no. dolphins | Stainable layer % | Unstainable layer no. dolphins | Unstainable layer % | Total no. | Total % |
|---|---|---|---|---|---|---|
| October | 16 | 76.2 | 5 | 23.8 | 21 | 100 |
| November | 62 | 96.9 | 2 | 3.1 | 64 | 100 |
| February | 40 | 95.2 | 2 | 4.8 | 42 | 100 |
| July | 1 | 7.7 | 12 | 92.3 | 13 | 100 |

* Stained dark or pale by haematoxylin.

of death. Only the animals younger than 9 growth layers were selected here, because the accumulation of the layer ceases in some animals after this age. The frequency of the dolphins with the stainable layer at the pulp wall is about 75% in the catch of late October, and it increases to about 95% in November and February. However the ratio is reversed in early July. This is an indication of that the formation of stainable layer starts, on the average, in early October and that of the unstainable layer in between March and June.

Kasuya *et al.* (1974) suspected from the observation of undecalcified tooth sections of the same animals that the translucent dentine is formed in the season from December or January to April or May and opaque dentine in the other season. As it is easily expected that Kasuya *et al.* (1974) might have overlooked some of the translucent layers or opaque layers which were too thin to be detected on the thicker and undecalcified section, the seasons when the alternation of the layer occurs can be shown slightly delayed in their study than the result of this study. So the slight difference between the two conclusions is not significant. This is another indication of the fact that the dentinal layers stainable with haematoxylin correspond, as mentioned before, with translucent layers or with the part transitional from the opaque layer to the translucent layer of undecalcified section (Plate III, Fig. 2). As the seasonal change of the condition of the incomplete latest dentinal layers of *S. coeruleoalba* studied by Kasuya (1972) on undecalcified tooth section is same with that of *S. attenuata* reported by Kasuya *et al.* (1974), the seasonal alternation of the dentinal layers of the two species seems to follow the same pattern. The present results on the season of formation of dentinal layers is consistant even with the results on *G. melaena* (Sergeant 1962), *Hyperoodon ampullatus* (Christensen 1973, Mitchell and Kozicki 1975), and *Physeter catodon* (Ohsumi *et al.* 1963).

In order to know the growth rate of dentinal layers, the seasonal change of the thickness of the most recent incomplete layer must be detected. As a preparatory procedure of this, the change of the thickness of the layers accompanied with the age of the animal was checked on the enlarged photographs of the decalcified and stained tooth sections of two *S. attenuata* and two *S. coeruleoalba*, some of which are shown in Plates. In these measurements the first incomplete layer which start from the neonatal line was not included. The measurements of the subsequent layers are shown in Fig. 3. The thickness of the layer of *S. coeruleoalba* decreases rapidly untill 3rd or 4th layers. After this age the decrease is almost constant, and the thickness of a layer is about 95% of that of the preceeding layer. This feature seems to be same even in the case of *S. attenuata*, though the thickness of each layer is larger during the first few years.

The following relationship is lead from this result.

$$T_{n-2} : T_{n-1} = T_{n-1} : T_n$$

when $t_n$=the thickness of the most recent incomplete layer

$T_n$=the expected thickness of the same layer at the time of completion

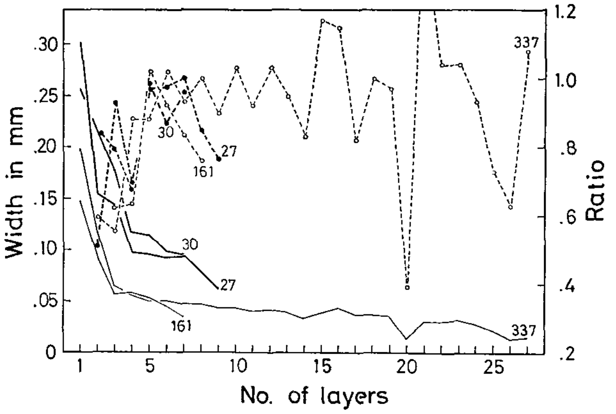

Fig. 3. Thickness of dentinal growth layers shown in relation to the age of the animals. Solid line indicate the thickness of each layer, and circle and dotted line ratio of one layer to the former layer. 27 : *S. attenuata*, 183 cm, male, school no. 7. 30 : *S. attenuata*, 202 cm, female, school no. 7. 161 : *S. coeruleoalba*, 221 cm, female, school no. 38. 337 : *S. coeruleoalba*, 232 cm, male, school no. 44.

$T_{n-1}$=the thickness of the one cycle earlier complete layer
$T_{n-2}$=the thickness of the two cycles earlier complete layer

Then, the rate of completion of the most recent incomplete layer, $t_n/T_n$, is shown as follows.

$$\frac{t_n}{T_n} = t_n \cdot \frac{T_{n-2}}{T_{n-1}^{2}}$$

In the present study the thickness of one layer was measured from the start of a stainable layer to that of next stainable layer, on the selected teeth of *S. attenuata* at the age betwen 4 to 12 layers. These teeth were selected considering the preparation, clearness of layers, the regularity of layers, and in older animals the coincidence of the numbers of layers in dentine and in cementum.

The result is shown in Fig. 4, where 4 schools caught in November are grouped and plotted on the mean date of catch. Though there is observed a smaller peak in October, November and February, they will have been caused by the measurements of young tooth where the thickness changes rapidly. If the highest modes were connected there is suspected a slower growth in the period from November to June. The extraporation of the line connecting the modes in October and November suggests that the starting date of the accumulation of stainable layer is in early October, which coincides well with the estimation has been made from the seasonal change of the frequency of the two kinds of layers being calcified. As the completion rate at the beginning of July is only 45%, the rate of 16.5% per month, which is close to the rate in October 15.0%, must be achieved in the accumulation of unstainable layer formed in the summer months in order to expect the annual formation of the layer. This rate will not be improbable in view of the accumulation rate of opaque layers

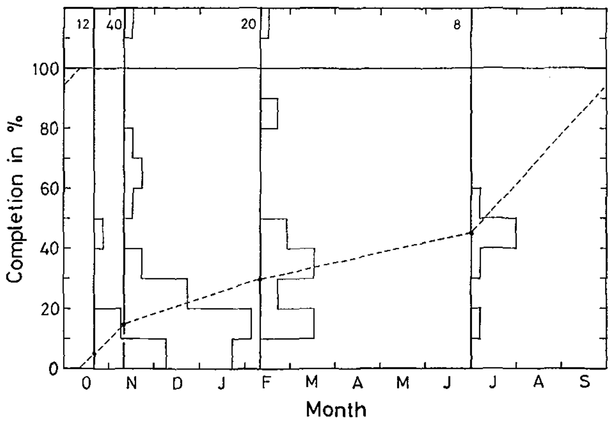

Fig. 4. Seasonal change of the completion rate of dentinal growth layers. The numerals at the top indicate the sample size. The interval of one month corresponds to 5 animals. For further explanation see text.

of *Hyperoodon ampullatus*, about 30% in the fishing season of May and June, suspected by Mitchell and Kozicki (1975, see their discussion) based on the data reported by Christensen (1973). Possibly the growth of dentine in *S. attenuata* is rapid in the summer season when the unstainable layer (≒ opaque layer on ground section) is accumulated, and slower in winter when the stainable layer (≒ translucent on ground section) is accumulated. Though Ohsumi *et al.* (1963) showed a different feature on the growth rate of dentine of *Physeter catodon*, as they measured the layer not on the thin ground section but on the half-cut longitudinal section, the exact comparison is difficult at present.

As the conclusion it will be safe to say that the accumulation rate of the dentinal growth layers is annual in case of *S. attenuata*, and that the similar rate will be expected on the closely related species *S. coeruleoalba*. Since the numbers of layers in cementum and dentine are equal in young animal and the alternation of the layers will be affected by the same physiological change, the accumulation of cemental layer is also considered to be annual.

### *Mean growth curve*

The relationship between body length and age in *S. attenuata* and in *S. coeruleoalba* are shown in Figs. 5 and 6. As the ages are grouped into each n−0.5 years, where n indicate the number of stainable cemental layers, and the stainable layer start to be accumulated in the average in early October, the animals of almost similar age can be grouped into separate age groups affected by the slight difference of the dates of birth and death, or of the formation of stainable layer, even if there is no misreading of the layer. In other words, the difference of one year in the age of each individual is not significant.

The mean growth curves of *S. attenuata* in Fig. 5 were drawn by eye referring the curves of *S. coeruleoalba* where the samples are more abundant,

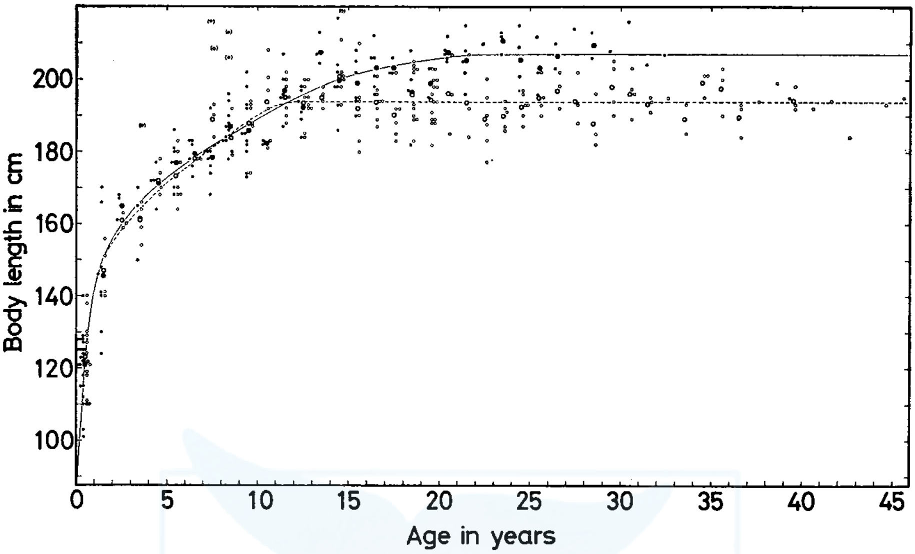

Fig. 5. *S. attenuata*, scatter diagram of the relationship between body length and age estimated from the cemental layers (200 females and 158 males). Open circle and dotted line indicate female, closed circle and solid line male, smaller circle one animal, and larger circle mean body length. Data in parenthesis are excluded from the calculation.

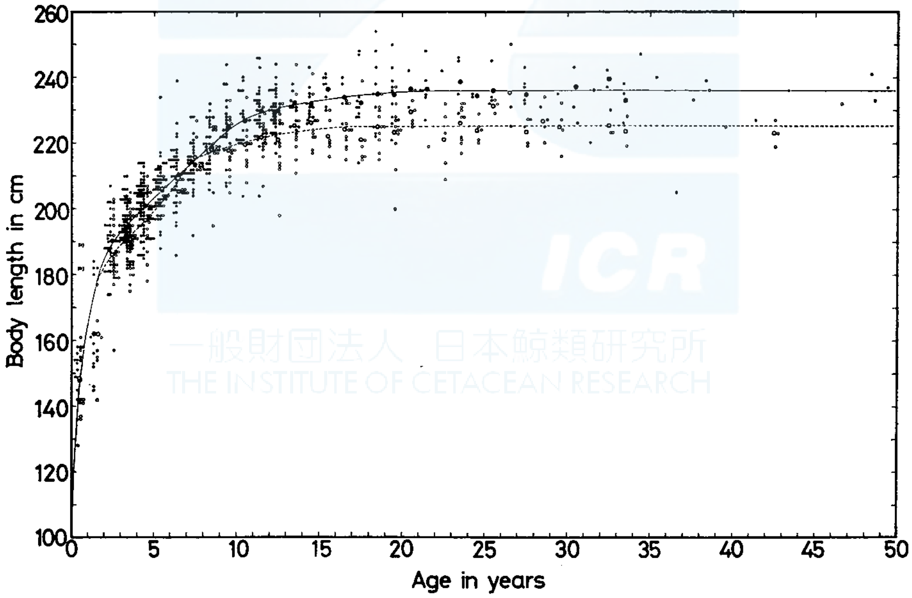

Fig. 6. *S. coeruleoalba*, scatter diagram of the relationship between body length and age (340 females and 488 males). The age data of the school no. 22 estimated by ordinaly method were included. The age of other animal was based on cemental layers. For other marks see Fig. 5.

and are liable to the alteration when more data is accumulated. The body length at birth is about 89 cm (Kasuya *et al.* 1974). The animals of both sexes attain the mean length of 142.5 cm in the first year. Then the male length seems to exceed that of female at the age of two years. Though the data is scanty and the minor change of the growth rate is not clear, there might be again a period, approximately at the age between 9 and 11 years, when the mean length of the female may exceed or equal with that of the male. Apart from these minor and uncertain features, the general trend of the mean growth curve of the immature stage does not differ from that shown by Kasuya *et al.* (1974). But, as reasonably expected from the possible underestimation of the age in their study, the growth in immature period shown in the present study appears slightly slower (Table 7). The mean asymptotic length of the female *S. attenuata* is attained at 11 or 12 years (Fig. 7), and the length is estimated to be 193.9 cm from the mean length of 135 animals at the age more than 12 years. The mean growth curve of the male indicate slower growth after 12 years of age and seems to reach the asymptonic length of 207.1 cm at the age

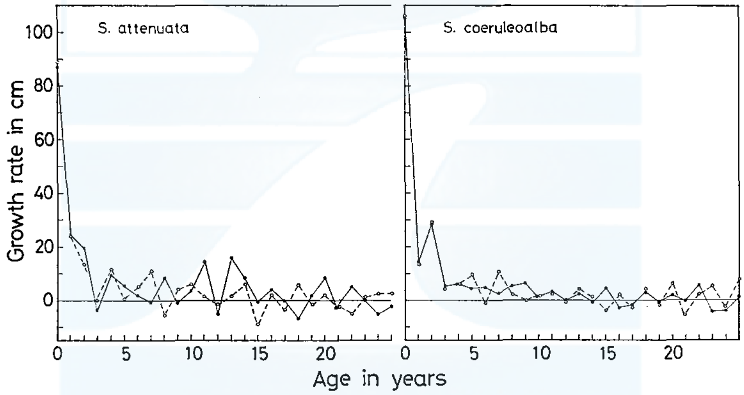

Fig. 7. Annual growth rate of the two kinds of dolphins. The increase in mean body length between n−0.5 and n+0.5 year groups is plotted at n years of age. Closed circle and solid line indicate male, and open circle and dotted line female. The fetal length was cited from Fig. 7 of Kasuya *et al.* (1974).

TABLE 3. ESTIMATION OF THE MEAN ASYMPTOTIC LENGTH

| Species | *S. attenuata* | | *S. coeruleoalba* | |
|---|---|---|---|---|
| Sex | Males | Females | Males | Females |
| Age range (years) | ≧22. 5 | ≧12. 5 | ≧21. 5 | ≧17. 5 |
| No. of animals | 21 | 135 | 41 | 89 |
| Smallest (cm) | 195 | 177 | 220 | 200 |
| Largest (cm) | 216 | 211 | 248 | 250 |
| Mean (cm) | 207. 1 | 193. 9 | 236. 0 | 225. 3 |
| Standard dev. (cm) | 8. 63 | 4. 04 | 6. 14 | 15. 29 |
| Standard error (cm) | 1. 88 | 0. 35 | 0. 96 | 1. 62 |

of about 22 years.

The mean growth curves of *S. coeruleoalba* was drawn by eye assuming 99.8 cm for the body length at birth (Kasuya 1972). The age of the school no. 22 was estimated from the number of dentinal growth layers counted by the ordinary method, because this does not seem to give bias since the animals constituting this school are young ranging from 1.5 to 10.5 years of age (Figs. 18 and 19). As the dolphins of larger body length tend to attain the sexual maturity at an age younger than the shorter animals do (see Kasuya 1972 Fig. 4), and other schools are mainly composed of adult animals, it is necessary to add the age-length data of the school no. 22 to eliminate this bias.

*S. coeruleoalba* attains the mean length of 164.0 cm at the age of 1 year. The sexual dimorphism of the body length appears at the age of about 2 years as in the case of *S. attenuata*, and then the lengths of both sexes increase at an almost constant rate retaining the difference of about 4 cm until the age of 6 years. As shown in Table 7, the growth rate of this period is slightly smaller than that estimated by Kasuya *et al.* (1974). The mean growth rate of the females increases at the age from 6 to 7 years, and attains at age from 7 to 8 years a length slightly exceeding that of the male. After the age of 8 years, which is about one year before the onset of sexual maturity, the mean growth of the female becomes slower, and mean growth curve reaches the asymptotic length of 225.3 cm at about 17 years. Though the growth of the male is slightly faster at the age between 7 and 10 years than the preceeding period, the accelerated growth is not conspicuous. After the age of 10 years the growth of the male becomes slower and attains the asymptotic length of 236.0 cm at the age of about 21 years (Table 3).

The mean growth curves of the two species of *Stenella* discussed here show a similar pattern. The ages when the growth rate changes correspond to the completion of weaning at 1.5 to 2.4 years indicated by Kasuya (1972) and in the latter section of this study, attainment of sexual maturity discussed below, and the completion of the attainment of physical maturity. Though the accelerated growth of the male near the attainment of sexual maturity is not conspicuous, the growth rate of the female seems to become higher just before the attainment of sexual maturity. The fact that the body length of the female near the onset of sexual maturity exceed that of male at the same age is at close resemblance to *G. melaena* (see Sergeant 1962, Fig. 11). The low growth rate preceding the age at asymptotic length might by a reflection of the decrease of the growth rate of each animal and of the increasing ratio of the animals which have attained the physical maturity. The age when mean growth curve attains the asymptotic length will correspond to the age when all the individuals attain the physical maturity.

### *Attainment of sexual maturity*

When the presence of the scar in the ovary or the testis weighing more than 68 g (Kasuya *et al.* 1974) is used as the criterion of the sexual maturity in

*S. attenuata*, the youngest sexually mature animals are found in the age group of 7.5 years (both sexes) and the oldest immature animals in that of 11.5 years (female) or 15.5 years (male). The following formulae are obtained by the least aquares for the relationship between the ratio of mature animals (y) and the age of the animals (x).

$$\text{Female}: y=17.43x-106.93 \qquad 6.5\leqq x\leqq 12.5$$

$$\text{Male} \quad : y=10.59x-74.84 \qquad 6.5\leqq x\leqq 16.5$$

The age where 50% of the animals are sexually mature is estimated from the above formulae to be 9.0 (female) or 11.8 (male) years (Fig. 8). These values are slightly higher than those obtained by Kasuya *et al.* (1974), as expected from the limit of ageing by dentinal layers.

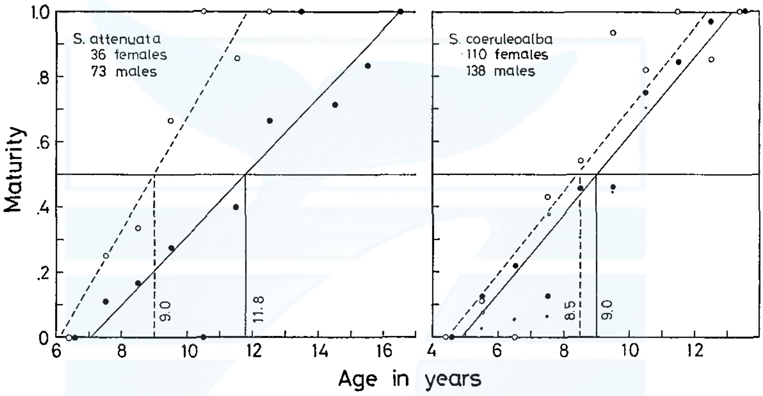

Fig. 8. Relationships between age and the ratio of sexually mature animals. Open circle and dotted line indicate female, and closed circle and solid line male. In *S. coeruleoalba* smaller circles include school no. 22, and the larger exclude it.

In case of male *S. coeruleoalba* the mean weight of testis at the attainment of sexual maturity, 16.5 g, was determined Miyazaki (1975), where the presence of spermatozoa or spermatid in the tissue taken from the center at the midlength of testis was considered to be mature. In spite of this criterion, there were always observed both spermatozoa and spermatid in the mature testis (Miyazaki 1975) as in the case of *S. attenuata* (Kasuya *et al.* 1974). As shown in Table 4, this criterion seems to give a same age at the onset of sexual maturity with the criterion based on the presence of spermatozoa in the epididymal smear. However other criterion may give different results. For the female *S. coeruleoalba*, the maturity was determined by the presence of the corpus in the ovaries.

If the age-maturity data of 152 (146 immature and 6 mature) males and 25 immature females of the school no. 22 are dealt together with the data of school nos. 38, 43 and 44, the ratios of immature males are unreasonably low in the age groups below 9 years and the age of 9.7 years is obtained as the mean age of the male at the attainment of sexual maturity (Fig. 8). However,

TABLE 4. COMPARISON OF DIFFERENT CRITERIONS FOR THE MATURITY OF MALE *S. COERULEOALBA*

| No. of | Age in | Testicular smear | | | Epididymal smear | | | Testicular weight[1] | | |
|---|---|---|---|---|---|---|---|---|---|---|
| layers | years | imm. | mat. | mat. % | imm. | mat. | mat. % | imm. | mat. | mat. % |
| 2 | 1.5 | 2 | 0 | 0 | 2 | 0 | 0 | 9 | 0 | 0 |
| 3 | 2.5 | 8 | 2 | 20.0 | 9 | 1 | 10.0 | 11 | 0 | 0 |
| 4 | 3.5 | 0 | 1 | 100 | 1 | 0 | 0 | 8 | 0 | 0 |
| 5 | 4.5 | 2 | 1 | 33.3 | 3 | 0 | 0 | 7 | 0 | 0 |
| 6 | 5.5 | 3 | 3 | 50.0 | 4 | 2 | 33.3 | 7 | 1 | 12.5 |
| 7 | 6.5 | 1 | 6 | 85.7 | 2 | 5 | 71.4 | 7 | 2 | 22.2 |
| 8 | 7.5 | 4 | 1 | 20.0 | 5 | 0 | 0 | 7 | 1 | 12.5 |
| 9 | 8.5 | 0 | 7 | 100 | 2 | 5 | 71.4 | 6 | 5 | 45.5 |
| 10 | 9.5 | 2 | 6 | 75.0 | 3 | 4 | 57.1 | 7 | 6 | 46.2 |
| 11 | 10.5 | 0 | 8 | 100 | 0 | 8 | 100 | 4 | 12 | 75.0 |
| 12 | 11.5 | 0 | 17 | 100 | 1 | 16 | 94.1 | 4 | 22 | 84.6 |
| 13 | 12.5 | 0 | 29 | 100 | 2 | 27 | 96.4 | 1 | 32 | 97.0 |
| 14 | 13.5 | 0 | 2 | 100 | 0 | 3 | 100 | 0 | 6 | 100 |
| 15 | 14.5 | 0 | 7 | 100 | 1 | 6 | 85.7 | 0 | 11 | 100 |
| 16 | 15.5 | 0 | 4 | 100 | 0 | 5 | 100 | 0 | 8 | 100 |

1) Less than 16.5 g was considered to be immature (Miyazaki, 1975).

as mentioned before, this school is mostly composed of the immature males affected by the special schooling behavior, and the data from this school may not be suited for the present purpose. On the other hand, as the other 3 schools show less specialized age distribution even if the frequency below 9 years is rather low, they will give better estimation of the mean age at onset of sexual maturity. The least squares regressions of the age-maturity relationship calculated for the data of these 3 schools are as follows.

$$\text{Female}: \ y=12.60x-56.51 \qquad 4.5 \leqq x \leqq 13.5$$

$$\text{Male} \ : \ y=12.05x-58.94 \qquad 4.5 \leqq x \leqq 13.5$$

They give 8.5 years for female and 9.0 years for male as the age where 50% of the animals are sexually mature. Though the figure of the female is slightly lower compared with the corresponding age of female 8.8 years (Kasuya 1972) or 9.1 years (Miyazaki 1975), these difference may not be significant because a slight underestimation is expected from the scarecity of the immature animals below 9 years of age in the 3 schools discussed here. The mean age of the male at the attainment of sexual maturity estimated above shows good coincidence with 9.2 years and 9.0 years estimated by Kasuya (1972) and Miyazaki (1975) respectively.

Fig. 9 shows the relationship between age and the weight of a testis. The weight shows a rapid increase at the age between 9 and 13 years in *S. attenuata* or between 7 and 11 years in *S. coeruleoalba*, which correspond to the age at

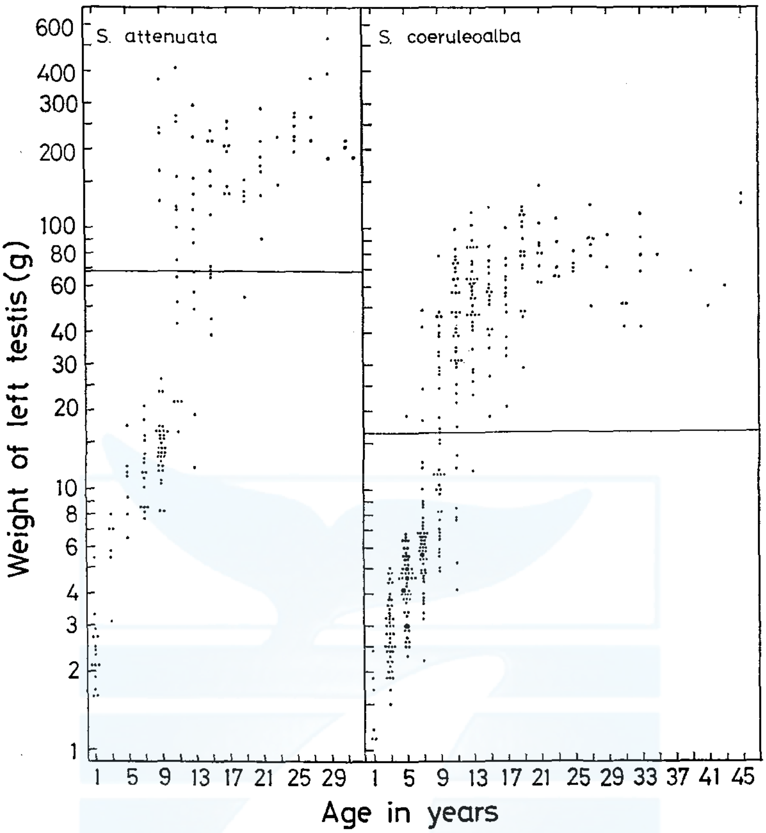

Fig. 9. Scatter diagrams of the relationship between age and the weight of testis. Two age groups are combined. In *S. coeruleoalba* data from school no. 22 are included. Weight of right testis is plotted if the left is not available. Larger circle indicates 5 animals and the smaller one.

onset of sexual maturity. However after the age of 15 years, the weights are distributed between 120 g and 600 g (*S. attenuata*) or between 40 g and 150 g (*S. coeruleoalba*) and there is observed no increase related with the age of the animal. This stage will correspond to the full sexual maturity and probably to the stage of social maturity as suspected by Miyazaki (1975). This feature is completely different from that observed in *Physeter catodon* where the weight of testis increases after the attainment of sexual maturity at or little above the previous rate (Gambell 1972).

*Accumuration rate of corpora in the ovaries*

The persistency of the corpora for entire lifetime of the female was suggested in *S. attenuata* by Kasuya *et al.* (1974). Possibly this is also true for *S. coeruleoalba* (Hirose *et al.* 1970, Miyazaki 1975).

In *S. attenuata*, though the individual variation is large, there is expected a linear relationship between the number of corpora and the age (Fig. 10). The following regression is obtained by the least squares for the animals older than 7 years of age,

$$y=0.412x-1.97$$

where y indicates the number of corpora, and x the age in years. This indicates the mean annual ovulation rate of 0.412, or 1.62 ovulations in one reproductive cycle of 3.94 years (see page 88). Kasuya *et al* (1974) estimated, through the analyses of corpora diameter, the annual ovulation rates of between 0.407 and 0.595 for 5 age groups classified by the corpora number. And they concluded from these estimates that the annual ovulation rate changes from 0.432 of young animal to 0.487 of the animals with highest corpora number. Though they considered that this indicates the change of the ovulation rate related with the age of the animal, it is theoretically incorrect because the number of corpora in the ovaries is the function of both the age of the animal and of the individual specific ovulation rate, and these two factors could not be separated in their study. It should have been interpreted that the mean annual ovulation rate of the dolphins which may attain higher corpora number is higher than the mean rate of the other dolphins. Furthermore, the diameter of the corpora is not a much reliable indicator of the time elapsed after the ovulation, and the ovulation rate estimated from its analysis is less accurate. Accordingly the ovulation rate of *S. attenuata* estimated in this study will be the present best estimate.

As shown in Fig. 11, the relationship between the number of ovulations and the age of *S. coeruleoalba* may not come on a single linear relation. If the regression lines are calculated separatly for the age classes from 5 to 25 years and for those from 26 to 43 years. The following relations are obtained by the least squares.

$$y=0.414x-2.40 \qquad 5\leqq x\leqq 25$$

$$y=0.115x+6.55 \qquad 26\leqq x\leqq 43\,.$$

However, the first regression line seems to fit to the animals up to 33 years of age. There are expected three reasons for this. The first is the simple sampling error caused by the scarcity of the samples of higher age, the second is the decline of the ovulation rate or the resorption of corpora at higher age, and the third is the recent increase of ovulation rate might have happened as the response of the population to heavy exploitation started since the last war. The possibility of miscounting of the corpora will be neglected, because the counting was made by myself with the same method for both species of *Stenella*. The third possibility is also improbable because the ovulation rate of 0.115 per annum is too low even as the rate at initial population level, and because the ovulation rate of *S. attenuata* possibly at the initial level (Kasuya *et al* 1974) is almost identical with the first rate 0.414 per annum. Accordingly, the possible explanations can be only the first or the second. And, though the first might be more probable, the conclusion on this problem will have to wait until more data are accumulated.

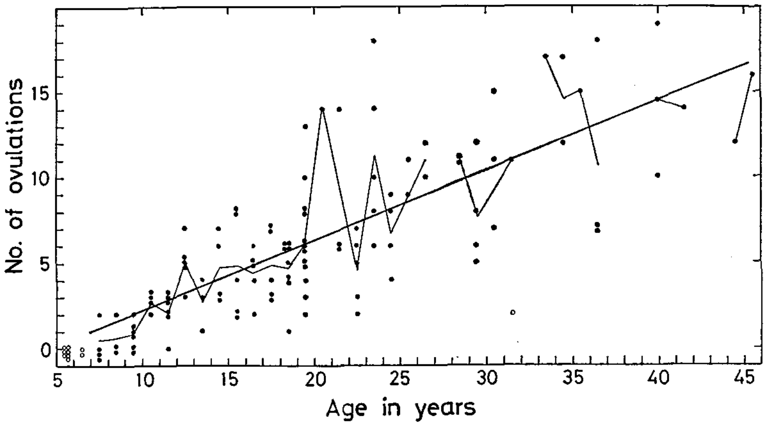

Fig. 10. *S. attenuata*, scatter diagram showing the relationship between age and number of corpora in the ovaries (124 females). Thin straight line and thick straight line indicate mean corpora number and regression line obtained by least squares respectively, for both only the data reoresented by closed circles are used.

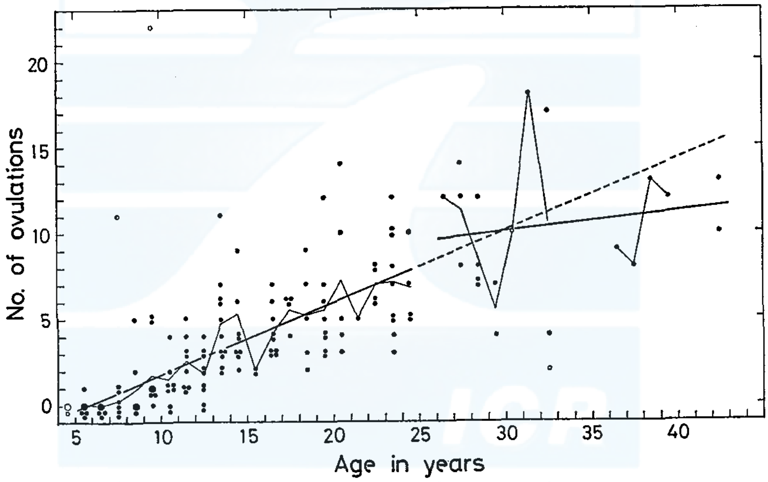

Fig. 11. *S. coeruleoalba*, scatter diagram showing the relationship between age and number of corpora in the ovaries (170 females). The data from school no. 22 are not included. Larger circle indicates five animals and smaller one. For other marks see Fig. 10.

*Reproductive cycle*

In this section the reproductive parameters of the adult females are analysed in relation to the age of the animals. When the ratio of pregnant females in the total adult females is shown by P, that of pregnant and simultaneously lactating by PL, that of lactating by L, that of resting by R, and the mean length of gestation by G years, the annual pregnancy rate and the mean calving interval in years are estimated as follows.

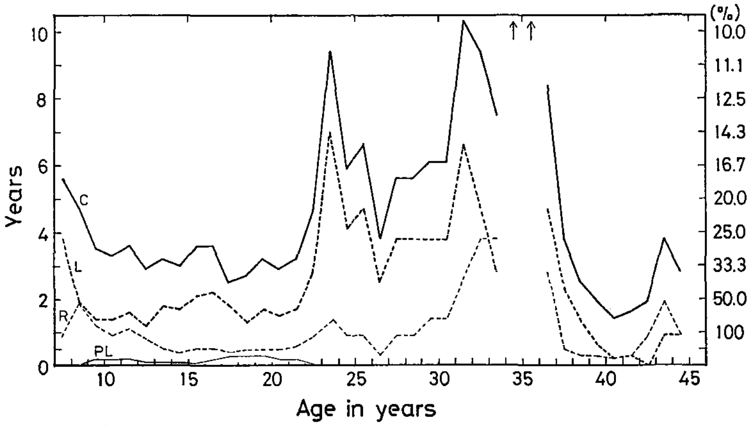

Fig. 12. *S. attenuata*, relationship between age and the mean reproductive parameters estimated from the ratio of reproductive stages. C: calving interval (left scale) and annual pregnancy rate calculated from it (right scale), L: length of lactation, R: length of resting period, PL: length of the period lactating and simultaneously pregnant. Each value is calculated combining the data of nearest 5 age classes. The age classes indicated by arrow containe no pregnant female.

TABLE 5. DIFFERENCE OF REPRODUCTIVE PARAMETERS OF ADULT FEMALES BETWEEN AGE CLASSES

| Species | *S. attenuata* | | | | |
|---|---|---|---|---|---|
| Age class (year) | 7—15 | 15—25 | 25—35 | 35—46 | Total[1] |
| No. animals | 31 | 64 | 22 | 13 | 130 (164) |
| Pregnancy (years) | 0.83 | 0.72 | 0.94 | 0.94 | 0.79 (0.82) |
| PL (years) | 0.10 | 0.22 | 0 | 0 | 0.14 (0.12) |
| Lactation (years) | 1.46 | 2.04 | 4.06 | 1.40 | 1.99 (2.23) |
| Resting (years) | 0.83 | 0.55 | 1.87 | 0.70 | 0.77 (0.77) |
| Calving interval (years) | 3.23 | 3.53 | 6.87 | 3.04 | 3.69 (3.94) |
| Annual pregnancy rate (%) | 31.0 | 21.7 | 14.6 | 28.8 | 27.1 (25.4) |
| Species | *S. coeruleoalba* | | | | |
| Age class (year) | 5—15 | 15—25 | 25—35 | 35—49 | Total |
| No. animals | 72 | 63 | 22 | 8 | 165 |
| Pregnancy (years) | 0.95 | 0.73 | 0.94 | 0.75 | 0.86 |
| PL (years) | 0.05 | 0.27 | 0.06 | 0.25 | 0.14 |
| Lactation (years) | 0.24 | 0.46 | 0.24 | 0.75 | 0.33 |
| Resting (years) | 0.07 | 0.07 | 0.06 | 0.25 | 0.08 |
| Calving interval (years) | 1.31 | 1.54 | 1.29 | 2.00 | 1.41 |
| Annual pregnancy rate (%) | 76.4 | 65.1 | 77.3 | 50.0 | 70.9 |

[1] In parenthesis includes age unknown animals cited from Kasuya *et al.* 1974, Table 14.

$$\text{Annual pregnancy rate} = (\text{Calving interval})^{-1} = \frac{P+PL}{G}$$

Then mean length of each reproductive stage is estimated by the formula

$$\frac{X}{P+PL} \cdot G$$

where X indicates the ratio of females at one of the above 4 stages. This method gives correct estimates only when the samples are not seasonally biased. As the present data, especially those of *S. coeruleoalba*, were collected in the limited season, there might occur some bias of this kind. However, since the mating of both species of *Stenella* occurs in wide range of the seasons and there exist probable three mating peaks in *S. attenuata* (Kasuya *et al.* 1974) and two (Kasuya 1972) or three (Miyazaki 1975) peaks in *S. coeruleoalba*, such kind of bias can be small enough compared with the bias caused by the inclination of the dolphins to form separate schools by the sex, growth and reproductive stages suggested by Kasuya (1972), Kasuya *et al.* (1974), and Miyazaki (1975).

The length of gestation of *S. attenuata* was estimated by Kasuya *et al* (1974) to be 11.24 months or 0.94 years. If this gestation length is used for the above calculation, the mean length of calving intervals is estimated to be 3.94 years, mean length of lactation (L+PL) 2.35 years, and mean length of resting period 0.77 years (Table 5). Though the data used here are same with those in Kasuya *et al* (1974), as the treatment of the females pregnant and simultaneously lactating is different the figures are slightly changed. The analyses of the parameters in relation to the age of the female reveals that the mean calving interval is shorter in the females below the age of 23 years and only in those age classes the pregnant and simultaneously lactating females are observed. After this age the length of calving interval increases, which at first step accompanies the increase of the length of lactation and then the increase of resting period. This phenomenon can be interpreted that, in the younger females, the lactation ceases at about 2 years after the former parturition almost synchronizing with the start of the next conception, and in the older females as the start of the next conception delays the period of lactation is extended up to about 4 years in the average when the calf stops suckling affected by the change of the behavior. This age of the calf is the time when the calves are expected to leave the school of their mothers (Kasuya *et al* 1974). If, then, the next gestation does not start for more than 4 years, there can occur the increase of resting females. The extremely rapid increase of the mean calving interval after the age of 30 years seems to suggest the presence of the females that ceases the ovulatory activity. The decline of the length of calving interval or the increase of annual pregnancy rate after the age of 37 years is the reverse of the former trend, but the similar phenomenon is found also in *S. coeruleoalba*. One possible explanation for it might be that the old females which ceases the ovulatory activity die, by the age between 35 and 40 years, earlier than the still active females which is fewer in number, and even the latter females they often die at the last parturition without followed by the lactation.

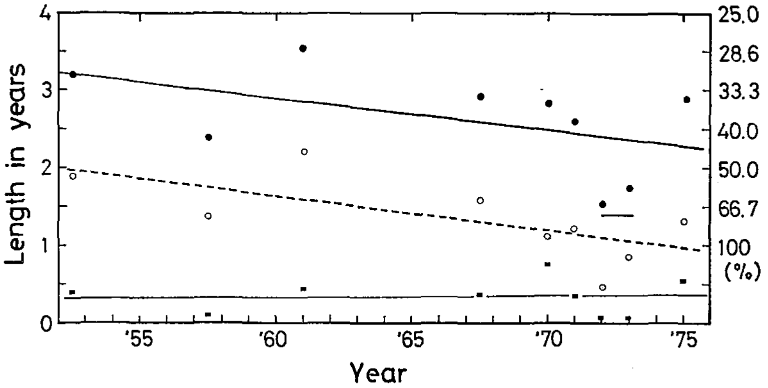

Fig. 13. *S. coeruleoalba*, annual fluctuation of the mean reproductive parameters estimated from the ratio of the reproductive stages. Closed circle and solid line indicate the length of calving interval (left scale) and the annual pregnancy rate (right scale), open circle and dotted line length of lactation (L+PL, left scale), and square and thin solid line length of resting period (left scale). For further explanation see text.

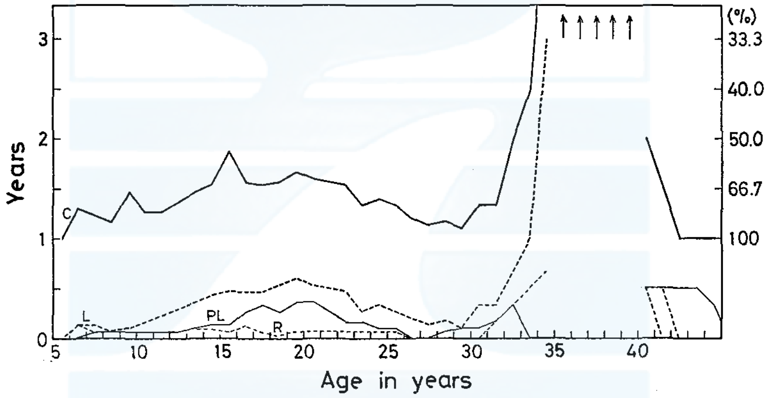

Fig. 14. *S. coeruleoalba*, relationship between age and the mean reproductive parameters. For further explanation see Fig. 12.

