AN OSTEOLOGICAL STUDY OF THE CUVIER'S BEAKED WHALE, *ZIPHIUS CAVIROSTRIS*, IN THE NORTHWEST PACIFIC

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ABSTRACT

Skulls and postcranial skeletons of *Ziphius cavirostris* were studied for eleven specimens, mostly stranded on the sandy beach of Japan. Some distinctions between the adult male and female and/or juvenile are noted in the skull measurements. The fusiform tooth and the massive mesorostral bone with posterior truncation in the male will be completed after the attainment of the physical maturity. The total number of the vertebrae is 46–47, and not differs from that of the other oceans. The proportional development of bones of skull as well as the vertebrae according to the growth of whale body is also studied in some extent.

INTRODUCTION

The Cuvier's beaked whale or the goose-beaked whale, *Ziphius cavirostris*, distributes in all temperate and tropical seas (Rice and Scheffer, 1968). In the North Pacific, strandings of this species were reported from the coast of western North America by various authors (for example Hubbs, 1946) and these are well summarized and studied of its seasonality by Mitchell (1968), which contains records of 41 strandings. These strandings range between Alaska and the tip of Baja California. From the Central Pacific also strandings were reported from Hawaii (Richards, 1952) and Midway Islands (Galbreath, 1963).

In the northwest Pacific two large skulls were found on the coast of Kamchatka in 1951 (Tomilin, 1957). The only place where this whale is regularly hunted is on the coast of Japan (Backus and Schevill, 1961), but as yet no comprehensive study has been published (Mitchell and Houck, 1967). Hitherto only two papers were published (Ogawa, 1936–37; Omura *et al*. 1955).

Strandings of *Ziphius cavirostris* are not uncommon also on the coast of Japan. These are reported in local newspaper articles, and when the strandings had occured near to Tokyo the staff of the Whales Research Institute have endeavored to collect samples of these animals. Thus from 10 individuals skulls and sometimes with post-cranial skeletons have been collected. Once someone of the institute made a study of these bones, but he could not finish it before he moved to the other research laboratory where he is not able to continue the study of this kind.

I have investigated the material again, stimulated by the situation mentioned above, and they are now reported in this paper. To my regret the data on the exact time, place, body length, sex, and other particulars of the animals are missing, but if I correctly remember most of them had stranded on the sandy beach of Sagami Bay at different times and not in mass. One animal which stranded on the coast of Tokyo Bay is also included. In any case all of them were collected from several places near to Tokyo.

Buckus and Schevill (1961) write "Japanese whalers and cetologists seem not yet to have recorded their observations of the living animal—a thing we may all look forward to." On this problem I am not able to contribute anything in this paper yet.

MATERIAL

The skeletons used in this study are as follows:

ZC2. Very young specimen. Skull, right mandible, vertebrae, scapulae, 12 pairs of chevron bones, a pair of pelvic bones, fragments of ribs, a part of sternum are preserved.

ZC11. Juvenile specimen. All bones except those of the flippers and pelvic bone are preserved.

ZC12. Adult but suspicious of its sex. Nearly all bones are preserved as in the case of ZC11, but each rib was cut into several pieces by saw, possibly just after the stranding by spectators.

ZC6. Only skull and mandibles are preserved.

ZC3. Possively young adult female. Nearly all bones are preserved as in the case of ZC11.

ZC7. Juvenile specimen. Nearly all bones are preserved as in the case of ZC11, but each rib was cut into several pieces by saw.

ZC4. Only skull, mandibles, ribs and stermum are preserved.

ZC8. Possibly adult male. Only skull and mandibles are preserved.

ZC1. Possibly adult female. Nearly all bones are preserved as in the case of ZC11.

ZC10. Possibly adult female. Nearly all bones are preserved as in the case of ZC11.

TWM1. Adult male. Skull and mandibles. This specimen does not belong to our collection. This whale was taken off Taiji on some day and the skull is being kept at the Taiji Whale Museum.

SKULL

Diagnosis. According to Moore (1968) the diagnostic characters of the skull of *Ziphius* are as follows:

1. Where the premaxillary bones ascend posteriorly on either side of the superior nares and terminate, their anterior faces are oriented mesially a small but obvious amount from directly forward.

2. The combined breadth of the nasal bones is greatest anteriorly and where the right nasal is out on contact with the right premaxillary bone.

3. When the skull is upright and the long axis of the beak is horizontal, in

lateral view the nasal bones both project somewhat farther anteriorly from the synvertex of the skull than do the up-curled posterior ends of the premaxillary bones.

Further, in his key to the living genera of the beaked whales by characters of the skull he separates *Ziphius* from *Berardius* in the character that when the posterior aspect of the skull is viewed from a point aligned with the long axis of the rostrum, and from a distance of at least two meters, in the former the synvertex of it is completely occuluded by the supraoccipital, or so little of the synvertex shows that the profiles of both descending sides are not seen to become sheer, whereas in the latter the profile of the synvertex projects above the supraoccipital as a slightly asymmetrical block with sheer sides.

The eleven slulls of *Ziphius* I examined are all in agreement with the above descriptions (Plates I-V).

Adulthood and sex. As already stated the data on sex and body length of the specimens are lacking. But in *Ziphius* the adult male can be distinguished from the adult female and juvenile by the presence of the prenarial basin, prominent mesorostral bone, and by the size and eruption from the gum of the tooth (True, 1910; Fraser, 1942; Moore, 1968). Further, it is common practice among mammalogists to regard a mammal as morphologically adult when the epiphyses have become so fused to the centrum of each of the vertebrae that their sutures are obliterated (Moore, 1968). Using these criteria I have tried to determine the adulthood and sex of the specimens. In the following the specimens are arranged in the order of their skull length.

ZC2. (Pl. I, Fig. 1) The skull length is 590 mm and evidently from a young animal. Bones of the skull articulated each other very loosely and the sutures between them are open. Mesorostral ossification is not developed at all and no prenarial basin present. This specimen has 47 vertebrae and none of the epiphyses has become fused to its centrum. Further, from 7th up to and including 15th vertebra, the bones consisted of the spinous and transverse processes are not united to the bodies of the centra. In 5th, 6th, 16th, and 17th vertebra they are united to their centra, but sutures are still visible. Sex is not known.

ZC11. (Pl. I, Fig. 2; Pl. III, Fig. 1) The skull length is 707 mm and also evidently from a juvenile animal. In this specimen too the mesorostral ossification is undeveloped and no prenarial basin is present. The sutures of the each bone of the skull are visible. It has 46 vertebrae and none of the epiphyses is united to its centrum.

ZC12. (Pl. I, Fig. 3; Pl. III, Fig. 3) The skull length is 811 mm and it looks like to be from an adult male, because there present the prenarial basin distinctly as shown in Pl I, Fig. 3. The mesorostral bone is developed, but it does not rise beyond the level of the premaxillaries. It begins about 10 cm from the tip of the rostrum as a narrow ridge, and it increases its height and width towards the middle of the rostrum, and then depressed gradually, and not abruptly, to the prenarial basin. At the middle part of the beak the width of the ridge is about 18 mm and about 10 mm below the level of the premaxillaries.

Fraser (1942) reports a case that the mesorostral is prominently developed with the skeleton of young animal, and with the widely open pulp cavity of the teeth (young male, Unionhall, 1913. 2. 11. 1.). In the specimen ZC12 the mesorostral is developed in much lesser degree than in this specimen, but it is from an adult animal, because all of the epiphyses of the 47 vertebrae are so entirely fused to their centra that the sutures are obliterated. Further the teeth of this specimen exhibit a typical feature of an adult female. Their roots are completely closed and the shape is cylindrical and not fusiform (Fig. 1). The greatest diameter is only 11 mm in the both teeth, as shown in Table 3.

The above mentioned characters of this specimen suggest that this is an adult female, but a question to this conclusion is the presence of the distinct prenarial basin. True (1910) describes " in those specimens in which the sex is known to be female, or is marked as such, the premaxillae are comparatively narrow ". Further Harmer (1927) notes " in the male the outer border of the expanded parts of each premaxilla

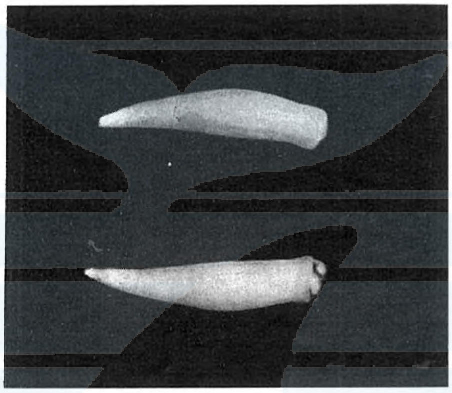


Fig. 1. Teeth of the specimen ZC 12.

is raised far above the inner border, so that the part in question slopes down steeply into the prenarial basin ". The measurements of the skull are shown in Table 1 and in Fig. 3. This specimen has comparatively wider premaxillae than in the other specimens which are thought to be female or juvenile. Harmer's description is thought to be applied also to this specimen. Further, in this specimen the shape of the inner border of the right premaxillary is different from the other specimens. Its width at the position of the premaxillary foramen is narrow, but posterior to that it gains abruptly its width and the inner margin directs transversely, and lies at nearly the posterior margin of the prenarial basin.