For *S. coeruleoalba*, there is no reliable estimation of the gestation length, however it was roughly suspected by Kasuya (1972) to be about 12 months. In the present study this estimation is used without further confirmation. Kasuya and Miyazaki (1976) indicated that the mean calving interval in the population of *S. coeruleoalba* off the Pacific coast of Japan is decreasing accompanied with a decrease in the population level. If the data of 33 pregnant, 44 lactating, and 18 resting females obtained from the two schools caught in 1975 (see Table 1) are added to the data reported by Kasuya and Miyazaki (1976), the following trend is estimated by the least squares (see also Fig. 13).

$$\text{Calving interval} = -0.040838x + 82.944$$

$$\text{Length of lactation} = -0.044982x + 89.811$$

$$\text{Resting period} = 0.001951x - 3.485$$

where x indicates the calender year, and length of each stage is indicated by year. The length of lactation includes both the period of lactation and that of lactating and simultaneously pregnant. The above formula gives the estimation of the mean calving interval of 2.39 years in between 1972 and 1973 when the present materials were collected. This is slightly longer than the calving interval estimated from the regression in Kasuya and Miyazaki (1976). As shown in Fig. 13, the catch in these two seasons is strongly biased by the high ratio of pregnant females, and the mean calving interval estimated from the materials used in this study is only 1.41 years (see the short bar in Fig. 13), which is only 59.0% of the unbiased estimate calculated from the above regression. Accordingly only a general trend of the change of reproductive parameters related with the age of the female can be discussed in this study, and if necessary the above bias must be corrected.

In *S. coeruleoalba*, the period of shorter calving interval lasts about 10 years longer than *S. attenuata* until about 32 years of age, and the period when the lactating and simultaneously pregnant females occur also last longer. After this period, the pregnancy rate declines rapidly and then increases as observed in *S. attenuata*. Though the reason of the difference of the period of the high reproductive activity between the two species of *Stenella* is not conslusive, it seems to be possible to attribute it to the difference of the population level because the Japanese coastal population of *S. attenuata* is close to the unexploited level (Kasuya *et al.* 1974) and that of *S. coeruleoalba* has been exploited since before 1897 and the decline of the population is indicated (Kasuya and Miyazaki 1976).

### *Sex ratio*

The sex ratio of *S. attenuata* was already analysed by Kasuya *et al.* (1974) and the predominance of the male in fetal and juvenile stages was indicated. Table 6 shows the sex ratio of fetus and of the juvenile animals not exceeding 142 cm in body length which corresponds to the age of one year on the mean growth curve. As the sex ratio of the species at the time of birth will be between those of the above two growth stages, the ratio of females at the instance of birth, 41.6%, was obtained by combining the data of the two categories.

The ratio of females at the instance of birth in the population of *S. coeruleoalba* was estimated by Kasuya and Miyazaki (1976) to be 47.6% based on large number of samples (Table 6). Though they included the animals corresponding, on the mean growth curve, to the age up to 1.25 years, it will not give significant bias.

Fig. 15 shows the change of the sex ratio related with the age of the dolphins. The extraordinaly high ratio of the males at the age between 5 and 11 years in *S. attenuata* or between 2 and 15 years in *S. coeruleoalba* is considered to be the result of the sexual segregation in the period between weaning and the attainment of full sexual maturity. Possibly the ages when the young dolphins move from the nursery school to the school of immature animals and

TABLE 6. SEX RATIO OF THE DOLPHINS AT BIRTH

| Species | *S. attenuata* | | | *S. coeruleoalba*[1] | | |
|---|---|---|---|---|---|---|
| Stage | fetus | juvenile[2] | Total | fetus | juvenile[3] | Total |
| No. males | 39 | 79 | 118 | 351 | 385 | 736 |
| No. females | 31 | 53 | 84 | 310 | 359 | 669 |
| Female, % | 44.3 | 41.4 | 41.6 | 46.9 | 48.3 | 47.6 |
| Male/Female | 1.26 | 1.49 | 1.40 | 1.13 | 1.07 | 1.10 |

1) Data cited from Kasuya and Miyazaki 1976.
2) Not exceeding 142 cm.
3) Not exceeding 172 cm.

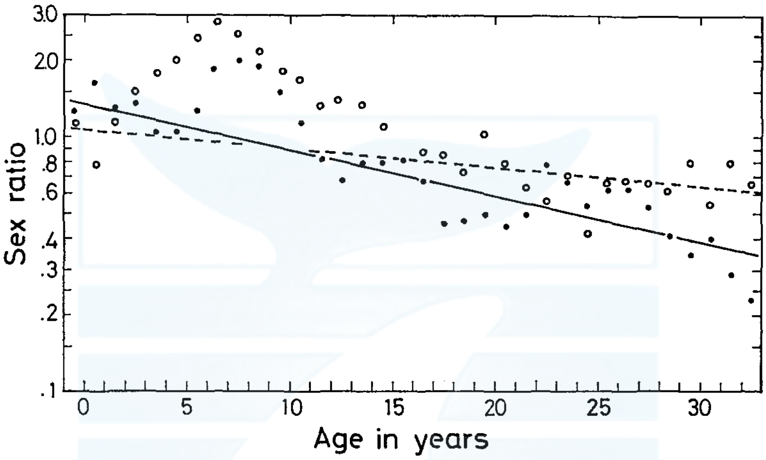

Fig. 15. Relationship between sex ratio (male/female) and the age of *S. attenuata* (closed circle and solid line) and of *S. coeruleoalba* (open circle and dotted line). The ratio for the age more than one year is calculated combining the data of the nearest 5 age classes. For other explanation see text.

then to the school of adult dolphins will be different between the sexes, and this in combination with the kinds of schools studied by me will give such a bias in the sex ratio. If these age classes are excluded there is observed a decline of the ratio with the progress of the age of the animals, which will indicate the sexual difference of the mortality rate. When $\mu$ and $\mu'$ indicate the annual natural mortality coefficient of male and female respectively, and $R_x$ the sex ratio (male/female) at the age of x years, there is expected the following relationship.

$$R_x = R_0 e^{-(\mu-\mu')x}.$$

The regression lines in Fig. 15 and the following figures are calculated by the least squares based on the sex ratio at birth obtained above and the points in Fig. 15 corresponding to the ages above 11 years (*S. attenuata*) or 15 years (*S. coeruleoalba*). In case of *S. coeruleoalba* the mortality is affected by natural mortality and fishing mortality. However, as the fishing mortality rate of the species is not expected to be different between sexes, it can be neglected in the calculation.

| | $\mu-\mu'$ | $R_0$ |
|---|---|---|
| *S. attenuata* | 0.0412 | 1.32 |
| *S. coeruleoalba* | 0.0171 | 1.06 |

These figures indicate that the difference of the natural mortality coefficient between the sexes is higher in *S. attenuata*, and that it is partially compensated by the higher ratio of the male at birth.

### *Age composition and mortality*

The age composition of *S. attenuata* obtained from 158 males and 200 females are shown in Figs. 16 and 17. The age composition suggests the presence of segregation related with the age and the sexual maturity of the animals below the 13 years of age as already mentioned in the former sections. The slope of the age frequency at the right side of this point indicates the natural mortality, as the fishing mortality is negligible in this population. Though the mortality seems to be slightly higher in the females above 31 years, the least squares calculated ignorering this minor change gives the following annual mortality rate for *S. attenuata*.

| Sex | Coefficient | Rate in % | Age in years |
|---|---|---|---|
| Female | 0.0779 | 7.49 | 14≦ |
| Male | 0.1135 | 10.73 | 14≦ |

The difference of the annual mortality coefficient between sexes is 0.356 and coincides well with the corresponding figure estimated from the sex ratio.

Since the above rates can be considered to represent the mean annual mortality rate of the adult animals, the mean mortality of the immature stage is estimated as follows. When the following abreviations are used

A : Number of mature females
$l_x$ : Number of females at the age of x years
C : Calving interval in years
L : Litter size
m : Mean age at the onset of sexual maturity
s : Ratio of females at birth
$\mu_1$ : Mean annual mortality coefficient of immature females
$\mu_2$ : Mean annual mortality coefficient of mature females

there must be the next relations in an unexploited stationary population.

$$l_0=\frac{A\cdot L\cdot s}{C}$$

$$l_m=l_0e^{-\mu_1 m}$$

$$A=l_m\int_m^\infty e^{-\mu_2(x-m)}dx$$

As C=3.94, s=0.416, m=9.0, and $\mu_2$=0.0779 are obtained in this study, and the

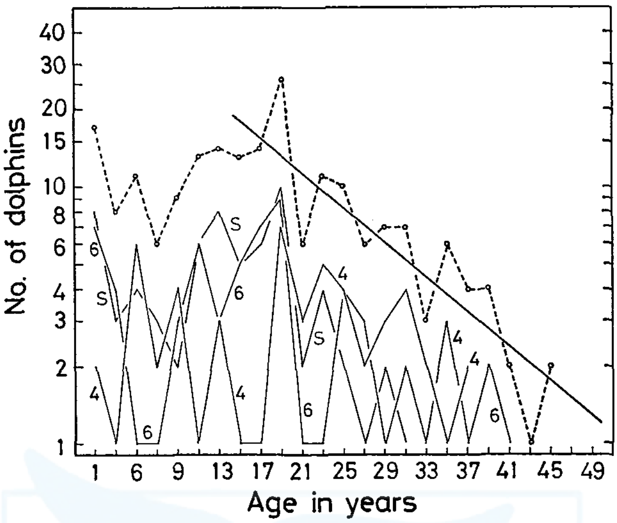

Fig. 16. *S. attenuata*, age composition of the 200 females based on cemental layers. 4 indicate School no. 4, 6 school no. 6, S sum of the school nos. 1, 2, 3, 5 and 7, and the open circle and dotted line the total of the seven schools. Each two age groups are combined.

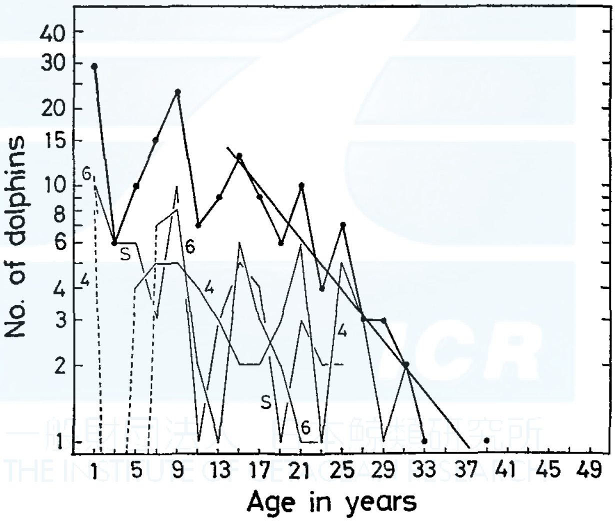

Fig. 17. *S. attenuata*, age composition of the 158 males. Closed circle and thick solid line indicate the total of seven schools. For other explanation see Fig. 16.

litter size is 1.0 (Kasuya *et al.* 1974), the following estimate of the mean annual natural mortality rate of immature female of *S. attenuata* is obtained from the above formulae.

| Sex | Coefficient | Rate in % | Age in years |
|---|---|---|---|
| Female | 0.0338 | 3.32 | ≦9.0 |

As the difference of the mortality coefficient between the sexes is between 0.0412 and 0.0356 or approximately 0.038, the rough estimate of the mean annual natural mortality of the immature male is as follows.

| Sex | Coefficient | Rate in % | Age in years |
|---|---|---|---|
| Male | 0.072 | 6.9 | ≦9.0 |

The natural mortality rates of the immature dolphins estimated here are the mean of the mortality of all the age classes from 0 year to the age at the attainment of sexual maturity, and the possible higher mortality expected for the suckling calves is not separated. It was already indicated by Kasuya *et al.* (1974) on *S. attenuata* that the mean natural mortality rate in the immature period must be lower than that in the adult stage. The present study gives results similar to those obtained in the previous study.

The age compositions of 341 females and of 488 males of *S. coeruleoalba* are shown in Figs. 18 and 19. In these age data, the age of 62 females and 217 males of the school no. 22 was determined by counting the dentinal layers by ordinary method. Because of the segregation of the immature individuals (Kasuya 1972, Miyazaki 1975) as in the case of *S. attenuata*, only the slope above the age of 12 years in females or that above 14 years in males can indicate the mortality under certain assumption mentioned below. They are as follows.

| Sex | Coefficient | Rate in % | Age in years |
|---|---|---|---|
| Female | 0.0919 | 8.78 | 12≦ |
| Male | 0.1143 | 10.80 | 14≦ |

Above values can indicate the mean annual total mortality during the period from 1920's to 1959's only when the population is assumed to be stationary. However, as the exploitation of this population became higher near the end of the last war as in the case of *Phocoenoides* (Kasuya 1976 a and b) and the population has been decreasing (Kasuya and Miyazaki 1976), the estimation is not fully accurate. The total mortality rate in the postwar period must be estimated separately. This can be made using the frequency of corpora number, because the method can afford more abundant data. Fig. 20 shows the age composition of sexually mature females calculated from the frequency of corpora number cited from Kasuya and Miyazaki (1976) and the accumulation rate of corpora (0.414/year) estimated in this study. There is observed two slopes in the age frequency. The first is from 15.9 (4 corpora) to 28.4 years (9 corpora) of age and the second slope is from 30.9 years (10 corpora) and above. If the mortality is calculated separately, the following figures are obtained as the estimates of the total annual mortality rate of mature females.

| Sex | Coefficient | Rate in % | Age in years |
|---|---|---|---|
| Female | 0.1258 | 11.82 | 15.9–28.4 |
| Female | 0.0951 | 9.07 | 30.9–51.1 |
| Female | 0.0896 | 8.57 | 15.9–51.1 |

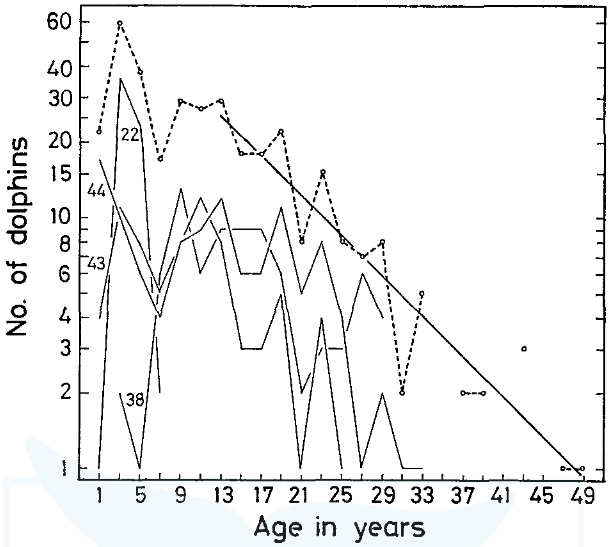

Fig. 18. *S. coeruleoalba*, age composition of the 341 females. Numerals indicate the school number. The age composition of school no. 22 was based on the ordinary method of reading of dentinal layers. For other marks see Fig. 16.

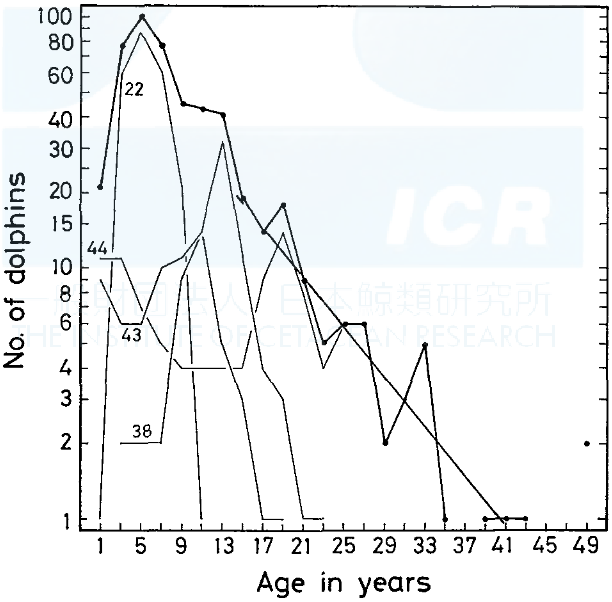

Fig. 19. *S. coeruleoalba*, age composition of the 488 males. For marks see Figs. 17 and 18.

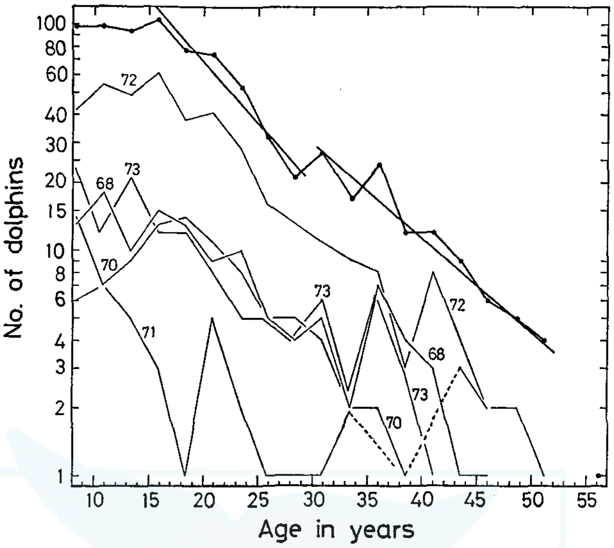

Fig. 20. *S. coeruleoalba*, age composition of the 772 adult females based on the number of corpora in the ovaries. Number indicate the sampling year, and closed circle and thick line the total. For further explanations see text.

The mortality rate calculated from all the age classes above 15.9 years coincides well with the figure obtained above based on the cemental layers. This may indicate the correctness of the above calculation. Furthermore, since the date of birth of dolphins at the boundary of the two slopes, 28 to 30 years before 1972 when most of the samples were collected, approximately coincides with the end of the last war in 1945, the annual mortality rate of 11.8% seems to indicate the rough estimation of the mean total mortality rate of the females in the years near the end of the war to late 1950's. As the difference of the annual mortality coefficient between sexes is in between 0.0171 and 0.0224 or about 0.020, the total mortality coefficient of the adult male in the corresponding years might be $0.126+0.020=0.146$ or 13.6% per year. Though the mean mortality rate in the immature stage is expected to be lower than that of adult dolphins as in the case of *S. attenuata*, it is not possible to estimate it at present. The natural mortality rate is also unknown.

## DISCUSSION

### *Age determination method*

When the layers in dentine and cementum are compared, the higher number is almost always found in the latter in case of the dolphins older than 9 (*S. attenuata*) or 11 (*S. coeruleoalba*) years of age. If, after these ages, the number of dentinal layers plotted against the number of cemental layers showed an increase slower than that in younger stage, it would be possible to interpret that the accumulation rate of cemental layers increases after these ages and that of dentinal layers stays constant. However, as the number of dentinal layers of older age groups is constant without showing any correlation with that of cemental layers, it is concluded that the accumulation of the dentinal layers stops at various ages between 9 or 11 years and about 25 years, or that the dentinal layers become too thin to be distinguished by the present method. Recently same phenomenon was confirmed by Dr. P. B. Best (person. comm.) on *Lagenorhynchus obscurus* through tetracyclin marking. He considers that "dentinal layers accumulate annually in young dolphins, but deposition of dentine slows down in older animals and may cease altogether". As the tooth at this stage is hardly distinguishable from that at preceeding stage through the observation of the pulp cavity, it seems to be safe to use the cemental layers for the age determination of the dolphins with more than 9 (*S. attenuata*) or 11 (*S. coeruleoalba*) dentinal layers. However it must be noted for the practical use of the cemental layer that the counting of the layers is more difficult and unreliable than that of dentinal layers, and that it is necessary to confirm the coincidence of the counts of the two kinds of layers on the decalcified and stained preparation of the tooth of young dolphin.

Furthermore, it should be remembered that the suitable way of preparing the tooth for age determination can be different between species of dolphins. If the present method of preparation is applied on *Phocoenoides* or *Lagenorhynchus* tooth, it gives good result for reading the cemental layers. However, in cases of *Globicephala macrorhynchus* and *Pontoporia blainvillei* the decalcification and staining are not necessary if the tooth is ground thinly enough, and the thick and irregular cemental layers in *Platanista gangetica* seems difficult to use for age determination.

### *Life history parameters*

From the above reasons, the life history parameters estimated previously by reading dentinal layers and concerning the sexually mature dolphins are now unreliable. They are the accumulation rate of the corpora, mortality rate, and the age at the attainment of asymptotic length. In case of *S. attenuata*, the mean age at the onset of sexual maturity must also be corrected. However, as the accumulation rate of the corpora of this species was estimated from the comparison of corpora diameter and the growth of suckling calves, and the mortality rate from the corpora number and the accumulation rate (Kasuya *et al.* 1974), they are not much affected by the present study (Table 7). It is also confirmed that the ovulation rate and the calving interval estimated in the present study give the mean number of ovulations in one reproductive cycle 1.62 which is close to the estimation of 1.7 to 1.8 made by Kasuya *et al.* (1974).

Miyazaki (1675) estimated, for *S. coeruleoalba*, the annual ovulation rate of 0.59 based on the age-number of corpora relationship of the animals between the age of 11 and 15 dentinal layers, and this result was used by Kasuya and Miyazaki (1976) for the estimation of the mortality rate and the population.

TABLE 7. COMPARISON OF LIFE HISTORY PARAMETERS OF THE TWO SPECIES OF *STENELLA* OFF THE PACIFIC COAST OF JAPAN

| Species<br>Parameters | *S. attenuata*<br>Previous study[1] | <br>Present study | *S. coeruleoalba*<br>Previous studies | <br>Present study |
|---|---|---|---|---|
| 1. Gestation (months) | 11.24 | — | 12 | — |
| 2. Length at birth (cm) | 89 | — | 99.8[1] | — |
| 3. Length at 1 year of age (cm) | 142.7 | 142.5 | 164.5 | 164.0 |
| 4. Length at 3 years of age (cm) | | | | |
| male | 166.0 | 163.0 | 194.0 | 193.0 |
| female | | 161.5 | 191.0 | 189.0 |
| 5. Length at 9 years of age (cm) | | | | |
| male | 191.5 | 186.0 | 220.5 | 222.0 |
| female | 190.0 | 187.5 | 217.0 | 218.0 |
| 6. Length at 50% maturity (cm) | | | | |
| male | 194.3 | — | 218.3[3] | — |
| female | 181.9 | — | 211.5 | — |
| 7. Asymptotic length (em) | | | | |
| male | 203.3 | 207.1 | 234.4[1] | 236.0 |
| female | 194.9 | 193.9 | 223.5 | 225.3 |
| 8. Age at asymptotic length (years) | | | | |
| male | 12 | 22 | 12 | 21 |
| female | 11 | 12 | 11 | 17 |
| 9. Age at 50% maturity | | | | |
| male | 10.3 | 11.8 | 9.2[2] | 9.0 |
| female | 8.2 | 9.0 | 8.8 | (8.5) |
| 10. Maximum age (years) | | | | |
| male | 24 | 40 | 25[1] | 50 |
| female | 24 | 46 | 26 | 49 |
| 11. Calving interval (years) | 4.19 | 3.94 | 2.20('73)[3] | 2.37('73) |
| 12. Length of lactation (years) | 2.44 | 2.35 | 0.89('73)[3] | 1.06('73) |
| 13. Annual pregnancy rate (%) | 23.8 | 25.4 | 45.5 ('73)[3] | 42.2 ('73) |
| 14. Annual ovulation rate | 0.43-0.49 | 0.412 | 0.590[4] | 0.414 |
| 15. Annual mortality rate (%) | | | | |
| adult female | 7.4 | 7.5 | 12.8[3] | 11.8 |
| immature female | 3.2 | 3.3 | — | — |
| adult male | 14.8 | 10.7 | — | 13.6 |
| immature male | 11.8 | 6.9 | — | — |
| 16. Ratio of female at birth (%) | 38.9 | 41.6 | 47.6[3] | — |
| 17. Maximum no. of calves produced by one female | 8.3 | 9 | — | 16 |
| 18. Mean no. of calves produced by one female | — | 2.40[5] | — | 0.96[5,6] |

1) Kasuya *et al.* 1974, 2) Kasuya 1972, 3) Kasuya and Miyazaki 1976, 4) Miyazaki 1975, 5) $e^{-9\mu_1}\int_0^\infty e^{-\mu_2 x}dx$/calving interval, 6) $\mu_2=0.07$, fishing mortality coefficient 0.0558, and calving interval 2.90 years in 1960 are assumed.

However, in view of the result of the present study, it seems to be improbale that the age-number of corpora relationship can fit such a linear line as indicated by Miyazaki (1975, and see Kasuya and Miyazaki 1976). Actually, any data possessed by myself or by Dr. Miyazaki, both of which were used in Miyazaki (1975), failed to reproduce the graph cited in Kasuya and Miyazaki (1976). Possibly many individuals younger than 16 dentinal layers and with high corpora count might have been arbitrarily excluded from his calculation. Accordingly, the accumulation rate of corpora estimated in this study, 0.414 per annum, is considered to be more reasonable.

However, as this ovulation rate is estimated from the gradient of age-number of corpora relationship, it gives only the ovulation rate in the year when the dolphin attained the sexual maturity. Even if the ovulation rate is changing in recent years, it will not be detected by this method until the recently matured females attain a certain age and the change of the gradient is detected. As the ovulation rate of *S. coeruleoalba* estimated in this study is not different from that of *S. attenuata* at initial population level, and is close even with 0.38 to 0.45 the rate of the *P. catodon* estimated by dentinal layers (Bannister 1969 cited in Gambell 1972, Best 1970, Gambell 1972), 0.5 of *H. ampullatus* (Christensen 1973), and 0.39 to 0.51 of *G. melaena* estimated by indirect method (Sergeant 1962), it is suspected that the annual ovulation rate of toothed whales at their initial population level will not be much different between the species, and that the annual ovulation rate of two kinds of *Stenella* estimated in this study must be that at initial population level.

The population of *S. coeruleoalba* off the Pacific coast of Japan has been depleted in recent years to about half of the initial level, and the mean calving interval is changing shorter (Kasuya and Miyazaki 1976, and see Table 8 and Fig. 14 of this study). If the mean calving interval of this population in between 1972 and 1973 is 2.39 years as calculated from the regression line (see page 89) and the mean annual ovulation rate is 0.414, the mean number of ovulations in one reproductive cycle is only 0.989. This is not significantly different from one ovulation per cycle, or the rate only theoretically possible when all the ovulations are followed by the conception and seems to be actually impossible. This problem can be explained by one or two of the following assumptions.

1. Annual ovulation rate has started to increase in recent years, when the calving interval is so shortened that the further shortening can not be achieved by the improvement of the ratio of successfull ovulation.
2. Length of calving interval is underestimated.

Though it is sure that the estimation of the mean calving interval is liable to alteration when better estimation of gestation length is obtained or when the data of the ratio of females at various reproductive stages covering wider seasons are obtained, the bias of the present estimation was expected not to be large (page 88). And I suspect that the first assumption is more probable.

It has been generally supposed that when the population is depleted by the exploitation, the pregnancy rate or the calving interval of the cetaceans will change in order to result in the increase of recruitment (Laws 1961). This phenomenon seems to have been detected with insufficient accuracy in the population of *S. coeruleoalba* off the Pacific coast of Japan (Kasuya and Miyazaki 1976). The difference of pregnancy rate between *S. coeruleoalba* and *S. attenuata* indicated in the present study can be the reflection of different strength of exploitation. If the relationships between pregnancy rate and age of the animals of the two species of *Stenella* are compared (Figs. 12 and 14) in view of the above hypothesis, there are expected several factors influencing the change of mean pregnancy rate in a population. The first and the most direct is the shortening of calving interval in all the age classes. This is expected from the fact that the mean calving interval of the unexploited *S. attenuata* is about 3.4 years in the age classes of high reproductive activity, and the corresponding figures of exploited *S. coeruleoalba* is about 1.4/0.590=2.4 years when the bias of the data is corrected (see page 90). The second factor is the extension of the period of high reproductive activity from up to 22 years of age as observed in *S. attenuata* to up to 32 years of age in *S. coeruleoalba.* These two factors will result in the decrease of the mean length of lactation, which is suggested from the facts that the shortening of mean calving interval of *S. coeruleoalba* in recent years is achieved by the shortening of the period of lactation (Kasuya and Miyazaki 1976, page 89 of this study) and that the length of lactation in the ages of high reproductive activity is generally shorter than that in older age classes (page 88). The third and the most indirect factor will be the increase of the ratio of young and reproductively active females, which is the result of the high recruitment rate brought by the former two factors and of higher fishing mortality rate. Though the attainment of sexual maturity at younger age is expected when the population decreases as already observed in fin whale (Lockyer 1972), it ts not clear if the difference of the mean age at the onset of sexual maturity between the two species of *Stenella* observed in this study is due to it. It seems to be probable in the delphinids that the length of nursing period is more variable than the age at the onset of sexual maturity. So, when the population is depleted by the exploitation, the shortening of the calving interval directly related with that of nursing period as indicated in this study will occur before the change in the age at the attainment of sexual maturity does.

Kasuya *et al.* (1974) estimated from the analysis of the size distribution of the corpora in the ovaries that the maximum number of calves produced by one female is 8.3 in *S. attenuata.* It was shown in the present study that the age of the oldest female of the species is about 46 years, mean calving interval 3.94 years and the mean age at the start of the sexual maturity 9 years. These figures give the estimation of the maximum number of calves that can be produced by a female, or (46-9)/3.94=9 calves. This figure coincides extremely well with the estimate made by Kasuya *et al.* (1974) through the analysis of corpora. If the similar calculation is made for *S. coeruleoalba* in the early 1970's, it gives approximate figure (49-9)/2.4=16 calves. The extremely higher number of production of calves in the latter species must be the sum of the above mentioned reaction of the population to the exploitation.

*Estimation of the population of* S. coeruleoalba

In view of the present study indicating the minor change of the parameters, the population analysis made by Kasuya and Miyazaki (1976) shall be reconsidered based on the improved parameters concerning total mortality rate of post-war period, annual change of mean calving interval, and calving interval at initial population level taken from that of *S. attenuata*. Furthermore, the catch statistics at Taiji in 1973 and the total catch of the same year shall be corrected to 1,000 and 8,200 dolphins respectively instead of 7,500 and 14,700 used by Kasuya and Miyazaki (1976), and the total catch of the species in 1974, 13,000 animals, was added.

If the analyses of the population is made by the same principle as used by Kasuya and Miyazaki (1976), the relationship between net annual recruitment rate (R in %) and the population (P in thousands) estimated for each year between 1960 and 1975 based on the recruitment and catch is shown by the following least squares regressions.

$$R=-0.01190P+4.437, \quad \text{when } \mu_2=0.07$$
$$R=-0.01598P+6.462, \quad \text{when } \mu_2=0.08\,.$$

TABLE 8. COMPARISON OF POPULATION ANALYSIS OF *S. COERULEOALBA* BETWEEN PREVIOUS AND PRESENT ESTIMATES

| | Kasuya and Miyazaki1) | | Present estimation | |
|---|---|---|---|---|
| Assumption, $\mu_2$ 2) | 0.07 | 0.08 | 0.07 | 0.08 |
| Presumed $\mu_1$ 3) | 0.05354 | 0.03870 | 0.0606 | 0.0458 |
| Mean annual catch around 1960 | 14,000 | 14,000 | 14,000 | 14,000 |
| Total mortality coefficient | 0.1365 | 0.1365 | 0.1258 | 0.1258 |
| Fishing mortality coefficient | 0.0665 | 0.0565 | 0.0558 | 0.0458 |
| Fishing mortality rate | 0.0643 | 0.0549 | 0.0543 | 0.0448 |
| Population around 1960 | 218,000 | 255,000 | 258,000 | 313,000 |
| Population at 1974 | 129,000 | 186,000 | 176,000 | 252,000 |
| R4) at 1974 level | 3.09% | 3.21% | 2.34% | 2.44% |
| SY5) at 1974 level | 3,980 | 5,960 | 4,120 | 6,140 |
| Initial population | ≧321,000 | ≧340,000 | ≧373,000 | ≧404,000 |
| Population, MSY6) level | 161,000 | 170,000 | 186,000 | 202,000 |
| R at MSY6) level | 2.57% | 3.53% | 2.22% | 3.23% |
| MSY | 4,130 | 6,010 | 4,140 | 6,530 |

1) Kasuya and Miyazaki 1976, 2) Annual natural mortality coefficient of adult female, 3) Mean annual natural mortality coefficient of immature female calculated from $\mu_2$, sex ratio 0.476, and calving interval of *S. attenuata* at initial level, 4) Net annual recruitment rate, estimated from the relationship between P and R in the above, 5) Sustainable yield, 6) Maximum sustainable yield.

These equations give reproductive rate slightly lower than that in Kasuya and Miyazaki (1976). The minimum initial population is estimated as the value of P corresponding to $R=0$. Other revised population parameters based on the above equations are shown in Table 8. Though, the population is suspected to be continuously decreasing since 1970 at an mean rate of 2,700 ($\mu_1=0.08$) or 4,800 ($\mu_2=0.07$) dolphins per year, it is unnecessary to alter their conclusion saying that the present status of the population is " close to the level producing the maximum sustainable yield of 4,000 to 6,000 dolphins per annum ". This is the result of the interference of the higher population estimate lead from the lower fishing mortality rate in the post-war period and the lower recruitment rate calculated from the new estimate of mean calving interval. However it is also important to note that the population parameters lead from the assumption of the natural mortality coefficient $\mu_2=0.07$ might be closer to the truth. The reason is that, if we consider that the length of lifetime of *S. coeruleoalba* is probably longer than that of *S. attenuata* by about 10% (see Table 7), the natural mortality coefficient of adult female of the former species is suspected to be about 10% lower than that of the latter species $\mu_2=0.0779$.

The annual net recruitment rate at the instance of extinction is extraporated from the above equations as 0.04437 (when the natural mortality coefficient of adult female $\mu_2=0.07$) or 0.06462 ($\mu_2=0.08$). The mean calving interval giving these recruitment rates, under the assumption that other parameters stays unchanged, are calculated with the following equations modified from those in page 92 of this study (Kasuya and Miyazaki 1976),

$$l_0 = A \cdot L \cdot s / C$$
$$A = l_0 e^{-(\mu_1+f)m} / (\mu_2+f)$$
$$R = 1 - e^{-f}$$

where f indicates sustainable fishing mortality coefficient. They are 1.59 (when $\mu_2=0.07$) or 1.18 ($\mu_2=0.08$) years. If the ratio of females which start the next conception increase linearly after the preceding parturition and the length of gestation of this species is about 12 months (Kasuya 1972), all the females must start the conception within 1.2 or 0.36 years respectively after the last parturition. Though they are not impossible, the latter seems to be difficult to be accomplished if the mating peaks of two (Kasuya 1972) or three (Miyazaki 1975) times in a year are retained unchanged. However, it is possible to expect at the lower population level, the non linear change of recruitment rate affected by the change of other reproductive parameters (age at the attainment of sexual maturity, sex ratio, or mortality rate of weaning calves) which are not detected at present.

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# EXPLANATION OF PLATES

## PLATE I

Fig. 1. Decalcified and stained tooth section of *S. attenuata*, 167 cm male (school 5, no. 54), pulp cavity at the right. White spots indicate 3 stainable cemental layers, and numerals stainable postnatal dentinal layers. Scale indicates 0.1 mm.

Fig. 2. Another part of the same tooth section in Fig. 1, cusp at the left and pulp cavity at the bottom. 0 indicates prenatal dentine. For other marks see Fig. 1.

Fig. 3. Cemental part of a decalcified and stained tooth section of *S. attenuata*, 195 cm female (school 3, no. 35), dentine at the right. 46 cemental layers are counted. Scale indicates 0.1 mm.

## PLATE II

Fig. 1. Decalcified and stained tooth section of *S. coeruleoalba*, 232 cm male (school 44, no. 337), cusp at the lower left and pulp cavity at the lower right. 28 dentinal layers are counted. Scale indicates 0.1 mm.

Fig. 2. Cemental part of the same tooth section in Fig. 1, dentine at the bottom. 28 cemental layers are counted. Scale indicates 0.1 mm.

Fig. 3. Cemental part of a decalcified and stained tooth section of *S. coeruleoalba*, 227 cm male (school 44, no. 166), dentine at the right. 40 cemental layers are counted. Scale indicates 0.1 mm.

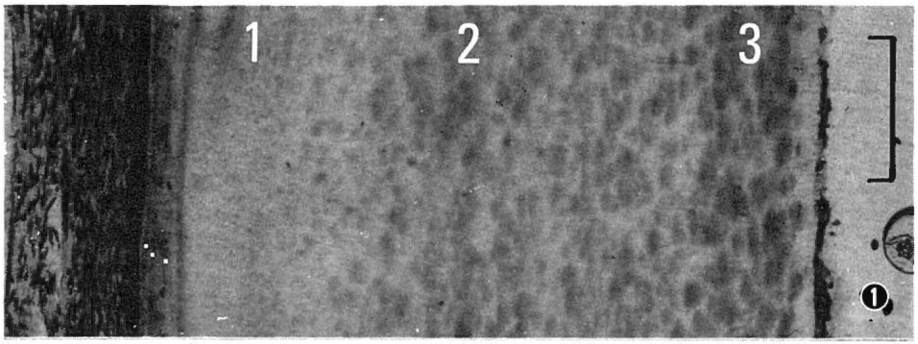
## PLATE III

Fig. 1. Cemental part of a decalcified and stained tooth section of *S. coeruleoalba*, 241 cm male (school 44, no. 295), dentine at the lower left. 49 cemental layers are counted. Scale indicates 0.1 mm.

Fig. 2. Comparison of a tooth section before and after the decalcification and staining. *S. coeruleoalba*, 161 cm male (school 38, no. 161), pulp cavity at the right. Scale indicates 0.1 mm. Top: After decalcification and staining. Bars indicate stainable dentinal layers. Bottom: Before decalcification. Bars indicate opaque dentinal layers.

## PLATE IV

Decalcified and stained tooth of *S. attenuata*, 183 cm male (school 7, no. 27). 10 stainable layers are counted in both cementum and dentine. Numerals indicate prenatal dentin (0) and postnatal dentinal layers (1–10). Pulp cavity at the lower right. Scale indicate 0.1 mm.



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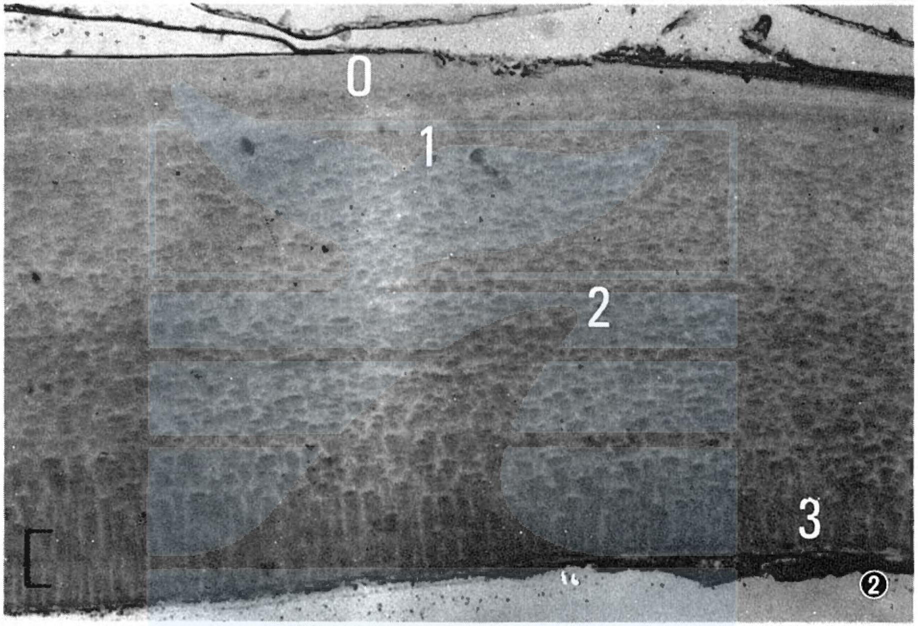

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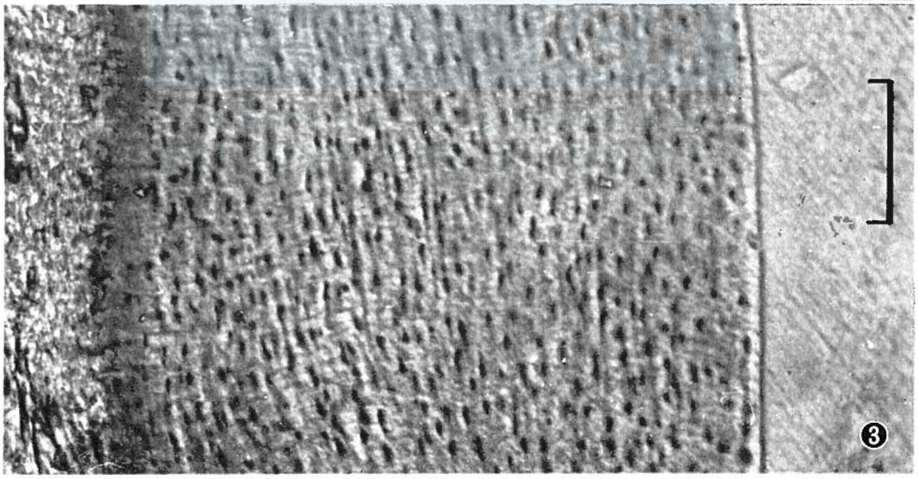

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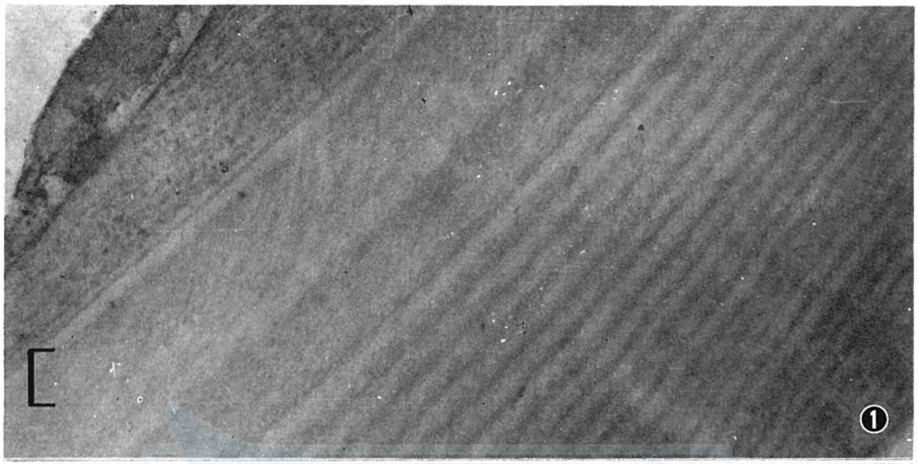
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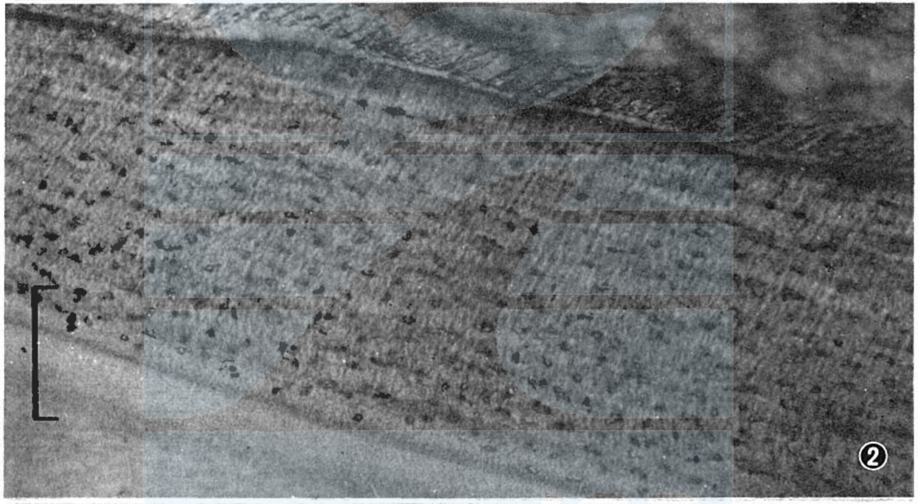
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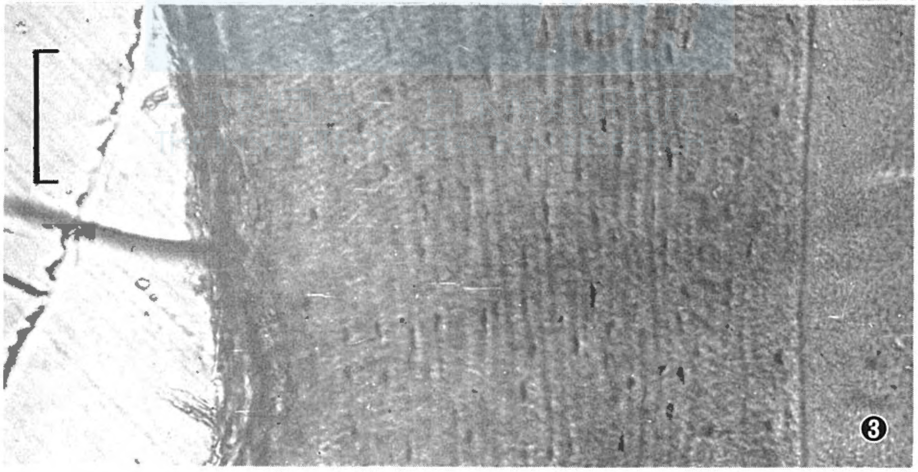
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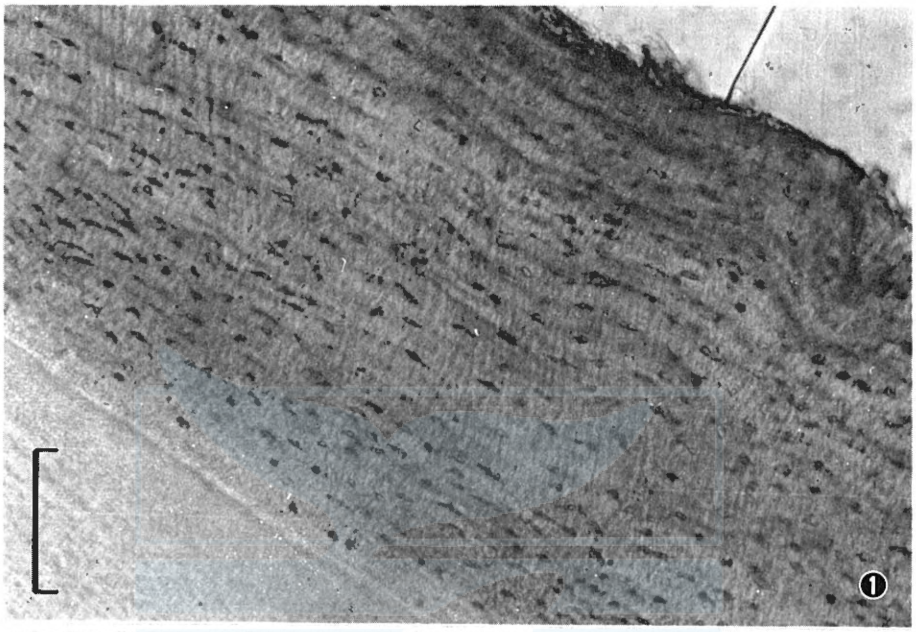

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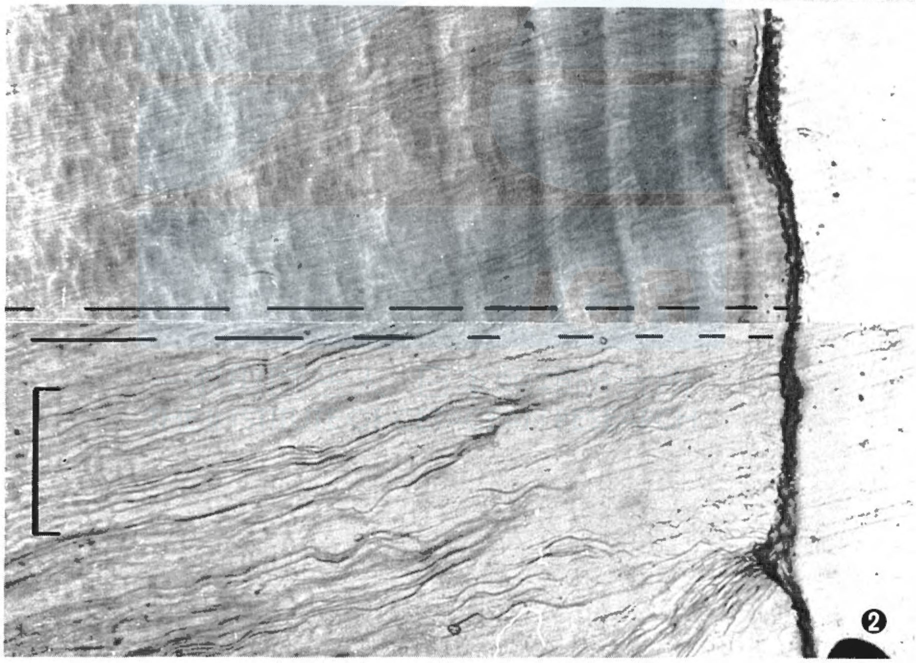

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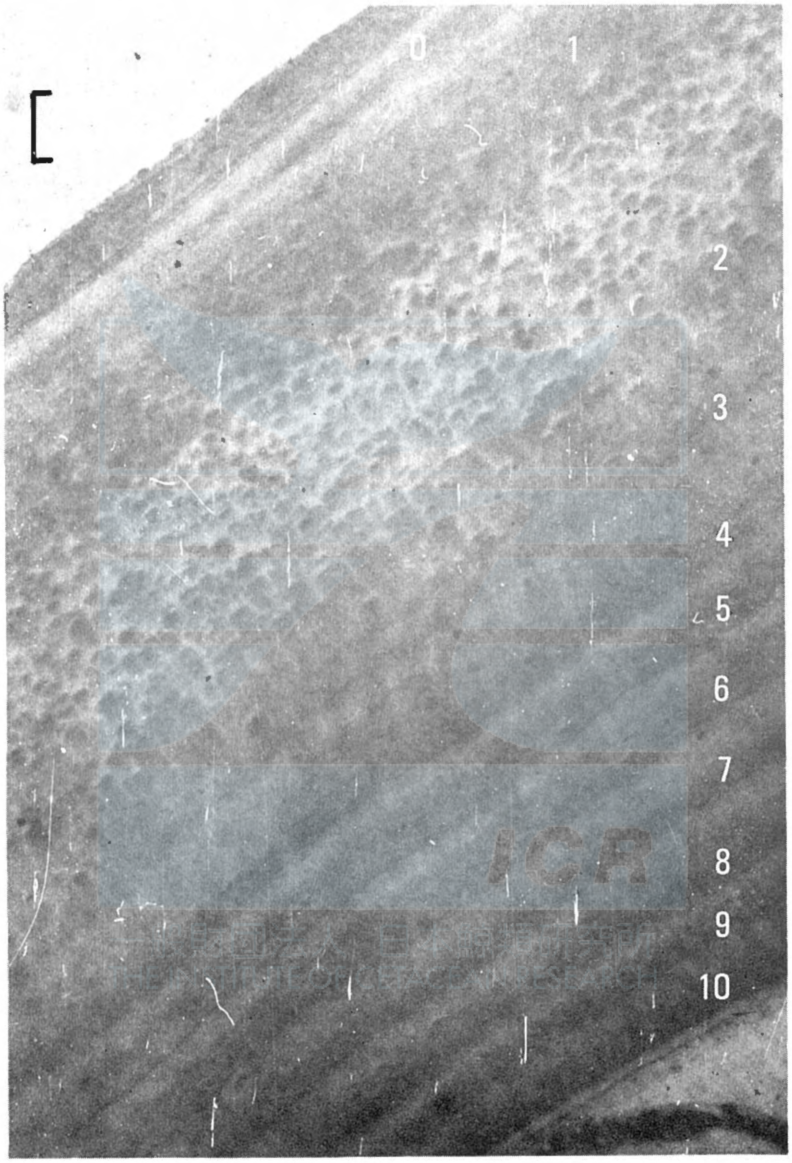
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# NOTES ON THE FOETAL SKULL OF *MESOPLODON STEJNEGERI**

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## ABSTRACT

The cranial anatomy in the skull of a foetal *Mesoplodon stejnegeri* True is described and illustrated. Some of the more important changes which take place in the structures in the course of their development from the foetal to the adult state are discussed.

## INTRODUCTION

The Ziphioid skull is, perhaps, the most asymmetrically distorted of all mammalian crania. In the adult some of the elements are partially or completely overlaid, fused or so closely interdigitated that they defy separation and their relationship to one another is often most puzzling. In the advanced foetal stage the bones fall apart readily, on maceration, and allow of a greater understanding of the complex arrangement of the cranial components. However, it is seldom that a specimen, young enough, is available to study the intricate anatomy of such a skull.

On the 28th September, 1937, the late Dr. W.R.B. Oliver collected a specimen of *Mesoplodon stejnegeri* True which stranded on the Waiterere Beach, near the Manawatu Heads (*Dom. Mus.* 619). The specimen, a female, contained a full term foetus (*Dom. Mus.* 620, skeleton). The skeletons of both are preserved in the Dominion Museum, Wellington.

In the flesh, the adult measured 4,200 mm (14 ft) in total length and the foetus 1,550 mm (5ft 2 in). *Mesoplodon stejnegeri* is, perhaps, the smallest species in the genus. As the neonatals of *Mesoplodon* are approximately one third the length of the parent at birth, there seems little doubt that the adult presumably came inshore to calve, when she met her death. Three species of *Mesoplodon*, *M. grayi*, *M. layardi* and *M. stejnegeri*, are known to calve in New Zealand waters during the spring of the Southern Hemisphere.

Unfortunately, portions of the skull of the foetus have been lost or disintegrated during maceration; nevertheless, there is sufficient material available worthy of description and comment. As most of the cranial elements have fallen apart along their sutures, description of the various components and their relationship to each other is made comparatively simple. I draw attention to the main features of the skull below.

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* This paper was compiled during my service with the National Museum, Wellington.

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## ANATOMICAL OBSERVATIONS

At this early age the axial base of the cranium (*basis crani*) is composed of three separate masses: anteriorly, the vomer-presphenoid mass; mesially, the basisphenoid mass; and, posteriorly, the basioccipital mass.

*Vomer-presphenoid mass.* (Pls. 3, fig. 1; Pl. 4, fig. 1)

Viewed dorsally, the rostral portion of the vomer (V) is a lanceolate channel or trough, deepest proximally (Pl. 3, figs. 1, 4). At the point of fusion with the presphenoid (PS), a portion of the vomer is obscured by the superimposition of the presphenoid (PS) and the ethmoid, but the vomer reappears posteriorly as a thin, horizontal, retuse, somewhat ligulate bone, the lateral lobes of which are slightly depressed on either side of the mid-line (Pl. 3, fig. 4). Viewed laterally, the vomer is somewhat canoe-shaped with a short 'drop-keel' (K) near the middle of its length. Ventrally, the vomer is strongly keeled except for the posterior, horizontal expansion. At the point of fusion between the internal, lateral walls of the vomer, and the presphenoid, there is an articular surface for union with the pterygoid bone. On the interior wall of the presphenoid are clearly seen the lines of fusion between it (presphenoid) and the ethmoid. The ethmoid fuses also with the adjacent walls of the vomer, but at this early age the base of the ethmoid is not in contact with the vomer below; at a later stage of development the union is completed.

The presphenoid rises in a steep curve from its almost horizontal floor to form the fore part of the cranial cavity. It lies across the axial base of the vomer, but it is free from the vomerine channel at this period of development. No foramina are apparent on the walls of the presphenoid, but a shallow sulcus is formed on the lateral edges which eventually contribute to the formation of the *optic foramen* and the *foramen lacerum.* The suture between the presphenoid and the basisphenoid is filled with cartilage. In the adult, although the suture narrows, the two bones never seem to fuse; there is always a gap between them.

Proximally, the ethmoid is composed of rather spongy bone fusing with the presphenoid and the vomer; anteriorly, it continues in the trough of the vomer (mesorostral groove) as the *masorostral cartilage.* With advancing age this cartilage ossifies and fuses with the adjacent bones and, in adult males completely fills the groove with dense, ivory-like bone; but in females the ossification is net so marked, the groove is only partially filled with bone of a more spongy nature (Pl. 1, OC). Some authorities hold that the filling of the mesorostral groove is effected by proliferation of the vomer itself (Forbes, 1893)*, but this view does not appear to be borne out by careful examination of transverse sections of the rostrum.

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* Forbes, H. O., 1893. *Proc. Lool. Soc. Lond.* pp. 216-236, pls. 12-15.

*Basisphenoid mass.* (Pl. 3, figs. 2, 12; Pl. 4, fig. 2)

Viewed dorsally, the basisphenoid (BS) is somewhat butterfly-shaped (Pl. 3, figs. 2, 12), with great 'pedunclate' wings (alisphenoid) outspread obliquely forwards, the anterior margins of which articulate with the pterygoids. About the middle of the body of the basisphenoid is a shallow depression (*pituatary fossa*); on either side of this fossa is a large foramen (*foramen ovale*) (FO). The foramina pass obliquely backwards to the exterior.

As already observed, the anterior articulation is imperfect mesially, but the antero-lateral edges articulate with the presphenoid. The posterior articular surface of the basisphenoid is not markedly separated from the basioccipital. In the adult this suture fuses completely, and this union between the basisphenoid and the basioccipital becomes almost invisible. Ventrally, the basisphenoid is shallowly grooved, longitudinally (Pl. 3, fig. 12). Posteriorly, on either side of the median groove, are the elevated articular surfaces which articulate with the basioccipital crests or wings.

*Basioccipital mass.* (Pl. 3, fig. 3; Pl. 4, fig. 3)

Viewed dorsally, the surface of the basioccipital (BO) is somewhat triangular; the articular surface of the basioccipital with the basisphenoid is marked by four scollops (Pl. 3, fig. 3; Pl. 4, fig. 3); mesially there is a shallow fossa on either side of which there are articular surfaces for the adjacent bones. Posteriorly, a rounded projection forms the lower margin of the *foramen magnum* between the bases of the occipital condyles. Laterally, the basioccipital crests fall away obliquely with forwardly directed projections articulating beneath the basisphenoid. Postero-laterally, the basioccipital crests articulate with the exoccipitals.

With advancing age, the basisphenoid is 'crushed' between the presphenoid and the basioccipital, and, eventually, it (basisphenoid) fuses completely with the latter bone. The alisphenoids appear as irregularly shaped bones on the exterior of the skull, adjacent to the squamosal. The posterior horizontal portion of the vomer overlies the greater part of the basisphenoid and a portion of the basioccipital subsequently fusing with them.

*Maxilla.* (Pl 3, figs. 5, 6; Pl. 4, fig. 14)

Adpressed to the lateral portion of the vomer is the lanceolate projection of the maxilla (MX); posteriorly, the maxilla flattens out almost horizontally to form a broad supra-orbital expansion as in the adult (Pl. 3, fig. 6). Its posterior margin bends round towards the mid-line of the skull and contributes to the formation of the *vertex* and the lambdoidal ridge. In the foetus, a basirostral groove (DN) is present, extending from below the maxillary tubercle to the anterior extremity, just below the dorsal profile of the maxilla. This groove is believed to be homologous with the dentary groove of other mammals. This canal apparently houses the dentary branch of the superior maxillary nerve. In the adult of *Mesoplodon stejnegeri* the basirostral groove

(BG) is *absent*, being completely filled with secondary bone. In some species this grove is present throughout life (*M. grayi*) and forms a useful accessory character in diagnosis of the species.

The dorsal profile of the rostral portion of the maxilla slopes gently upwards towards the nares (NR); the lower is almost straight, rising abruptly (at an angle of about 45 degrees) at a vertical dropped at the maxillary tubercle (MT). The cranial portion of the maxilla is expanded laterally, as already indicated above, but does not margin the orbit. The inner face of the maxilla is sculptured to articulate with the premaxilla and the vomer. The outer face is sculptured posteriorly to articulate with the palatine bone (PL), (Pl. 3, figs. 5, 6). From above, on the inner side of the maxillary tubercle, the large maxillary foramen (MXF) is visible. Another large foramen (sometimes additional secondary foramina are present), the *post-maxillary foramen* (PMXF), is to be seen near the middle of the flattened expansion or 'maxillary plate'. The expanded portion of the maxilla over-rides the malar bone (jugal), the lachrymal bone and the frontal bone (F), except for its (frontal) lateral margin which forms the orbit.

*Premaxilla.* (Pl. 4, figs. 13)

The premaxilla (PMX) is a much elongated, compressed and twisted bone, anteriorly wedged between the vomer and the maxilla and posteriorly margining the anterior nares (NR) and forming part of the vertex. Its posterior extremity forms part of the 'hood' over the anterior nares (the hood is most pronounced in *M. stejnegeri*).

Dorsally, the premaxilla is perforated by the *premaxillary foramen* (PMF). In the foetus the premaxillary foramina are approximately on the same transverse level as the maxillary foramina, but with the elongation of the rostral bones, the premaxillary foramina mores a short distance behind the maxillary foramina as in the adult. A canal, carrying a branch of the trigeminal nerve and the associated blood vessels, enters the matrix of the premaxilla and travels to its anterior extremity. This canal is connected with the premaxillary foramen. The dorsal margin of the premaxilla, together with the wall of the vomer, encloses the mesorostal cartilage, but the premaxilla exceeds the vomer in length, and, anteriorly, the premaxillae alone constitute the groove. In the adult the bone of the premaxilla is much denser than that of the maxilla.

*Palatine bone* (PL). (Pl. 3, figs. 5, 6; Pl. 4, fig. 15)

The palatine bone is sandwiched between the maxilla and the pterygoid and when the latter bone is in place the major portion of the palatine is obstrucured, with only a narrow margin of its anterior extremity and dorsal edge margining the pterygoid above. Anteriorly, the palatine bone is somewhat arrow-headed in shape (Pl. 3, fig. 5, 6 (PL)). Postero-dorsally, two short articular surfaces project, the upper in contact with the maxilla, frontal and the lachrymal bones; the lower, with the lachrymal alone. Postero-ventrally, the palatine bends round the angle of the maxilla forming a small lobe compressed between the maxilla and the vomer. The external face of the palatine articulates with the pterygoid and eventually fuses with it completely. A portion of the palatine enters the anterior nares.

### *Pterygoid bone* (PY). (Pl. 3, figs. 1, 8; Pl. 4, fig. 16)

The pterygoid bone is somewhat triangular in general shape. Postero-dorsally the pterygoid articulates with the vomer and the base of the presphenoid and, in time, fuses with them; its internal lateral face abuts the exterior of the palatine bone and eventually fuses with it. Externally, the pterygoid is concaved and forms what is known as the *mesial lamina* (PML); its lower margin turns outwards and posteriorly forms the pterygoid *hamulus* (H). Together the paired pterygoids form the posterior nares which contains the laryngeal mass. The pterygoids approximate each other along the axial line but, normally, do not fuse with each other, even in the adult.

### *Lachrymal bone* (L). (Pl. 3, figs. 11a, 11b; Pl. 4, fig. 12)

The lachrymal bone is roughly oblong in shape. Viewed ventrally, the anterior half is flat, but the posterior half presents a strong keel. Dorsally, it is in contact with the maxilla and the anterior portion of the frontal, forming the orbital margin. Posteriorly, it is also in contact with the palatine and with the pterygoid. Anteriorly it is in contact with the malar bone. (Pl. 3, figs. 11a, 11b)

### *Malar bone* (*jugal*).

The malar bone is missing in the specimen under discussion. In the adult, the malar is a flattish, triangular bone giving off, posteriorly, the slender zygomatic process; it is in contact with the maxilla internally and with the lachrymal externally. Anteriorly, it borders the antorbital notch.

Together with the lachrymal, and the anterior extrenity of the frontal forming the orbit, the malar contributes to the formation of the antorbital tubercle.

### *Frontal bone* (F). (Pl. 4, figs. 9, 11).

Dorsally, the frontal bone (F) is almost completely overlaid by the expansion of the maxilla, but, laterally, it borders the maxilla and contributes to the foramation of the orbital—the lateral border of the frontal forms the superior border of the orbit. Anteriorly, its extremity interlocks between the maxilla and the lachrymal; posteriorly, the orbital ridge terminates in a free process above the squamosal. Posteriorly, the edge of the frontal can be followed, wedged between the maxilla and the supraoccipital, and thence twisting round into the vertex of which it forms part, under the maxillary 'plate'. Its posterior wall forms part of the brain case.

*Nasal bone* (N). (Pl. 4, fig. 10)

The nasal bone (N) are paired. Each bone is somewhat cuboidal in shape (Pl. 4, fig. 10) in the foetus; they are 'free'—they drop out of position on maceration. In the adult the nasals lose some of their shape and become welded to the adjacent bones posterially and laterally; anteriorly they are free, and contribute to the formation of the anterior nares. In the foetus the two nasals are in contact with each other mesially, but not fused; laterally the bones are adpressed to the internal faces of the premaxillae; ventrally they are in contact with the mesethmoid.

*Narial passage* (NR).

The narial passage is divided into two by a septum formed largely by the vomer and the ethmoid. The recurved walls of the vomer, together with a portion of the pterygoids, compose its posterior wall; the lateral walls are formed largely by the pterygoids and small segments of the maxillae and palatines; and, the anterior wall, partly by portions of the premaxillae, maxillae and pterygoids. The superior wall of the posterior passage is formed largely by the horizontal, posterior expansion of the vomer and a small segment of the frontals. The inferior walls are formed by the pterygoids.

A large foramen perforates each of the lateral walls of the anterior nares, carrying a branch of the trigeminal nerve and the associated blood vessels.

*Interparietal* (IP). (Pl. 3, figs. 9a, 8b, 9e, 10; Pl. 4, fig. 4)

The interparietal is a dense obovoid bone with a ventral keel which fuses with the *falx cerebri*. Anteriorly, it is in contact with the frontals; laterally and posteriorly it fuses with the adjacent bones and with age loses its identity as a separate element. In the foetal specimen its sutures are still visible on its ventral aspect.

*Parietals.*

The parietals are damaged beyond recognition in the specimen.

*Supra-occipital* SO. (Pl. 4, fig. 4)

The suppraoccipital at this early stage is very fragile. It is domed, with a median depression exteriorly; interiorly a deep flange forms part of the *falx cerebri*. At the posterior end of the *falx cerebri* is the internal occipital protuberance.

*Exoccipital* (EO). (Pl. 4, fig. 5)

The exoccipital is somewhat squarish. The superior margin fuses with the supraoccipital eventually; ventrally it articulates with the posterior margin of the basioccipital crest and, eventually, fuses with it; its lateral margin articulates with the squamosal and fuses with it; at its inner angle is the occipital condyle. Between the lateral margin and the condyle there is a deep notch along its ventral border; within this notch there is the exist leading outward from the internal *condylar foramen.* The fusion of the exoccipital with the basioccipital is so complete in the adult that it appears as though the exit foramen was situated between the two bones.

*Squamosal bone* (SQ).

The squamosal bones (SQ) have been lost in the foetal specimen. A portion of one is preserved but is insufficient for description.

*Mastoid process.*

A mastoid process arises from the posterior of the auditory bulla and interdigitates with the posterior protuberance of the squamosal; it is connected to the bulla by a narrow neck. On its latero-ventral surface is an articular face which articulates with a corresponding surface on the posterior lobe of the periotic bone. (Pl. 4, fig. 8).

*Tympanics.*

Viewed ventrally, it will be seen that the bulla (B) (Pl. 4, fig. 6) obscures much, if not all (all in adult) of the periotic bone (Pl. 4, fig. 7) lying beneath it. The two bones are connected to one another by a thin, fragile piece of bone. The eustachian canal opening is directed forward. Externally, the ventral surface of the bulla is divided into two lobes, an internal lobe running parallel with the basioccipital crest and an outer, smaller lobe.

The periotic bone (Pl. 4, fig. 4), perhaps, the most solid in the whole skeleton (of cetacea), fits closely into a hollow formed in the squamosal. Anteriorly, the periotic is margined by a thin *falciform process,* arising from the squamosal. The periotic bone may be divided into three regions; an anterior lobe with an articular face for the margin of the eustachian tube, a central lobe perforated by several foramina and a posterior lobe with an articular surface to receive the counter part of the bulla already referred to.

*Mandibles* (MN). (Pl. 4, fig. 17)

The mandibles at this early age are very fragile. Along the superior margin the dentary groove is completely open. Near the posterior union of the symphysis a single mandibular tooth is present in each ramus. The tooth is just a hollow triangular shell with an acute tip. (Pl. 4, fig. 17). On the exterior face of each ramus, in the vicinity of the tooth, there are the mental foramina. The posterior blade of the ramus is about twice as deep as the anterior; the coronoid is slightly anterior to the articular condyle and, the angular slightly posterior to it.

*Course of the 5th cranial nerve* (*trifacial*). (Pl. 5)

The course of the 5th cranial nerve in *Mesoplodon* calls for some comment because of the great departure of the cranial elements from the more familiar mammalian type of skull. Because of the distortion that takes place, it is difficult to correlate the various branches with the ramifications of the corresponding nerves observed in other mammals, including Man. The exit foramina of some of the major branches play an important role in taxonomic description.

The courses of the nerves and the associated blood vessels are represented in the skull by canals and these have been traced by means of wire tracers.

In the foetus of *Mesoplodon stejnegeri*, as with other mammals, the 5th cranial nerve leaves the brain case through the *foramen lacerum* and enters a large cavity (homologous to Meckel's cavity in Man) situated just below the *maxillary foramen* (MF). Within the cavity lies a large ganglion, *Gasserian Ganglion*, which gives off several branches to the facial region. Postero-ventrally, a short branch perforates the lateral wall of the anterior nares (NR) tnrough the maxilla ('Nasal' branch). Postero-dorsally, another large branch is given off which courses backwards, partly through the maxilla and partly between the maxillary and frontal 'plates', and emerges to the exterior of the skull through the *post-maxillary foramen* (PMXF). This branch probably corresponds to the *frontal branch* (of human anatomy).

Antero-dorsally, two closely associated branches are given off, the larger emerging to the surface through the maxillary foramen (MF) the smaller, passing under a bony ridge, crosses the suture between the maxilla and premaxilla and, finally energes through the premaxillary foramen to the dorsal surface of the skull.

Below the maxillary foramen a large branch from the ganglion courses forwards the full length of the maxilla, just below its superior margin, in an open channel. This branch is the homologue of the *dentary nerve* (DN) in other mammals. The bony channel is referred to, in cetacean parlance, as the *basirostral groove*. The presence (in *M. grayi* and *M. bidens*) or absence in *M. layardi* and others) of the basirostral groove in *Mesoplodon* is of some diagnostic value when describing or determining adult skulls and it has been made use of. In the adult skull of *M. stejnegeri* the basirostral groove (BG) is absent but in the foetal skull the groove is present. (Reference to the disappearance of the groove in the adult will be discussed below).

From below the premaxillary foramen, a branch leaves the ganglion and courses forwards, at first through the matrix of the premaxilla and then along the suture between the premaxilla and the maxilla, to the extremity of the rostrum. The canal for this nerve is readily seen in a cross section of the rostrum (PN).

Below the dentary branch (DN) another large division leaves the ganglion, at first descending between the maxilla and the palatine bone, then, entering the matrix of the maxilla at about the middle of its depth, it descends gradually to the inferior margin of the maxilla where it emerges by a foramen some distance short of the extremity of the maxilla (median maxillary nerve-MMN). Yet another large nerve leaves the ganglion and after coursing forwards through the matrix of the maxilla emerges by a foramen close to the exit of the median maxillary nerve (MMN). This lower nerve I refer to as the *inferior maxillary nerve* (IMN). The last two mentioned nerves probably correspond to the spheno-palatine nerves.

The presence of the basirostral groove in the foetal skull and its absence in the adult skull, already referred to above, calls for some explanation. As already observed, the dentary branch enters the so-called basirostral groove below the maxillary tubercle (MT). Apparently, at an early period of development, the dentary nerve (DN) is intact from the point of emergence from the ganglion to the extremity of the rostrum. As growth proceeds secondary bone develops at its proximal end and gradually strangles the nerve and blood supply, eventually cutting off both the neural and vascular supply completely. This severance of the nerve in *M. stejnegeri* appears to commence some time before birth, the groove itself gradually filling up, subsequently, with secondary bone, leaving little or no trace of the basirostral groove; however, its erstwhile position is sometimes demarcated by narrow, fragile planges on either side—its position is often visible throughout the length of the rostrum. Hence, *M. stejnegeri* is described as having "no basirostral groove". In the adult of *M. grayi*, although the channel is closed off proximally under the maxillary tubercle (MT), leaving the socalled 'pit', the rest of the channel remains open permanently.

It is remarkable that, in *M. grayi*, in which the basirostral groove is always present, rudimentary teeth frequently occur in the upper jaw, but such teeth are not socketed in the maxilla, whereas in species devoid of the basirostral groove in the adult, rudimentary teeth have not been observed. This observation seems to suggest that, in *M. grayi*, the dentary nerve is strangled at a later period of development than in those species in which the dentary channel (basirostral groove) is obliterated by the growth of secondary bone.

This suppression of the dentary nerve and blood supply at an early period of development possibly accounts, at least in part, for the absence of teeth in upper jaws of most *Mesoplodon* and in other ziphioid whales. However, it is interesting to observe that, in addition to the functional teeth (in males), vestigial teeth do sometimes occur in some members of the Ziphiidae and their presence may be dependent on the extent to which the dentary nerve has been 'strangled'.

The course of the mandibular branch of the 5th nerve is obviously not traceable in the foetal specimen. The inferior dental groove is however, open along its entire length and the functional mandibular teeth are present in the in the rami (one in each). As far as I am aware, rudimentary mandibular teeth have rarely been observed in *Mesoplodon*. Fraser (1953) illustrated the presence of such vestigial teeth in *M. bidens*. Rudimentary mandibular teeth have been more frequently reported in *Hyperoodon* (Boschma, 1950) and in *Ziphius*. In *Tasmacetus*, the rarest of the family, teeth are present in both upper and lower jaws. The presence of teeth in both jaws of *Tasmacetus* suggests, perhaps, that it is less specialised than the other ziphioids and retains part of its more 'primitive' characters.

## ACKNOWLEDGMENTS

My thanks are due to Dr. Sir Robert A. Falla, late Director, National Museum, Wellington, for the opportunity of undertaking the study; to Messrs F. O'Leary and P. M. Hedgland for the photographs accompany this paper, and, last but not least, to Miss M. Hall, our Librarian, for her help with the relevant literature.

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## EXPLANATION OF PLATES

### PLATE I

Stejneger's Beaked Whale: *Mesoplodon stejnegeri* True. Lateral aspect of cranium of adult female showing arrangement of elements.

*Courtey Nat. Mus. Wellington, N.Z.* Photo P. M. Hedgland

(For explanation of lettering see end of paper)

### PLATE II

Stejneger's Beaked Whale: *Mesoplodon stejnegeri* True. Dorsal aspect of cranium of adult female showing arrangement of elements.

*Courtesy Nat. Mus. Wellington, N.Z.* Photo P. M. Hedgland

(For explanation of lettering see end of paper)

### PLATE III

Stejneger's Beaked Whale: *Mesoplodon stejnegeri* True. Disarticulated elements of the foetal cranium.

1. Vomer-presphenoid mass (dorsal aspect); 2. Basisphenoid (dorsal aspect); 3. Basioccipital (dorsal aspect); 4. Vomer-presphenoid mass (lateral aspect); 5. Maxilla (internal face); 6. Maxilla and palatine bone (external face); 7. Pterygoid bone (external face); 8. Pterygoid bone (internal face); 9a. Interparietal (anterior face); 9b. Interparielal (lateral face); 9c. Interparietal (ventral face); 10. Interparietal with adjacent frontals (dorsal aspect); 11a. Lachrymal bone (ventral aspect); 11b. Lachrymal bone (dorsal aspect); 12. Basisphenoid (ventral aspect).

del. C. McCann

## PLATE IV

Stejneger's Beaked Whale: *Mesoplodon stejnegeri* True. Disarticulated elements of foetal cranium.

1. Vomer-presphenoid mass; 2. Basisphenoid; 3. Basioccipital; 4. Supraoccipital; 5. Exoccipitals; 6. Bulla; 7. Periotic bone; 8. Portion of squamosal; 9. Posterior portion of frontal (damaged); 10. Nasal bone; 11. Orbital portion of frontal (damaged); 12. Lachrymal bone; 13. Premaxilla; 14. Maxilla (posterior portion incomplete); 15. Palatine bone; 16. Pterygoid bone; 17. Mandible (with tooth). (Excepting nos. 5, 9, paired bones show opposite faces; all other bones show the dorsal aspect only.

*Courtesy Nat. Mus. Wellington, N.Z.* Photo F. O'Leary

## PLATE V

Stejneger's Beaked Whale: *Mesoplodon stejnegeri* True. Showing courses of the main nerves and vascular supply traced in the rostrum of a foetal specimen (*Semidiagramatic*).

1. Outer aspect of left rostral portion of moxilla. 2. Transverse section on maxilla. 3. Proximal portion of right maxilla showing maxillary foramen and passage of premaxillary branch to premaxillary foramen. 4. Divisions of the 5th cranial nerve (*Diagramatic*).

(For explanation of lettering see end of paper.) del. C. McCann

## EXPLANATION OF LETTERING ON PLATES

AN—Antorbital notch.
AT—Antorbital tubercle.
B—Bulla.
BG—Basirostral groove.
BO—Basioccipital.
BOC—Basioccipital crest.
BS.—Basisphenoid.
C—Occipital condyle.
DN—Dentary nerve.
EO—Exoccipital.
F—Frontal.
FO—Foramen ovale.
FP—Falsiform process.
GG—Gasserian genglion.
H—Hamulus.
IMN—Inferior maxillary nerve.
IP—Interparietal.
K—Keel of vomer.
L—Lachrymal.
MC—Meckel's cavity.
ME—Mesethmoid.
MMN—Median maxillary nerve.
MN—Maxillary notch.
MT—Maxillary tubercle.
MX—Maxilla.
MXC—Maxillary crest.
MXF (MF)—Maxillary foramen.
N—Nasal bone.
NF—'Nasal' nerve foramen.
NR—Anterior nares.
OC—Ossified mesethmoid cartilage.
OG—Optic groove.
OT—Antorbital tubercle.
PL—Palatine bone.
PMF—Post maxillary foramen.
PML—Pterygoid median lamina.
PMX—Premaxilla.
PMXF—Premaxillary foramen.
PS—Presphenoid.
PY—Pterygoid bone.
SO—Supraoccipital.
SQ—Squamosal.
TF—Temporal fossa.
V—Vomer.
VN—Fifth cranial nerve.