As regards to the teeth some more mention is needed. They are slender and cylindrical in shape. Their tips are pointing, but in close observation the tip of the left tooth exibit a very slight wear, and the right tooth has a fractured tip (Fig. 1). According to the working hypotheses adopted by Moore (1968) of the criterion of adulthood and sex of the Hyperoodontidae (Ziphiidae) 1) Teeth with filled or virtually filled pulp cavities provide a criterion of adulthood. 2) Teeth exhibiting natural wear as evidence of having erupted in life a criterion of male sex. 3) Teeth exhibiting no such wear but with pulp cavities completely or virtually filled are a criterion of female sex. A slight wear or fracture of the teeth in the specimen ZC12 are not sure that these are caused by natural or by damage during or after the maceration. If these are caused by natural wear this specimen is possibly from an adult male, notwithstanding of their slender shape. It resembles to the specimen reported by Fraser (" Young adult " male, Garrynamonie, South Uist, 1935. 4. 18.1), in which one of the teeth has a fractured tip but the other is complete, and the greatest diameter of these teeth are 15 and 14 mm respectively. As to the mesorostral he states " The mesorostral is well developed . . . , but in the region where, in the typical old male, the mesorostral is suddenly depressed, that of the South Uist specimen dips down in a gradual slope to the floor of the prenarial basin ". In this respect too the specimen ZC12 resembles to the South Uist specimen, as stated already. I assumed this specimen to be an adult male in the later analysis of the skull proportions.

Another one feature of some interest of this specimen is the unusual development of some of the vertebrae. The posterior part of the 17th vertebra (1st lumbar) and the anterior part of the 18th vertebra (2nd lumbar) are irregularly developed and at center of the vertebral body there present an irregular pit (Fig. 2). Such abnormality is also found between 29th vertebra (2nd caudal) and 30th vertebra (3rd caudal). These are possibly due to some pathological cause, but it is not certain that these abnormality had any effect to the growth of the skull and the teeth.

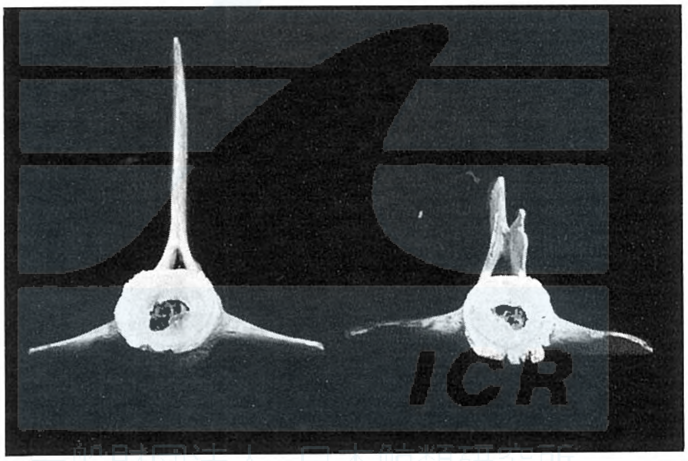


Fig. 2. 17th and 18th vertebrae of the Specimen ZC 12.
Left: Posterior view of the 17th vertebra.
Right: Anterior view of the 18th vertebra (spinous process partly broken).

ZC6. (Pl. I, Fig. 4; Pl. IV, Fig. 1) The skull is larger than the foregoing specimen and measures 819 mm in length, but it seems to be from a younger animal. The sutures between bones of the skull are visible. The mesorostral bone is undeveloped and the canal is empty. The prenarial basin is undeveloped. All of the vertebrae and teeth are lacking, but presumably from a juvenile animal.

ZC3. (Pl. III, Fig. 4; Pl. IV, Fig. 3) The skull length is 823 mm. The mesorostral bone is developed, but its superior face is below the level of premaxillaries by about 5 mm towards the middle part of the rostrum, and then depressed gradually and finally ends just after the region where, in the premaxillaries, the foramina are situated. It is separated from the anterior end of the bony ethmoid, the vertical face of which is tuberculated, and rests on the vomer. The sutures between premaxillaries and the maxillaries are visible in most parts. No prenarial basin is developed.

This specimen has 46 vertebrae and all of the epiphyses are fused to their centra, but in the dorsal vertebrae sutures are still visible, especially in the posterior part of each vertebra. It is possible that this specimen is of an adult, at least semi-adult, female, though the teeth are lacking. The length and the breadth of the mandibular alveoli are 17 and 12 mm in the right and 18 and 12 mm in the left.

ZC7. (Pl. II, Fig. 1; Pl. III, Fig. 2) The skull length is 826 mm. There is a low ridge which runs antero-posteriorly on the superior surface of the vomer, which begins about 4 cm posterior from the tip of the vomer and ends after the level of the premaxillary foramina. The prenarial basin is undeveloped and the premaxillaries, maxillaries, and the vomer articulate loosely. The anterior end of the bony ethmoid rests on the flattened part of the vomer.

This specimen has 47 vertebrae and the epiphyses are not fused to their centra, but separated, except a few vertebrae in the cervical and caudal vertebrae. Accordingly, it is possible that this specimen came from a juvenile animal.

TWM1. (Pl. V, Figs. 1 and 2) The skull is 837 mm in length and evidently from an adult male. The mesorostral bone is developed conspicuously and its superior surface rises over the level of the premaxillaries. It extends from the tip of the beak posteriorly and at a point, 92 mm from the tip, it is truncated abruptly. At this point the bone is 55 mm wide and 50 mm thick. On either sides of the middle part of the mesorostral there are a groove of about 3 cm deep which separates it from the ridge of the premaxillaries. The prenarial basin is also developed conspicuously and the skull itself is well ossified.

The teeth are massive, and fusiform in shape. Their measurements are given in Table 3.

ZC4. (Pl. II, Fig. 2) The skull is 844 mm in length and not well ossified. The mesorostral is undeveloped and the canal is empty. The prenarial basin is undeveloped and the right premaxillary is nearly flat at this region. The beak is slender, and it seems that the specimen is of a female. None of the vertebrae and teeth has been preserved.

ZC8. (Pl. IV, Fig. 2; Pl. VII, Fig. 2) The skull is 886 mm in length and rather heavy. Most of the sutures of the articulating bones are visible, but that of the vomer and premaxillaries is not clear. The mesorostral bone is developed as a ridge of about 5 mm width. It begins at the tip of the vomer or about 10 cm posterior to the tip of the beak and ends at just after the line connecting the premaxillary foramina, and then depressed. The superior face of the mesorostral is about 5 mm below the level of the premaxillaries. The inner part of the right and left premaxillaries are steeply depressed at the prenarial portion and forms the basin, together with the depressed part of the mesorostral. The teeth are lacking, but the alveoli of the both mandibular teeth are large, and measures about 20 mm width and 28 mm

TABLE 1. SKULL MEASUREMENTS OF *ZIPHIUS CAVIROSTRIS* IN NORTHWEST PACIFIC. (in mm)