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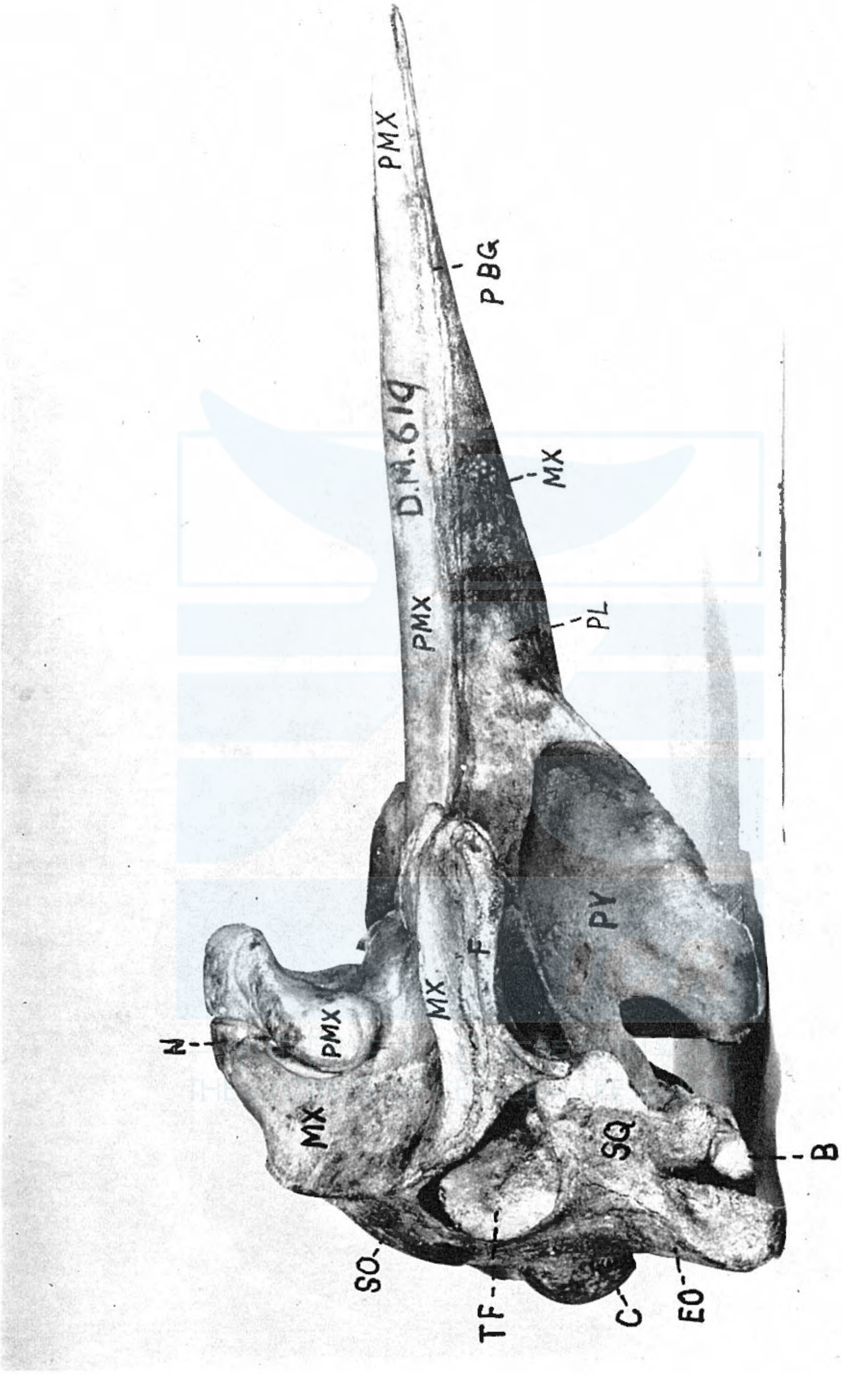
PLATE I



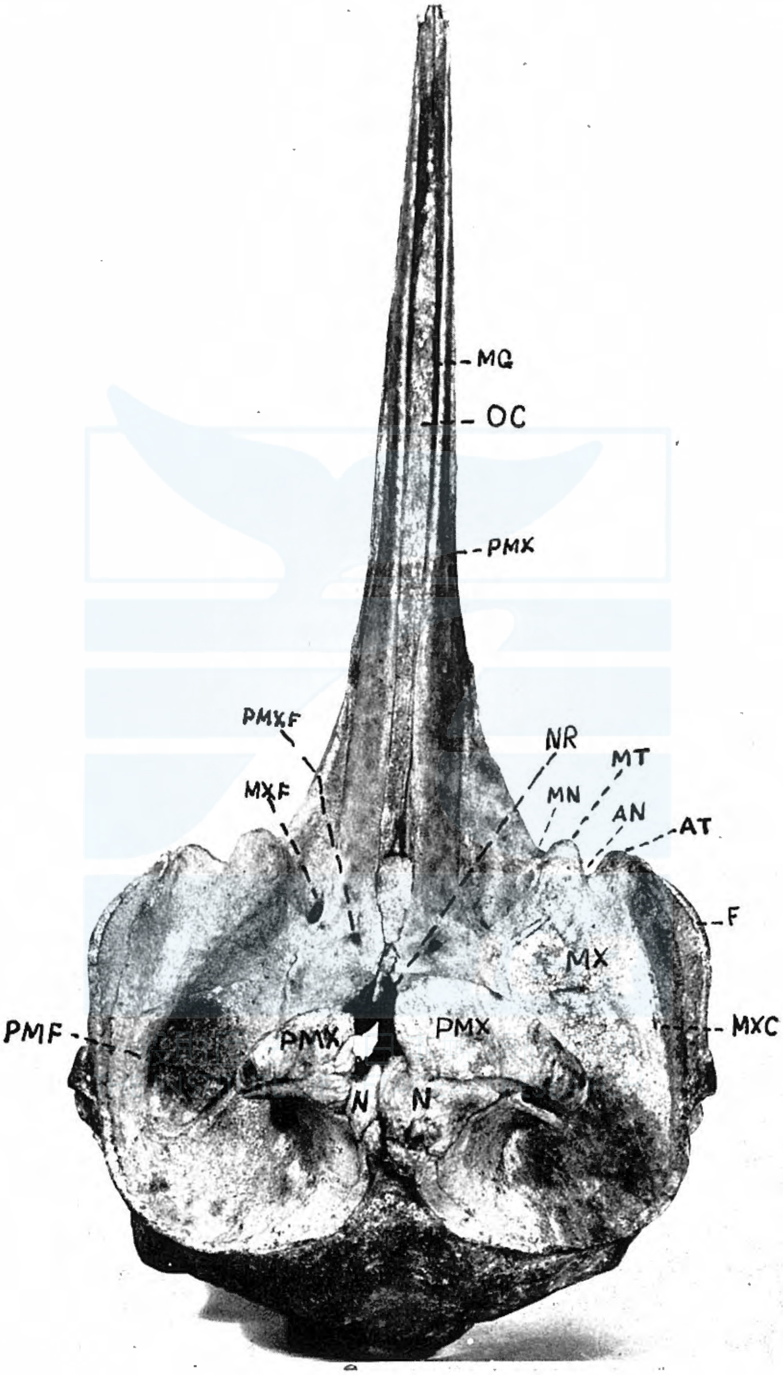

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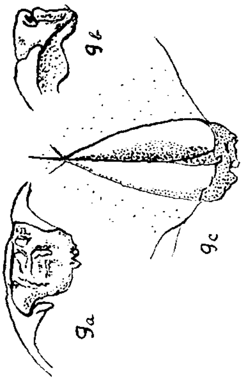
PLATE III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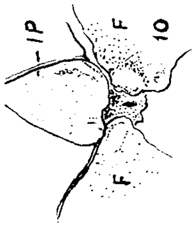
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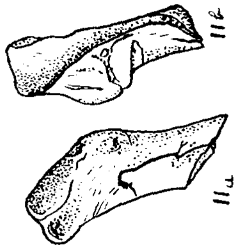
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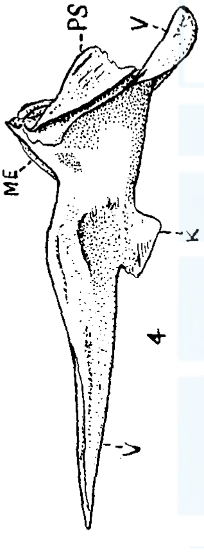
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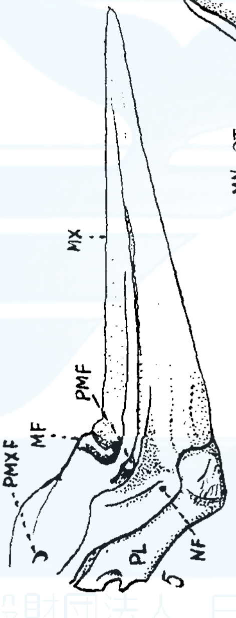
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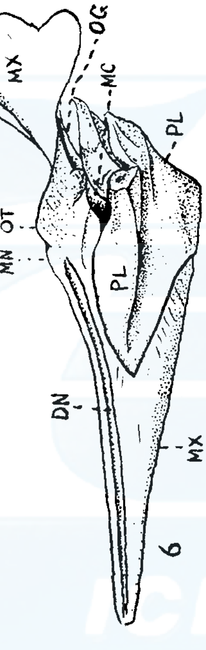
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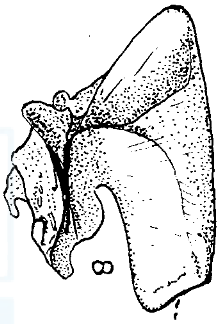
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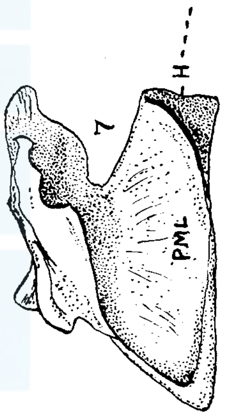
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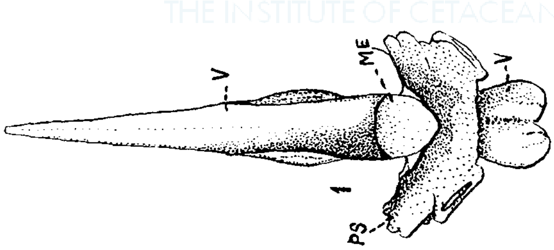
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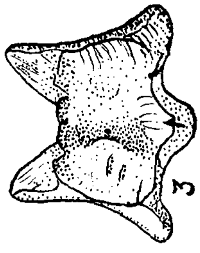
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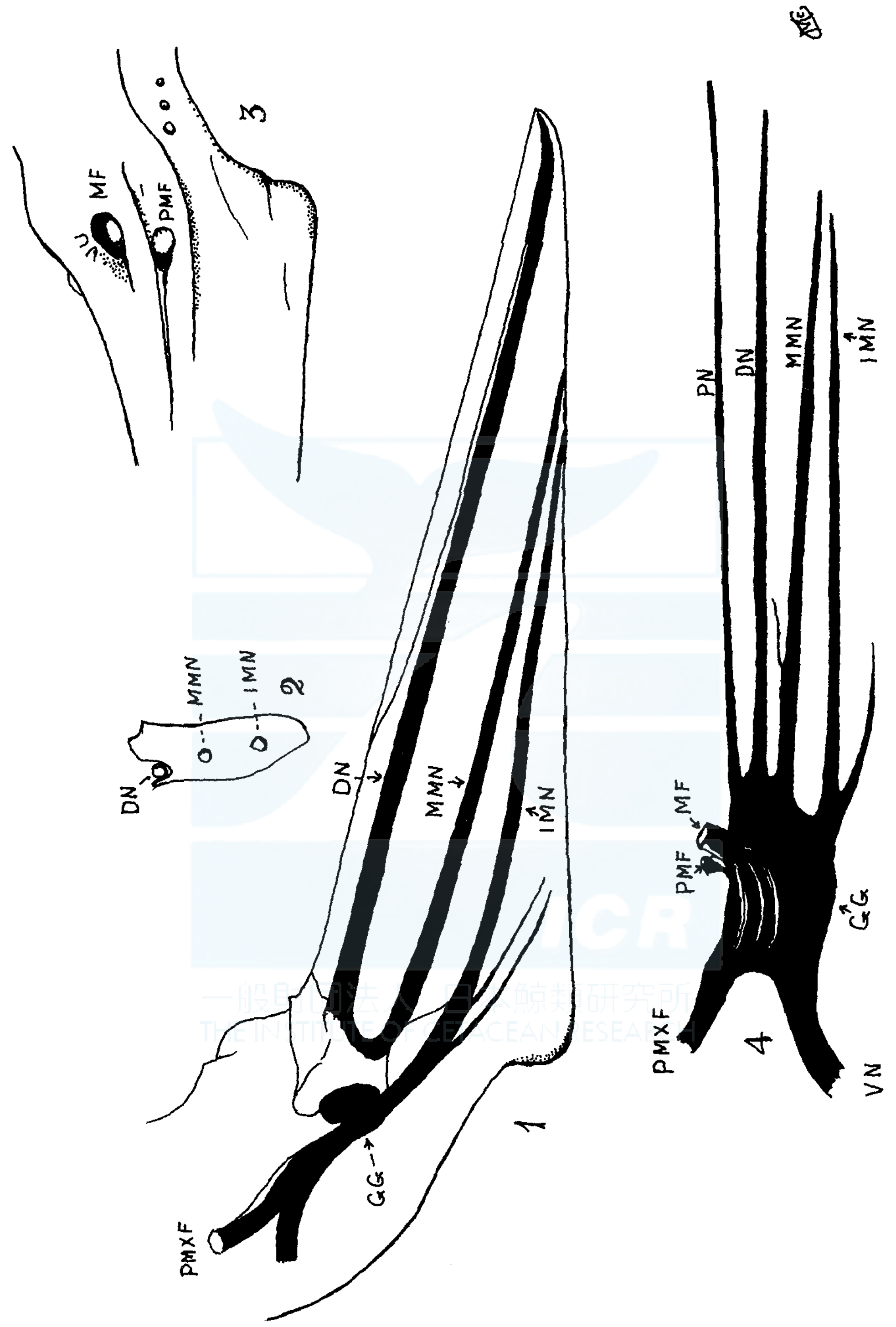
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# FIRST RECORD OF THE SOUTHERN BOTTLENOSE WHALE, *HYPEROODON PLANIFRONS* FROM BRAZIL

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## INTRODUCTION

On the 26 March, 1975 a specimen of the southern bottlenose whale, *Hyperoodon planifrons* was discovered on the beach, 5 km north of Chui, near the Brazilian frontier with Uruguay.

The carcass had been partially flensed on the middle of the back by native fishermen who removed some neural spines with fresh meat. When first observed by staff members of the Museo Oceanografico de Rio Grande (M.O.R.G.) it had probably been dead more than a month and almost all entrails and some of the left ribs were lacking. The skin, except on the head and the flukes had sloughed and was partially discolored. A number of photographs were taken, dissections were made and the entire skeleton was collected. Lately it was cleaned and mounted (M.O.R.G. cetacean coll. n°15) and it is being exhibited in the Cetacean Hall of the previously mentioned institution. The Brazilian specimen, in addition to extending the range of the species from southern Buenos Aires province (Argentina) coast, has provided data in relation to bone pathology of the species.

## EXTERNAL FEATURES

The animal was an adult, total length 7500 mm, black greyish coloured. The head presented a prominent rounded melon or forehead and a well defined beak (Fig. 1). The V-shaped grooves, 300 mm long each, beneath the chin, a distinctive character of the *Ziphiidae*, were deep and well defined, The blowhole showed no curvature, it was 50 mm wide and took the form of a transverse slit lying just anterior to a transverse plane through the eye.

The pectoral fins, 750 mm long, were small; the dorsal fin that in other previously described specimens is falcate, was lost. A pair of alveoli, 30 mm wide, with spongy bone on the base can be clearly seen in the tip of the lower

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Fig. 1.

jaw. Unfortunately the teeth could not be found and the sex of the specimen could not be determined.

## VERTEBRAL FORMULA

The Rio Grande specimen has a vertebral formula C7+D9+L10+C20=46 which completely agree with that counted by Hale (1931) and mentioned by Nishiwaki (1972). However, Moreno (1895) counted in a Buenos Aires province specimen and also in a South Pacific juvenile C7+D8+L12+C17=44, but he stated that in his Argentine skeleton, the last caudal vertebrae were lacking. Also some of the last caudal vertebrae of the South Georgia specimen described by Fraser (1945) were lost and the resulting vertebral formula is C7+D8+L11+C17=43. Another South Georgia skeleton of this species on the exhibition in the Museo Argentino de Ciencias Naturales at Buenos Aires has the following formula: C7+D8+L12+C19=46. This specimen has only 8 ribs on both sides, 6 of which are double-headed, while in the Rio Grande do Sul specimen the ninth right rib and the last three left ribs were lost.

## SKELETON PATHOLOGY

On the neural arches between the posterior part of the 25th vertebra and the anterior arch of the 26th there is a very interesting hyperostotic growth that will be described in a future note. The left mandible shows fractures on the posterior half as does the right one, but while the first one completely healed in life, the last one broke again during the stranding along the same old fracture lines. The scapula and the skull show a decalcification process in some parts. The right VIIIth rib and the left IVth and Vth were broken

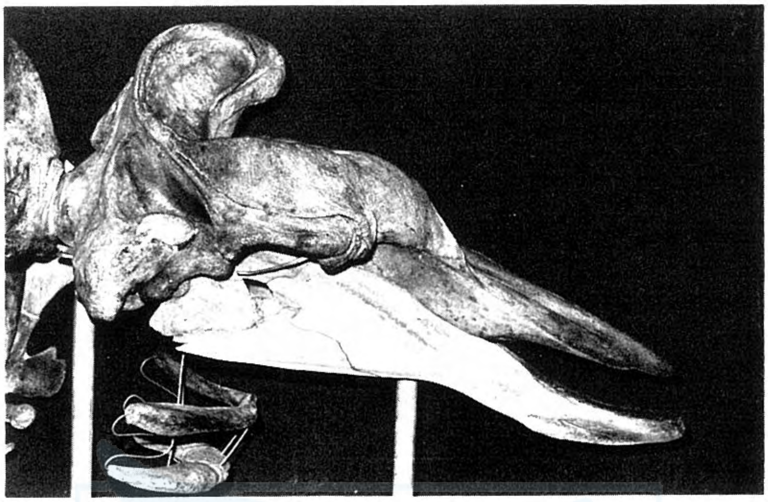

Fig. 2.

during the life of the individual and lately healed.

## PREVIOUS RECORDS OF THE SOUTHERN BOTTLENOSE WHALE

The species has not been mentioned for Brazil by Vieira (1955) and it was not recorded for Uruguay by Ximenez *et al.* (1972).

The northern record for Argentina was that of Moreno (1895), and adult about 6.25 m long, stranded on the shore of the Arroyo Sauce Viejo, S. of Buenos Aires province. In the same article Moreno also gave some information about two other specimens, one from Chubut river and another from Santa Cruz Bay.

A recent record for the Rio Negro province (erroneously maped by Brownell in 1974 for Buenos Aires province-ref. n°25) is that mentioned by the newspaper La Nacion, 19th October, 1965. The stranded specimen was an adult, over 7 m long and was beached 60 km S. of Viedma. The skull was recovered and is preserved in the Salesian Museum of that city, there it was studied and photographed by Dr. Robert Menni and Lic. Raul Aramburu from La Plata Natural Sciences Museum.

Hamilton (1952) briefly reported on the collection of remains from three specimens in the Falkland Islands; others had been collected, measured or photographed at the South Georgia Islands (three records) by Fraser (1945) and Carcelles (1948) (one record: 54-110 Mus. Arg. Cs. Nat.) and at South Orkney Islands, also by Fraser (1945). Near the South Shetland Islands, on the base of whaling statistics, Marelli (1922) reported five hunted Hyperoodontids. Mörch (1911) had stated that near those islands bottle-nosed whales had been observed swimming in small schools.

Fraser (1964) mentioned one lactating female caught at 61°09′S-84°44′W.

TABLE 1. SPECIMENS OF THE SOUTHERN BOTTLENOSE WHALE, *HYPEROODON PLANIFRONS* COLLECTED, PHOTOGRAPHED OR MEASURED IN SOUTHERN HEMISPHERE WATERS.

| Record No. | Locality or latitude and longitude at sea | Date of stranding | Authors | Sex | Total length | Skull length | Evidence | Museum collection n° |
|---|---|---|---|---|---|---|---|---|
| 1 | Beach of Lewis Island Dampier Archipiel.; NW Australia | before 1882 | Flower, 1882 | | | +1.20 mt | Mutilated skull | Type, 1814A British Mus. (Nat. Hist.) |
| 2 | 13 miles S. Port Victoria, Yorke Penins.; S. Australia | 22 November, 1929 | Hale, 1931 | ♂ | 6.93 mt | 1.39 mt | Complete skeleton | 2852, South Australia Museum |
| 3 | Humewood, Port Elizabeth; S. Africa | 18, January, 1964 | Tietz, 1966 | ♂ | 6.36 mt | 1.21 mt | Skull and mandible | |
| 4 | Beach at East Cape; N. Island; New Zealand | before 1912 | Waite, 1913 | | 7.50 mt | 1.15 mt | Skull fragment | Canterburry Mus.; not available |
| 5 | Brown's beach, near Timaru, 5 miles from Winchester, S. Island; New Zealand | before 1959 | McCann, 1961 | ♀ | | | Symphyseal mandible portion | 1417 Dominion Museum |
| 6 | Malvinas (Falkland) Isl.; Gran Malvina and Soledad Island | August* 1950 | Hamilton, 1952 and Fraser, 1964 | ♀ | 6.70* mt | | Rest of three specimens | British Museum (Nat. Hist.) |
| 7 | Vicinity of Orcadas del Sur (S. Orkney) Isl. | January, 1915 | Fraser, 1945 | | | | Photographed on a whal. ship | |
| 8 | Vicinity of Georgias del Sur (S. Georgia) Isl. | near, 1934 | Fraser, 1945 | ♀ | 6.50 mt | 1.19 mt | Complete skeleton | 1934.7.23.3 Brit. Mus. |
| 9 | Leith Harbour, Georgias del Sur (S. Georgia) Isl. | 3 January, 1927 | Fraser, 1945 | ♂ | 4.63 mt | 0.69 mt | Photographed in whal. stat. | |
| 10 | Near Gritviken, Georgias del Sur (S. Georgia) Island | November, 1929 | Carcelles 1948 | ♂ | 6.54 | 1.44 | Complete skeleton | 54-110, Mus. Arg. Cs. Nat.; Buenos Aires |
| 11 | Near Shetlands del Sur (S. Shetland) Isl. | before, 1929 | Marelli, 1929 | | | | Five specimens hunted | |
| 12 | On the beach near Arroyo Sauce Viejo, S. Buenos Aires Prov.; Argentina | early, 1884 | Moreno, 1895 | | 6.25 mt | 1.15 mt | Complete skeleton | 1121, Mus. Cs. Nat. La Plata Argentina |
| 13 | 60 km SW of Viedma, Rio Negro Province; Argentina | 25 August, 1965 | La Nacion 19/X/65; Brownell, 1974 | | +7.00 mt | | Photographs and skull | Salesian Museum at Viedma |
| 14 | Vicinity of Chubut River, Chubut Province; Argentina | | Moreno, 1895 | | | +1.10 mt | Skull | Mus. Cs. Nat. La Plata |

(Continued of Table 1.)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 15 | Beach at Santa Cruz Bay, Santa Cruz Province; Argentina | | Moreno, 1895 | | | | Left mandible | Mus. Cs. Nat. La Plata |
| 16 | South Pacific Coast; Chile ? | | Moreno, 1895 | ♀ | 4.50 mt | 0.81 mt | Complete skeleton | Mus. Cs. Nat. La Plata |
| 17 | 61°09'S-86°44'E | | Fraser, 1964 | ♀ | 7.45 mt | | Complete skeleton | Brit. Mus. (Nat. Hist.) |
| 18-20 | 45°15'S-58°10'W | 3 April, 1962 | Zemskii and Budylenko, 1970 | | 6.80 mt | 1.31 mt | Photographed and measured on a whaling vessel | ? |
| | 57°33'S-05°08'E | 16 December, 1966 | | | 7.00 mt | | | ? |
| | 56°14'S-86°58'E | 18 January, 1968 | | | 5.70 mt | | | ? |

* Female complete skeleton collected at East Falkland.

More recently at 45°'S-58°10'W, one bottlenose whale 6.80 m long was hunted by a Russian whaling ship and was measured by Zemski and Budylenko (1970).

In the Chilean coast, Clarke (1962) reported a sighting of five specimens off Valparaiso (21/X/1958). Mörzer Bruyns (1971) saw a pod off Chile, estimated to comprise about 40 specimens (May, 1965).

According to McCann (1962), *Hyperoodon planifrons* is restricted to the southern Hemisphere, south of 20 degree latitude and it has been also mentioned (Table 1) for New Zealand by Waite (1913), McCann (1961) and Gaskin (1968), for South Africa by Tietz (1966) and Australia by Flower (1882) and Hale (1931).

During the summer it seems to be abundant in the Subantarctic and Antarctic oceans (Table 2).

## CONCLUSIONS

Including the Rio Grande do Sul specimen, 8 complete skeletons of the southern bottlenosed whale had been recovered, half of them are stored in Argentine and Brazilian museums. Only one specimen is known to have stranded alive. The Rio Grande do Sul specimen, probably a male, was surely very old as the several hyperostotic growths and decalcification signs may suggest.

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TABLE 2. SIGHTINGS ATTRIBUTED TO *HYPEROODON PLANIFRONS* IN THE SUBANTARCTIC AND ANTARCTIC OCEANS ACCORDING TO LIOUVILLE (1915), LILLIE (1915), WILSON (1907), TOMILIN AND LATYSHEV (1967) AND DUGUY (1973).

| Record No. | Locality | Latitude and longitude | Date of sighting | Number of specimens | Observer |
|---|---|---|---|---|---|
| 1 | Weddel Sea | 72°22′-19°10′ | 4 March, 1904 | some | Wilson |
| 2 | „ | 69°46′-19°10′ | 21 Febr., 1903 | scarce | „ |
| 3 | „ | 73°30′-24°00′ | 13 March, 1904 | several | „ |
| 4 | „ | 60°05′-32°10′ | 10 Febr., 1903 | 2 | „ |
| 5 | „ | 65°29′-44°06′ | 12 March, 1903 | 2 | „ |
| 6 | South Atlantic | 59°43′-48°10′ | 28 Nov., 1903 | ——— | Brown |
| 7 | Drake Passage | ——— | 7 Dec., 1972 | 2 | Duguy |
| 8 | Deception Island | 63°00′-60°40′ | 28 Nov., 1909-<br>6 Jan., 1910 | ——— | Liouville |
| 9 | Petermann Island | 65°10′-66°12′ | 5 May, 1909 | 2 or 3 | „ |
| 10 | Bransfield Strait | 64°49′?-65°40′ | 27 Nov., 1909 | 2 | „ |
| 11 | Matha Bay | 66°50′-70°00′ | 14 Jan., 1909 | 20 | „ |
| 12 | Mer de la Belgique | 69°54′-82°35′ | 7 Nov., 1898 | 1 or 2 | Racovitza |
| 13 | „ | 69°55′-82°36′ | 6 Sept., 1898 | 3 or 4 | „ |
| 14 | „ | 69°29′-85°47′ | 1st Jan., 1910 | 1 | Liouville |
| 15 | „ | 70°15′-87°05′ | 19 Jan., 1899 | 3 or 4 | Racovitza |
| 16 | „ | 70°16′-87°12′ | 20 Jan., 1899 | 1 | „ |
| 17 | „ | 70°30′-93°57′ | 15 Feb., 1899 | 3 or 4 | „ |
| 18 | „ | 70°38′-88°56′ | 2 May, 1898 | 4 | „ |
| 19 | „ | 70°41′-86°34′ | 3 July, 1898 | 5 or 6 | „ |
| 20 | Admunsen Sea | 68°24′-122°38′ | 22 Jan., 1910 | 1 | Liouville |
| 21 | Ross Sea, Balleny Islands area | 69°51′-166°17′ | 29 Dec., 1912 | ——— | Lillie |
| 22 | McMurdo Strait | 77°00′-166°00′ | 25 Febr., 1902 | 6 or 8 | Wilson |
| 23 | „ | 77°30′-166°00′ | Febr., 1904 | ——— | Wilson |
| 24 | Ross Sea | 62°00′-162°03′ | 10 March, 1911 | 2 | „ |
| 25 | „ | 69°51′-166°17′ | 29 Dec., 1912 | ——— | „ |
| 26 | „ | 77°32′-173°22′ | 1903 | ——— | Racovitza |
| 27 | Subantarctic Indian Ocean sector | 48°00′-100°00′E | 5 Nov., 1904? | 1 | Wilson |
| 28 | Antarctic Indian Ocean sector | 57°00′-150°00′E | 17 Jan., 1965 | 3 | Tomilin and Latyshev |
| 29 | Antarctic Pacific Ocean sector | 62°00′-162°03′E | 10 March, 1911 | 2 | Lillie |

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# A SHEPHERD'S BEAKED WHALE, *TASMACETUS SHEPHERDI*, FROM THE EASTERN SOUTH PACIFIC

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W.R.B. Oliver (1937) described a new genus and species of beaked whale (Family: Ziphiidae) from a carcass found stranded on the coast of North Island (Ohawe, Taranaki), New Zealand. Since the holotype was described only six additional records of this species have been described: five from the New Zealand region and a sixth from Peninsula Valdez, Province of Chubut, Argentina (Mead and Payne, 1975). We report here a new record from the eastern South Pacific.

A cranium, left mandible, and cervical vertebrae were found by Aguayo and Torres just south of Loberia Vieja (see Figure 2 in Aguayo *et al.*, 1971) on the eastern coast (*ca.* 33°46'S, 80°47'W) of Isla Mas Afuera (Alejandro Selkirk Island), Juan Fernandez Archipelago, Chile, 19 February 1970. The specimen was not collected, but was photographed. These photographs are on file at the Division of Mammals, Smithsonian Institution. It was identified as *T. shepherdi* by comparing these photographs with those published by Oliver (1937) and Moore (1968). The photographs also agree with the specimen of *T. shepherdi* in the U.S. National Museum (No. 484878). The characters of the vertex and the numerous alveoli are clear in the photographs and leave no question about the identity of the specimen. The skull length of the new specimen, with part of its rostrum damaged, is estimated at 100 cm. We estimate that the original condylobasal and mandible lengths were 125 cm and 107 cm respectively. This specimen, with no reference, was one of the eight records of *T. shepherdi* recorded in Anonymous (1975: 897). The Isla Mas Afuera and Peninsula Valdez specimens suggest that *T. shepherdi* may have a circumpolar distribution in the Southern temperate oceans, as do many other species of cetaceans (Brownell, 1974).

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# RECORDS OF THE DELPHINID GENUS *STENELLA* IN WESTERN SOUTH ATLANTIC WATERS

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## INTRODUCTION

Little information has been published on *Stenella* spp. from the western South Atlantic Ocean. Numerous references (Lahille, 1899 and 1905; Beddard, 1900; van Beneden and Gervais, 1880; Figueira, 1894; and others—see text) exist citing the long-snouted dolphin, *S. longirostris*, in Brazil, Uruguay, and Argentina, but none of these reports are confirmed with specimens. A single report of *S. attenuata* in this area is an unconfirmed mention from Cape Horn (Beddard, 1900). The holotype of the striped dolphin, *S. coeruleoalba*, was collected somewhere around the mouth of the Rio de la Plata (River Plate) between Uruguay and Argentina (Meyen, 1833). Since that time only three additional specimens have been reported from this region (Malm, 1871; and Praderi, *In*: Ximenez, *et al.*, 1972).

The purpose of this note is to provide information on museum specimens of *Stenella* spp. in Uruguay and Argentina. We will also discuss the older references of *S. longirostris* in western South Atlantic waters.

## MATERIALS

The present study is based on the examination of the cetacean collections in five South American museums. These are: Museo Argentino de Ciencias Naturales "Bernardino Rivadavia", Buenos Aires, Argentina (MACNBA); Museo de La Plata, La Plata, Argentina (MLP); Museo Nacional de Historia Natural de Montevideo, Uruguay (MNHNM); Museu Nacional do Zoologia de la Universidad de Sao Paulo, Brazil (MZSP); and Museu Nacional do Rio de Janeiro, Brazil (MNRJ). No specimens of *Stenella* were found in either of the Brazilian museums.

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## SPECIES ACCOUNTS

*Stenella coeruleoalba*—Fraser and Noble (1970) have concluded, based on pigmentation patterns of specimens, that several nominal species of *Stenella* (*Delphinus coerulealbus* Meyen, 1833; *D. marginatus* Desmarest, 1855±1; *D. euphrosyne*, Gray 1846; *D. styx*, Gray, 1846; and *D. lateralis* Peale, 1848) with a spinal blaze and eye-to-anus stripe (terminology of Mitchell, 1970) probably belong to one species, *S. coeruleoalba* Meyen, 1833). Hubbs *et al.* (1973) have stated that their records of *S. coeruleoabla* across the tropical Pacific supports the view "that the northern and far-southern populations of this species are conjoined and thus confirms the synonymy adopted by Fraser and Noble (1970)."

We have examined two *S. coeruleoabla* specimens: (1) a skull (MNHNM 1305) from Balneario Solymar, Depto. de Canelones, Uruguay (34°49'S., 55°55'W), Rio de la Plata; and (2) a skull (MACNBA 2625) from Miramar, Pcia. Buenos Aires, Argentina (38°17'S.) Atlantic Ocean. The cranium from Punta Jose Ignacio, Uruguay that Praderi reported in Ximenez *et al.* (1972) was not available to us.

The only skull measurements available for this species from the type locality are those of Meyen (1833) and Malm (1871: 63, holotype of *Clymenia burmeisteri*). Cranial dimensions in millimeters and dental counts of the two specimens we examined of *S. coeruleoalba* are presented in Table 1. No additional information is available for the Miramar specimen. The Solymar skull was collected from a stranded specimen by Praderi on 23 August 1959. The total length of the carcass (notch to tip of lower jaw) was 242 cm. The specimen was a male.

*Stenella* spp.—Various scientific names are currently used for spotted dolphins. These include *S. attenuata* (Gray, 1846) in the Pacific, Indian, and Atlantic Oceans, and *S. dubia* (G. Cuvier, 1812); *S. frontalis* (G. Cuvier, 1829), and *S. plagiodon* (Cope, 1866) in the Atlantic. There are probably only two valid species (Perrin, 1975).

We examined one skull that can be referred to the spotted dolphin complex. This specimen (MACNBA 23-46) is from Mar del Plata, Pcia. Buenos Aires, Argentina (38°00'S.) Atlantic Ocean. The date of collection was 1923, but no additional information is available for this specimen. Skull measurements and dental counts of this specimen are presented in Table 1. The skull is illustrated in Plate 1.

*Stenella longirostris*—This species was described as *Delphinus longirostris* from an unknown locality (Gray, 1828). Van Bree (1971) stated that the complete synonymy proposed by Hershkovitz (1966: 37-40) is probably correct, but "much more must be known before definite conclusions can be drawn about the taxonomic status and nomenclature of *Stenella longirostris*." This species has been reported from both sides of the tropical Atlantic Ocean (Moore, 1953; Cadenat and Doutre, 1959; Layne, 1965; van Bree, 1971; Caldwell *et al.*, 1971; and van Halewijn and van Bree, 1972). We found no specimens referable to

TABLE 1. SKULL MEASUREMENTS (MILLIMETERS) AND DENTAL COUNTS OF *STENELLA* SPP. FROM WESTERN SOUTH ATLANTIC WATERS.

| Measurements | MACNBA 2625 mm | % CBL | MNHN 1305 mm | MACNBA 23-46 mm | % CBL |
|---|---|---|---|---|---|
| Condylo-basal length | 442 | 100.0 | 402+ | 389 | 100.0 |
| Rostrum length | 260 | 58.8 | — | 230 | 59.1 |
| Rostrum basal width | 111 | 25.1 | 120 | 93 | 23.9 |
| Rostrum, width 60 mm anterior to base | 70 | 15.8 | 77 | 60 | 15.4 |
| Rostrum, width at middle | 59 | 13.3 | — | 45 | 11.6 |
| Rostrum, width at 3/4 the distance from the base | — | — | — | 34 | 8.7 |
| Premaxillae width at middle | — | — | — | 24 | 6.2 |
| Tip of snout to blowhole | 305 | 69.0 | — | 272 | 69.9 |
| Tip of snout to pterygoid | 321 | 72.6 | — | — | — |
| Preorbital width | 185 | 41.8 | 217 | 163 | 41.9 |
| Post-orbital width | 206 | 46.6 | 236 | — | — |
| Orbital width | 191 | 43.2 | 215 | 162 | 41.6 |
| Zygomatic breadth | 209 | 47.3 | 233 | — | — |
| Blowhole, width at | — | — | — | 43 | 11.1 |
| Maximum width premaxillae | — | — | — | 70 | 18.0 |
| Braincase width across parietals | 150 | 33.9 | 174 | 142 | 36.5 |
| Temporal fossa length | 71 | 16.1 | 71 | 65 | 16.7 |
| Temporal fossa height | 46 | 10.4 | 45 | 48 | 12.3 |
| Length of tooth row upper R. | 230 | 52.0 | — | 186 | 47.8 |
| Length of tooth row upper L. | 229 | 51.8 | — | 189 | 48.6 |
| Mandible length | 374 | 84.6 | 407 | — | — |
| Coronoid height | 67 | 15.1 | 76 | — | — |
| Length of symphysis | 50 | 11.3 | — | — | — |
| Length of tooth row lower R. | 226 | 51.1 | 231 | — | — |
| Length of tooth row lower L. | 226 | 51.1 | 227 | — | — |
| Number of teeth upper R. | 44 |  | — | 34+ |  |
| Number of teeth upper L. | 45 |  | — | 37 |  |
| Number of teeth lower R. | 43 |  | 50+ | — |  |
| Number of teeth lower L. | 43 |  | 49+ | — |  |

*S. longirostris* in five eastern South American museums. As noted in the introduction, numerous authors have reported *S. longirostris* and the probably conspecific nominal species (see van Bree, 1971) *Delphinus alope* and *D. microps* from localities including Brazil, Uruguay, Argentina and Cape Horn. All southern " records " are without documented specimens or observations. In view of this confusion, we present below the genesis and chronological review of western South Atlantic " records " for this species.

Gray (1866) reported *Delphinus alope* from " Cape Horn ", but the specimen is apparently now not extant in the British Museum (Natural History) and no additional information is available in the museum on the collection locality of this specimen (W. F. Perrin, per. comm., 1973). Based on the valid records of *S. longirostris*, this species is known worldwide only in tropical waters. It is extremely unlikely that *S. longirostris* will ever be recorded from the cold-temperate waters of southern South America. In fact, this species is still not known from any of warm-temperate waters of the world. The reports of this species from Chilean waters by Schneider (1946) and Mann (1957) are without any type of documentation and should be discounted. The "records" of Gray (1866), Schneider (1946) and Mann (1957) are probably what influenced Marcuzzi and Pilleri (1971) to map the erroneous distribution of *S. longirostris* around Cape Horn.

Gray's comments (1850 : 126, 1866 : 240 and 1871 : 69) are all apparently based on one specimen of *Delphinus microps* from the "coast of Brazils" from Dr. Dickie's collection. This specimen was probably collected in the tropical waters somewhere north and east of Rio de Janeiro. Burmeister (1867 and 1879) provided the following accounts about *D. microps:* (1867) "vive en el alto mar Atlantico al sud del ecuador y se presenta muchas veces a los viajeros en buques de velas. Tenemos en el Museo Publico dos craneos completos, el uno regalado por el Sr. Dr. D. Miguel Olaguer Feliu", (We could not find either of these skulls in the museum, MACNBA.) and (1879) "on trouve cette espece dans l'Ocean Atlantique, principalement au sud de l'Equateur, par troupes de 20 a 30 individus. Ils suivent quelquefois la marche du navire et passent en bondissant a son avant. Je les ai apercus et etudies plusieurs fois pendant les quatre voyages que j'ai faits dans cette partie de l'Ocean. (Voyez mon voyage du Bresil, page 37, Berlin 1853)". Van Beneden and Gervais (1880) cited *D. microps* from the mouth of the Rio de la Plata and the coast of Brazil. They provided no new data and probably just followed the above statements by Gray and Burmeister. Figueira (1894) noted that "*Delphinus microps* Gray. Tonina. Es una de las especies mas comunes en nuestras costas sobre el Rio de la Plata, especialmente en los meses de Noviembre a Febrero". *Tonina* is used today in Uruguay by laymen for *Tursiops* cf. *truncatus* and this is what Figueira's records of *D. microps* must have been. Lahille only noted the following : (1899) "*Delphinus delphis* Linneo. Esta especie (*D. microps* Burm, nec Gray) se ha notado en las costas del Chubut" and (1905) "*Prodelphinus longirostris.* Cabo de Buena Esperanza, Australia; Costas de la Provincia de Buenos Aires". Carcelles (1948) stated that "*Prodelphinus longirostris* Cuvier, Habita tambien el litoral atlantico bonaerense, asi como las Islas Galapagos, Panama, Australia. En el Museo de la Estacion Hidrobiologica de Puerto Quequen, puede verse un modelo en yeso del craneo".

## RESUMEN

Se proporcionan medidas y detalles de 3 especimenes de delfinidos del genero *Stenella* del Oceano Atlantico Sudoccidental. Se cita por primera vez para esta area un ejemplar del "spotted species complex". Se mencionan tambien 2 especimenes de *S. coeruleoalba*, 1 de Uruguay y 1 de Argentina, de las proximidades de la localidad tipica (desembocadura del Rio de la Plata). De *S. longirostris* no se encontraron ejemplares en ninguna de las colecciones de 5 museos sudamericanes (ver Materials) del cual tampoco existen datos de especimenes documentados en la literatura, citados para el Oceano Atlantico Sudoccidental.

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## EXPLANATION OF PLATE

### PLATE I

Fig. 1. *Stenella* sp. referred to the spotted dolphin complex (see text). This specimen (MACNBA 23-46) is from Mar del Plata, Pcia. Buenos Aires, Argentina (38°00'S.) Atlantic Ocean. Dorsal view of specimen.

Fig. 2. *Stenella* sp. (MACNBA 23-46) ventral view of specimen.

Fig. 3. *Stenella* sp. (MACNBA 23-46) lateral view of specimen.

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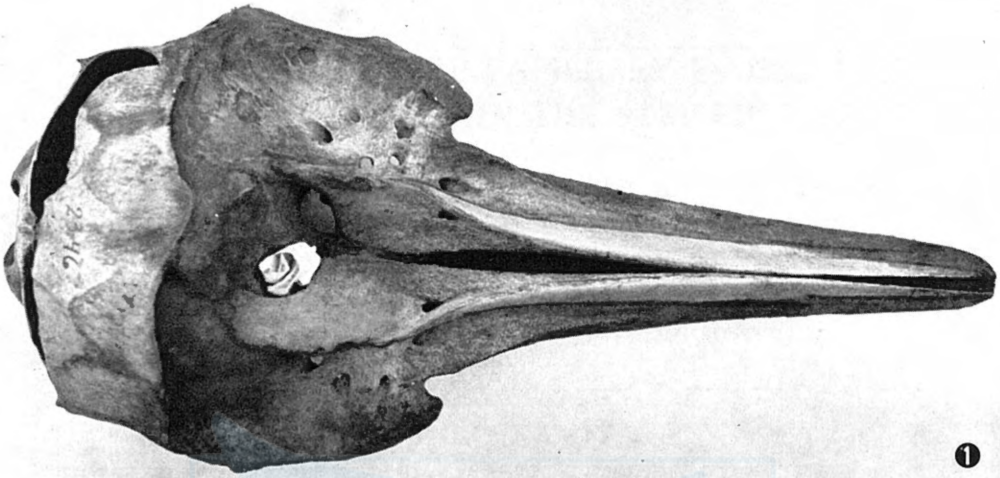

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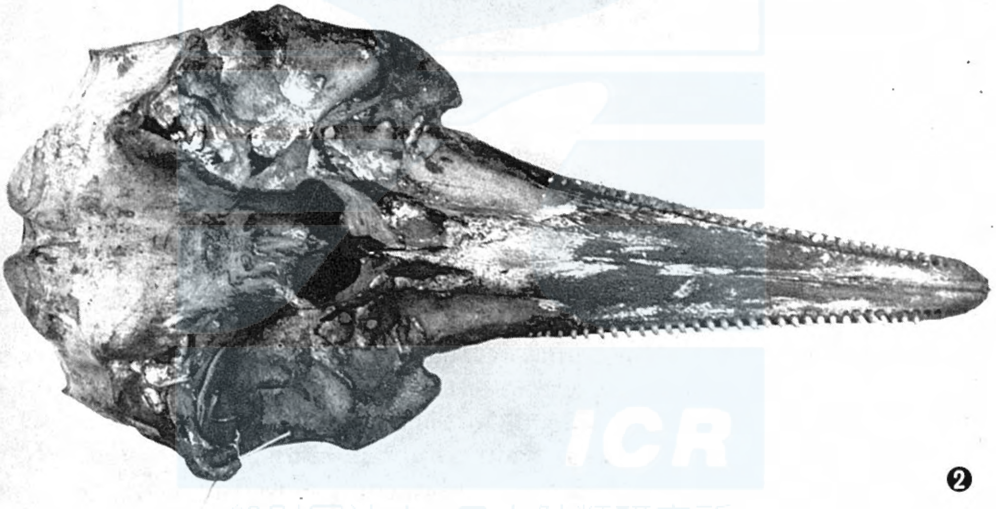

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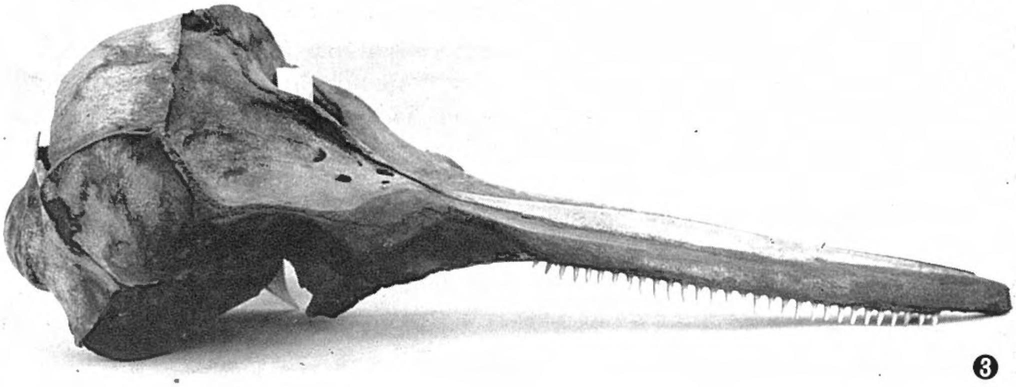

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# AN OBSERVATION ON THE PAPILLARY PROJECTIONS AT THE LINGUAL MARGIN IN THE STRIPED DOLPHIN

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## ABSTRACT

Papillary projections were observed along the anterolateral margins of the tongue in fetal and young stages of the striped dolphin, *Stenella coeruleoalba*. The projections appear in the fetal stage and attain maximum development in the early postnatal period. They disappear almost completely by weaning, although small vestigial eminences remain at the corresponding region in the adult. The projections may have a close relation to suck milk.

There are few descriptions of the anatomy of the tongue in Cetacea, and many uncertainties remain concerning lingual structure and function in many species of this order of mammals. One of the most remarkable features of the tongue in Cetacea is the completely absence of lingual papillae.

We have found papilla-like projections at the anterolateral margin of the tongue in fetal and young individuals of some species of dolphins. Growth and involution of these projections were demonstrated in the striped dolphin, *Stenella coeruleoalba*. The fact that the projections appear temporarily, and do not persist throughout life, has not been reported previously.

As shown in Fig. 1, small projections, approximately 0.5 mm in length and about twenty in number on each side, are present at the lateral margins of the anterior one-third of the body of the tongue in a 27 cm fetus. The projections are distinct (1 to 2 mm long) occupying the entire anterior margin of the tongue in an 80 cm fetus. In a 98 cm fetus, they have grown longer (2 to 5 mm) and wider than those in the 80 cm fetus (Fig. 2) and some of them are subdivided at their tips (arrows in Fig. 2). In a young *Stenella* (body length 150 cm), projections have become somewhat thinner and broken, and some of them have disappeared in the posterior part (Fig. 3). In an adult animal, several distinct

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eminences are present near the apex of the tongue (Fig. 4). In another larger adult one, the eminences have reduced in size and the lateral margins are slightly uneven in appearance. The entire dorsum of each tongue we observed was quite smooth and no lingual papillae of any type were present.

Since the body length of *Stenella coeruleoalba* is about 100 cm at the time of birth (Kasuya, 1972), the appearance of the tongue in the newborn animal is probably similar to that in the 98 cm fetus we observed. Thus, it is certain that the papillary projections in the *Stenella* appear during intrauterine life and gradually develop towards parturition. The projections may be most numerous and well developed in the early postnatal period and they may begin to degenerate and disappear at about the 150 cm stage, which roughly corresponds to weaning in *Stenella coeruleoalba* (Kasuya, 1972). How the number of the projections increase and how the projections disappear are interesting points. It can be assumed that the former increase due to subdivision of the projections that are present in the 98 cm fetus as shown with arrows in Fig. 2, and the latter vanish through repeated narrowings in several parts of each projection (arrows in Fig. 3) and finally shed off from the tongue proper.

In the adult Franciscana dolphin, *Pontoporia blainvillei*, no papillae were present on the dorsum of the tongue but small eminences were observed at its lateral margins. Distinct papillary projections (2 to 3 mm long) were found at the anterior free margin of the tongue in a young, 98.5 cm, *Pontoporia* (Yamasaki, *et al.*, 1976), and the same region was dotted with warts and fringes in a young animal (Burmeister, 1869). The small eminences at the anterolateral margins of the tongue of the adult *Stenella* and also of the adult *Pontoporia* appear to be the remnants of the papillary projections seen in the young animals. We also observed well developed projections (2 to 4 mm long) at the anterior margin of the tongue in a newborn finless porpoise, *Neophocaena phocaenoides* (71.5 cm). And foliate projections (3 to 6 mm), which decrease in their number with age, were observed in young bottlenose dolphin, *Tursiopus truncatus*, and Risso's dolphins, *Grampus griseus* (Nakajima, *et al.*, 1963). Thus, the papillary projections will be found in the fetuses and the young of some other dolphins or toothed whales. Although Anderson (1879) and Sonntag (1922) described filiform and fungiform papillae on the tongue of Ganges dolphin, *Platanista gangetica*, the dorsum of the tongues of the adults was completely smooth and no type of lingual papillae could be observed (Arvy and Pilleri, 1970, Yamasaki, *et al.*, 1976). As they only observed the tongue in the young stage without observation in the adult, projections were propably described as the lingual papillae mentioned above.

The projection is composed of a core of the lamina propria mucosa and a thick stratified squamous epithelium without taste buds. Both are continuous with those of the tongue proper. This structure, as a whole, is similar to that of filiform or fungiform papillae. However, the projections differ markedly from the lingual papillae of the general mammalian tongue in that they are temporary, localized at the anterolateral margin in a radial manner and large in size. Sonntag (1922) stated that the apex of the tongue in toothed whales may or may not have processes and warty growths, however, we suppose that he observed the tongues in variable stages of involution of the papillary projections. Since the projections only appear in a specific period during life, more care is neccessary as to the estimation of the age when observing the appearance of the cetacean tongue.

The function of the lingual papillary projections described above is not known. Because they are well developed during the suckling period they may have an important mechanical functions during suckling in these aquatic mammals.

As there as yet seem to be several unclear and interesting problems concerning the papillary projections in dolphins, further observations will be done on the relationship between the existence of the projections and the suckling period as well as on food habits and on the process of their development and degeneration, macro- and microscopically. In addition, comparative functional anatomical studies with other cetaceans will be neccessary to clarify this problem.

## ACKNOWLEDGMENTS

Greatest thanks are due to Dr. M.M. Bryden, School of Anatomy, University of Queensland, Australia, who gave us valuable suggestions and kindly checked the draft. Dr. T. Mitsui, Department of Anatomy, Keio University, Dr. T. Ogawa, Department of Medical History, Juntendo University, Dr. K. Takahashi, Department of Anatomy, Sappro Medical College, Dr. H. Ohmura, Whales Research Institute, Dr. T. Kasuya, Ocean Research Institute, University of Tokyo, and Dr. R.L. Brownell Jr., Department of Vertebrate Zoology, National Museum of Natural History, Washington, D.C. are also acknowledged for their advice for our study.

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# EXPLANATION OF PLATE I

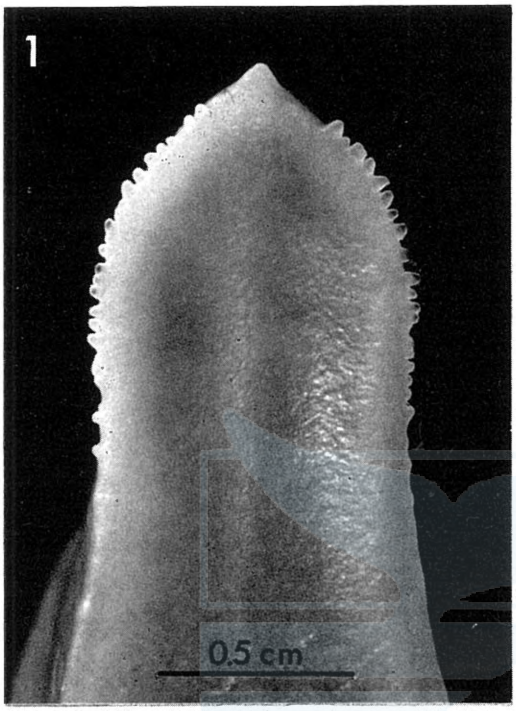
Four stages of the growth and degeneration of the lingual papillary projections of the striped dolphin, *Stenella coeruleoalba*.

Fig. 1. Small projections have already appeared at the lateral margin of the anterior part of the tongue in a 27 cm fetus.

Fig 2. Projections in a 98cm fetus are distinct and occupy the entire anterior margin of the tongue in a radial manner. Some of the projections are subdivided at their tips (arrows). The dorsum of the tongue is concave along the long axis.

Fig. 3. In young *Stenella* (150 cm), projections have become thinner and some at the posterior part have been broken and have disappeared. Note the narrowing seen in some projections (arrows). The transverse and longitudinal incisions were made to improve fixation.

Fig. 4. Vestigial small eminences of the projections can be seen at the margin near the apex in an adult.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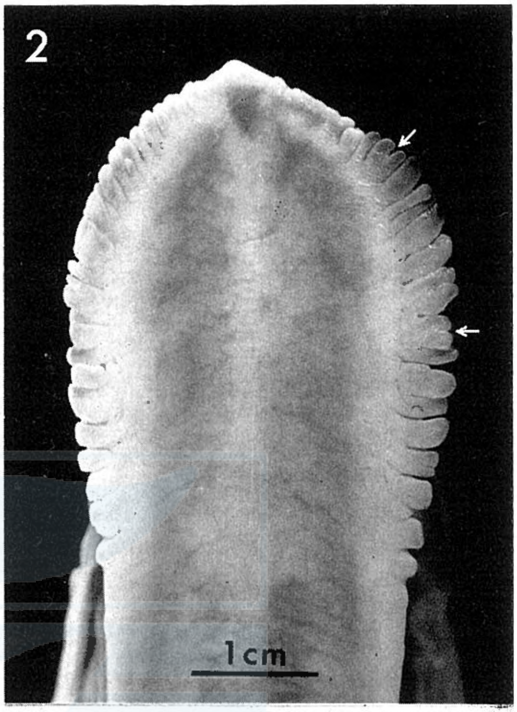
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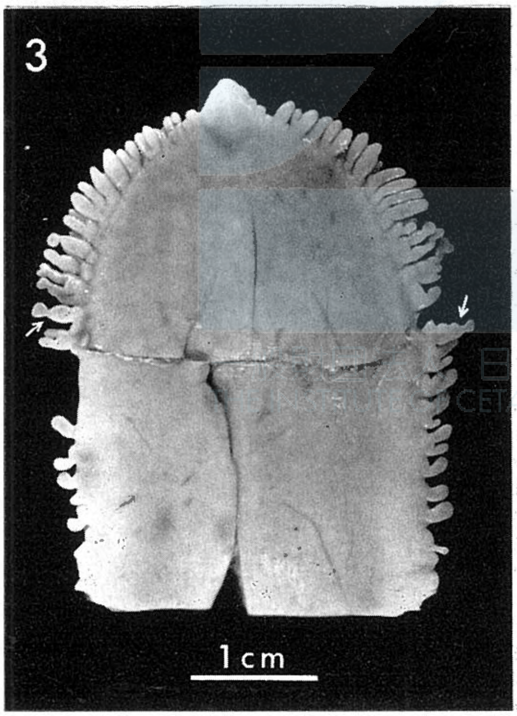
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# AN OBSERVATION OF EPIMELETIC BEHAVIOR OF *LAGENORHYNCUS OBLIQUIDENS*

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The records of the epimeletic behavior in various cetaceans are documented in Caldwell and Caldwell (1966). On the Pacific whitesided dolphin *Lagenorhynchus obliquidens* Gill 1865, he showed three cases where the behavior was directed to wounded or captured animals of the same species, and another case where it was directed to the dead carcass. The present observation adds another example of the latter, and will show that the behavior is common in this species.

On board of the research vessel Tanseimaru, we had a cruise (KT75-7) for the observation of marine mammals. The cruise started at Toyama (36°46′N, 137°13′E) on 9 June 1975 and ended at Tokyo on 18 June. During the two days' observation in the Sea of Japan, the surface water temperature was between 17°C and 21°C, and only two schools of *L. obliquidens* were observed at 39°46′N, 139°33′E and at 41°15′N, 140°16′E. They were composed of about 30 and 10 animals respectively. In the Pacific area the species was concentrated in the coastal waters between 38°N and 36°30′N. In the south and north of this range, there, were observed tropical and boreal species respectively (Fig. 1). Among many *Phocoenoides* observed, only one *dalli*-type was confirmed swiming with 5 *truei*-type. The identified *truei*-type were 34 animals.

The sea was calm on 15 June, and at 1300 hr. a carcass of *L. obliquidens* floating on the side by its own buoyancy was found. The position was 36°47′N 141°56′E. The surface water temperature at the spot was 17.9°C. When the ship approached it to pick up, it was found that the carcass was moving rhythmically by a dorsal fin of the live animal of the same species. As the dorsal fin of the latter was moving vigorously above and beneath the water, it was considered that the animal was tossing the carcass. However, it is sure that the carcass does not sink without this effort. When the ship came at the distance of about 20 m, the dolphin which was larger than the carcass and probably an adult or subadult swam around beneath the carcass. It disappeared when the carcass was caught by a hook and pole. Though we found only one live dolphin near the carcass, the captain Mr. K. Ueno who stayed at a higher place observed two *L. obliquidens* of the same size swam away from the carcass. At this spot, there was observed no other dolphins in the sight.

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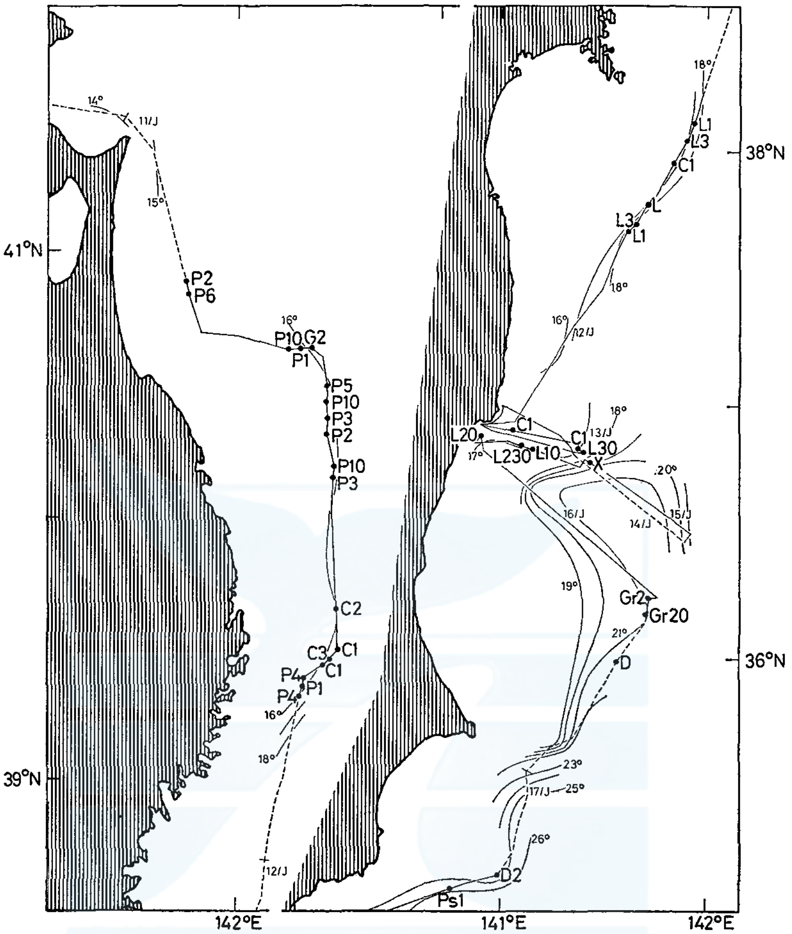

Fig. 1. Distribution of marine mammals and surface water temperature (°C) observed from 11 June to 17 June 1975. C: fur seal, D: delphinids unidentified, G: *Globicephala* sp., Gr: *Grampus griseus*, L: *Lagenorhynchus obliquidens*, P: *Phocoenoides*, Ps: *Pseudorca crassidens*, X: carcass of *L. obliquidens*. Numerals by the species indicate the number of individuals, and the dotted line course passed in the night.

The dead dolphin was a young male measuring 176 cm in body length. On the decalcified and stained tooth slide, there were observed three postnatal dentinal layers stainable by haematoxylin. The first stainable layer was thin, and the last was wide and situated on the pulp wall. If the layer is formed annually and the stainable layer is accumulated in the season from autumn to spring as in the case of *S. attenuata* (Kasuya 1976), the age of the dead animal can be little more than two years. There was found no external or internal injury on the carcass. The carcass was already cold and the skin and muscle were very fresh, but the internal organ showed a very slight smell of decomposition. The stomach was empty. The several barnacles found at the posterior edge of tail fluke were identified by Dr. T. Yamaguchi to be

*Xenobalanus globicipites* Steenstrup 1851. Possibly the dolphin died of some natural cause in the preceding day and had been floating since the death. Though the succorant behavior may not be rare in this species (Caldwell and Caldwell 1966), it is not known in the present case if the live dolphins were continuously with the carcass after the death.

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# SQUIDS FOUND IN THE STOMACH OF SPERM WHALES IN THE NORTHWESTERN PACIFIC*

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## ABSTRACT

The squids obtained from the stomachs of sperm whales caught off Joban, the northwestern Pacific in November, 1972 were examined. It was found that the squids were the most important food for sperm whales in this sea area. The species found were *Moroteuthis robusta*, *Gonatus* sp., *Gonatopsis borealis*, a member of Gonatidae, *Ommastrephes bartrami* and *Histioteuthis dofleini*.

## INTRODUCTION

It is well known that squids are the important food for sperm whales, *Physeter catodon* (Linnaeus).

Omura (1950) and Mizue (1951) also reported that squids were the most important for the food of sperm whales in the waters adjacent to Japan. Ishikawa and Wakiya (1914) reported a gigantic squid, *Moroteuthis robusta* (Verrill), from the stomach of a sperm whale caught " in the open sea off the south of the strait of Tugaru " in August, 1911.

The specimens of squids in the stomachs of eight sperm whales caught in the waters off Joban in November, 1972 were examined. Here this report deals with the result of identification of these specimens.

## MATERIALS

The present samples were collected through the surveys carried out at the whaling station in Ayukawa in November, 1972.

The field observations were made on all sperm whales caught, and the contents of stomachs were classified into squids, fish and others. The observation was made on the first stomach contents. The squids were preliminary classified into A, B, C, D, E and F, and a part of samples were preserved in 10% formalin water to be brought home for close examination.

The localities of the capture of the sperm whales observed are shown in Fig. 1.

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* Contribution from Tokai Reg. Fish. Res. Lab., B628.

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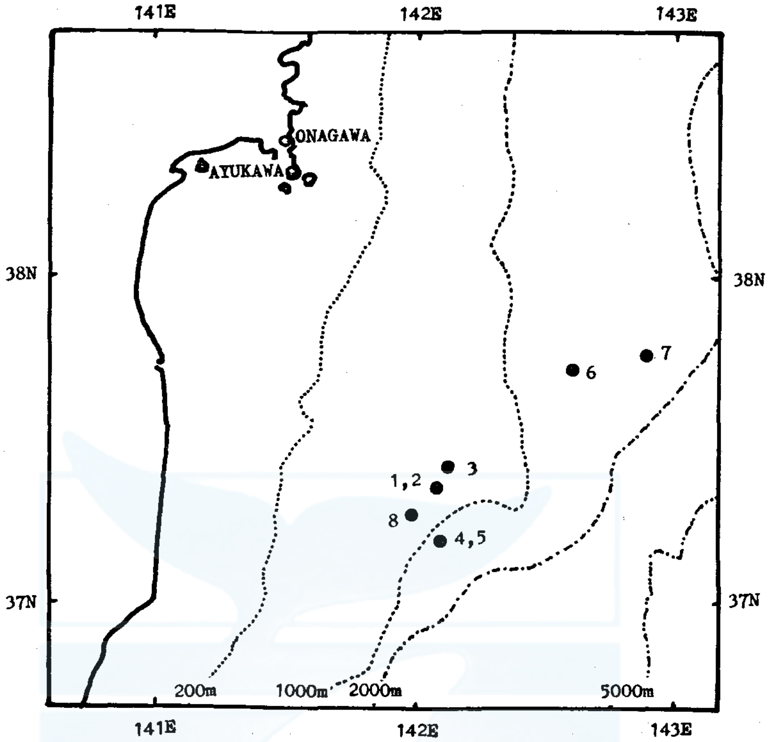

Fig. 1. Localities of catch of sperm whales off Joban, the northwestern Pacific. Numerals in the figure suggest the animals given in Table 1.

## SYNOPSIS OF THE SPECIES IDENTIFIED

The species of squids are shown in Table 1. On the basis of the samples brought to the Whales Research Institute, each group was found to be composed of the species as follows:

A: *Histioteuthis dofleini* (Pfeffer, 1912)
B: *Moroteuthis robusta* (Verrill, 1876)
Gonatidae (species is unknown)
*Gonatus* sp.
*Gonatopsis borealis* Sasaki, 1923
E: *Moroteuthis robusta* (Verrill, 1876)
F: *Ommastrephes bartrami* (Lesueur, 1821)

The exact identification for C and D could not be made, because no specimens of these two groups were brought home. The reason why only the Group B contained four species may be due to that they are much looked alike each other since specimens removed from stomach are so frequently badly mutilated and lost the characters such as hooks and suckers. Sometimes samples are only stripped mantles without arm-head part.

TABLE 1. SPERM WHALES OBSERVED AND THEIR STOMACH CONTENTS

| No. | Date of capture | Locality of capture | Sperm whale | | Stomach contents | | | Species of squid |
|---|---|---|---|---|---|---|---|---|
| | | | Sex | Body length | Kind (Group) | Quantity | Freshness | |
| 1 | 14 Nov. '72 | 37-21 N<br>142-04 E | Female | 11.3 m | Squid (A) | rr | ff | *Histioteuthis dofleini* (Pfeffer) |
| 2 | „ „ „ | „ | „ | 10.2 | „ (B) | rrr | fff | *Moroteuthis robusta* (Verrill)<br>*Gonatopsis borealis* Sasaki |
| 3 | 16 „ „ | 37-24 N<br>142-07 E | Male | 9.5 | „ (AB) | rrr | fff | *Moroteuthis robusta* (Verrill)<br>*Histioteuthis dofleini* (Pfeffer) |
| 4 | „ „ „ | 37-11 N<br>142-05 E | Female | 11.4 | „ (AB) | rr | ff | Gonatidae (species is unknown)<br>*Histioteuthis dofleini* (Pfeffer) |
| 5 | „ „ „ | „ | „ | 10.9 | „ (AB) | rrr | ff | *Gonatus* sp.<br>*Gonatopsis borealis* Sasaki<br>*Histioteuthis dofleini* (Pfeffer) |
| 6 | 20 „ „ | 37-49 N<br>142-36 E | Male | 10.8 | „ (ABCD) | rrr | ff | *Moroteuthis robusta* (Verrill) |
| 7 | 23 „ „ | 37-46 N<br>142-52 E | „ | 12.3 | „ (E) | r | ff | *Moroteuthis robusta* (Verrill) |
| 8 | 24 „ „ | 37-16 N<br>141-59 E | Female | 10.1 | „ (F) | rr | ff | *Ommastrephes bartrami* (Lesueur) |

Remarks) R, rrr, rr and r indicate the relative quantity in decreasing order.
F, fff, ff and f indicate 4 grades of freshness in decreasing order.

## OEGOPSIDA

### Onychoteuthidae

### *Moroteuthis robusta* (Verrill, 1876)

This species was found in the stomachs of four of eight sperm whales.

The specimens brought home were measured about 43.5 cm, 30 cm, 26.5 cm, *ca.* 80 cm and *ca.* 90 cm. The last two specimens are only of very large broken mantles like waste pieces of cloth. But, characteristic warty sculptures of the integument showed that they belong to *M. robusta*.

### Gonatidae

### *Gonatus* sp.

This species was found in the stomach of only one of eight sperm whales. The dorsal length (on only remaining portion) was measured 12 cm, but the gladius length was 16.5 cm. The specimen has very long tentacles of about 30 cm (right) and 28 cm (left) long. Both of them have a single large hook on their club. This is decidedly one of a species so far called *G. fabricii* (Lichtenstein, 1818) (Plate I, fig. 1).

### *Gonatopsis borealis* Sasaki, 1923

This species was found in the stomachs of two of eight sperm whales. The mantle of one specimen without head and arms is about 26 cm long and has a large rhombic fin (length: *ca.* 10.5 cm, width: *ca.* 16 cm). The posterior end of the mantle is obtuse (Plate I, fig. 2). The mantle of the other specimen is about 22.5 cm long and the width and the length of the fin is about 16 cm and 8 cm respectively. The ends of the both sides of the fin are deformed to be sharp as shown in Plate II, fig. 1. The mantle and fin might have shrinked lengthwise in formalin water. Arm formula is 3, 2, 1≒4. From the characters of general shape, skin and mantle cartilage these specimens were identified to be this species.

### A member of Gonatidae, the species of which is unknown

A specimen of only mantle of about 14 cm long was found from the stomach of a sperm whale. It has no fin, which seems to have been attached to the posterior part of the mantle. It has no character for identification to species, but seeing from its shape and the feature of muscle, it seems to belong to Gonatidae (Plate II, fig. 2).

### Ommastrephidae

### Ommastrephinae

### *Ommastrephes bartrami* (Lesueur, 1821)

This species was found in the stomach of only one of eight sperm whales. The specimen is lacking in head and arms. The mantles is about 40.5 cm long and has a muscular and rhomboidal fin of *ca.* 15.5 cm long and 25.5 cm wide (Plate III, fig. 1). The inverted T-shaped funnel elements of the mantle-funnel fusion are easily separated from the mantle elements. A lot of photogenic tissues are observed in the ventral integument of the mantle.

### Histioteuthidae

### *Histioteuthis dofleini* (Pfeffer, 1912)

Nine specimens from the stomachs of four of eight sperm whales were examined, the dorsal mantle length of which measured from about 6.5 cm to about 12 cm. The neck is separated from the mantle. Arms have no hooks, the both sides of the fin attached to the posterior part of the mantle are muscular and convex. All specimens have tentacles missing. Because of numbers of photophores over the surface of the mantle, head and arms, these specimens were easily discriminated to belong to Histioteuthidae. The final identification to the species was made because of the triserial photophores on the arm IV and the shape of the funnel organs (Plate III, fig. 2).

## THE OCCURRENCES OF SQUIDS

Among the sperm whales caught off Joban and Sanriku and dissected at the whaling stations at Onagawa and Ayukawa in November, 1972, 65 whales were observed of their stomachs, all of which had only squids. Though the number of samples may not be large enough for discussing the important species as food for sperm whales, *Histioteuthis dofleini* and *Moroteuthis robusta* might be considered the most important for this sea area (Table 1). The members of Histioteuthidae have not been reported as the food for the sperm whales in the North Pacific, but were reported numerically dominantly in the diet of sperm whales from the Azores Region (R. Clarke, 1956) and Madeira (M. R. Clarke, 1962). The members of Onychoteuthidae have already been reported as the most important food for sperm whales in the waters adjacent to the Aleutian Islands (Okutani and Nemoto, 1964: *M. robusta*), off central California (Rice, 1963: *M. robusta*) and in the Antarctic (Korabelnikov, 1959: *Onychoteuthis banksii*). The members of Gonatidae also seem to be important as the food for sperm whales in the waters off Joban, because Beteshava and Akimushkin (1955) and Sleptozov (1955) reported that the members of Gonatidae are the most important diet of sperm whales in the Kuril waters. Okutani and Nemoto (1964) also found considerable number of Gonatid family in the sperm whale's food in the Bering Sea and the northern North Pacific. This time *Ommastrephes bartrami* was found in the stomach of one sperm whale. It is noteworthy that this species has not hitherto been reported as the food for sperm whales before the present finding.

## ACKNOWLEDGMENTS

My thanks are due to Dr. H. Omura, the Director of the Whales Research Institute, who encouraged me to carry out this investigation, and Dr. S. Ohsumi of Far Seas Fisheries Research Laboratory and the staffs of the Ayukawa whaling station of Taiyo Gyogyo K. K. for their kindness of collecting the samples. I also like to thank Dr. T. Okutani of the Tokai Regional Fisheries Research Laboratory for his help in identifying the specimens.

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# EXPLANATION OF PLATES

## PLATE I

Fig. 1. *Gonatus* sp., gladius length 1.65 cm.
Fig. 2. *Gonatopsis borealis*, dorsal mantle length *ca.* 26 cm.

## PLATE II

Fig. 1. *Gonatopsis borealis*, dorsal mantle length *ca.* 22.5 cm.
Fig. 2. A member of Gonatidae, dorsal mantle length *ca.* 14 cm.

## PLATE III

Fig. 1. *Ommastrephes bartrami*, doral mantle length 40.5 cm.
Fig. 2. *Histioteuthis dofleini*, dorsal mantle length *ca.* 12 cm.


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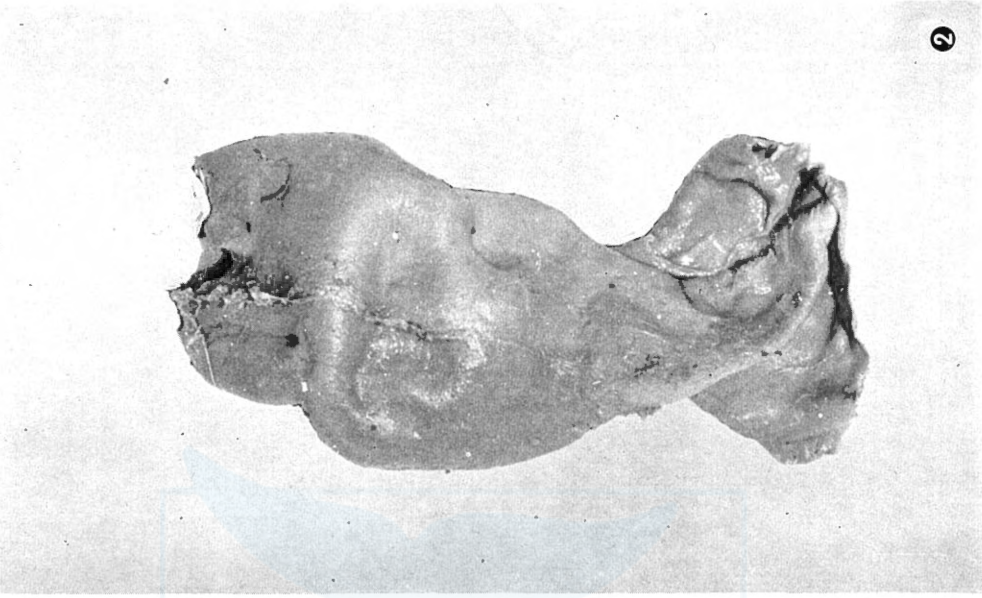
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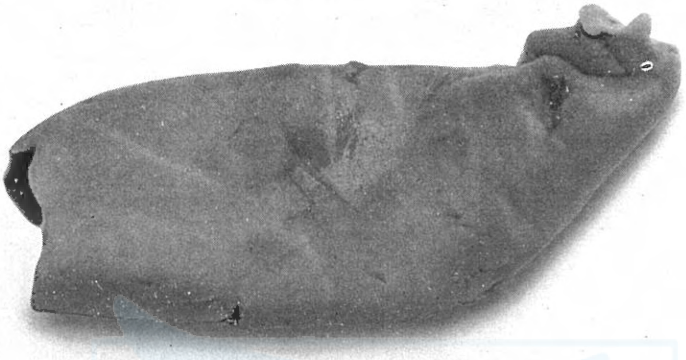

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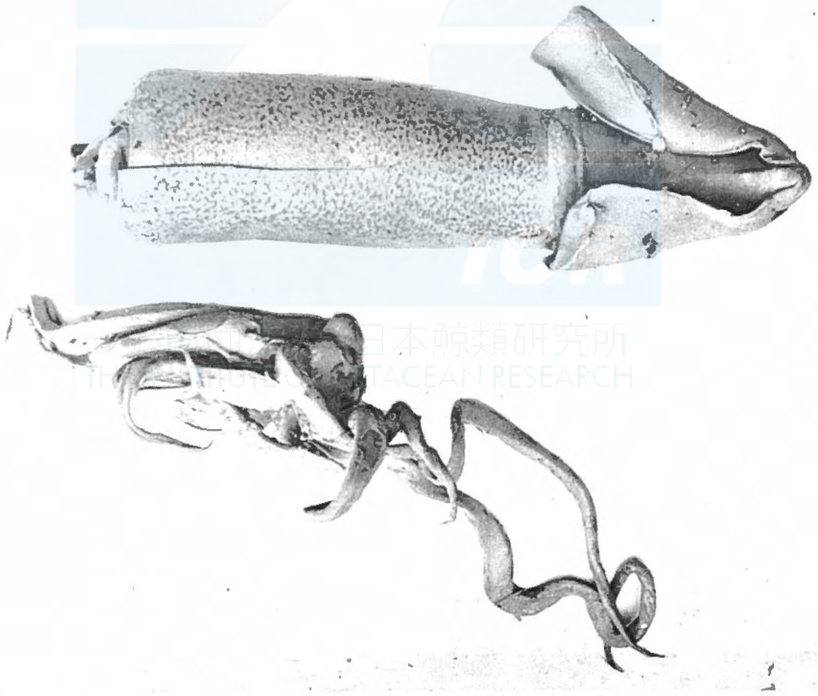


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# LIFE CYCLE OF *CYAMUS SCAMMONI* (AMPHIPODA: CYAMIDAE), ECTOPARASITE OF GRAY WHALE, WITH A REMARK ON THE ASSOCIATED SPECIES

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## ABSTRACT

*Cyamus scammoni*, parasitic exclusively on gray whale, was studied under the provision of special scientific permit. Its life cycle was completed during the journey of winter migration. *C. ceti* and *C. kessleri*, messmates of *C. scammoni*, followed the same pattern in many respects. Significantly, the whale-lice can survive out of water for several days though other amphipods are poorly adapted for terrestrial life. The cyamid causes certain damage to the cutaneous tissue of the host when the juvenile begins its livelihood.

## INTRODUCTION

The whale-louse, ectoparasite of mysticete and odontocete, has been recognized ever since *Oniscus ceti* of the bowhead whale recorded by Linnaeus in 1758. Although scores of papers on taxonomy have elaborately been published, yet many facets are still unexplored. This accounts for the fact that systematic investigation is not always feasible, not only because the population of the whale species is widely distributed in different hemispheres, but the cyamids are often discarded by the commercial whalers. Moreover, the whales are legally protected so that collecting is no longer available.

The gray whale, *Eschrichtius robustus*, summers in Chukchi, Beaufort, and western Bering Seas for food, and in winter it migrates along the Californian coast to the lagoons of Baja California, Mexico, for breeding and calving. As the herd travels along a defined course in definite seasons, the life cycle of the cyamid may well be traced through a successive survey during the entire journey. Under the provision of the specific scientific permit, the author was privileged to participate the whaling expedition on several occasions, and visited the shore station at intervals to collect series of samples of which the accumative data were of significance to make this study possible.

## MATERIAL AND METHOD

This study was based on series of *Cyamus scammoni* and the associated species, *C. ceti* and *C. kessleri*, taken aboard the catcher boat off central California during 1966–1967 season, and in the shore station at Pt. San Pablo, California in 1963–1964 and 1968–1969 seasons. Included were both individuals migrating southward and homeward bound in the months of December to April. It also covered the material collected at Pt. Barrow, Alaska in the summer months of 1954, 1959 and 1961 (Leung 1965).

Some 85 males, 200 ovigerous females, and 250 juveniles were studied, of which the total length of each stage, and the number of eggs and young in the ovary and brood-pouch were recorded. The stage of development was examined from some 4000 individuals taken at Pt. Barrow, and the living specimens were studied at sea and at the shore station.

## LIFE HISTORY

*Cyamus scammoni* (Fig. 1) is the largest species of the family as the male is ranging up to 27 mm, and the female to 16 mm. Its double cock-screw gills and the unevenly purple coloration on the dorsal somites constitute unique features of the species. The development, alike other amphipods, is direct. The brood was apparently full-grown in summer before migrating southwards, and mating began when it reached sexual maturity (Fig. 2). An ovigerous female carried a clutch of 980–1078 eggs in the brood-pouch, and the eggs, spherical, creamy white, measuring 325–420 μ, were fertilized when the whale

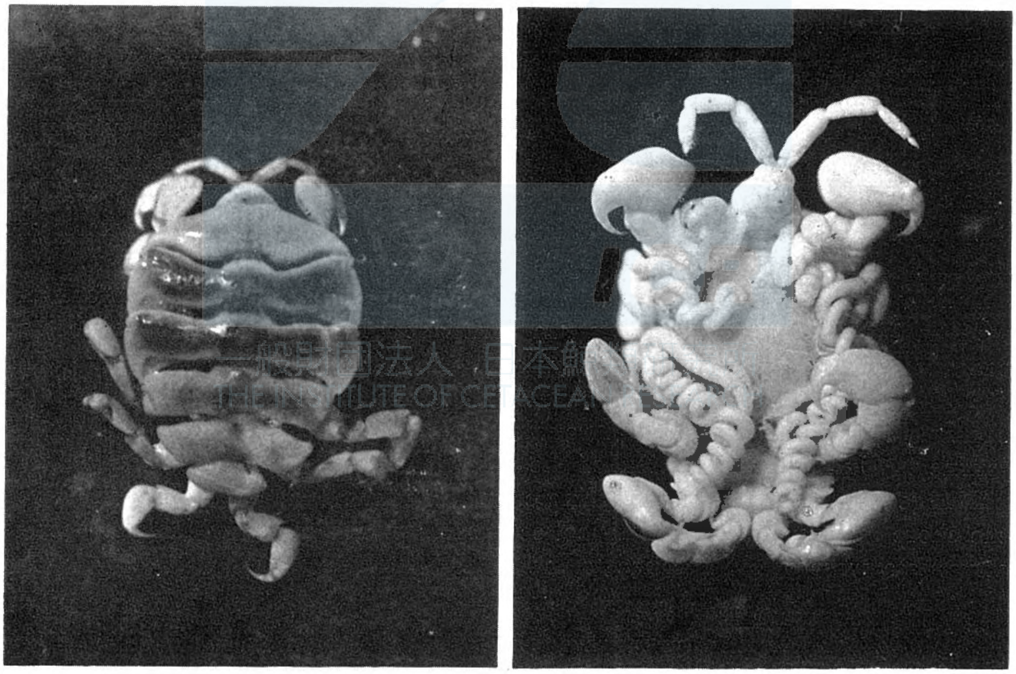

Fig. 1. *Cyamus scammoni* Dall, male, dorsal view (left) ×6; female, ventral view (right) ×10.