Measurement no.	ZC 2 juv.	ZC 11 juv.	ZC 12 ad.♂	ZC 6 juv.	ZC 3 ad.♀	ZC 7 juv.	TWM 1 ad.♂	ZC 4 ♀	ZC 8 ad.♂	ZC 1 ad.♀	ZC10 ad.♀
1	590	707	811	819	823	826	837	844	886	891	921
2	313	386	460	472	459	487	475	489	499	503	517
3	413	514	581+	616	630+	637	651	636	659	661	728
4	444	555	611+	667	630+	676	687	675	694	695	764
5	272	345	390	394	415	400	413	399	425	435	470
6	283	368	440	429	427	456	438	467	469	450	458
7	501	603	689	730	701	738	742	747	774	766	769
8	372	465	531	560	550	577	573	591	588	589	609
9	383	458	534	582	546	569	557	585	575	578	587
10	525	626	717	745	743	744	753	767	794	801	821
11	463	566	623	675	645	663	654	680	698	690	701
12	282	369	419	437	435	435	444	454	462	451	490
13	106	105	144	141	154	128	128	135	142	143	138
14	89	120	127	121	131	137	117	129	128	130	149
15	83	98	98	119	123	108	120	100	116	110	130
16	72	87	86	105	111	95	106	94	105	99	124
17	328	378	471	448	477	463	486	448	502+	517	522
18	320	381	468	449	476	454	476	445	451+	507	517
19	300	357	433	439	462	447	456	437	499	486	498
20	215	248	261	258	250	261	300	271	311	322	340
21	130	127	170	139	139	139	141	129	148+	165	161+
22	42	50	66	48	50	51	54	53	—	69	—
23	76	88	102	95	91	96	95	87	—	—	—
24	67	53	55	52	52	50	55	54	—	60+	—
26	52	67	69	77	63	67	87	60	74	75	73
27	48	66	63	73	61	50	69	52	67	66	65
29	135	157	177	183	163	166	210	166	202	181	185
30	120	143	174	164	157	158	207	154	193	176	182
31	119	144	177	168	164	160	212	156	204	178	187
32	47	56	54	48	46	52	68	55	68	71	66
33	188	250	288	305	283	291	285	312	305	310	332
34	140	192	224	233	215	222	244	226	248	246	275
35	79	103	97	109	105	93	98	101	125	110	125
36	41	58	64	62	68	66	104	57	83	74	84
37	61	84	91	90	76	88	119	85	103	99	91
38	81	104	107	112	124	102	118	106	115	111	132
39	290	355	367	402	411	382	430	388	455	427	453
40	64	68	92	91	105	80	65	83	91	96	96
41	75	101	137	106	118	119	155	107	147	126	125
42	29	36	59	45	50	48	—	45	66	51	53
43	118	138	133	150	140	122	116	131	168	158	142
44	172	190	203	234	226	260	313	198	250	255	268
45	0	0	0	20	0	0	0	0	35	0	0
AB—left*	53	50	—	50	—	50	54	54	—	57	53
AB—right*	55	54	55	54	—	55	—	57	—	60	57

* Greatest length of auditory bulla.

length, whereas in the specimen ZC10, which is thought to be an adult female, the corresponding figures are 14 and 20 mm respectively.

All of the vertebrae of this specimen are lacking, but it is probable that this skull was obtained from an adult male.

ZC1. (Pl. II, Fig. 3) The skull is 891 mm in length and well ossified, especially in the region of the beak. A very low and narrow ridge is present on the vomer, even the highest part of which lying over 10 mm below the level of the premaxillaries. No prenarial basin is developed. The mandibles of this specimen is lacking, but both teeth have been secured, of which measurements are given in Table 3. They are slender and resembles in shape to those of the specimen ZC12 and the root is completely closed in the both teeth.

In this specimen the number of the vertebrae is 47 and all of the epiphyses are so completely fused to their centra that the sutures are obliterated.

In conclusion above it may possibly be concluded that this specimen is from an adult female.

ZC10. (Pl. II, Fig. 4; Pl. VII, Figs. 1 and 2) The skull is 921 mm in length and this is the largest skull among my collection. It exhibit characters of an adult female. The mesorostral bone is less developed and there is a low and narrow ridge which runs from the tip of the vomer, about 10 cm from the tip of the rostrum, posteriorly to the prenarial region where the anterior end of the bony ethmoid rests. The height of the ridge is about 5 mm at the highest part and well below the level of the premaxillaries. No prenarial basin is developed. The broadened part of the right premaxillary is nearly flat, except the extreme outer part where a ridge is formed.

This specimen has 47 vertebrae and all of the epiphyses are so entirely fused that the sutures are obliterated. No tooth was left from this specimen, but the size of the mandibular alveoli is small as stated already. Accordingly this specimen is possibly from an adult female.

Skull proportions. The measurements of each skull are shown in Table 1 in actual length in mm. The measurement numbers are those used by Moore (1963) and followed by Mitchell and Houck (1967) and Mitchell (1968). These are as follows:

Descriptions of measurements provided in Table 1.

1. Greatest length of skull.
2. Greatest length of rostrum, tip of beak to line connecting apices of antorbital notches.
3. Tip of rostrum to posterior margin of pterygoid nearest mid-sagittal plane.
4. Tip of rostrum to most posterior extension of wing of pterygoid.
5. Tip of rostrum to most anterior extension of pterygoid.
6. Tip of rostrum to most posterior extension of maxillaries between the pterygoids on the palate.
7. Tip of rostrum to most posterior extension of maxillary plate.
8. Tip of rostrum to anterior margin of superior nares.
9. Tip of rostrum to most anterior point on premaxillary crest (i.e. to anterior tip of nasals).

10. Tip of rostrum to most posterior extension of temporal fossa.
11. Tip of rostrum to most posterior extension of lateral tip of left premaxillary crest.
12. Tip of rostrum to most anterior extension of pterygoid sinus.
13. Greatest length of temporal fossa.
14. Greatest length of orbit.
15. Greatest length of right nasal on vertex of skull.
16. Length of nasal suture.
17. Greatest breadth of skull across postorbital processes of frontals.
18. Greatest breadth of skull across zygomatic processes of squamosals.
19. Greatest breadth of skull across centers of orbits.
20. Least breadth of skull across posterior margins of temporal fossae.
21. Greatest span of occipital condyles.
22. Greatest width of an occipital condyle.
23. Greatest length of an occipital condyle.
24. Greatest breadth of foramen magnum.
26. Greatest breadth of nasals on vertex.
27. Least distance between premaxillary crests.
29. Greatest span of premaxillary crests.
30. Least width (strictly transverse) of premaxillae where they narrow opposite superior nares.
31. Greatest width of premaxillae anterior to place of measurement no. 30.
32. Width of premaxillae at midlength of rostrum.
33. Width of rostrum in apices of antorbital notches.
34. Width of rostrum in apices of prominential notches.
35. Greatest width of rostrum at midlength of rostrum.
36. Greatest depth of rostrum at midlength of rostrum.
37. Greatest transverse width of superior nares.
38. Greatest inside width of inferior nares, at apices of pterygoid notches, on the pterygoids.
39. Height of skull. Distance between vertex of skull and most ventral point on pterygoids.
40. Greatest width of temporal fossa approximately at right angle to greatest length.
41. Least distance between main or anterior maxillary foramina.
42. Least distance between premaxillary foramina.
43. Distance from posterior margin of left maxillary foramen to most anterior extension of left maxillary prominence.
44. Greatest length of vomer visible at surface of palate.
45. Amount added to skull length because of breakage of occipital condyle.

The measurement number 45 of Moore is "Amount added to beak because of breakage ", but it is slightly changed. In the present specimen some skulls were cut open of their supraoccipital bones triangularly by saw in order to extract brain for the anatomical study at the Department of Anatomy, Faculty of Medicine, University of Tokyo. Most of them were so carefully cut that the occipital condyles were not damaged, but in the specimens ZC6 and ZC8 their tips were slightly cut down. Accordingly I have estimated the lost length, comparing them with other specimens.

Mitchell and Houck (1967) have studied some of the differences between the large male and female skulls on the one hand and the juvenile male skull on the other. I have tried to find out the difference in the skull proportion, if any, which separates

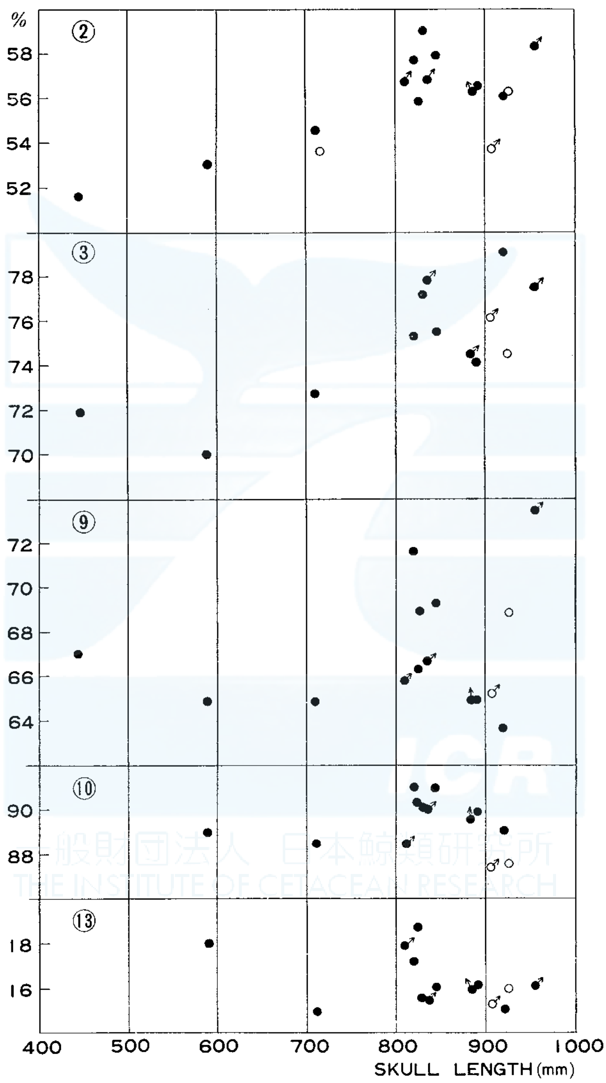
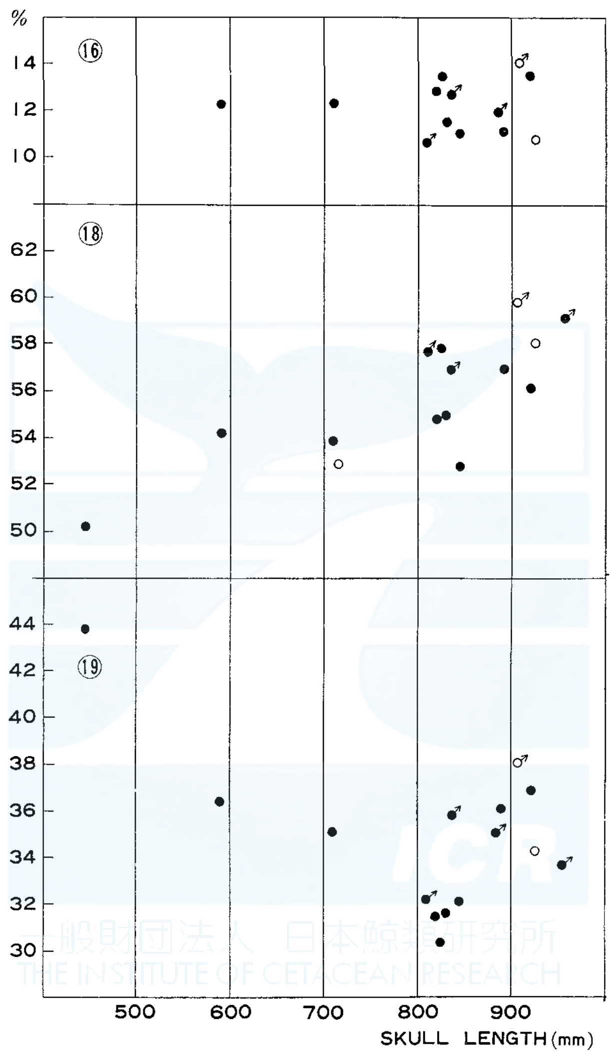


Fig. 3. Skull proportion of *Ziphius cavirostris* in the North Pacific. Closed circle indicates specimens from the northwest Pacific, and open circle those from the northeast Pacific. Presumed adult males are denoted by male symbol. Numeral in circle in each figure indicates measurement number described in the text.

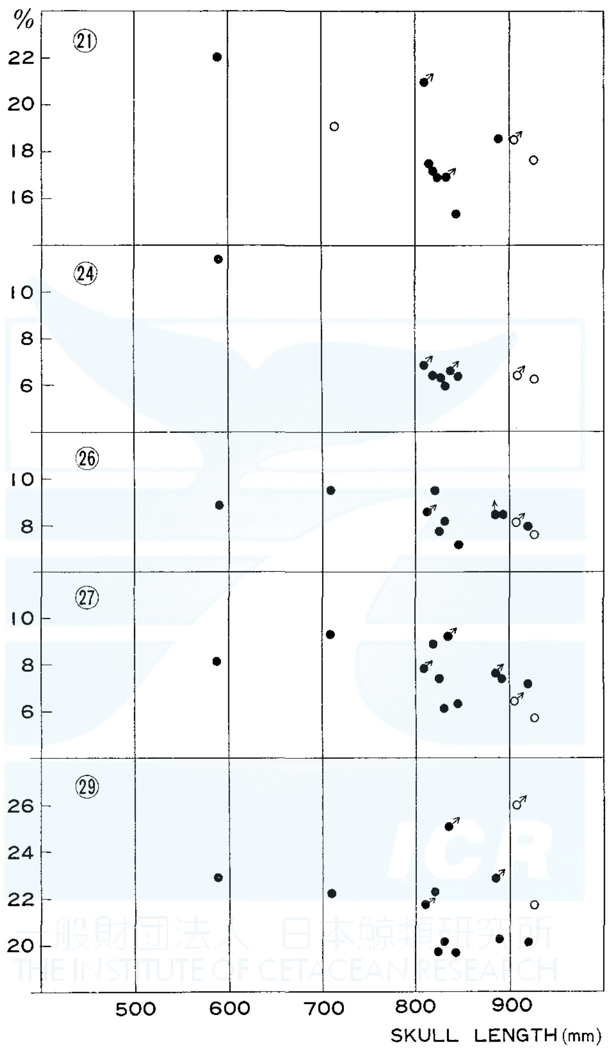
the adult male from the adult female and/or juvenile as well as the proportional change according to growth of the skull. I have calculated the percentage figures against the skull length of the measurements and then plotted them in the order of skull length (Fig. 3). In Fig. 3 I also included two skulls reported by Ogawa (1936–37). One of these skulls is the smallest which measures 445 mm in length, and ob-



Fig, 3. Continued.

tained from a female of 247.6 cm long, taken off Shiogamashi, Miyagi-ken. The other skull is the largest and measures 956 mm in length, obtained from a 590 cm long male at Taiji. I also included, for the sake of comparison between skulls from the northwest and northeast Pacific, a skull reported by Hubbs (1946), of which length is 716 mm and obtained from an immature female, and two skulls reported by

Mitchell and Houck (1967). The skull length of their specimens are 907 mm (HSC 57–1) and 923 mm (HSC 59–3), and the former is from a male and the latter from a female. Both are presumed to be adult in their report. Further, Mitchell (1968) reports measurements of skulls of northeast Pacific, but they are not cited in Fig. 3, mainly due to the unknown sex and maturity.

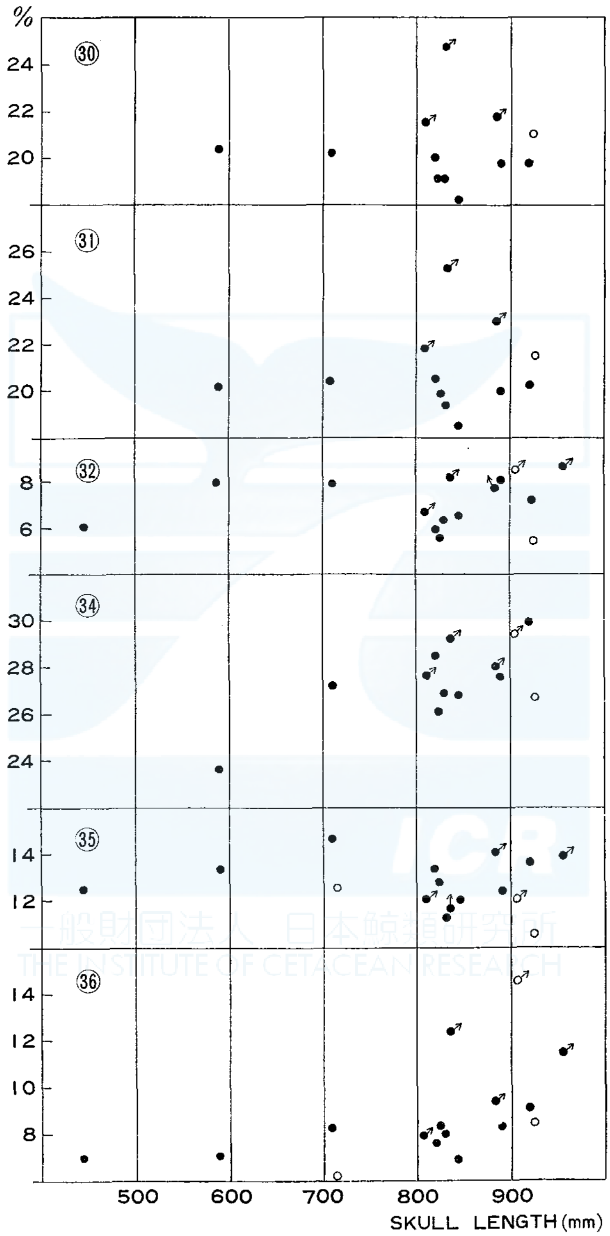


Fig, 3. Continued.

In this figure the skulls of the northwest Pacific are marked by closed circle and those from the northeast Pacific by open circle. The skulls presumed to be adult male are so marked with symbol, and others without symbol. As to the specimens of the other authors I calculated the percentage figures from their measurements.