Fig. 2. *C. ceti*, mating on side of the jaw of the host. × 10

arrived in central California in October. Although the female carried a considerable number of eggs in a clutch, only 450–760 (about 60%) were fertilized. The young, measuring about 0.5 mm, resembled the parent except that the gills, instead of double and spirally coiled, were single and knobshaped, and there was no trace of genital appendages in both male and female (Fig. 3). Being not a free-swimming amphipod, the vulnerable young retained in the brood-pouch for two to three months until it reached the stage of miniature adult. Those arriving in December and January the juveniles had been released from the brood-pouch to maintain life independently. The free juvenile, measuring 1.0–1.5 mm, fastened itself with peavey hook-like ungulae in the soft skin tissue of the belly of the host (Fig. 4 and 5), or shielded itself in the scar or orifice of the endemic cirriped (*Cryptolepas rachianecti*) along both jaws of the whale. Subsequently, the young was able to cover itself for protection against the turbulent current (Fig. 6). After remaining in the recess of the corium of the host and crevice of the cirriped for some time, the juvenile began to set foot on the cuticle of the host with its strong peraeopoded claws. At this stage, the knob-shaped gills began to expand and curve in, and bifurcate when the young attained 4 mm in length; at full growth the number of coils of the second branch was almost double the number of the first one. When the individual measured about 6 mm, the oostegites of the female projected inwardly on the gill-bearing somites (3rd and 4th body segments), and the purple coloration of both male and female appeared gradually on the dorsum. In February when the host was returning to the habitat from the south, the miniature male adult attained 8–10 mm, and the female from 6–8 mm; the male accessory gills (absent in female) and the genital appendages began to appear; the paired

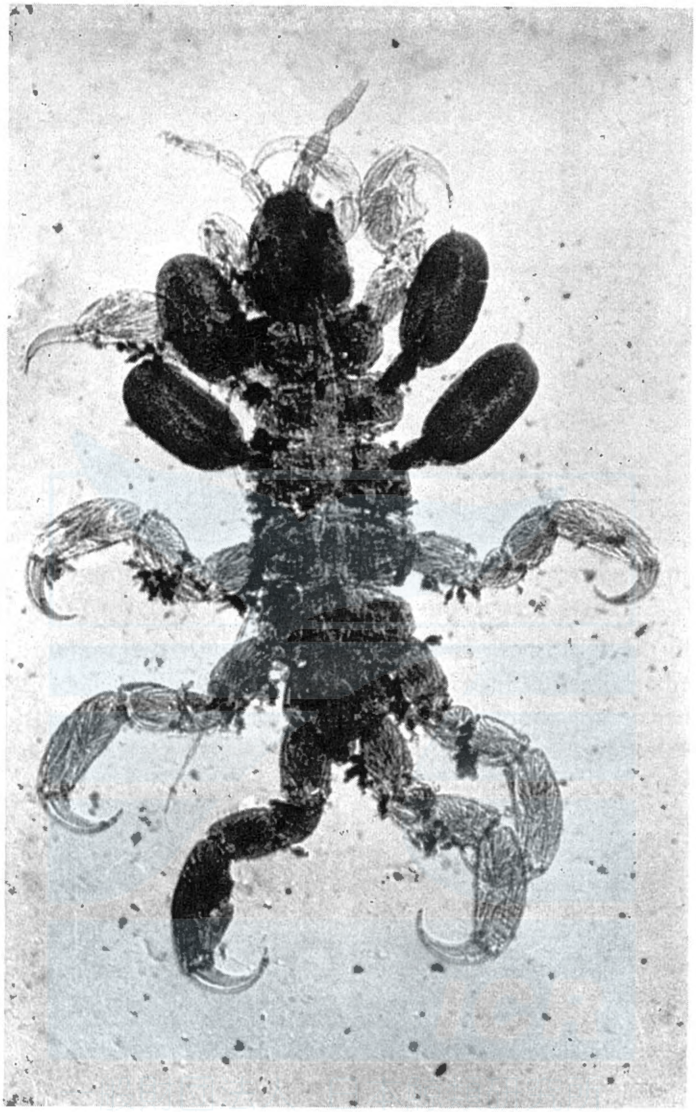

Fig. 3. Micrograph of a juvenile *C. scammoni*, ventral view, showing the knob-shaped gills before bifurcating. ×45. Note the unnamed chonotrichous ciliates infesting the ventral surface of the body.

genital valves on the 5th somite of the female could be traced. In March most of the individuals reached maturity measuring 14–18 mm in male, and 10–12 mm in female; the gills, accessory gills and the genital appendages of the male were fully developed; whereas the oostegites of the female had shaped to form a brood-pouch, of which the posterior plates extended over the anterior ones. The elaborate overlapping arrangement of the oostegites sheltered the eggs and the young in the brood-pouch throughout the incubation period, but

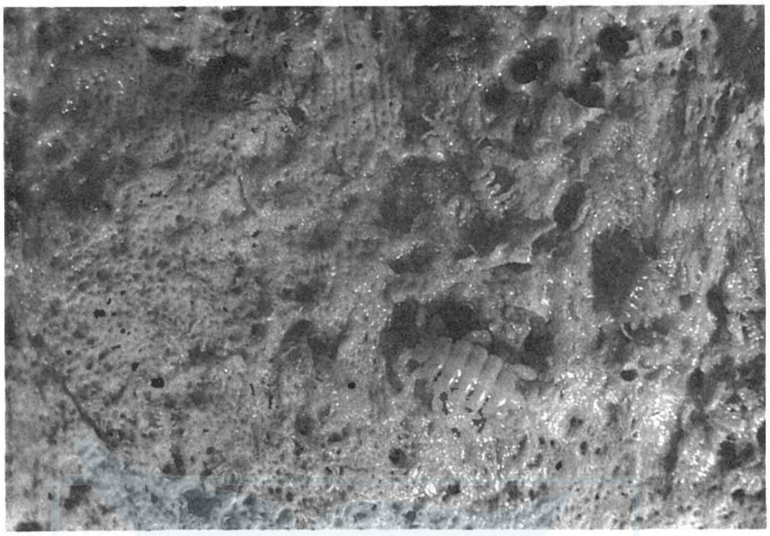

Fig. 4. Young *C. scammoni* boring holes on the belly of the host. ×25.

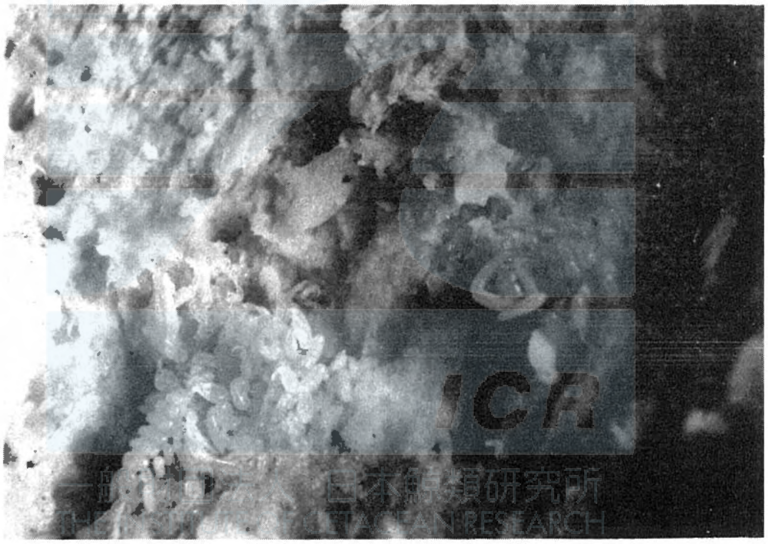

Fig. 5. The outermost skin tissue heavily damaged by young *C. scammoni* ×25

it was automatically opened when the young was full-grown. A female might deposit 350–380 eggs in the brood-pouch homewards, and the number would increase to its full capacity after some time. Finally, the brood was fully developed upon the arrival of the whale in the summer habitat, and it was estimated that it underwent eight to nine months to complete the life cycle.

*C. scammoni* was the counterpart of its messmates, *C. ceti* and *C. kessleri*, but the last matured more earlier since the eggs were hatched before the

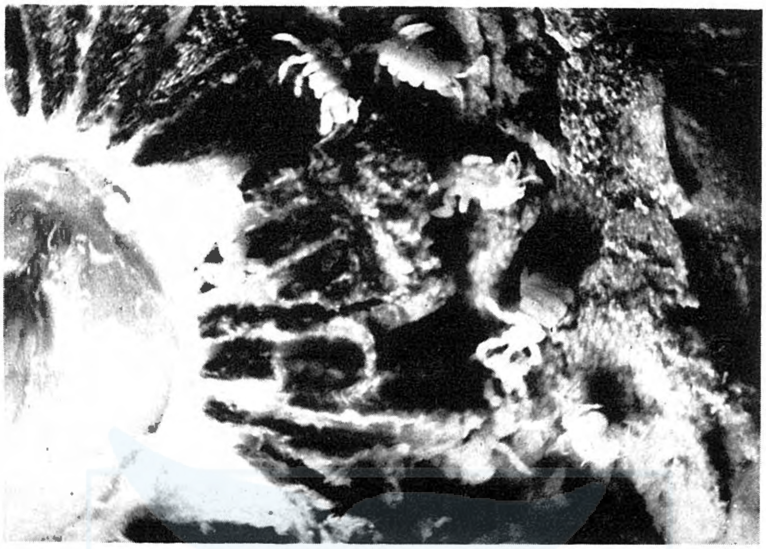

Fig. 6. Juveniles embedding in the clefts of the endemic cirripeds on the side of the lower jaw. ×25.

seasonal migration began. Of 3921 *C. kessleri* taken at Pt. Barrow in July and August, 3534 were juveniles, only 387 adults. When the host migrated southward passing central California in mid January, some of the females had already been depositing eggs in the brood-pouch. During the course of returning northward in late March, the new generation attained full maturity as among 58 females examined, 25 were carrying eggs, 18 with juveniles in the brood-pouch, and 15 having released their young. An ovigerous *C. kessleri* carried 215–300 eggs, only 150–260 (about 75–80%) were fertilized, whereas *C. ceti* carried 154–242 embryos, but 131–146 (about 70–75%) were fertilized. Obviously, the number of embryos produced is varied according to the species and the size of the female.

There is speculation as to the number of instars of *C. scammoni* and the associated species as the number of ecdysis is untraceable. However, it seems likely that there may be at least seven or eight stages as far as the range of size and the development of the morphological structures are concerned. Furthermore, it is probable that the cycle overlaps by reason that some juveniles are always present on each colony.

## GENERAL CONSIDERATION

Despite the cyamid belongs to the same group with the caprellid (Caprellidea), it has diverged from the general plan to a great extent inasmuch as the modified structure of the peraeopods and the possession of accessory gills are extraordinary in amphipod. Possessing these unique structures, the whale-louse is, so far as is known, the only true parasitic form among the amphipods. The cyamids, particularly those of infesting larger mysticetes, have rigid host specificity and site restrictiveness (Leung 1970a) as *C. scammoni* occurs habitually either on the delicate skin tissue of the belly or on the scar of the endemic cirriped along both jaws of the whale; *C. ceti*, being received at the same table occasionally with *C. scammoni*, is found generally on the creases of the lips, flippers and flukes; whereas *C. kessleri* localizes only on the umbilicus, genital opening and anal aperture of the host. During the whaling seasons, nine whales had been inspected aboard the catcher boat and in the shore station, and all animals were heavily infested with cyamids of different stages. Among the three species, *C. scammoni* exceedingly predominated over the other two.

The cyamids breathe by means of gills, however, it is remarkable that they are able to exist beyond the environmental condition. At the shore station it was not uncommon to see the whale-lice crawling for many hours after the whale drawn from the sea. While cruising on the catcher boat, it was curious to observe three individuals of *C. scammoni* reposing on a steel cable of the winch in the late afternoon as no whale was taken during the day. Obviously, these individuals had survived from the catch of the previous day. Further surprising evidence was afforded by G. J. B. Ross of the Snake Parks and Oceanarium of S. Africa (per. comm.) who reported that the cyamids could outlive for three days on a stranded south right whale at Algoa Bay in 1971. Integumentary respiration of the whale-lice is of considerable significance, because they were able to survive for several days divorced from the aquatic environment even though the amphipods are poorly adapted for terrestrial life.

The mouth parts of the cyamid are for piercing. There is some likelihood that whale-lice are omnivorous feeding on the algal filaments and the outermost layer of skin tissue of the host. However, the bill of fare seems to be the cutaneous tissue of the host as the young customarily encases itself by piercing the delicate skin tissue or embedding itself in the cleavages of the sessile cirriped when it begins to maintain its livelihood. Since the host provides favorable sites and adequate food supplies, opportunity of building up large population is eminent. On the other hand, the small streamlined odontocete furnishes neither adequate accommodation nor profuse provisions, and the survival rate is therefore in a reverse direction (Leung 1970b).

Three species of cyamids occur on the gray whale. With the exception of *C. scammoni*, the systematic status of *C. kessleri* and *C. ceti* have long been bewildered. Although *C. kessleri* was recorded by E. Wosnessensky in 1864 at Metschigmensky in the vicinity of the Bering Strait, yet the host had not been identified. It did not come to light until 1954 when Mohr (Hurley and Mohr 1957) collected a few hundred individuals of this species from a gray whale killed by the Eskimos off Pt. Barrow, Alaska, and the host proper was finally justified. *C. ceti* was described from the bowhead or the Greenland right whale, but the association with the gray whale is poorly known. Since the bowhead and the gray whale inhabit in Arctic waters, the possibility of accidental transfer by bodily contact is not unlikely to happen. However, it is seemingly not the case as our colleague, Dr. F. E. Durham, a bowhead biologist, reported that he found neither *C. scammoni* nor *C. kessleri* but *C. ceti* on the bowhead (per. comm.). For this reason, the likelihood of interchange seems unlikely. Virtually, *C. ceti* is akin to *C. monodontis* of the narwhal which Lutken (1873) described it as a " peculiar dwarf-form " of *C. ceti.* In view of *C. ceti* of the gray whale, there is reason to speculate that it may fall within the original description from the bowhead, and a concept of specific independent species has been conceived. Consequently, both species should be thoroughly reviewed.

There are various unnamed species of chonotrichous ciliates (Chonotricha) infesting the ventral surface of the young cyamids (Fig. 4). It is of interest that these collar ciliates, alike the cyamids, demonstrate an extraordinary mode of parasitism that shares on other congeners to occupy the same community, and the occurrence of interchange is uncommon even though the messmates are colonized at the adjoining locality. Accordingly, it is suggested that it may be a contributing factor to identify the whale-lice and the cetaceans in the presence of the ciliates.

Finally, the whale-lice cause certain damage to the whale skin when the young begin to maintain their livelihood, and the injury is a result of piercing the tissue in which they shelter for safety and for food. As a matter of fact, the outermost layer of whale skin is extremely thin and delicate in structure, hence it is no wonder that the unwelcome guests frequent these haunts for living.

## ACKNOWLEDGMENT

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# ON THE HELMINTHUM OF FRANCISCANA, *PONTOPORIA BLAINVILLEI*

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## ABSTRACT

Three helminthes, *Anisakis typica* (Diesing, 1860), *Procamallanus* sp. and *Corynosoma cetaceum* Johnston and Best, 1943, were isolated from a Franciscana, *Pontoporia blainvillei* (Gervais, 1842), collected at Punta del diabulo, Urguay. This is the new host-record against these helminthes.

## INTRODUCTION

In January 1973, many materials were obtained from the stomach of a Franciscana, *Pontoporia blainvillei* (Gervais, 1842), collected at Punta del diabulo, Urguay, for scientific studies. These materials consists of two species of nematodes and one of Acanthocephala and all mounted as microscopic preparations in glycerinejelly, lactophenol or gum-chloral after the fixation in 70% ethyl alcohol. Further details may now be added the description of the species.

### *Anisakis typica* (Diesing, 1860)

*Materials:* Thirty-one worms obtained from the second stomach of Franciscana.

The materials consisted of 2 larvae, 10 males and 19 females (Table 1).

The worms (Photograph 1) were whitish in color, in alcohol fixation.

TABLE 1. COLLECTION RECORDS OF HELMINTHES IN THE STOMACH OF FRANCISCANA *PONTOPORIA BLAINVILLEI* (GERVAIS, 1842)

| Species of Parasites | Sex | No. Worms recovered | Habitat |
|---|---|---|---|
| *Anisakis typica* | Larvae | 2 | 2 nd stomach |
| | Male | 10 | |
| | Female | 19 | |
| *Procamallanus* sp. | Female | 2 | 2 nd stomach |
| *Corynosoma cetaceum* | Male | 111 | 3rd and 4th stomach |
| | Female | 99 | |

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*No. 28, 1976, 161-166.*

*Description:* Anisakinae, Nematoda. Three lips each bearing a bilobed anterior projection which carries the single dentigerous ridges (arrow at Photograph 2); interlabia absent; lateral cervical alae absent; cervical papillae bear the nerve-ring. Body attenuate more toward anterior than toward posterior extremity, which ends conically. Cuticle with cuticular striations 19–59$\mu$ broad. Excretory gland with duct opening between ventro-lateral lips; oesophagus composed of two portion; anterior muscular portion (M. at Photograph 3) and posterior ventriculus (V. at Photograph 3), the latter being oblong and somewhat sigmoid or else as broad as long; no ventricular appendix or intestinal caecum.

*Male:* 28.3 to 56.4 mm in length by 0.60 to 1.39 mm in breadth; anterior muscular portion 2.28–3.62 mm in length at the body length 28.3–47.0 mm, ventriculus 0.90–1.50 mm in length; tail (0.16–0.26 mm in length. Photograph 4) compressed dorso-ventrally with dorsal median rounded keel and with lateral alae. It is curved ventrally and bears numerous papillae; 10 pairs of postanal papillae without doublepapilla, of which 1, 2 and 3 are conical and near the tip; 4 to 10 shorter and near the cloaca; spicules unequal, the right spicules (R. of Photograph 5) measured 0.94 mm while the left (L. of Photograph 5) measured 2.86 mm at the worm of body length 46.0 mm (ratio, 1 : 3.04).

*Female:* 21.7 to 90.8 mm in length by 0.56 to 2.00 mm in breadth; vulva in 10.2–11.3 mm (46.3–47.0%) from anterior extremity of body. Anterior muscular portion 1.98–3.52 mm; Ventriculus 0.56–1.20 mm at female of body length 21.7–42.4 mm. Tail length 0.14–0.30 mm (Photograph 6).

*Larva:* 25.4 and 25.8 mm in length and 0.56 and 0.57 mm in breadth, with length muscular region of esophagus of 1.96 and 2.02 mm, ventricular length of 0.84 and 0.83 mm (Photograph 8) and tail length of 0.08 and 0.12 mm (Photograph 9). The larvae had the characteristic boring tooth on their lip mass (Photograph 7 and 10), and the one-shaped cuticular mucron on their tail end, and their long ventriculi were connected with their intestines obliquly. Therefore, the authors consider that these larvae belong to the Type-I larva of *Anisakis* described by Berland (1961).

*Discussion:* Examination of the material detailed above shows that this species is characterized by the very marked unequality of the spicules (1 : 3). This range is clearly distinct from that found for *A. simplex* (1 : 1.6).

The postanal papillae are also different from *A. simplex* (*A. typica* 10 pairs; *A. simplex* 6 pairs with one double papilla).

It is interesting that Davey (1971) described that although *A. simplex* distributed on the wordwide, but more particularly in colder temperature and polar water, *A. typica* found on warmer temperature and tropical waters between 40°N and 36°S.

*A. typica* were recorded only from cetaceans of the families Stenidae, Delphinidae and Phocaenidae. Accordingly, this host (*Pontoporia blainvillei*; Platanistidae) is the new record against *A. typica.*

### *Procamallanus* sp.

*Materials:* Two females were obtained from the second stomach of a Franciscana.

*Description:* Camalanidae; Spiruroidea; Nematoda. The materials consisted one mature and one immature female (Table 1 and Photograph 11). The worms whitish in collor, in alcohol fixation. Body slender; attenuated towards both extremities. The materials are in length from 29.1 mm and 41.7 mm, and in breadth from 0.31 mm and 0.54 mm. The cuticle thick, and finely striated transversely. The anterior end without lip bears 6 papillae—2 lateral and 4 median. The brownish-yellow buccal capsule (Photograph 13) is broadly barrel-shaped, and its anterior opening is hexagonal. It is in length 0.10 mm and 0.12 mm, and in breadth 0.08 mm and 0.09 mm. The internal surface of the wall of buccal capsule is probided with ridge like thicknings, numbering 12–13, which traverse it in a spiral fashion. The esophagus is divided into the two parts. The anterior muscular portion is club-shaped and measured 0.65 mm and 0.66 mm in length by 0.12 and 0.14 mm in maximum width. The posterior glandular portion measures 0.95 mm and 1.05 mm in length, and unlike the muscular part, has a uniform breadth. The intestine was conspicuous on account of its being full of partly difested blood. The nerve ring encircles at narrowest point of the muscular esophagus, 0.36 mm from the anterior end. Excretory pore situated in the region of the nerve ring and a short distance from anterior to junction of muscular and glandular portion of esophagus.

Posterior extremity is bluntly rounded; it has length 0.12 mm. Numerous conspicuous muscle strands extend across body cavity region of anus. Tail (Photograph 12) terminates in a small conical tip, 0.05 mm long, at extremity of which are two extremely minute spinal projections, apparent only under the higher magnification.

The vulva is situated on the middle of body (14.5 and 19.4 mm; 46.5 and 49.8% from the anterior part). Eggs were seen in the uteri, which contained a larva.

*Discussion:* Up to the present, 40 species of *Procamallanus* have been recorded, all of which, exception of the batrachian parasites, *P. xenopodia* and *P. slomei*, are intestinal parasites of marine and freshwater fishes, and 11 species posses the spiral thicknings in the inner surface of the wall of buccal capsule, viz., *P. spiral*, *P. amarali*, *P. hilarii*, *P. hanoslimai*, *P. fariasi*, *P. fulvidraconi*, *P. wrightii*, *P. monotazis*, *P. murrayensis*, *P. pereirai* and *P. globoconchus*. Five species, *P. amarali*, *P. hilarii*, *P. barroslimai*, *P. wrightii* and *P. feriasi*, in these species were reported from fishees from Brazil. However, they differs our species in the following points.

The main points of difference are in the length of posterior glandural esophagus (*P. soiral* and *P. hilarii*) and in the tail of female. In our species the tail of the female appears to have a process with two spines; in other species there are not spine.

The species resembles *P. montaeis* in some features, but differs in the form of the buccal capsule, which is more spherical.

The present species could not identified, because of not-finding the male. I (N.K.) think that these dolphin is not the definitive host of these worms.

### *Corynosoma cetaceum* Johnston and Best, 1943

*Materials:* Two hundred-ten worms obtained from the third and fourth stomach of a Franciscana (Table 1). The materials consisted of 111 males and 99 females. The worms (Photograph 14 and 15; scale is mm.) were witish-yellow in collor, in alcohol fixation. They have been preserved in fixative for many days. Observations were based on whole mount with gum-chloral.

*Description:* Corynosomatinae; Acanthocephala. In body from there is distinct sexual dimorphism (Male: Photograph 14; Female: Photograph 15). Anterior part of trunk bulbously swollen and spined, and in male tapered towared posterior extremity which is about two-third to three-fifth of the body length (Photograph 16), with extro-atached bursa (0.93-1.40 mm by 1.00-1.25 mm. Photograph 23) having the many sucker-like projections in the inner surface of the wall (Photograph 24); female more roundish than male, pouchlike, with small attenuated posterior extremity (Photograph 17). Male very in length from 7.15 mm to 9.25 mm, and in width from 2.35 mm to 2.80 mm. Female in length from 3.90 mm to 4.65 mm, and in width from 2.50 mm to 2.70 mm; maximum width at level of anterior trunk.

Trunk spines (Photograph 20 and 21) of female extending almost entire length of the body ventrally but dorsally reaching only the region of maximum diameter; in males the spines extend along ventral surface to point only a short distance posterior to the hind margin the cement glands, much of hind-trunk devoid of spines (Photograph 22). Trunk spines usually 22.8$\mu$ to 65.4$\mu$ long in males. Genital spines lacking in males.

Proboscis (Photograph 18) of both sexes arising from discoid swelling of trunk and bent ventrally, cylindrical, 0.80-1.13 mm length; maximum width at lowere third of proboscis (0.30-0.40 mm).

Proboscis hooks, sickle-shape, arranged in 18-19 longitudinal rows with 12-13 in each row, becoming grandually stouter (70.0-75.1$\mu$) from apex toward swallen region, than abruptly small. Hooks nearest to base of proboscis smallest in size (30.6-35.8$\mu$).

Proboscis receptacle double-walled, slightly longer than proboscis (1.55-1.75 mm by 0.40-0.53 mm) (Photograph 19).

Lemnisci somewhat shorter than proboscis receptacle, leaf-shaped.

Testes elliptical, 0.93-1.40 mm by 1.00-1.25 mm, lying symmetrically to the posterior region of the for-trunk, reaching anteriorly to the level of the posterior and of the proboscis receptacle.

Six cement glands, immediately posterior to testes, in two groups of these each.

Egg fusiform with polar prolongations of middle shell; 154.8 (136.6-163.5) $\mu$ length and 46.1 (42.6-51.5) $\mu$ width (Photograph 25).

*Discussion:* Although *Corynosoma* had reported 22 species from marine mammals, the present species, except for *C. cetaceum*, differs from these species in size of the body, number of hooks at the proboscis and size of the eggs.

Morphorogical features and the measurements agreed well with the description of *C. cetacum* Johnston and Best, 1943 from *Delphinus delphis* and *Tursiops truncatus.* Accordingly, although *Corynosoma* sp. had been reported by Dailey and Brownell (1972) from Franciscama, *Pontoporia blainvillei*, *C. cetaceum* was first record from the precent host.

## ACKNOWLEDGMENTS

We wish to express our hearty thanks to Dr. Masaharu Nishiwaki of the Ocean Research Institute, University of Tokyo, as the leader of Japanese Scientific Research Expedition against the Franciscana.

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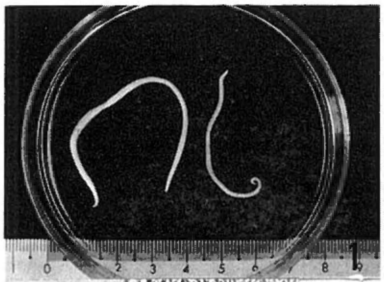
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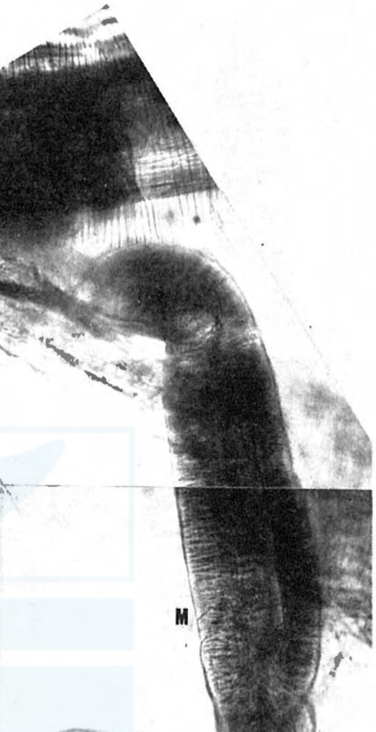

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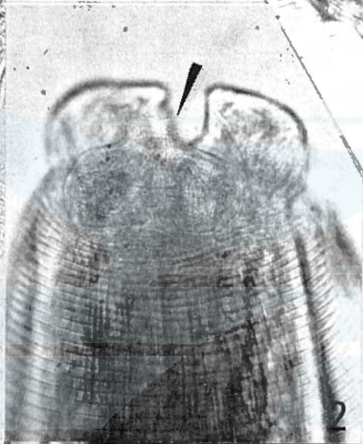
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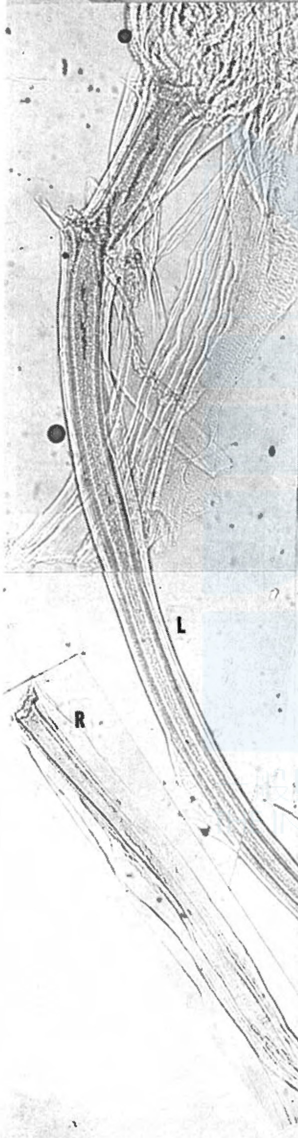

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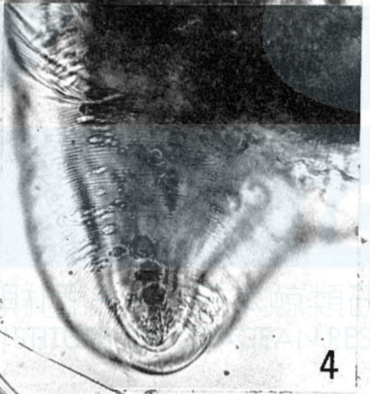
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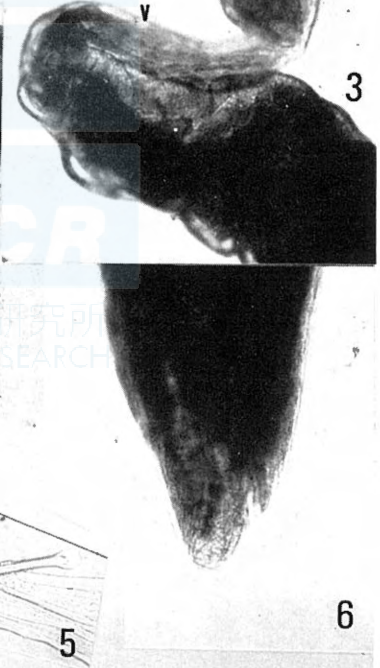

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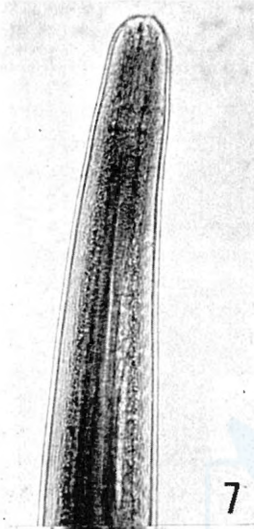

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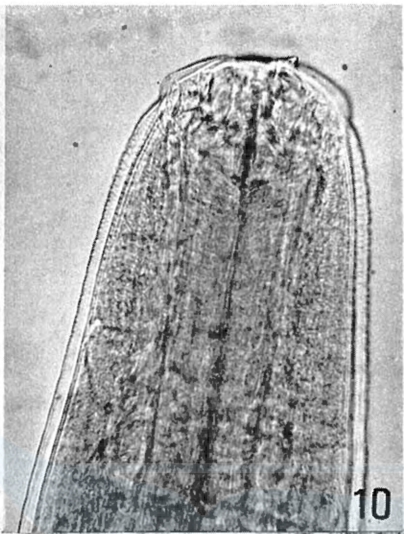

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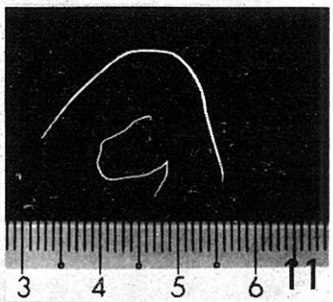

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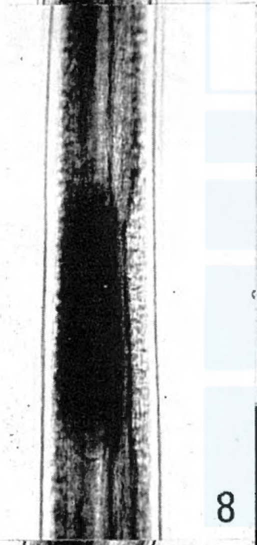

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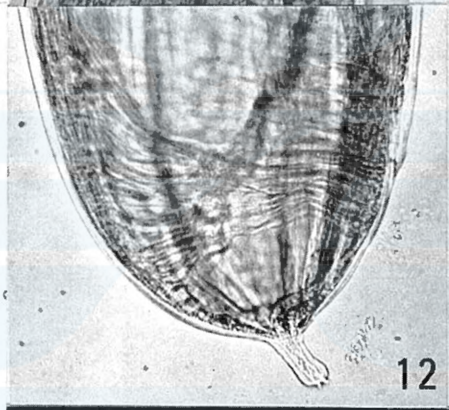

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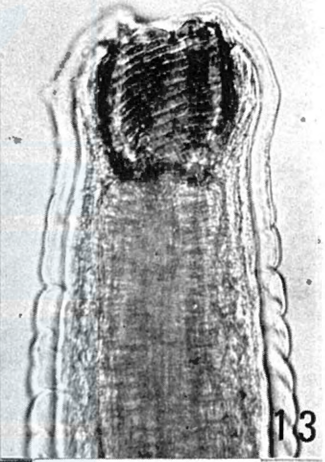

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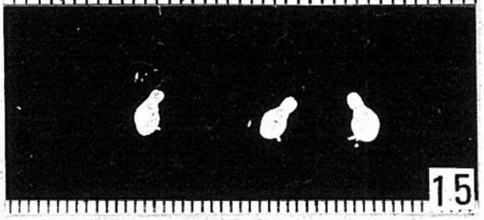

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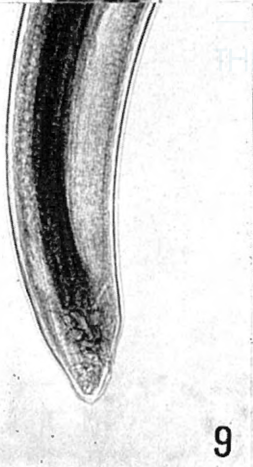

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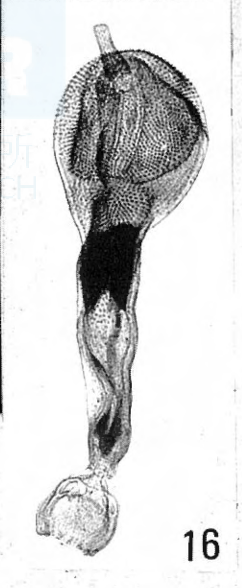

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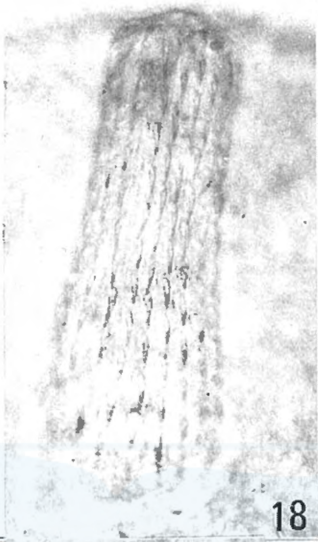
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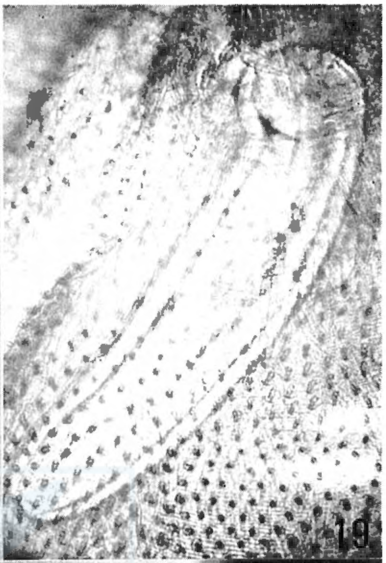
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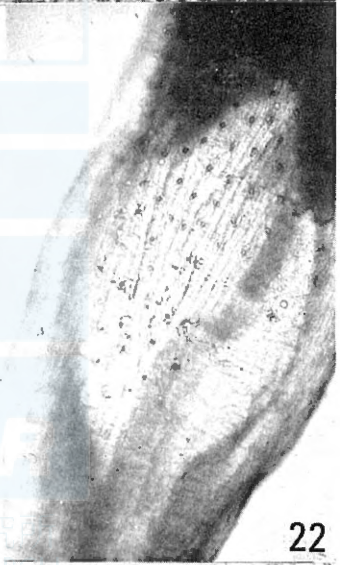
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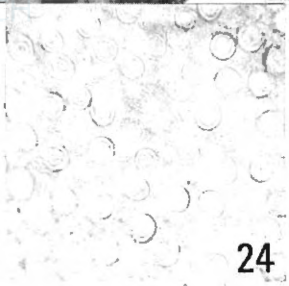
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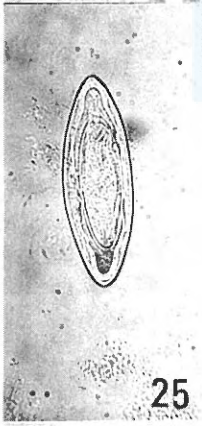
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# FATTY ACID COMPONENT OF LIPID OF *EUPHAUSIA SUPERBA*

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## ABSTRACT

Lipids extracted from the raw frozen and boiled-frozen krill, *Euphausia superba*, harvested in the Antarctic Ocean were identified and quantitated by a combination of thin-layer and gas-liquid chromatography.

The lipid contents of *E. superba* on the wet weight basis were 3.41% of the raw frozen sample and 5.62% of the boiled-frozen sample. There were shown to consist of 0.8% of steryl esters, 27.4% of free fatty acids, 52.3% of triglycerides, 4.7% of sterols, a trace amount of diglycerides, 2.2% of monoglycerides, 6.9% of phospholipids and 4.1% of pigments in the raw frozen sample, and 0.6% of steryl esters, 4.6% of free fatty acids, 76.8% of triglycerides, 4.2% of sterols, 9.2% of phospholipids and 3.5% of pigments in the boiled-frozen sample. The predominant fatty acids contained in total lipids and the fractions of free fatty acids, triglycerides and phospholipids were myristic (5.98-22.16%), palmitic (16.83-30.49%), palmitoleic (5.92-26.31%), oleic (19.31-29.17%), eicosapentaenoic (0.52-12.59%) and docosatrienoic (0.50-11.74%) acids.

## INTRODUCTION

*Euphausia superba* is a shrimp-like crustacean of about 5 cm in body length, and inhabits only in the Antarctic Ocean, though many euphausiid species are found widely over the world oceans. *E. superba* composes one of the most important prey organisms for the inhabitants in the oceanic regions of the Antarctic ecosystem. In addition to utilization by the faunistic inhabitants there, *E. superba* should be regarded as the food resources for mankind in the future. The present study stands on such viewpoint, and intends to give a basic knowledge for utilizing *E. superba* as to be a possible humans' food.

There have been several reports on the chemical properties and the fatty acid composition of *E. superba* lipids (Saiki and Mori, 1953; Saiki *et al.*, 1959; Tsuyuki *et al.*, 1964a and b). So far as these works were carried out by the fractional distillation method, the minute examinations of the fatty acid component have not been reported yet.

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On the other hand, Kayama and Nakagawa (1975), and Kayama and Ikeda (1975) reported on the lipids of some micronektonic shrimps.

The objective of this study is to identify and quantitate the lipids and the fatty acid components of *E. superba* by a combination of thin-layer and gas-liquid chromatography.

## MATERIALS AND METHODS

*Euphausia superba*, used in this study were harvested in the waters off Enderby Land, 10°E in the Antarctic Ocean between December, 1974 and February, 1975 by a expedition of commercial basis Nippon Suisan Co. Ltd. A part of the *E. superba* harvested was quickly frozen as the raw frozen products and another part of them was similarly quick frozen as the boiled-frozen products after flash boiling. Both products were processed as the whole body of *E. superba*. They were in the range from 0.4 to 0.7 g in the body weight and in the range from 3.5 to 5.5 cm in the body length.

The method of Bligh and Dyer (1959) was used to extract and purify the lipids in these samples. The extracted lipids were then weighed and stored at −20°C under nitrogen atmosphere. The chemical properties of the extracted lipids were examined by ordinary methods.

The fractionation of *E. superba* lipids was subsequently separated by thin-layer chromatography using 20×20 cm glass plates coated with activated Silica gel G (Merck Chemical Co.). The solvent systems used were petroleum ether : diethyl ether : acetic acid, 85 : 15 : 1, v/v/v. The pure standards *e. g.* phospholipids, cholesterol, steryl palmitate, mono, di, triglycerides, oleic acid (Nihon Chromato Works Ltd.) were used to identify zones on the thin-layer plates which were removed, dried, sprayed with 50% sulfuric acid and charred at 110°C for 15 min. The fractionated zones were scraped into Toyo filter paper No. 2 cones (Toyo Roshi Kaisha Ltd.) and eluted with chloroform respectively. The eluting solvents were evaporated off with a stream of nitrogen and weighed.

The three major fractions were recovered triglycerides, free fatty acids and phospholipids for analyzed the fatty acid components. The other minor fractions were noted on the plates but were not in sufficient quantity to be recovered.

The fatty acid methyl esters from total lipids, triglycerides, free fatty acids and phospholipids of *E. superba* lipids esterified by the saponification-transesterification method as described by Metcalfe *et al.* (1966). 5 ml of a 0.5 N methanolic KOH solution were added to approximately 30 mg of total lipids, triglycerides, free fatty acids and phospholipids, and heated over a steam bath for 5 min. Then, 5 ml of 12.5% boron trifluoride in methanol were added to these mixtures and boiled for 3 min. Thin-layer chromatography was used to determine the completeness of the transesterification. Silica gel G plates were spotted with the reacted products and known standards, and developped with petroleum ether : diethyl ether : acetic acid as previously described. A comparison of the $R_f$ values of the reacted products, triolein, methyl oleate and oleic acid (Nihon Chromato Works Ltd.) indicated that the conversion of total lipids, triglycerides, free fatty acids and phospholipids fractions to methyl esters was complete.

The methyl esters were analyzed weth a Shimadzu Gas Chromatograph Model 5A (Shimadzu Seisakusho Co.) equipped with a dual flame ionization detector. The columns used were 3 m×3.0 mm I. D. glass coil tubing packed with Diasolid ZF on 80/100 mesh, and with 3% SE-30 on 80/100 mesh Chromosorb W (Nihon Chromato Works Ltd.). The carrier gas was nitrogen at flow rate of 40 ml per min. The column were operated isothermally at 185°C for Diasolid ZF and 225°C for SE-30. The injector block and detector were at 215°C for Diasolid ZF and 245°C for SE-30, respectively.

Some of the gas-liquid chromatographic peaks were identified by comparison with standard peaks obtained from pure methyl ester mixture (Nihon Chromato Works Ltd.). Also, equivalent chain-length values were determined according to the method of Miwa (1963) and were compared with those reported by Hofstetter *et al.* (1965) for identifying peaks for which no pure methyl esters were available. A portion of each sample esterified was hydrogenated to confirm the correctness of identification of the unsaturated acids. Approximately 20 mg of methyl esters, 1 ml of methanol and a pinch of platinum black were added to a screw cap vial. Hydrogen was bubbled in for 5 min, the vial sealed and then reacted for 15 min with frequent shaking. After reaction, the methyl esters were transferred to *n*-hexane, dried, then taken up and injected into the gas-liquid chromatograph with the same condition as above mentioned. The area of each chromatographic peak representing a fatty acid present was obtained by multiplication of the height of each peak by the width at half-height. The areas of each peak was then compared with the total combined area at all of the peaks to obtained the percentage of each specific fatty acid.

## RESULTS AND DISCUSSION

The chemical properties of the total lipids extracted from *Euphausia superba* are shown in Table 1. The lipid contents are comparatively low *i.e.*, 3.41% of the raw frozen sample and 5.62% of the boiled-frozen sample on the wet

TABLE 1. PROPERTIES OF TOTAL LIPIDS FROM *EUPHAUSIA SUPERBA*

| | Lipids | |
|---|---|---|
| | Raw frozen sample | Boiled-frozen sample |
| Appearance (20°C) | Reddish brown liquid | Reddish brown liquid |
| Oil content (%) | 3.41 | 5.62 |
| Refractive index (40°C) | 1.4788 | 1.4820 |
| Acid value | 74.1 | 18.2 |
| Iodine value | 142.3 | 127.9 |
| Saponification value | 181.3 | 197.6 |
| Unsaponifiables (%) | 5.6 | 5.8 |

weight basis. The total lipid of the raw frozen sample was higher in iodine and acid values, and lower in saponification value than those of the boiled-frozen sample. These are seemed to be autoxidized during frozen storage or thawing.

The lipid composition of each extract as determined by thin-layer chromatography is markedly different between the samples of the raw frozen and boiled-frozen. By visual evaluation of these chromatograph as shown in Fig. 1, the zones of steryl esters, triglycerides, free fatty acids, monoglycerides, sterols, diglycerides, phospholipids and pigments are appearently present in the raw frozen sample while the boiled-frozen sample is not found the presence of diglycerides and monoglycerides. There are also appearent differences in the compositions of triglycerides and free fatty acids between two samples. The lipid compositions of these fractions are reported in Table 2. In the extracts of the boiled-frozen sample, triglycerides are the preponderant fraction comprising 76.8% of the total lipid fractions, whereas in the raw frozen sample, triglycerides fraction is much lower. On the other hand, the composition of free fatty acids fraction is much higher in the raw frozen sample than in the boiled-frozen sample. These appearently explained to the difference of acid value in Table 1. Also, the raw frozen sample had 2.2% of monoglycerides

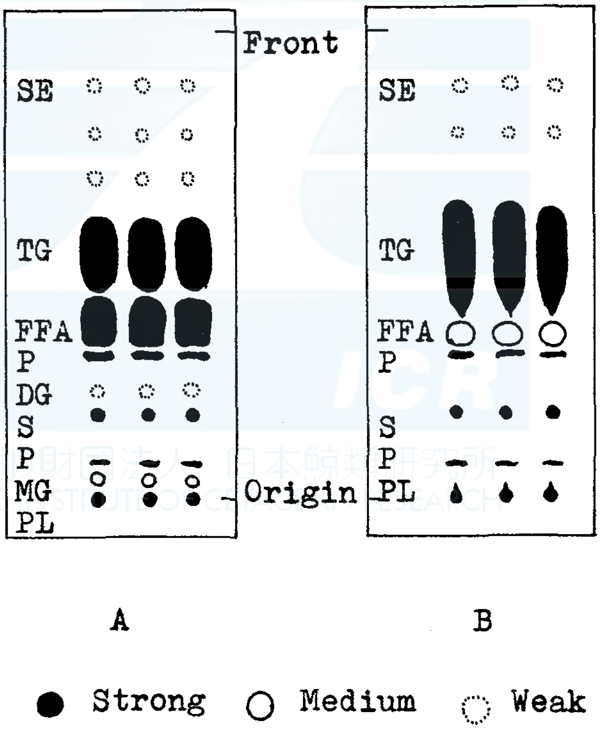

Fig. 1. Thin-layer chromatograms of total lipids extracted from *E. superba*. A: the raw frozen sample. B: the boiled-frozen sample. SE: steryl esters. TG: triglycerides. FFA: free fatty acids. P: pigments. DG: diglycerides. S: sterols, MG: monoglycerides. PL: phospholipids.

and a trace of diglycerides fractions while the boiled-frozen sample was not detected them.

The fatty acid methyl esters of the total lipids and the main three fractions contained fatty acids *i. e.*, triglycerides, free fatty acids and phospholipids were analyzed by gas-liquid chromatography, but no attempt was made to further study the component of other fractions. The presence of the fatty acids contained in *E. superba* lipid is a very wide variety as reported in Table 3, plus trace quantities of unidentified fatty acid methyl esters. With a few exceptions, the fatty acids of the total lipids and the three main fractions in both samples had nearly similar chromatographic patterns and distributions with each other. The major fatty acid compositions of both total lipids were 14: 0, 16: 0, 16: 1, 18: 1, 20: 5 and 22: 3 acids and contained more than 87% of the total fatty acids. Both triglyceride fractions contained 14: 0, 16: 0, 16: 1 and 18: 1 acids as the predominate fatty acids whereas were not detected the fatty acids of 22: 5, 22: 6 and 24: 1 which contained in the total lipids. The total composition of 14: 0, 16: 0, 16: 1 and 18: 1 acids accounted for more than 85% of the total fatty acids. The free fatty acid fractions of both samples were mainly consisted of 14: 0, 16: 0, 16: 1, 18: 1, 20: 5 and 22: 3 acids similar to the total lipids. The total composition of the six main fatty acids were more than 77% of the total fatty acids. The fatty acids of 22: 5 and 22: 6 which contained in the total lipids were not found in this fraction of the boiled-frozen sample. In both phospholipid fractions, the fatty acids of 14: 0, 16: 0, 16: 1, 18: 1 and 20: 5 as the predominant fatty acids comprised approximately 76% of the total fatty acids.

The compositions of the total saturated acids in the raw frozen sample were 39.96% of the total lipids, 56.17% of the triglyceride fraction, 37.96% of the free fatty acid fraction and 27.14% of the phospholipid fraction, and those of unsaturated acids were 58.95%, 42.83% 60.84% and 71.56% respectively. On the other hand, those of the total saturated acids in the boiled-frozen sample

TABLE 2. LIPID COMPOSITION OF *EUPHAUSIA SUPERBA* BY THIN-LAYER CHROMATOGRAPHY.

| Composition | Lipids | |
|---|---|---|
| | Raw frozen sample (%) | Boiled-frozen sample (%) |
| Triglycerides | 52.3 | 76.8 |
| Diglycerides | trace | —— |
| Monoglycerides | 2.2 | —— |
| Free fatty acids | 27.4 | 4.6 |
| Phospholipids | 6.9 | 9.2 |
| Sterols | 4.7 | 4.2 |
| Steryl esters | 0.8 | 0.6 |
| Pigments | 4.1 | 3.5 |
| Unknowns | 1.6 | 1.1 |

TABLE 3. FATTY ACID COMPOSITION OF *EUPHAUSIA SUPERBA* LIPIDS. (percentage of total lipids)

| Fatty acids | Lipids in raw frozen sample | | | | Lipids in boiled-frozen sample | | | |
|---|---|---|---|---|---|---|---|---|
| | Total lipids | Triglycerides | Free fatty acids | Phospholipids | Total lipids | Triglycerides | Free fatty acids | Phospholipids |
| 12:0 | 0.21 | 0.27 | 0.16 | 0.54 | 0.22 | 0.32 | 0.47 | 0.85 |
| 12:1 | 0.02 | 0.05 | 0.02 | 0.03 | 0.05 | 0.01 | 0.03 | 0.12 |
| 13:0 | 0.05 | 0.08 | 0.03 | 0.08 | 0.07 | 0.11 | 0.09 | 0.19 |
| *Iso*-14:0 | 0.01 | 0.03 | 0.01 | 0.04 | 0.02 | 0.02 | 0.02 | 0.19 |
| 14:0 | 8.71 | 22.16 | 9.07 | 5.98 | 11.54 | 21.35 | 8.66 | 9.62 |
| 14:1 | 0.14 | 0.15 | 0.13 | 0.10 | 0.09 | 0.15 | 0.19 | 0.24 |
| *Iso*-15:0 | 0.07 | 0.05 | 0.03 | 0.01 | 0.08 | 0.04 | 0.04 | 0.06 |
| 15:0 | 0.37 | 0.84 | 0.52 | 0.46 | 0.59 | 0.73 | 0.33 | 1.08 |
| 15:1 | 0.06 | 0.13 | 0.07 | 0.15 | 0.12 | 0.10 | 0.09 | 0.28 |
| *Iso*-16:0 | 0.04 | 0.10 | 0.04 | 0.12 | 0.05 | 0.06 | 0.06 | 0.12 |
| 16:0 | 28.94 | 30.49 | 26.01 | 16.83 | 29.20 | 24.04 | 24.82 | 25.22 |
| 16:1 | 5.92 | 8.86 | 7.96 | 26.31 | 6.27 | 13.37 | 6.49 | 9.53 |
| 16:2 | 0.14 | 0.53 | 0.71 | 0.58 | 0.25 | 0.83 | 0.41 | 0.45 |
| *Iso*-17:0 | 0.02 | 0.02 | 0.01 | 0.01 | 0.02 | 0.03 | 0.02 | 0.02 |
| 17:0 | 0.69 | 0.55 | 0.57 | 0.88 | 0.64 | 0.68 | 0.73 | 0.90 |
| 17:1 | 0.09 | 0.17 | 0.07 | 0.06 | 0.09 | 0.06 | 0.11 | 0.10 |
| *Iso*-18:0 | 0.04 | 0.05 | 0.04 | 0.01 | 0.07 | 0.05 | 0.02 | 0.09 |
| 18:0 | 0.40 | 1.18 | 0.96 | 1.78 | 0.78 | 1.02 | 1.60 | 4.52 |
| 18:1 | 19.84 | 28.25 | 29.17 | 28.49 | 19.31 | 25.87 | 21.82 | 26.24 |
| 18:2 | 2.79 | 1.87 | 3.47 | 2.53 | 2.43 | 2.03 | 3.03 | 2.42 |
| 18:3 | 0.12 | 0.12 | 0.80 | 0.54 | 0.06 | 0.49 | 4.10 | 0.41 |
| 19:0 | 0.15 | 0.20 | 0.20 | 0.07 | 0.16 | 0.13 | 0.39 | 0.11 |
| 20:0 | 0.10 | 0.09 | 0.13 | 0.20 | 0.04 | 0.55 | 0.24 | 0.15 |
| 20:1 | 1.02 | 0.76 | 0.52 | 0.52 | 0.65 | 1.47 | 0.77 | 0.53 |
| 20:2 | 0.28 | 0.13 | 0.12 | 0.47 | 0.24 | 0.74 | 1.46 | 1.37 |
| 20:3 | 1.45 | 0.35 | 0.95 | 0.83 | 0.82 | 0.60 | 4.61 | 0.29 |
| 20:4 | 0.94 | 0.26 | 1.15 | 0.47 | 0.55 | 0.87 | 1.64 | 0.63 |
| 20:5 | 12.59 | 0.52 | 7.04 | 6.59 | 10.96 | 1.40 | 8.84 | 6.12 |
| 21:0 | 0.21 | 0.06 | 0.18 | 0.13 | 0.07 | 0.10 | 0.22 | 0.12 |
| 22:1 | 0.34 | 0.08 | 0.92 | 0.43 | 0.41 | 0.11 | 0.51 | 0.37 |
| 22:2 | 0.56 | 0.10 | 0.31 | 0.25 | 0.30 | 0.07 | 0.06 | 0.53 |
| 22:3 | 11.29 | 0.50 | 6.89 | 2.66 | 11.74 | 1.20 | 6.38 | 4.12 |
| 22:5 | 0.48 | — | 0.13 | 0.33 | 0.23 | — | — | 0.12 |
| 22:6 | 0.67 | — | 0.13 | — | 0.41 | — | — | — |
| 24:1 | 0.37 | — | 0.27 | 0.22 | 0.36 | — | 0.59 | 0.78 |

were 43.60%, 49.20%, 38.71% and 43.28% respectively, and 55.34%, 49.40%, 61.19% and 55.69% in the total unsaturated acids of them, respectively. Among the saturated acids, 14: 0 and 16: 0 acids were the most constituents in the

total lipids and all fractions of both sample lipids. Although the fatty acids of 16 : 1, 18 : 1, 20 : 5 and 22 : 3 among the unsaturated acids were the main constituents in the total lipids, free fatty acid and phospholipid fractions of both samples, these were the least of amount in both triglyceride fractions. The most pronounced difference between the trigylceride fractions and other lipids was in the higher level of 14 : 0 acid and the lower level of the fatty acids more than 20 carbon atoms. Moreover, the phospholipid fraction of the raw frozen sample contained very higher level (26.31%) of 16 : 1 acid as compared to one of other lipids whereas 14 : 0 acid comprised slightly lower level of 5.98%. The fatty acids of 18 : 3 (4.10%) and 20 : 3 (4.61%) in the free fatty acid fraction and 18 : 0 acid (4.52%) in the phospholipid fraction of the boiled-frozen sample were slightly higher levels compared to others. Finally, there were little differences in the fatty acid compositions and distribution patterns of both samples except of the phospholipid fraction in the raw frozen sample.

Saiki *et al.* (1959) reported that the fatty acid composition of *E. superba* lipid were 16.0% of 14, 33.0% of 16, 36.1% of 18 and 13.6% of 20 carbon fatty acids. Also, Tsuyuki *et al.* (1964a) reported that these were 6.2% of 14, 25.9% of 16, 35.2% of 18, 24.5% of 20 and 8.2% of 22 carbon fatty acids. We have found that these were 8.86–11.65% of 14, 35.04–35.77% of 16, 22.65–23.19% of 18, 13.26–16.38% of 20 and 13.09–13.34% of 22 carbon fatty acids in both total lipids.

Although the fatty acid components analyzed by gas-liquid chromatography between the raw frozen and boiled-frozen euphausiacea lipids was very low difference, the total lipid thin-layer chromatograms indicated that the free fatty acid fractions had appearently greater difference with each other. The results obtained with the free fatty acid fractions fractionated by thin-layer chromatography in this study indicated that the boiling procedure supported considerably in the maintenance of the *E. superba* lipid quality during handling and frozen storage.

## ACKNOWLEDGMENTS

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## SUMMARY

1. The chemical properties of lipid contained in *Euphausia superba*, were studied.

2. The lipid fractions of the euphausiacea were quantitated by thin-layer chromatography.

3. The main lipid compositions were triglycerides, phospholipids and free fatty acids fractions.
4. The component fatty acids of the total lipids and each fraction fractionated by thin-layer chromatography were analyzed by gas-liquid chromatography.
5. The predominant fatty acids were myristic, palmitic, palmitoleic, oleic, eicosapentaenoic and docosatrienoic acids.

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# THE OCCURRENCE OF THE PHOCID SEALS ALONG THE COAST OF JAPAN AND POSSIBLE DISPERSAL OF PUPS

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## ABSTRACT

The distribution of the phocid seals was studied both outside area and in the border area of their habitat. Sixteen catch or observation records from Honshu, Shikoku and Kyushu of Japan were examined. Three species appeared, the ice-breeding harbour seal (*Phoca vitulina*), the ringed seal (*Pusa hispida*) and the bearded seal (*Erignathus barbartus*) occurred while the land-breeding harbour seal (*Phoca vitulina*) and the ribbon seal (*Histriophoca fasciata*) did not occur in those areas. In the border area of the habitat, all four species of the ice-breeding seals occurred. These seals were mostly pups indicating that the new born pups spread their distribution after ice season being carried by the ice floes and some of them occurred far south from their habitats.

## INTRODUCTION

The author has studied the pagophilic (ice-breeding) and the pagophobic (land-breeding) harbour seals (*Phoca vitulina*) comparing their ecology and morphology. The pagophilic form annually shifts their habitat from the edge zone of drifting ice to coastal area, while the pagophobic form stays at the same habitat (coastal) even in breeding season. These differences of their life systems between two forms may strongly relate with their adaptation systems, especially in the period of new born pups. In the pagophilic form the shift of habitat occurs several weeks after their birth, and during this short period, important life events occur on the new born pups such as suckling, weaning, moulting, and moreover physical and morphological changes. It is the problem that these events are performed on unstable ice floes in the edge zone of the drifting ice. If the shift of habitat was unsuccessful processing these events, as Naito and Nishiwaki (1972b) suggested, the pups would be carried away by ice drift so as to spread their distribution. In the pagophobic form, however, such habitat shift does not occur, and mother-pup relationship continues longer to result the steady and successful weaning and independent life of the pups. Therefore, the pup distribution of this form is settled.

The present study is aimed to examine the above understandings by studying the distribution of these seals (including other species) in the border area of their habitat and also out side of the border.

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## DISTRIBUTION OUT SIDE OF THE BORDER OF THE HABITAT

The present study deals with occurrences along the coast of Japan other than Hokkaido (Honshu, Shikoku and Kyushu). Catch or sighting records of the seals along the coast of Japan other than Hokkaido are rare and scarce, so it is difficult to collect such records. In the present study records and informations were collected from following three sources. (1) The newspaper or T. V. broadcasting as a local news; the seals in these areas are very strange animals, therefore if they were caught or sighted such seals were sometimes reported by them. (2) Aquariums; if the animals were caught alive, they were usually sent to the aquariums near by for display, and aquariums kindly sent me the informations to my requests. (3) The prefectural fisheries research station or local museum; the catch or sighting informations by local people were given to them. As to the biological informations, species, date, place and length or approximate length were available from above informations. However, to my regret, sex, body-weight and age determined from canine teeth are unknown.

*Appeared species*

Three species, bearded seal, ringed seal and harbour seal were accidentally caught or sighted along the coast of Honshu, Shikoku and Kyushu (Fig. 1). Only two bearded seals were recorded at Akita and Niigata of the Japan Sea coast of the Northern Honshu, and there are no records from Shikoku and Kyushu. Out of 5 records of ringed seals, two were from Japan Sea coast of Honshu and two were from Pacific Ocean coast of Honshu and Shikoku. The

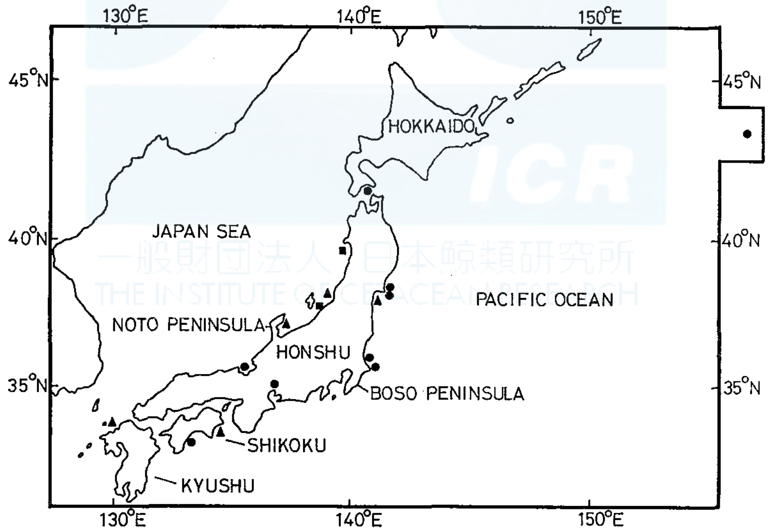

Fig. 1. Some catch or observation records of the phocid seals from the coast of Honshu, Shikoku and Kyushu of Japan and others. ●, the ice-breeding harbour seal; ▲, the ringed seal; ■, the bearded seal.

far south record was from Fukuoka-city, Kyushu. Nine ice-breeding harbour seals were recorded. Out of nine, 6 seals were recorded from the Pacific Ocean coast of Honshu and only one seal was from Japan Sea coast of Honshu. None were recorded from Kyushu. In the present study, records of occurrences from Japan coast other than Hokkaido were dealt with as a materials, however, in this chapter additional two examples were also included. One was the catch record by fishing boat from the Pacific Ocean, about 300 miles from the coast. The other is sighting record by research vessels at the mouth of Port Hakodate, the most south of Hokkaido. From above records, it is supposed that the ringed seal and the ice-breeding harbour seal occur more often and futhermore south than the bearded seal, but it is quite difficult to get any conclusion as to the migration route of these seals from their habitat towards southern areas. The most stressed facts in this chapter is that none of the ribbon seals which are as popular as the ice-breeding harbour seal in the Sea of Okhotsk, and none of the land-breeding harbour seal of which habitats distribute in the furthest south of Hokkaido, were recorded in the coast of Honshu, Shikoku and Kyushu.

*Appeared season*

The seasons when the seals occurred along the coast of Honshu, Shikoku and Kyushu were shown in Fig. 2. In this chapter, the seals were not treated separately by species but as a total records of 3 species were treated, and addional 2 records of the ice-breeding seal from the Pacific Ocean and the port of Hakodate were excluded because they were not the records from intended area (Honshu, Shikoku and Kyushu). As shown in Fig. 2, the seals begin to occur from April at 12.5% frequency, and the highest frequency was 25% in May. After May seals decrease to occur. In June and July 18.7% of the total occurred

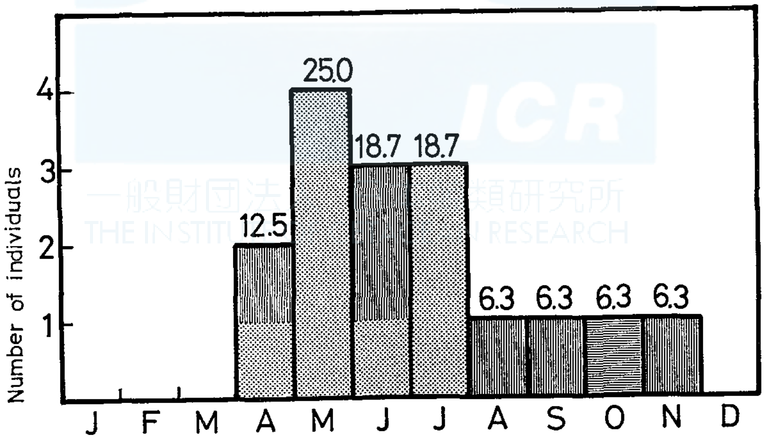

Fig. 2. The seasonal appearance frequency of the seals occurred along the coast of Honshu, Shikoku and Kyushu. Numbers were shown in percentage. Dotted space shows the ice-breeding harbour seal; horizontal line, the ringed seal; vertical line, the bearded seal.

respectively and none of seals occurred in December. Seventy five percent seals of all occurred from April to July. Being still short data, from mentioned above, the following two problems were indicated. 1) The seals begin to occur in April. This time well corresponds with after-season of drifting ice in Hokkaido. 2) The seals decrease to occur after May. This may indicate that the smaller number of seals occur in later season in farther south area. The problem 1) will be discussed later. The problem 2) may be explained by Fig. 3. In Fig. 3, the area where the seals recorded were separated to four districts, from north to south; northern Honshu, southern Honshu, Shikoku and Kyushu. Honshu was sepatated by the line between Boso Peninsula and Noto Peninsula. As shown in Fig. 3, in northern Honshu 9 seals (64.3%), in southern Honshu and Shikoku 2 seals (14.3%) in each and only 1 seal in Kyushu were recorded respectively. Furthermore, the seals were recorded from earier season in northern Honshu, and in Kyushu it recorded in latest season. From all above mentioned, it is suggested that the seals move towards south from main habitat in the Sea of Okhotsk and the adjacent waters.

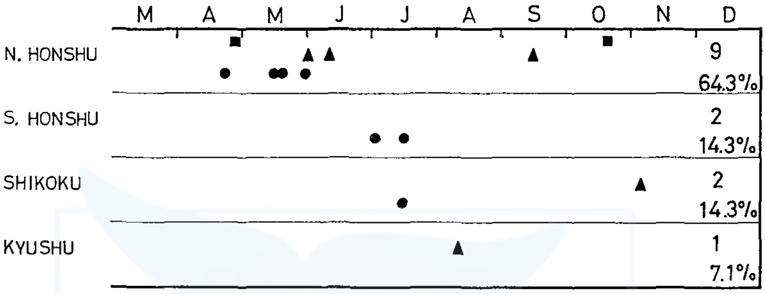

Fig. 3. Time difference of the first occurrence between each area. The seals begin to occur from north. They occur in Northern Honshu at ffrst and in Kyushu at latest. ●, the ice-breeding harbour seal; ▲, the ringed seal; ■, the bearded seal.

*Ages of the seals recorded*

In the present study, age informations based on examination of canine tooth were not available. Only measured body size or approximate body size was used for growth developmental class estimation. In general it is difficult to estimate ages by body size, however, body size indicates such growth stages as pup, young subadult and full adult. Tikomirov *et al.* (1969) showed the growth curves of the bearded seal, ringed seal and the ice-breeding harbour seal. Naito and Nishiwaki (1972) also showed the growth curves of the ice-breeding harbour seal. From these curves and the measured body size or approximate body size shown in Table 1, the growth developmental classes were possibly estimated to be pups in the ice-breeding harbour seal and ringed seal. In the bearded seals one was young or subadult and the other was also pup.

TABLE 1. THE LIST OF SEALS CAUGHT ALONG THE COAST OF JAPAN.

| Species | Date of catch | Locality | Sex | Body length | Body weight |
|---|---|---|---|---|---|
| *Erignathus barbartus* | Apr. 28, '68 | set net Teno-cho, Akita | male | 145 cm | — |
| „ | Oct. 18, '70 | Port of Niigata | — | 180 cm | 120 kg |
| *Pusa hispida* | Sep. 15, '73 | Senami-Beach Murakami-city, Niigata | — | 100 cm (total length) | — |
| „ | Jun. 11, '69 | Teisan-Cannal Yuriage, Natori-city Miyagi | male | 75.0cm | 11.3 kg |
| „ | Aug. 7, '74 | Creek in Tsuyasaki-Bay Fukuoka | — | 75.0 cm (total length) | 12.4 kg |
| „ | Jun. 2, '75 | Shiratori-Beach Toyama | male | 60 cm (total lenght 88 cm) | — |
| „ | Nov. 4, '75 | Azirozaki-Beach Hiwasa, Tokushima | — | 90 cm (total lengh) | 10 kg |
| *Phoca vitulina largha* | Jun. 7, '68 | mouth of Hakodate-Bay Hodkaido | — | — (young) | — |
| „ | May 20, '69 | 'Pacific Ocean 43°14′N; 156°34′E | male | — (pup) | 16 kg |
| „ | May , '54 | Port of Ayukawa, Miyagi | — | less than 100 cm | — |
| „ | May , '54 | Ayukawa, Miyagi | — | less than 100 cm | — |
| „ | Jul. , '58 | Susaki-Bay, Kochi | — | about 100 cm | — |
| „ | Jul. , '53 | Miyazu-Bay, Kyoto | — | about 100 cm | — |
| „ | Jul. , '73 | Kiso-River, 20-25 km up from mouth of river | — | about 150 cm | — |
| „ | — | Kominato.Bay, Chiba | — | 85 cm (measured by molted specimen) | — |
| „ | Apr. 23, '72 | Hazaki-Beach, Kashima, Ibaragi | — | 80 cm | — |
| „ | May 30, '49 | Kashimanada, Ibaragi | female | 104 cm (total length) | — |

## THE CATCH RECORDS IN THE BORDER OF THE HABITAT

As already described, the bearded seal, the ringed seal and the ice-breeding harbour seal had occurred along the coast of Honshu, Shikoku and Kyushu, and the ribbon seal and the land-breeding harbour seal had never occurred in these areas. It is also mentioned that these occurred seals were mostly pups. They begin to occur from north to south indicating the southwards moves, and these occurrences began from April indicating some relation with the time of habitat shift from the ice floe to the coast in these three species, because the ice floes melt and disappear from mid March to mid April in Hokkaido. In this chapter, to examine above problems more precisely the catch records by fishing nets in the border of the habitat were studied in two seasons, after ice season and in October (6 months after ice season).

There are two border parts in Hokkaido. One is the Soya Strait which connects the Sea of Okhotsk to the Japan Sea, and the other is the Nemuro Strait which connects the Sea of Okhotsk to the Pacific Ocean. The study was performed in the Nemuro Strait which is generally known as the southern border of the habitat of the pagophilic seals in the Sea of Okhotsk (the bearded seal, the ringed seal, the ice-breeding harbour seal and the ribbon seal, Naito, 1969). Especially in the ice-breeding harbour seal the lake Furen in the Nemuro Strait area is known as the southern edge of the distribution of their hauling grounds.

### *The catch records after the ice season*

The Nemuro Strait area are also known as almost southern limits of annual constant occurrence of the drifting ice from the Sea of Okhotsk. The ice prevails through this strait area from early February to mid or late March, sometimes mid April when the ice is eminent (Ruhyo-Sokuho, 1969–1975). During this season, the ice moves from north to south being carried by the wind and current, and it occurs in the Pacific Ocean passing through the strait (Fig. 4). After the ice occurred in the Pacific Ocean it melts quickly near around the Nemuro Peninsula. However, when the ice is extensive, it is occasionally driven as far as the Point Erimo. The ice condition in the Nemuro Strait is not constant, and it is always drifting making open seas somewhere in this strait. The ice floes occuring in these areas are relatively small but varied such as slush ice, ice-cake, small or medium floe berg, rafted or hummocked ice, brash ice. These ices in these areas are capable of supplying hauling or breeding site for the seals. However, the breeding population were found only in the area between the Shiretoko Peninsula and the Kunashiri Island (Naito, 1969; informations from the hunters). In this area, the dominant breeding species is the ice breeding harbour seal and the ribbon seal, and the ringed seal and the bearded seal are quite rare (Naito, 1969). After the ice season, from May only the ice-breeding harbour seal occurs along the coast to haul out the grass bars making 30–70 individuals groups in Odaito and the Lake Furen which open

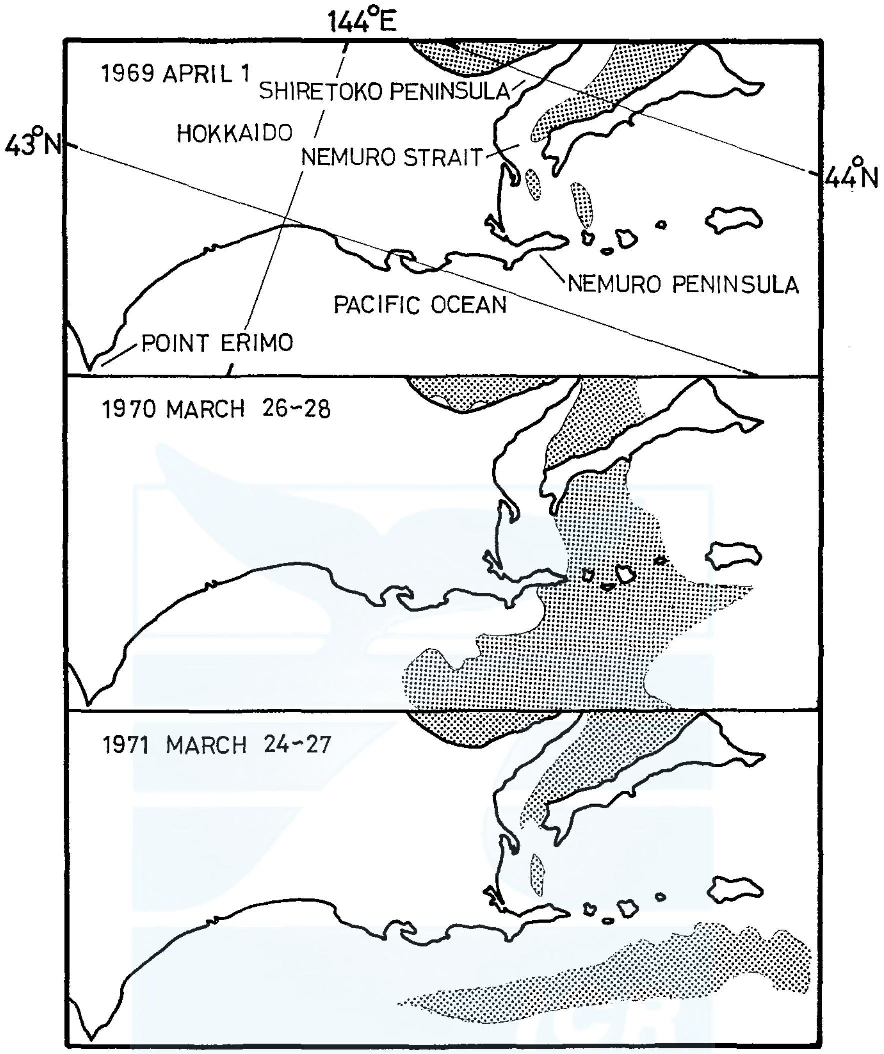

Fig. 4. The distribution of the pack ice in its southern border at the later puping season of the ice-breeding seals. The ice floes occur in the Pacific Ocean from the southern Sea of Okhotsk passing through the Nemuro Strait or near by.

to this strait.

Sampling was performed at Kanazawa Fur Company from 1969 to 1971 during later half of May and June (1969, 1970 May 8-June 30, 1971 May 11-June 30) when the ice completely disappeared. The results were shown in Table 2. The seals mostly caught accidentally by fishing nets along the Nemuro Peninsula (Both coasts of the Nemuro Strait and the Pacific Ocean) were collected at this Fur Company. Almost of these collected seals were examined in 1969 and 1970, however, in 1971 about half of the collected were examined. All 4 ice

TABLE 2. CATCH RECORDS ALONG THE NEMURO PENINSULA AFTER ICE SEASON.

| Species | Field number | Date of catch | Locality | Sex | Body size | Age |
|---|---|---|---|---|---|---|
| 1969 | | | | | | |
| Bearded seal | NM 17 | May 21 | Sankaku | female | 141.0 cm | pup |
| Ringed seal | NM 5 | May 13 | Nemuro | female | 68.0 cm | pup |
| ” | NM 15 | May 19 | — | female | 77.5 cm | probably pup |
| ” | NM 24 | May 30 | Nemuro | female | 72.5 cm | pup |
| Ice-breeding harbour seal | NM 10 | May 17 | — | male | 73.5 cm | pup |
| ” | NM 21 | May 26 | Sankaku | female | 87.0 cm | pup |
| ” | NM 22 | May 26 | Sankaku | female | 95.0 cm | pup |
| ” | NM 23 | May 28 | Tomoshiri | female | 91.0 cm | pup |
| 1970 | | | | | | |
| Bearded seal | 148 | May 14 | Sankaku | female | 149.5 cm | pup |
| ” | 213 | June 7 | Ochiishi | female | 146.0 cm | probably pup |
| ” | 227 | June 23 | Honioi | male | 151.5 cm | probably pup |
| Ringed seal | 166 | May 23 | Onneto | female | 83.5 cm | pup |
| Ice-breeding harbour seal | 145 | May 12 | Sankaku | female | 125.0 cm | 2 |
| ” | 150 | May 17 | Sankaku | female | 95.5 cm | pup |
| ” | 160 | May 20 | — | male | 100.5 cm | 1 |
| ” | 161 | May 20 | — | male | 101.0 cm | 1 |
| ” | 165 | May 23 | Horomoshiri | male | 76 cm | pup |
| ” | 167 | May 24 | Tokatan | male | 104.5 cm | 1 |
| ” | 175 | May 26 | Onneto | female | 78.0 cm | pup |
| ” | 182 | May 30 | Sankaku | female | 85.5 cm | pup |
| ” | 214 | June 7 | Hanasaki | male | 89.0 cm | pup |
| Ribbon seal | 147 | May 14 | Onneto | female | 89.0 cm | probably pup |
| 1971 | | | | | | |
| Ice-breeding harbout seal | 422 | May 22 | — | male | 88.0 cm | pup |
| ” | 439 | June 2 | Futatsuiwa | male | 97.0 cm | pup |
| ” | 446 | June 27 | Hokake | female | 98.0 cm | pup |
| ” | 452 | June 27 | Hokake | female | 99.0 cm | pup |
| Ribbon seal | 419 | May 16 | Sankaku | male | 91.0 cm | pup |

breeding seals occurred in this area. The ice-breeding harbour seal occurred at the highest frequency as same as seen in Honshu, Shikoku and Kyushu areas. The bearded and the ringed seals occurred at the same frequency. The ribbon seal has never been reported in Honshu, Shikoku and Kyushu, but occurred in this area at the lowest frequency. Concerning the ages of these seals, some were not examined by the canine tooth, for the whole skulls were reserved and attached to the skin for the moulted specimen. However, as well as in former chapter, the ages were estimated by the body size. In all species, the seals caught in this area were mostly pups indicating same tendency seen in Honshu, Shikoku and Kyushu areas. These facts may strongly relate to the movement of ice mentioned above. In the present study, there were no direct observation that the ice carried such pups through this strait to the Pacific Ocean. However, to examine the seasonal changes the author studied the distribution of these seals in other season, October, in the same area.

### *Catch records in October*

The sampling was performed in October 1969 (3–30) by visiting the fishing village when informations were brought by fishermen. The results were shown in Table 3. In this season the result was quite different from that of the after ice season. Only two species, the ice-breeding harbour seal and the ribbon seal were caught. None of the ringed seal and the bearded seal were caught. The data are quite small, however as seen in Table 3, half of the ice-breeding barbour seals were adults, which had been never caught after ice season. In the ribbon seal the adult seal was included.

TABLE 3. CATCH RECORDS ALONG THE NEMURO PENINSULA IN OCTOBER (1969)

| Species | Field number | Date of catch | Locality | Sex | Body size | Age |
|---|---|---|---|---|---|---|
| Ice-breeding harbour seal | 7 | — | Ochiishi | male | 162.0 cm | 8 |
| 〃 | 9 | — | Habomai | female | 149.0 cm | 3 |
| 〃 | 16 | October 14 | Toritoishi | female | 160.5 cm | 18 |
| 〃 | 18 | October 15 | Tohbai | female | — | adult |
| 〃 | 36 | October 23 | Habomai | female | 156 cm | 10 |
| 〃 | 39 | October 26 | Odaitoh | female | 130.5 cm | 3 |
| 〃 | 40 | 〃 | 〃 | male | 133.5 cm | 2 |
| 〃 | 41 | 〃 | 〃 | female | — | — |
| Ribbon seal | 33 | October 23 | Sankaku | male | 153.0 cm | adult |
| 〃 | 34 | 〃 | 〃 | male | 132.0 cm | immature |
| 〃 | 43 | October 27 | Sankaku | male | 149.0 cm | immature |

Aboves are quite short data to get some conclusion, however it is clear that age composition of the ice-breeding harbour seal which occurred in this area is quite different between after ice season and in October. In the former season, seals were mostly pups (76.5%) and none of adult seals occurred. On the other hand in the later season adult seals (50%) occurred in the same area. It is still uncertain when these age compositions change, yet it is supposed that the dispersion of adult seals in this area is due to the salmon migration, because these seals were caught by the salmon set nets which were operated from summer to autumn when the salmons migrate to the coast for their up river spawning migration. There is no clear explanation why the bearded seal and the ringed seal never occurred in this season. However, it is supposed that their habitats (hauling grounds) are too far north in Sakhaline (Inukai 1942) to occur in this area except ice season. Three ribbon seals were caught in this season, however, these seals were not caught by the coastal salmon nets but caught by the gill nets offshore in this area, and this seal is still seemed to be rare species in the coast.