As seen in this figure there are a wide range of variation and it seems that the individual difference is much greater than the difference by sexes. But in some characters the presumed adult male is separated from the others. These measurements are the following:

30. Least width (strictly transverse) of premaxillae where they narrow opposite superior nares.



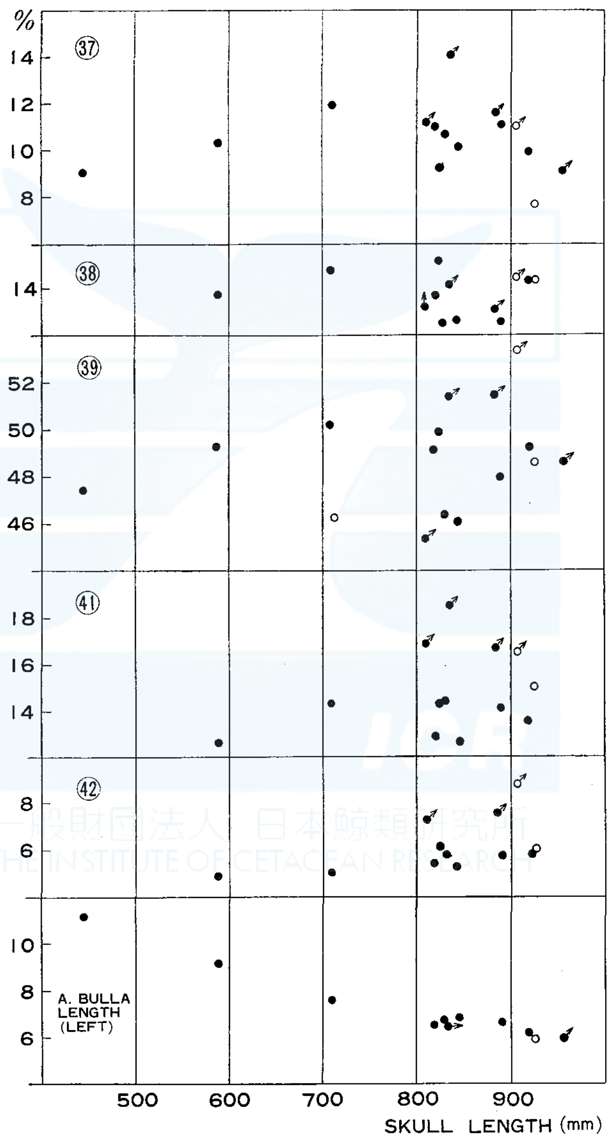
Fig, 3. Continued.

31. Greatest width of premaxillae anterior to place of measurement no. 30.
41. Least distance between main or anterior maxillary foramina.
42. Least distance between premaxillary foramina.

And also in the following measurements the presumed adult male shows greater value than the others with a few exceptions.

29. Greatest span of premaxillary crest.
36. Greatest depth of rostrum at midlength of rostrum.

Most of the above characters concern to the width of the premaxillae and it is



Fig, 3. Continued.

possible that in the adult male the width of the premaxillae posterior to the midlength of the rostrum is greater than in females and juvenile animals. It is also possible that in the adult male the depth of the rostrum increases with age and in the old aged male the greatest depth of rostrum at its midlength is very conspicuous.

The absolute length of the whale body is no good criterion of maturity in *Ziphius cavirostris* (Mitchell and Houck, 1967) and this is also applied to the skull length, as suggested by the present material. But in Fig. 3 there are suggested some general trend of the proportional changes in some of the measurements. They can be grouped in the following three categories:

1) The proportion increases with the growth of the body or age.

2. Greatest length of rostrum, tip of beak to line connecting apices of antorbital notches.
3. Tip of rostrum to posterior margin of pterygoid nearest mid-sagittal plane.
18. Greatest breadth of skull across zygomatic processes of squamosals.
29. Greatest span of premaxillary crests. Male.
30. Least width (strictly transverse) of premaxillae where they narrow opposite superior nares. Male.
31. Greatest width of premaxillae anterior to place of measurement no. 30. Male.
34. Width of rostrum in apices of prominential notches.
36. Greatest depth of rostrum at midlength of rostrum. Male.
41. Least distance between main or anterior maxillary foramina. Male.
42. Least distance between premaxillary foramina. Male.

2) Practically no proportional change is observed with age.

10. Tip of rostrum to most posterior extension of temporal fossa.
13. Greatest length of temporal fossa.
16. Length of nasal sutures.
26. Greatest breadth of nasals on vertex.
27. Least distance between premaxillary crests.
32. Width of premaxillae at midlength of rostrum.
35. Greatest width of rostrum at midlength of rostrum.
37. Greatest transverse width of superior nares.
38. Greatest inside width of inferior nares, at apices of pterygoid notches, on the pterygoids.

3) The proportion decreases with age.

21. Greatest span of occipital condyles.
24. Greatest breadth of foramen magnum.

Addition. Greatest length of auditory bulla.

The last mentioned measurement, greatest length of auditory bulla, is not included in the Moore's measurements, but I added this measurement in Table 1, following after Mitchell and Houck (1967).

In conclusion above the length of the rostrum becomes larger proportionally with age, and it becomes more wider at the base, but not at its midlength. The proportional breadth of the skull is also becomes wider with age.

TABLE 2. COMPARISON OF SKULL MEASUREMENTS BETWEEN ADULT MALE AND OTHERS, EXPRESSED AS PERCENTAGE OF SKULL LENGTH.

Measurement no.	Presumed adult male			Adult female and/or juvenile*		
	Number	Range	Mean	Number	Range	Mean
2	3	56.32–56.75	56.60	6	55.77–58.96	57.15
3	2	74.38–77.78	76.08	5	74.19–79.04	76.18
4	2	78.33–82.08	80.21	5	78.00–82.95	80.84
5	3	47.97–49.34	48.47	6	47.27–51.03	49.02
6	3	52.33–54.25	53.17	6	49.73–55.33	52.51
7	3	84.96–88.65	86.99	6	83.50–89.35	86.94
8	3	65.47–68.46	66.77	6	66.11–70.02	67.89
9	3	64.90–66.55	65.76	6	63.74–71.06	67.37
10	3	88.41–89.96	89.33	6	89.14–90.96	90.21
11	3	76.82–78.78	77.91	6	76.11–82.42	79.20
12	3	51.66–53.05	52.28	6	50.62–53.79	52.75
13	3	15.35–17.76	16.38	6	14.98–18.71	16.41
14	3	13.92–15.66	14.68	6	14.59–16.59	15.56
15	3	12.08–14.34	13.17	6	11.85–14.95	13.48
16	3	10.60–12.66	11.70	6	11.11–13.49	12.25
17	2	58.06–58.08	58.07	6	53.08–58.02	56.08
18	2	56.87–57.71	57.29	6	52.73–57.84	55.56
19	3	53.39–56.32	54.73	6	51.78–56.14	54.04
20	3	32.18–35.84	34.37	6	30.38–36.92	33.11
21	2	16.85–20.96	18.91	5	15.28–18.52	16.90
22	2	6.45– 8.14	7.30	5	5.86– 7.74	6.43
23	2	11.41–12.58	12.00	4	10.31–11.62	11.15
24	2	6.57– 6.78	6.68	4	6.05– 6.35	6.28
26	3	8.35–10.39	9.08	6	7.11– 9.40	8.10
27	3	7.56– 8.24	7.86	6	6.05– 8.91	7.17
29	3	21.82–25.09	23.24	6	19.67–22.34	20.39
30	3	41.45–24.73	22.65	6	18.25–20.02	19.33
31	3	21.82–25.33	23.39	6	18.48–20.51	19.76
32	3	6.66– 8.12	7.48	6	5.59– 7.97	6.57
33	3	34.05–35.51	34.66	6	34.39–37.24	35.78
34	3	27.62–29.15	28.25	6	26.12–29.86	17.62
35	3	11.71–14.11	12.59	6	11.26–13.57	12.54
36	3	7.89–12.43	9.90	6	6.75– 9.12	8.00
37	3	11.22–14.22	12.36	6	9.23–11.11	10.32
38	3	12.98–14.10	13.41	6	12.35–15.06	13.41
39	3	45.25–51.37	49.32	6	45.97–49.94	48.06
40	3	7.77–11.34	9.79	6	9.69–12.76	10.76
41	3	16.59–18.52	17.33	6	12.68–14.41	13.68
42	2	7.27– 7.45	7.36	6	5.33– 6.08	5.70
43	3	13.86–18.96	16.41	6	14.77–18.32	16.46
44	3	25.03–37.40	30.22	6	23.46–31.48	28.12
AB**–left	1	—	6.45	5	5.75– 6.40	6.14
AB**–right	1	—	6.78	5	6.19– 6.75	6.58

* Exclude smaller skulls than 800 mm in length.

** Greatest length of auditory bulla.

The temporal fossa, nasals, superior and inferior nares retain their size in porportion to their skull length, but the occipital condyles and the tympanic bulla grow very little with age, and hence their proportional sizes decrease with the growth of the skull.

Distinctions of adult male were already mentioned. One interesting feature among the measurements is the difference in the lengths of the right and left auditory bullae. In the seven skulls in which both bullae were retained, the right bulla is always greater than the left (see Table 1). In the skulls reported by Mitchell and Houck (1967) also the right bulla is longer than the left in two skulls with both bullae (HSC 57–2, HSC 59–3). It is not clear, however, whether or not this is related to some physiological matter such as difference in hearing between right and left ears in this species.

In Fig. 3 most of the measurements are shown in proportion to the skull length, but they do not cover all measurements. In Table 2 all measurements are arranged as percentages of skull length, separately by the presumed adult male and adult female and/or juvenile of my specimens. Of course more material, especially for the adult male, is needed for the tabulation of such nature. I present here this table, therefore, only for reference.

Further, I compared the proportions of the skull of the northwest Pacific specimens to those of the northeast Pacific specimens as reported by Mitchell and Houck (1967) and Mitchell (1968). They are partly included in Fig. 3. If all of the material from the northeast Pacific are plotted in Fig. 3 it shows more wide individual variation, and none of the difference between the specimens from the east and west North Pacific. But in the measurement no. 8, tip of rostrum to anterior margin of superior nares, some distinction is noted in which my measurement showing always smaller value, though this is not included in Fig. 3. It may possible, however, this is

TABLE 3. MEASUREMENTS OF MANDIBLES AND TEETH OF *ZIPHIUS CAVIROSTRIS* IN NORTHWEST PACIFIC.

Measurement no.	ZC 2	ZC 11	ZC 12	ZC 6	ZC 3	ZC 7	TWM 1	ZC 4	ZC 8	ZC 1*	ZC 10
a	494	605	710	718	737	730	753	737	777	—	808
b	91	108	134	158	156	162	153	157	171	—	145
c	85	111	130	139	138	170	140	160	186	—	170
d	261	330	341	397	391	393	420	413	417	—	451
e	101	120	150	134	138	136	139	137	160	—	156
f	24	38	45	40	49	35	49	46	50	—	48
g	—	374	423	416	443	403	434	422	474	—	488
h	—	—	49	—	—	—	48**	—	—	52	—
i	—	—	46	—	—	—	36**	—	—	55	—
j	—	—	11	—	—	—	21	—	—	11	—
k	—	—	11	—	—	—	22	—	—	12	—
l	—	—	10	—	—	—	15	—	—	10	—
m	—	—	10	—	—	—	15	—	—	9	—

* Only teeth were saved.

** Tip erased.

due to the difference in the method of measurement, because this is rather difficult to define and in the light of good agreement in the other measurements. I have not placed, therefore, much importance on this measurement.

In Table 3 measurements of mandibles and teeth are shown. It is regrettable that the teeth are lacking in most of the specimens and more mention on mandibles and teeth may not be needed here. The measurement number are as follows:

Descriptions of measurements of mandibles provided in Table 3.

a. Greatest length of right dentary bone.
b. Greatest length of right dentary to posterior end of symphysis.
c. Greatest length of right dentary to posterior border of mental foramen.
d. Greatest length of right dentary to anteromedial margin of mandibular vacuity.
e. Height at coronoid process.
f. Breadth of symphysis at posterior margin of mandibular alveoli.
g. Breadth of jaws across mandibular condyles.
h. Total length of tooth—*left*.
i. Total length of tooth—*right*.
j. Greatest diameter of tooth—*left*.
k. Greatest diameter of tooth—*right*.
l. Diameter at right angle to greatest diameter—*left*.
m. Diameter at right angle to greatest diameter—*right*.

VERTEBRAE (Pl. VI)

Complete sets of the vertebrae of *Ziphius cavirostris* in the northwest Pacific were secured from seven individuals. In some specimens the spinous and transverse processes, and sometimes the vertebral body too, were cut by saw just after the stranding by spectators. But still they are in such condition that they could be restored. Thus there is no difficulty in counting of their number and take measurements.

The vertebral formulae of each specimen are shown in Table 4. As seen from this table the total number of vertebrae is 46–47: cervical 7, dorsal 9–10, lumbar

TABLE 4. VERTEBRAL FORMULA OF *ZIPHIUS CAVIROSTRIS* IN NORTHWEST PACIFIC.

Specimen	Cervical	Dorsal	Lumbar	Caudal	Total
ZC 2	7	10	10	20	47
ZC 11	7	9	10	20	46
ZC 12	7	9	11	20	47
ZC 3	7	9	10	20	46
ZC 7	7	9	10	21	47
ZC 1	7	10	10	20	47
ZC 10	7	10	10	20	47

10–11, and caudal 20–21. True (1910) gives a table in which the vertebral formulae for eight specimens are shown, including those reported by the other authors. In his table the vertebral numbers are: cervical 7, dorsal 9–10, lumbar 9–11, caudal 19–20, and the total 46, excepting the specimens with question and the one which has 49 vertebrae, the Argentine specimen. But he comments " In the figures of the Argentine specimen the last ten caudals are practically without characters, and it is perhaps allowable to question whether the terminal two or three were not added to make an even taper to the end of the column. If such be not the case, this specimen had more vertebrae than any other ". It can be concluded, therefore, that in the vertebral count there is no distinct character which separates *Ziphius cavirostris* of the northwest Pacific from the other oceans.

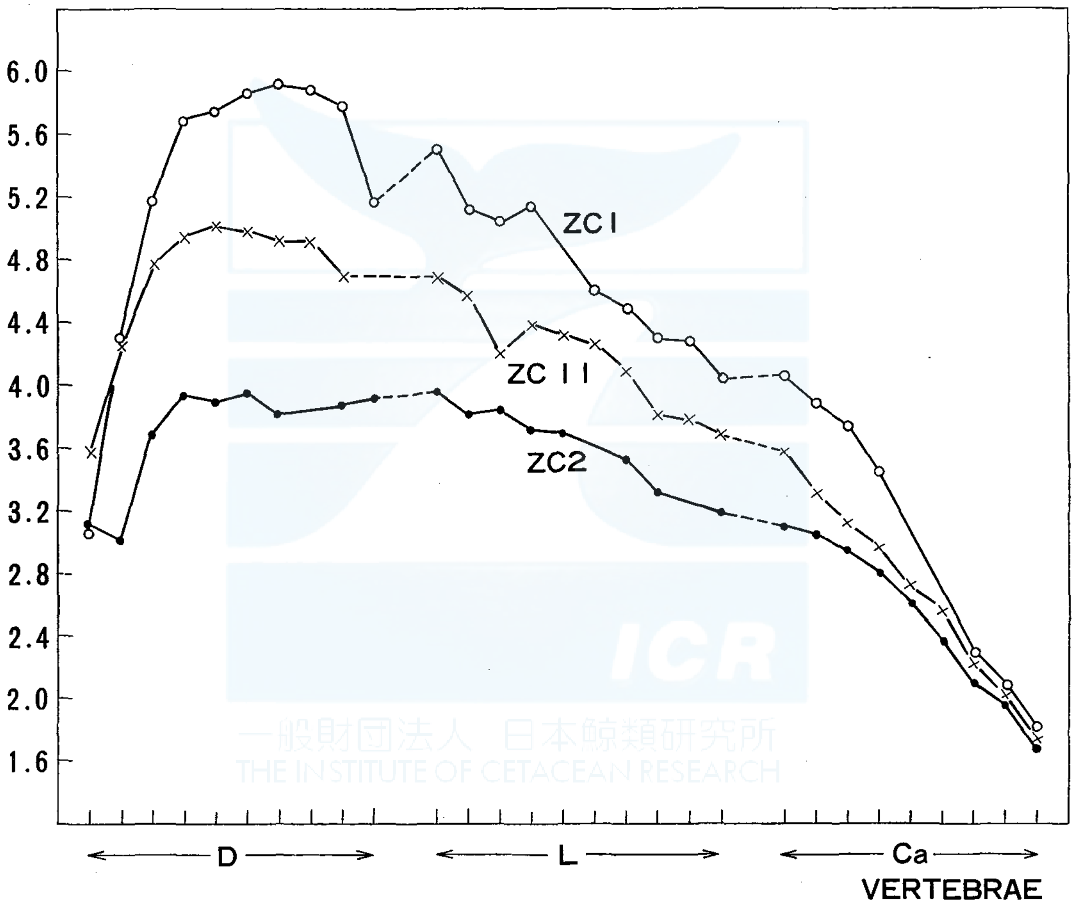


Fig. 4. Ratio of greatest height against height of centrum in each vertebra in dorsal, lumbar, and caudal vertebrae of *Ziphius cavirostris* in the northwest Pacific.