## DISCUSSION

The author examined the distribution of the pagophilic seals in area outside of their habitat and in the border area, and the followings are recognized. The ice-breeding harbour seal, the bearded seal and the ringed seal occurred in Honshu, Shikoku and Kyushu moving from north to south. These seals were mostly pups. The ribbon seal has never occurred in this out side area of their habitat. The land-breeding harbour seal also has never occurred in this area. In the border area of their habitat, all 4 pagophilic seals occurred along the coast of the Nemuro Peninsula after ice season. The most of these seals were pups. However in October in the same area, only two species, the ice-breeding harbour seal and the ribbon seal occurred, and the adult seals occurred in high frequency.

The present study depended on short data, however, above facts furthermore lead to the important conclusion as follows. The pagophilic seals especially ice-breeding harbour seal (except the ribbon seal) disperse their distribution during or after the drifting ice melted. On the contrary, the land-breeding harbour seal which distributes along the Nemuro Peninsula to the Point Erimo does not shows such wide dispersion not only by the pups but also by others. These difference may due to their mode of life. The ice breeding seals shift their habitat from ice floe to the coast except the ribbon seal. These shift may occur pretty shortly after birth for the pups especially in the ice-breeding harbour seal (2–3 weeks after birth), for they occupy the edge zone of the seasonal pack ice (Burns, 1970; Fay, 1972; Naito, 1972a). During this short period, pups have to accomplish their life events on ice floe such as suckling, moulting of the lanugo coat and the weaning for their swimming life. The dispersion carried by the ice floes is innevitable for the pups which possess such above life, and this periods is highly critical for their survivals. However, perhaps for compensating these critical early stage of life, pups of these seals possess the very thick blubber as energy storage (Naito and Nishiwaki, 1972b). The pups of the land-breeding harbour seal have much more stable life. They begin to swim soon after birth. The mother-pup relationship continues longer (about 4–6 months—Naito and Nishiwaki, 1972b; Belkin *et al.*, 1969), and the weaning occurs gradually. Therefore the dispersion of pups may not occur. In the present study the ribbon seal has not occurred in Honshu, Shikoku and Kyushu areas. This may relate with that the ribbon seal apparently becomes pelagic after the breeding and moulting season (Burns, 1970; Fay, 1972).

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# THE VARIATION IN THE DEVELOPMENT OF PELAGE OF THE RIBBON SEAL WITH REFERENCE TO THE SYSTEMATICS

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## ABSTRACT

More than four hundreds pelages of the ribbon seal (*Histriophoca fascita*) were examined to know the development of the patterns and their variation. To describe them, some terminology were devised. The formations of these bands pattern were closely related to the pigmentation. Concerning to the pigmentation, two types of the pigmentation were found such as basic pigmentation and secondary pigmentation. The former pigmentation was found in both sexes of all ages except pups (not white coat pups), and the later pigmentation was found in adult males and in some females. However, some adult males did not show secondary pigmentation exceptionary. From these formations of the pigmentation, the ancestral form of the ribbon seal was speculated. The small ringed pattern was also found, and systematic reverse or atavism was considered and discussed.

## INTRODUCTION

The ribbon seal (*Histriophoca fascita*) is generally known for its ribbon mark. Their color pattern is much characterized by sex. The ribbon seal and harp seal are the only seals with banded pelage, and in these seals the color pattern has not been discussed and argured while the sexual dimorphism seen in polygamous form has been well noted from the point view of social biology, evolution and so on. In general, however, divergence in the pinnipeds from meaning of adaptation occurs in many directions. The less arguments and discussions on the color pattern of the ribbon seal may due to the less knowledge on this seal. When we consider the problems on color patterns, we have quite small knowledges on their distribution, movements, breeding, social behaviour and etc. Yet, it is still necessary to discribe the color pattern itself for the sake of future study of adaptation, evolution and systematics on this seal. The present

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paper is written to introduce the color pattern itself of the ribbon seal, and variations are described with some new findings.

## MATERIALS AND METHODS

All pelages of the ribbon seal dealt in the present study were collected from the area along the Sakhalin (south to 50°N) in the Sea of Okhotsk from the mid to the end of May 1975. The pelages of these seals were stocked in the fur companies after they were tentatively tanned. The authors had a chance to examine the pelages in October 1975 at Engaru Fur Company and Hakodate Fur Company. The pelages were recorded by photo to examine. The pelages size were measured from the nose tip to the root of the tail. The measurements, however, were sometimes rough because the pelages were broken in the measuring points. The sexes were also recorded by examing the genital openings (penis openings in males and teats openings in females). The total numbers examined in this study were 472 pelages (280 males and 192 females).

### 1. *The formation of the ribbon pattern*

It is widely known that the adult male ribbon seal has the characteristic white bands on their head to neck part, lateral body sides and lumber part which are so-called ribbon pattern. These white bands are also found in adult females, yet they are not so distinct. It is also generally recognized that these white bands are not seen in both sexes of young seals. Concerning the revelation of these bands, however, it is still uncertain when and how these bands are formed.

According to the Tikhomirov (1966), during the time from the moulting of the lanugo coat to the first moulting the seals have no pattern showing dark grey color in the dorsal side and bright grey in the belly side. After the first moulting at one year old they begin to show the distinct shield shaped pattern against the darker grey back, however there found no sexual dimorphism in the color pattern. After the second moulting at 2 years old, they first begin to show the peculiar ribbon pattern in males, and sexual dimorphism was found in the color pattern. The seals show the full adult type ribbon mark in males at 3 years old.

In our pelage study, we failed to get age informations from canine teeth, however, we got almost same results as Tikhomirov (1966) attained. As shown Table 1 and Plate I, all pelages were easily classified into four categories in males and three in females such as stage I, stage II, stage III, and stage IV in males by the developmental stages of the pattern, and each stages of both sexes well corresponded with the results by Tikhomirov (1966). The seals of both sexes of stage I have no ribbon pattern but showed grey or brownish grey back and creamy white or brownish yellow bellies. The seals of this stage were identified to be pups by the sealers and the pelage process workers. Actually these pelages corresponded with the pelages of 0 year old described

TABLE 1. PELAGE MATERIALS USED IN THIS STUDY. ALL PELAGES WERE CLASSIFIED IN EACH 10 CM BY THE LENGTH, AND THE DEVELOPMENTAL STAGES OF PELAGE PATTERN WERE EXAMINED. NUMBERS IN PARENTHESIS SHOW PERCENTAGE OF EACH STAGE IN EACH CLASS.

| Class of pelage size in cm | Numbers | Developmental stage of pattern | | | |
|---|---|---|---|---|---|
| | | stage I | stage II | stage III | stage IV |
| Males | | | | | |
| 110-120 | 2 | 2 (100.0) | | | |
| 120-130 | 10 | 9 ( 90.0) | | 1 (10 ) | |
| 130-140 | 31 | 10 ( 32.2) | 16 (51.6) | 3 ( 9.7) | 2 ( 6.4) |
| 140-150 | 35 | 5 ( 14.3) | 11 (31.4) | 2 ( 5.7) | 17 ( 48.6) |
| 150-160 | 63 | 1 ( 1.6) | 1 ( 1.6) | 3 ( 4.8) | 58 ( 92.0) |
| 160-170 | 75 | | 1 ( 1.3) | 1 ( 1.3) | 73 ( 97.4) |
| 170-180 | 55 | | | | 55 (100 ) |
| 180-190 | 7 | | | | 7 (100 ) |
| 190-200 | 2 | | | | 2 (100 ) |
| | 280 | 27 | 29 | 10 | 214 |
| Females | | | | | |
| 110-120 | 6 | 6 (100.0) | | | |
| 120-130 | 12 | 10 ( 83.3) | 2 (16.7) | | |
| 130-140 | 28 | 6 ( 21.4) | 20 (71.4) | 2 ( 7.1) | |
| 140-150 | 17 | 2 ( 11.8) | 9 (52.9) | 6 ( 35.3) | |
| 150-160 | 45 | 1 ( 2.2) | 22 (48.9) | 22 ( 48.9) | |
| 160-170 | 63 | | 19 (30.2) | 44 ( 69.8) | |
| 170-180 | 18 | | 3 (16.7) | 15 ( 83.3) | |
| 180-190 | 3 | | 1 (33.3) | 2 ( 66.7) | |
| | 192 | 25 | 76 | 91 | |

by Tikhomirov (1966). From above the seals of stage I were supposed to be 0 year old. The seals of stage II still showed the same pattern between two sexes. They begin to show the peculiar shield pattern with narrow white line at its margin, and at the same time the initial pup dorsal dark color were still found. These seals of this stage were also estimated to be 1 year old by the sealers and the pelage process workers, and also the comparison with the results by Tikhomirov (1966) suggested these seals to be 1 year old. In stage III seals begin to show the sexual dimorphism. Being incomplete, male seal pelages of this stage showed the ribbon pattern with obscured white bands. These pelages did not show as strong contrast as seen in full adult type pelages as over all look, and shield pattern had developed extending four feet towards the belly side to connect each other from both sides making the ring patterns at each lateral sides. The margin of this developed shield pattern were relatively clear. On the contrary, the other margin of white bands were unclear, so that the ribbon pattern did not appear clearly at this stage. This may due to the time duration of pigmentation between four feeted dorsal pigmentation (developed shield pattern) and other pigmentation, and also due to decolorization in white bands parts. As a matter of facts in this stage unclear radial thin dark lines were found in the white bands. In this stage initial pup dorsal dark color which were found in stages I and II were already lost. Concerning the age of this stage, the sealers and the pelage process workers do not classify the pelages by age, however, seals of this stage were supposed to be 2 years old in accordance with pelages of 2 years old seals described by Tikhomirov (1966). Pelage pattern of female seals of stage III were apparently different from these of males. Wide variation being found, seals generally showed indistinct ribbon pattern. The pigmentations did not develop as strongly as males of same stage. The peculiar shield pattern which were always found in stage II usually changed to have extended four feet. Over all look, however, was very bright, for the pigmentations at lateral body side and hip parts were dim. The decolorization at white bands developed to vanish the initial pup dorsal dark color which was still found at stage II. The ages of female seals of this stage III were supposed to be over 2 years old. Only in males stage IV was possibly classified. Seals of this stage showed complete adult type ribbon pattern. The ages of seals of this stage were supposed to be over 3 years old.

As already described, we do not have any age informations from the canine teeth in this study, yet we could know the formation of the ribbon pattern by the age in accordance with the results by Tikhomirov (1966). However it is considered that age variation may occur in the formation of the ribbon pattern. To make this problem much surer, we studied on the captured ribbon seals. Kamogawa Sea World well succeeded in keeping a male and a female ribbon seals. A male and a female pups were kept from 1973 and 1974 respectively. This male seal developed his pattern showing the same stages as described above after each moulting in May, and showed complete ribbon pattern of the final stage in this study at age 3 years old. On the other hand a female seal showed the same pattern as stages I and II at age 0 and 1. However, she had died at age 1 year old in 1974. From above all, stages I, II, III and IV well corresponded to the age 0, 1, 2, and over 3 years old in males, and stages I, II, III also to the age 0, 1, and over 2 years old in females.

*2. Analysis from schematic diagram*

As mentioned above, the ribbon pattern was formed age by age showing the peculiar age classes such as stages I, II, III, IV in males and stages I, II, III in females. We already described when these pattern appear, however, we still do not know how they appear. To analize this problem, we made some schematic diagrams in each sex, and for the explanation convenience some terminology were used. Farther more in the former chapter, we used stage classes such as stages I, II, III, IV for the convenience, however, each stage corresponded to age classes such as 0 year old, 1 year old, 2 years old and over 3 years old respectively over all. Therefore we use age classes instead of stage classes in this chapter and later chapters.

*Male*

Plate II shows the schematic peculiar pattern of each age classes, this plate also shows the degrees of pigmentation. Seals of 0 year old have their dorsal pattern which are named pup pattern (P. P.). At age one, the darker shield pattern (S. P.) appears in the center part of pup pattern, and at the same time decolorization occurs at the margin of shield pattern. As a result pup pattern are divided into four pattern such as initial neck pattern (I. N. P.), initial lateral patterns (I. L. P.) and initial hip pattern (I. H. P.). The pigmentations of these patterns are same degree as pup pattern at age 0. The pigmentation and decolorization develop quickly at age 2. The basic shield pattern developed having four feet which connect each other to make round circle at lateral side. This developed shield pattern (D. S. P.) is almost real black. The same degree of pigmentation appears in the head and neck parts forming the neck pattern (N. P.) which took place the initial neck pattern (I. N. P.). The decolorization at the outer margin of developed shield pattern occurs as fast as pigmentation forming the neck band (N. B.), lateral bands (La. B.) and lumber band (Lu. B.), so that the initial lateral pattern at age 0 do not appear at age 2. At the same time, however, the lesser new pigmentation begin to occur innerpart of the lateral bands and at hip part forming the lateral pattern (L. P.) and the hip pattern (H. P.). The developemental stage of pigmentation and the decolorization attains the final stage at age 3. The neck pattern and the developed shield pattern come to much more black, and the delayed pigmentation of the lateral pattern and the hip pattern develop to come as black as the pigmentation of other patterns. At the same time each bands appears whiter by the developed decolorization.

As mentioned above, we could find out that time duration of the pigmentation and the decolorization exist in forming the so-called ribbon pattern, and furthermore we can classify the pigmentation of each pattern by their developmental stages, while the decolorization of each bands is impossible to classify because of their same developemental stage. Fig. 1 shows this pigmentation stage of each pattern. The pigmentation of pup pattern is decreasing and took over by other pigmentation or disappear. We call this as the degenerative pigmentation. The pigmentation of the shield pattern is very stable and very actively increase, and the neck pattern pigmentation is relatively stable and increasing. These pigmentations are classified as the basic pigmentation. The latest pigmentations of the lateral pattern and the hip pattern are not stable, for these are much variable (explained in the later chapter). These are classified as the secondary pigmentation.

*Female*

Plate III shows the schematic diagrams of pattern of each age class in females. As shown in Plates II and III, females show the quite same pattern and the same degrees of pigmentation and decolorization as males at age 0 and 1. At age 0 they possess the pup pattern, and at age 1 the shield pattern, initial neck pattern, lateral patterns and initial hip pattern appear as well. At age 2, the shield pattern develop its four feet at each corner making the round circles at lateral sides. This developed shield pattern is quite same as males not in the degrees of pigmentation but in form. The neck pattern, the lateral pattern, and the hip pattern also appear at this age, while the pigmentation of these pattern also not so strong as males. These pattern and pigmentation do not seem to change over 2 years old. Compared with males, overall look of female seems to be quite bright and no pattern seems to exist in females at first glance. However, these are due to the less pigmentation in females. They actually possess the each same pattern as males. These pigmentation stage of each pattern are also shown in Fig. 1. Concerning to the sexual dimorphism, it is generally believed that the male ribbon seal shows distinct ribbon pattern and the female seal does not show it. As already mentioned above, it was revealed that the sexual dimorphism are found not in the pattern itself but in the degrees of the pigmentation of the pattern. As seen in Fig. 1 and Plates II and III, the sexual dimorphism occurs after 2 years old, and completion of dimorphism is found at age 3. Probably, these are closely related to the sexual maturation. We do not know the age of sexual maturation of the ribbon seal. According to Tikhomirov (1966), however, it seems to mature after age 2 and 3 in females and males.

| | ages | 0 | 1 | 2 | 3 | |
|---|---|---|---|---|---|---|
| | P.P | + | + | | | degenerative pigmentation |
| | S.P. | | ++ | +++ | +++ | |
| Male | D.S.P. | | | +++ | +++ | basic pigmentation |
| | N.P. | | | +++ | +++ | |
| | La.P. | | | ++ | +++ | secondary pigmentation |
| | H.P. | | | ++ | +++ | |
| | P.P. | + | + | | | degenerative pigmentation |
| | S.P. | | ++ | ++ | ++ | |
| Female | D.S.P. | | | + | + | basic pigmentation |
| | N.P. | | | + | + | |
| | La.P. | | | + | + | secondary pigmentation |
| | H.P. | | | + | + | |

Fig. 1. Development of the pigmentation of each pattern. Plus simbols show the degree of the pigmentation. Abbreviation shows as follows. P.P., Pup Pattern; S.P., Shield Pattern; D.S.P., Developed Shield pattern; N.P., Neck Pattern; La.P., Lateral Pattern; H.P., Hip Pattern.

### 3. *The variations of bands, pigmentations and other charactor*

As already introduced, three types of distinct white bands are seen on the pelage such as head band and two lateral bands which encircle the fore flippers, and lumber band. Of all three type bands, head band showed the least variation. This band circulate the neck and the throat slightly prolonged anterior at the head, so that it shows the chevron when we saw the tanned sheet of pelage (Plate V). Being slight variation in this band, these are no individuals in our materials which never form the chevron. The lateral bands which form the large ringed patterns in the sheet of tanned pelages show much more variation than the head band. Some variation being found in the size of the ring itself and width of the band as well, and rather wide variations were found in the connection or the combination to other bands. Concerning to the way of connection three basic types were derived such as type 1, no connection to other bands; type 2, connection with lumber band (including the case of one side band connecting to the lumber band); type 3, connection to both head band and lumber band (including the case of one side band connecting to other band (Plate IV). The appearance frequency of each type were shown in Table 2. Type 1 is the most popular with 51.7% frequency, and 34.4% for type 2 and 13.9% for type 3 respectively. However, there seemed no pelages which showed the connection between the lateral bands and the head band. It also seemed that each lateral band never connect at dorsal side while they usually connect at belly side. The widest variation was apparently found in the lumber band. The variation found in this band was so much wide that it seemed quite difficult to describe or classify into some categories precisely. For the convienience in this study the lumber band variations were only shown in Plate V showing from simple form to complicated form.

The variation seen in the bands was described already from the understanding that these bands are peculiarly specialized in this species. The pattern of these bands, however, have never been interpreted from the point of view of its origin, for these white bands are too much distinct and attractive to draw the attention to the dark pigmented counter pattern against the white bands. The darker the pigmented counter parts the more remarkably the white bands appears. On the other hand, the less pigmentation makes the bands be

TABLE 2. APPEARANCE FREQUENCY OF EACH VARIATION TYPE OF THE LUMBER BANDS. NUMBERS IN PARENTHESIS SHOW THE NUMBER OF CASES THAT ONE SIDE OF TWO LUMBER BANDS CONNECTED TO OTER BANDS.

| Type | Numbers | % |
|---|---|---|
| Type 1. | 108 ( 0) | 51.7 |
| Type 2. | 72 (18) | 34.4 |
| Type 3. | 29 ( 9) | 13.9 |
| Total | 209 | 100 |

more obscure. In the present study such above mentioned obscure bands were found. As shown Plate VI, the less pigmentation were found in the lateral pattern and the hip pattern. We found six examples of this less pigmentation pelages out of 214 pelages of over 3 years old male seals, and the frequency was 2.8%. These less pigmentations make the lateral bands and lumber band obscure as if those bands do not exist. On the other hand the pigmentation at the neck pattern and the developed shield pattern were very strong and stable, and such less pigmentation were not found. This may relate to the less variation of the head band mentioned already. The less pigmentations in lateral parts and hip parts may relate to wider variation of the lateral bands and the lumber band already mentioned. With regards to the female pattern, the contrast being obscure, female shows the distinct dorsal pigmentation which form the same developed shield pattern as the males, while the pigmentation in the lateral pattern and hip pattern are not strong as much as in the developed shield pattern. Therefore in the females no lateral bands and lumber bands were often found. From above as already mentioned in the former chapter, the pigmentation of the ribbon seal were possibly classified into two stages from the phylogenetic aspects, basic pigmentation and secondary pigmentation, indicating speculately that the ribbon seal in its ancestral form had the pigmentation in smaller area such face-head parts and shoulder-dorsal parts showing the brighter phase as over all look (Plate VII), and secondary pigmentation had occurred in the lateral and hip parts resulted the formation of the peculiar bands so-called ribbon marks. Of course sexual dimorphism by the pigmentation degrees might existed even if it was not distinct as much as today's ribbon seal.

The variation of the bands and pigmentation were described above, and the formation of the ribbon pattern were explained. In the present study farther variation were found. As shown Plate VI, the small ringed pattern or spotted pattern was found in some of pelages. The appearance frequency was as shown in Table 3. According to the numbers of rings or spotted patterns they were classified into three degrees. Males showed higher frequency (8.8%) and in females these patterns are not distinct and they showed lower frequency (5.6%). This difference between sexes may due to that these small white ringed or spotted patterns are embossed against darker pelages of males and are easily found. This ringed or spotted patterns well resembles to those of the harbour seal (*Phoca vitulina*; both ice-breeding and land-breeding types) which were mentioned Belkin *et al.* (1969), and Naito (1973). On these ringed pattern of the harbour seal, McLaren (1966) pointed out to be atavism related to the ringed seal. In this study it is quite difficult to deny that these small ringed patterns are nothing but the only simple variation, because they appeared pretty high frequency (8.8%) in adult males. The present stage of study on this problem cannot settle the arguments, however, this fingding in the ribbon seal may support that these small ringed patterns are the pretty stable systematic or phylogenitic character which appears in some taxonimic groups.

TABLE 3. APPEARANCE FREQUENCY OF THE PELAGES ON WHICH THE SMALL RINGED OR SPOTTED PATTERN WAS OBSERVED. THE PELAGES WERE CLASSIFIED INTO THREE DEGREES BY NUMBERS OF THE RINGS AND SPOTS.

| | Males | Females | Total |
|---|---|---|---|
| Numerous | 2 | 0 | 2 |
| Medium | 4 | 0 | 4 |
| Rare | 14 | 5 | 19 |
| Total | 20 | 5 | 25 |
| Numbers examined | 226 | 90 | 316 |
| Total ratio for examined numbers | 8.8% | 5.6% | 7.9% |

## DISCUSSION

The pelage color pattern of the ribbon seal were studied, and revelation of the color pattern according to ages, sexual difference, the bands variation, the formation of the bands, and the small ringed patterns were examined as systematic character.

Concerning to the sexual segregation in the pinnipeds, the divergence occurred in many ways. The remarkable sexual segregation are well known in the land-breeding polygamous seals such as the fur seals, the elephant seals and etc. In these seals, sexual dimorphism seen in body size, size of canine teeth and etc. seem to be derived from the possession of territory and mating females through the struggles between males. On the contrary sexual dimorphism seen in the pelage pattern are only found in the ribbon seal and harp seal. The ribbon seal occurs in the unstable dispersed pack ice area in the breeding seaon (Burns, 1970; Fay, 1972). This seal dose not aggregate but appears alone on the ice floes. Each individual occupies each ice floe (Naito, unpublished). Therefore these remarkable pelage pattern may have some effects to increase a chance to mate, or may effect on females as display from a distance even on ice floes or darker under water where the surface is covered by ice floes. The breeding behaviours of this seal, however, are not known at the present stage of our study, therefore explanation on some significance of this pelage pattern seemed to be quite difficult from the aspects of breeding or scocial behaviour.

As to phylogenic problems, some findings were made in the present study. The peculiar pelage pattern of this seal were formed by the two stages of pigmentation such as the basic pigmentation and the secondary pigmentation. The basic pigmentation was found in all of adult males and females even in immature seals of both sexes, and the secondary pigmentation was not always occurred in some adult females and even in some of adult males. When we consider that the secondary pigmentation are the acquired character in their pathway of evolution, it is supposedly considered that the ancestral form of the ribbon seal would not have the lateral and lumber bands pattern, but showed dark patterns around the face and shoulder-dorsal area against the bright ground color. This speculated ancestral form would much resemblance to the harp seal in the Atlantic, because this seal shows smaller pigmentation parts and brighter color over all. However, to attain some conclusion on the relation between the ribbon seal and the harp seal, it is essential to examine the variation of the pelage pattern of the harp seal as well as the ribbon seal.

The small ringed patterns were also found in this study, and estimated to have some systematic characters. This may support the hypothesis that ringed patterns occur as atavism (McLaren, 1966). Burns and Fay (1970) showed the systematic relationship among the four smaller seals of the tribe Phocini (*Histriophaca, Pagophilus, Phoca, Pusa*) by the osteological study. They indicated the stronger interrelationship between Histriophoca and Pagophilus, and also suggested the stronger interrelationships between Pagophilus and Pusa-Phoca group than those between Histriophoca and Pusa-Phoca group. From above relationships we can expect to find the some ringed patterns from the harp seal, too.

## ACKNOWLEDGMENT

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## EXPLANATION OF THE PLATES

### PLATE I

The developmental stages of the color pattern. From top stage I (pup), stage II (1 year old), stage III (2 years old), stage IV (3 years old). Left, males; right, females.

### PLATE II

The schematic diagrams of male pelage pattern. From top to below 0 year old, 1 year old, 2 years old and 3 years old.

### PLATE III

The schematic diagrams of female pelage patterns. From top 0 year old, 1 year old and 2 years old.

### PLATE IV

The variation of lateral bands. From top, Type 1 (no connection to other bands), Type 2 (connection to lumber band), Type 3 (connection to both lumber and head bands).

### PLATE V

The variation of the lumber band. Arranged from simple form to more complicated form from left top to right bottom.

### PLATE VI

Examples of adult males which did not show the complete secondary pigmentation.

### PLATE VII

The schematic diagrams of the speculated ancestral form, which were devised from the developemtal process of the pigmentation.

### PLATE VIII

The examples of the small ringed or spotted patterns. The pelages were classified into three degrees A, B and C according to the numbers of ringed patterns.

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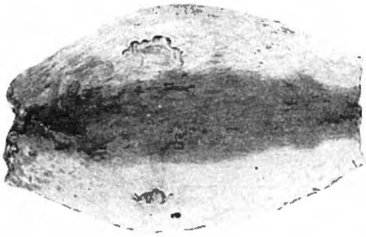

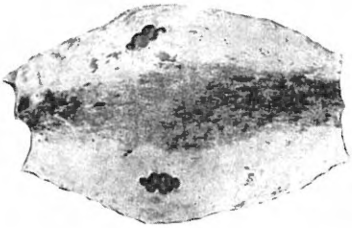

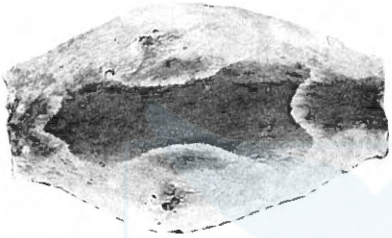

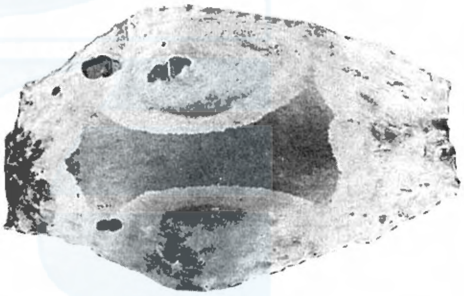

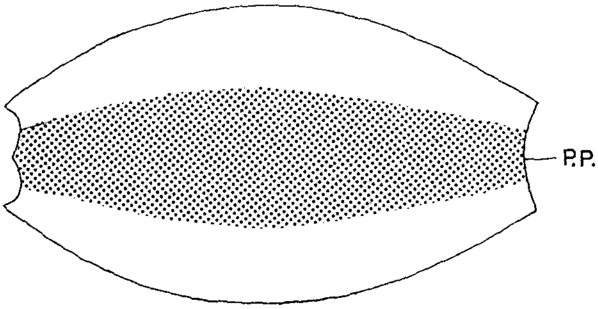
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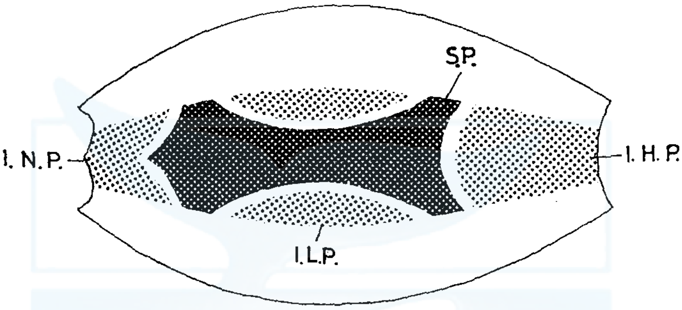
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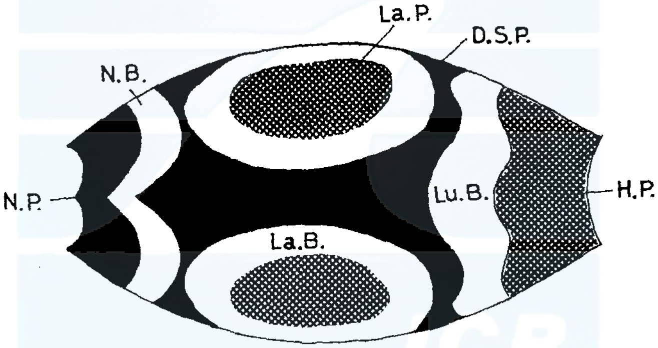
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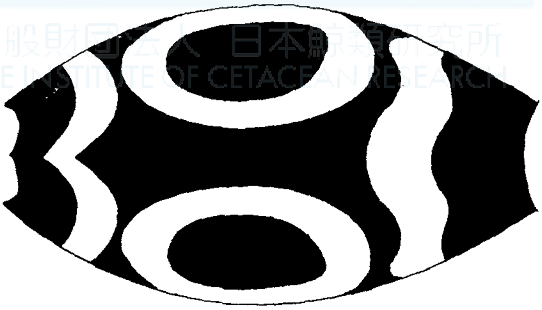

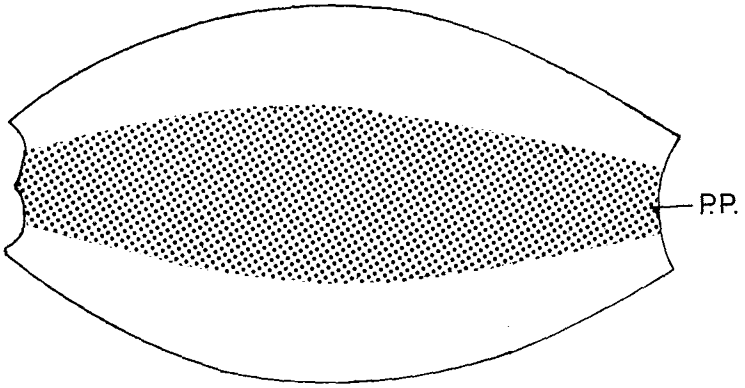
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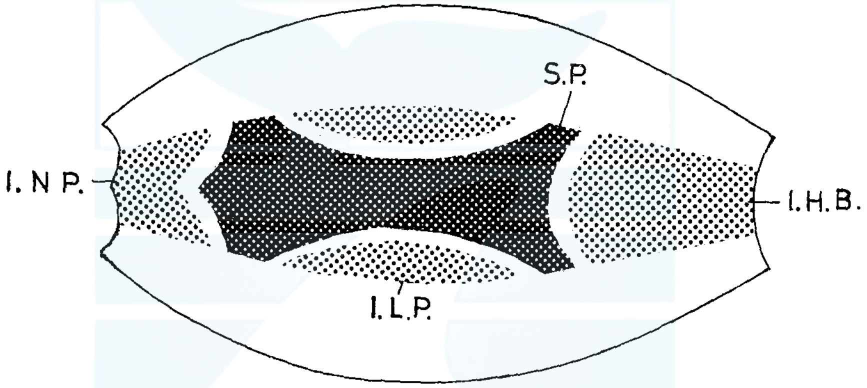
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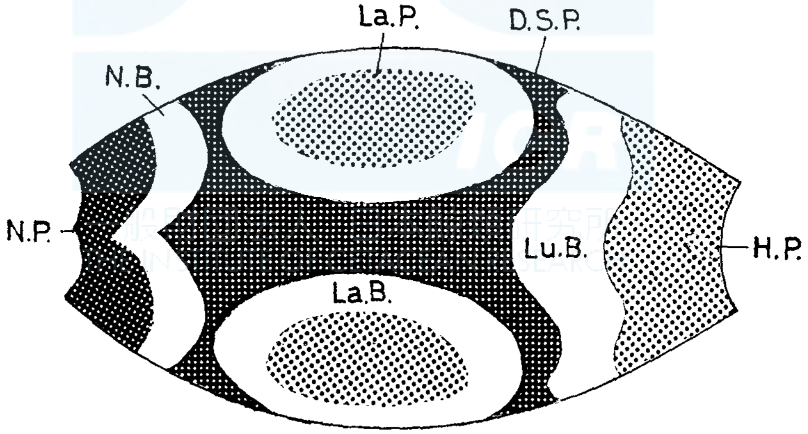
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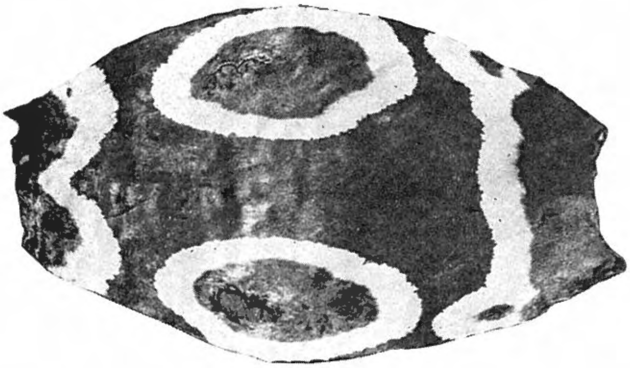

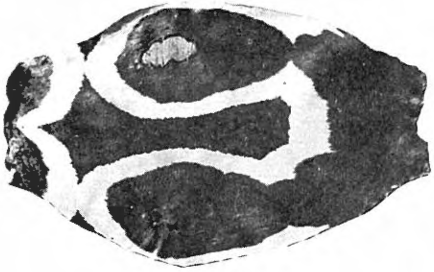

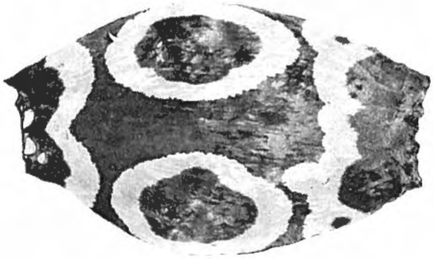

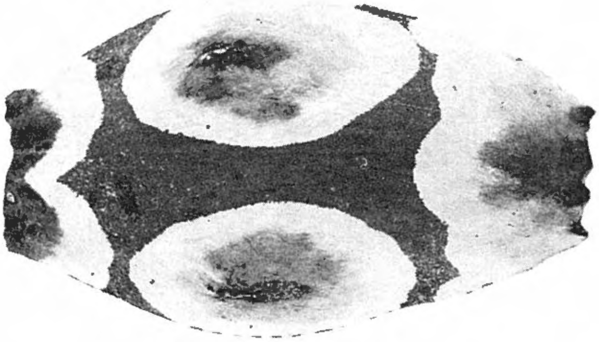

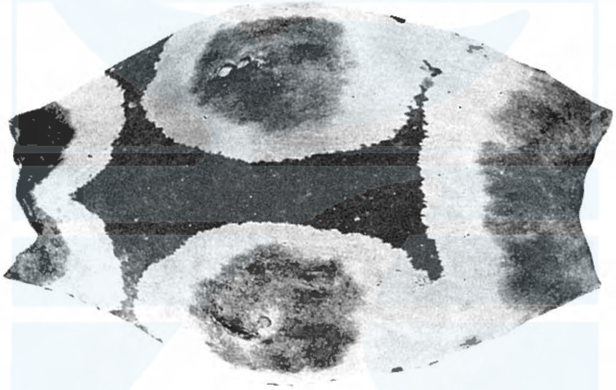

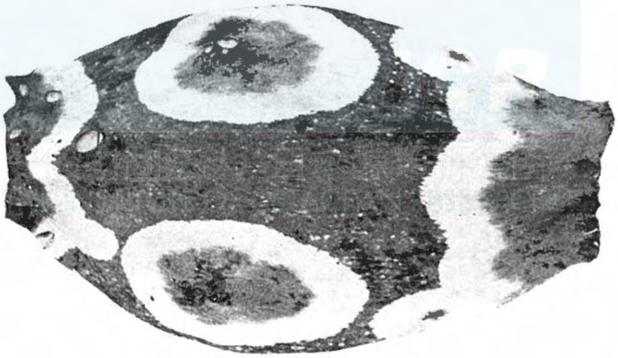

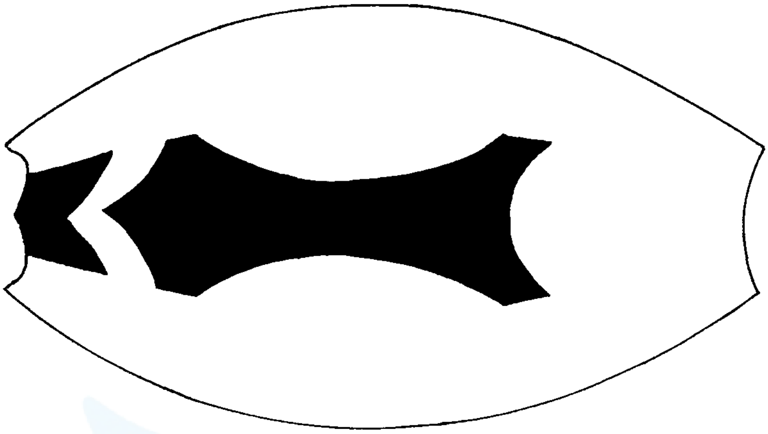

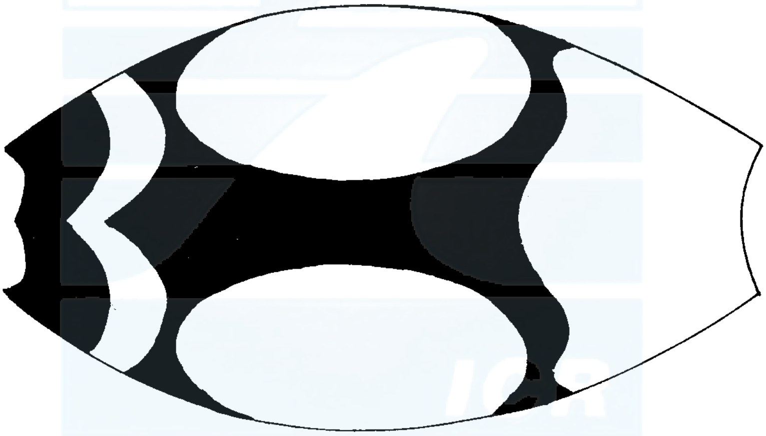

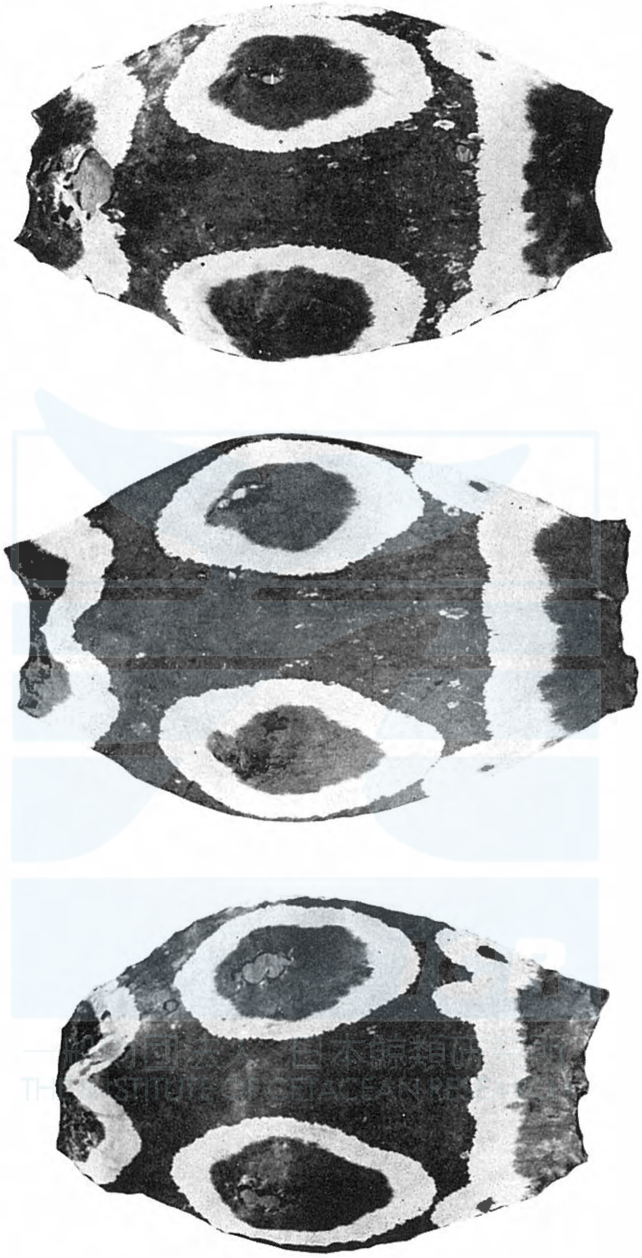

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