The measurements of vertebrae of the seven specimens are shown in Appendix Table with some notes of observations. Since the vertebrae were secured from the very young, juvenile, and adult animals it is possible to investigate the change in size of vertebrae according to the growth of the whale body.

In Fig. 4 are shown the ratios of the greatest height against the height of the centrum in each vertebra for the specimens ZC2 (very young), ZC11 (juvenile), and ZC1 (adult). This figure may demonstrate the relative height of the spinous process, and its change according to the age. As seen in this figure the relative height of the spinous processes becomes larger with growth, especially in the dorsal vertebrae, except the 1st dorsal.

In Fig. 5 are shown the ratios of the greatest breadth of each vertebra against its centrum breadth separately for the three specimens. This figure shows the relative growth of the transverse processes according to age, at least of those in the lumbar and caudal regions. It is of some interest to note that in the dorsal vertebrae the length of the transverse processes increase gradually, but in the 3rd vertebra anterior to the

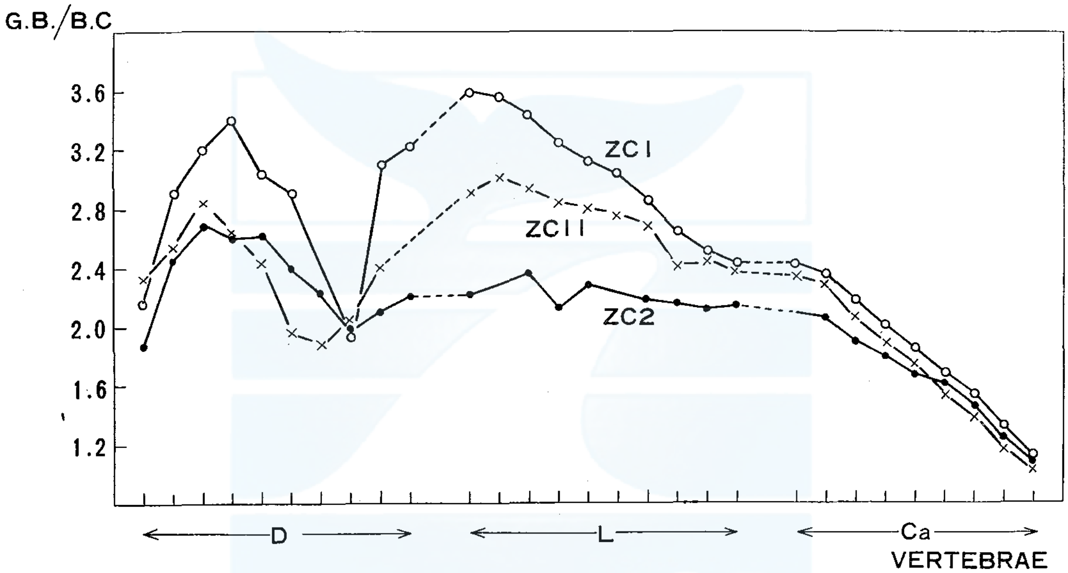


Fig. 5. Ratio of greatest breadth against breadth of centrum in each vertebra in dorsal, lumbar, and caudal vertebrae of *Ziphius cavirostris* in the northwest Pacific.

last it shows practically no relative growth and the value itself is very low, and after that vertebra they grow increasingly until the first lumbar where the value is greatest. This is partly due to the fact that in the dorsal vertebrae the transeverse processes are not situated at the level of the center of the centrum, but at more superior position, and in the 3rd vertebra anterior to the last they present at the highest position among the dorsal vertebrae. As seen in the Appendix Table the greatest breadth of this vertebra is always smaller than in the neighboring vertebrae.

Omura (1971) reports that in the baleen whales the long distant migrating species and fast swimmers have more developed vertebrae in the posterior portion of the lumbar and in the anterior portion of the caudal regions than in the other species. For the *Ziphius cavirostris* I also calculated the mean length of each centrum, using the same following formula:

Mean length $= \sqrt[3]{a \times b \times c}$

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

The calculated lengths are shown in Fig. 6 for the specimens ZC2, ZC11, ZC7 (larger juvenile than ZC11), and ZC1. This figure denotes that in this species the vertebrae in the posterior portion of the lumbar and in the anterior portion of the caudal regions become larger with the growth of the body. This fact is presumed to be applied to the other species of whales too.

In the *Ziphius cavirostris* the first several cervicals are fused into a mass. Among seven specimens four vertebrae, namely the atlas, axis, the 3rd, and the 4th cervicals are fused in five specimens, and the remainders are three and six, as noted in Appendix Table.

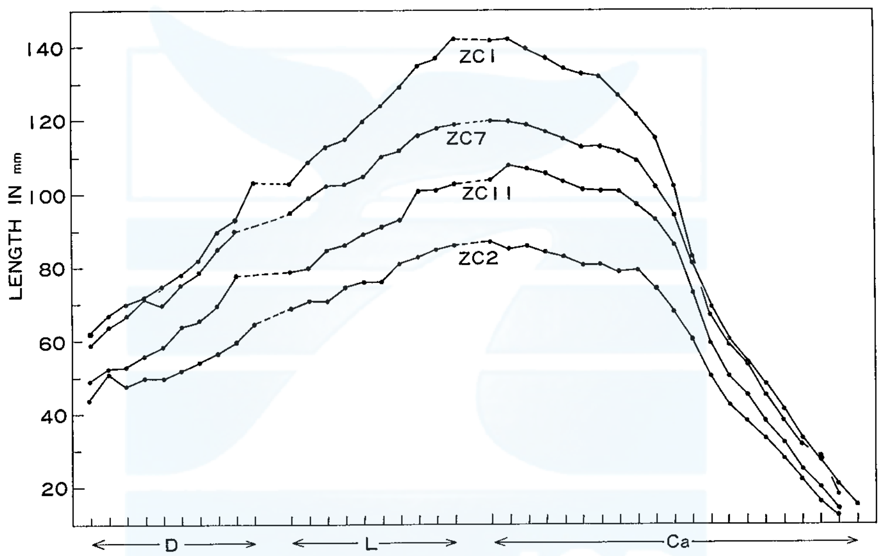


Fig. 6. Comparison of mean length of each vertebra in four specimens of *Ziphius cavirostris* in the northwest Pacific.

OTHER BONES

Rib. A complete set of ribs was obtained only from the specimen ZC3, and even in this specimen the last three (right side) and four (left side) ribs were cut into two or three fragments. The broken parts were restored and the measurements were made of their straight length, and the results are shown in Table 5.

Scapula (Pl. VII, Fig. 3) The scapula is fan shaped and the acromion is well developed with broadened distal end. The coracoid is also developed. From six specimens the scapulae were secured and their measurements are shown in Table 6.

The other bones e.g. sternum, hyoid, chevrons were also secured from some of the specimens, but they are mostly fragmental and have less value to report here, but the

TABLE 5. STRAIGHT LENGTH OF RIBS OF THE SPECIMEN ZC3.
(in mm)

Rib number	Right	Left	Rib number	Right	Left
1	453	435	6	753	745
2	614	595	7	745	740
3	698	693	8	710	710
4	755	753	9	630	635
5	770	763	—	—	—

TABLE 6. MEASUREMENTS OF SCAPULAE OF *ZIPHIUS CAVIROSTRIS* IN NORTHWEST PACIFIC. (in mm)

Specimen	Right		left	
	Breadth	Height	Breadth	Height
ZC 2	195	139	198	141
ZC 11	256	180	256	180
ZC 12	367	246	361	256
ZC 3	384	264	379+*	271
ZC 7	358	237	356	237
ZC 10	412	286	408	283

* Tip broken.

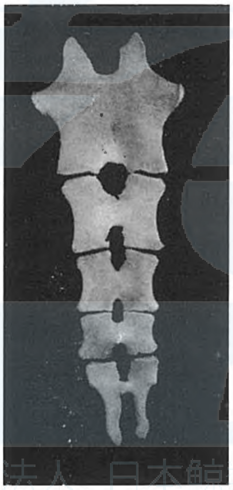


Fig. 7. Sternum of the specimen ZC 3.

sternum of the specimen ZC3 is complete (Fig. 7). It is consisted of five segments and the overall length is 796 mm and the greatest breadth of the first segment is 289 mm.

DISCUSSION

Among eleven skulls I investigated the most interesting one is the specimen ZC12. As I have already discussed this skull is presumed to be an adult male, chiefly due to the presence of the distinct prenarial basin. The skull measurements also suggest this to be the true. This specimen is the smallest among those with male symbols in

Fig. 3. As already mentioned, in the measurement number 29 (Greatest span of premaxillary crests) and 36 (Greatest depth of rostrum at midlength of rostrum) the adult male shows greater value than the others with a few exceptions, and this specimen is included among the exceptions in the both measurements. It is probable that the span of premaxillary crests and the depth of rostrum at midlength of rostrum will increase with age. The oldest male among my specimens is TWM1, next to the smallest in Fig. 3, judged from the well developed mesorostral bone with posterior truncation as well as the presence of the massive and fusiform teeth. This specimen shows far greater value in the both measurements than in the specimen ZC12. The teeth of the specimen ZC12 are slender and cylindrical in shape with closed roots. It is true that this specimen has already attained the physical maturity, but all evidences suggest that this specimen is not an old animal. Fraser (1942) describes " the massive fusiform teeth are indication of a late phase in the animal's life ", and it is possible that the passage from the cylindrical to the fusiform shape in the tooth of the male is brought about after the attainment of the physical maturity, but subject to the individual variation.

It is also suggested from the material used in this study that the development of the mesorostral bone is continued after the attainment of the physical maturity and the massive mesorostral with the posterior truncation in the male is completed with old age.

In seven specimens the mesorostral bone is recognized in varying degree of development, from mere a low ridge on the upper surface of the vomer (ZC7) to a well developed bone with posterior truncation (TWM1). These material confirms the finding by Fraser (1942) that the mesorostral ossification is demonstrably a development of the vomer, and not an ossification of the cartilaginous ethmoid.

On the other points I have already discussed in the foregoing chapters.

ACKNOWLEDGMENTS

My sincere thanks are due to Dr. Edward Mitchell of the Arctic Biological Station, Fisheries Research Board of Canada, who stimulated and encouraged me for the study of this species and kindly sent me a xeroxed copy of the very valuable literature on the skull of this species by Kernan (1918). I also express my gratitude to Dr. Richard G. Van Gelder of the American Museum of Natural History who sent me an original copy of the Kernan's paper, which contains many excellent photographs of bones of the skull, upon request from Dr. Mitchell.

REFERENCES

Backus, R. H. and W. E. Schevill, 1961. The stranding of a Cuvier's beaked whale (*Ziphius cavirostris*) in Rhode Island, U. S. A. *Norsk Hvalfangst-Tid.*, 50(5) : 177–181.

Fraser, F. C., 1942. The mesorostral ossification of *Ziphius cavirostris*. *Proc. Zool. Soc. London.*, (B) 112 : 21–30.

Galbreath, E. C., 1963. Three beaked whales stranded on the Midway Islands, Central Pacific Ocean. *J. Mamm.*, 44 : 422–423.

Harmer, S. F., 1927. Report on the cetacea stranded on the British coasts from 1913 to 1926. *Brit. Mus.* (*Nat. Hist.*), 10: 1–91.

Hubbs, C. L., 1946. First records of two beaked whales, *Mesoplodon bowdoini* and *Ziphius cavirostris*, from the Pacific coast of the United States. *J. Mamm.*, 27: 242–255.

Kernan, J. D., 1918. The skull of *Ziphius cavirostris*. *Bull. Am. Mus. Nat. Hist.*, 38: 349–394.

Mitchell, E., 1968. Northeast Pacific stranding distribution and seasonality of Cuvier's beaked whale *Ziphius cavirostris*. *Canadian J. Zool.*, 46: 265–279.

Mitchell, E., and W. J. Houck, 1967. Cuvier's beaked whale (*Ziphius cavirostris*) stranded in northern California. *J. Fish. Res. Bd. Canada.*, 24(12): 2503–2513.

Moore, J. C., 1963. Recognizing certain species of beaked whales of the Pacific Ocean. *Am. Mid. Natur.*, 70(2): 396–428.

Moore, J. C., 1968. Relations among the living genera of beaked whales with classifications, diagnoses and keys. *Fieldiana: Zoology.*, 53(4): 209–298.

Ogawa, T., 1936–37. Hompo no Hakujira ni kansuru Kenkyu (Studien über die Zahnwale in Japan). *Shokubutsu oyobi Dobutsu* (*Botany and Zoology*)., 4: 1159–1171, 1337–1344, 1495–1504, 1685–1694, 1837–1844, 2017–2024, 5: 25–34, 409–416, 591–598.

Omura, H., 1971. A comparison of the size of vertebrae among some species of the baleen whales with special reference to whale movements. *Sci. Rep. Whales Res. Inst.*, 23: 61–69.

Omura, H., K. Fujino, and S. Kimura, 1955. Beaked whale *Berardius bairdi* of Japan, with notes on *Ziphius carvirostris*. *Sci. Rep. Whales Res. Inst.*, 10: 89–132.

Rice, D. W. and V. B. Scheffer, 1968. A list of the marine mammals of the world. *U. S. Fish and Wildlife Ser. Spec. Sci. Rep. Fisheries.*, 579: 1–16.

Richards, L. P., 1952. Cuvier's beaked whale from Hawaii. *J. Mamm.*, 33: 255.

Tomilin, A. G., 1957. *Cetacea.* Mammals of the U. S. S. R. and adjacent countries (ed. S. I. Ognev) IX. English translation, Jersalem 1967, 717 pp.

True, F. W., 1910. An account of the beaked whales of the family Ziphiidae in the collection of the U. S. National Museum. *Bull. U. S. Nat. Mus.*, 73. 89 pp.

APPENDIX TABLE. MEASUREMENTS OF VERTEBRAE OF *ZIPHIUS CAVIROSTRIS* IN NORTHWEST PACIFIC. (in mm)

1. Specimen ZC 2

Serial no.	Vertebral no.	Greatest breadth	Greatest height (165 braced for C1–C4)	Centrum		(60 braced for C1–C3)	Notes
				Breadth	Height	Length	
1	C 1	168		151*	88*		* Articulating face.
2	2	136	165			60	Very young specimen.
3	3	88					All of the epiphyses are not
4	4	79		64	51	6	fused to their centra.
5	5	72	121	60	50	15	First 4 cervicals united
6	6	75	139	63	50	14	into a mass, but only
7	7	84	142	75	52	17	partly.
8	D 1	124	165	66	53	24	In vertebrae up to and
9	2	150	176	61	50	34	including 8th dorsal
10	3	149	180	55	49	41	the centra are not
11	4	141	185	54	47	49	fused with a mass of
12	5	131	187	50	48	52	processes, but separa-
13	6	122	193	51	49	56	rated. In 9th dorsal
14	7	117	195	52	51	60	these are fused, but
15	8	107	197+	54	53	64	sutures are visible.
16	9	128	205	61	53	67	10th dorsal and there-
17	10	158	216	72	55	70	after completely fused.
18	L 1	171	225	77	57	74	
19	2	164+	233	76	61	76	
20	3	174	241	74	63	78	
21	4	167	245	78	66	82	
22	5	177	248	78	67	85	
23	6	159+	246+	77	69	89	
24	7	172	254	79	72	92	
25	8	174	249	81	75	94	
26	9	181	245+	84	76	97	
27	10	183	245	85	77	98	
28	Ca 1	169+	233	88	75	99	
29	2	175	229	85	75	98	
30	3	163	224	87	76	95	
31	4	153	211	85	75	92	
32	5	143	196	85	75	89	
33	6	131	180	81	76	86	
34	7	118	163	81	78	83}	Transverse processes im-
35	8	103	148	82	76	80}	perfectly perforated
36	9	87	130	80	78	78	
37	10	—	113	75	77	71	Transverse processes dis-
38	11	—	93	66	74	65	appear.
39	12	—	70	63	65	52	
40	13	—	—	58	54	41	Spinous process disap-
41	14	—	—	51	43	34	pears.
42	15	—	—	48	36	31	
43	16	—	—	42	31	27	

Continued . . .

APPENDIX TABLE. Continued.

Serial no.	Vertebral no.	Greatest breadth	Greatest height	Centrum Breadth	Centrum Height	Centrum Length	Notes
44	17	—	—	35	25	24	
45	18	—	—	30	19	19	
46	19	—	—	22	13	15	
47	20	—	—	16	9	13	

2. Specimen ZC 11

Serial no.	Vertebral no.	Greatest breadth	Greatest height	Centrum Breadth	Centrum Height	Centrum Length	Notes
1	C 1	203	176	134*	88*	69	* Articulating face.
2	2	181		—	—		Juvenile. All of the epiphyses are not fused to their centra.
3	3	111		—	—		
4	4	83		73	60		
5	5	79	133	68	58	17	First 4 cervicals united into a mass, but the 4th fused only at the tip of spinous process.
6	6	87	145	68	58	17	
7	7	101	137	91	54	19	
8	D 1	166	199	72	56	29	
9	2	178	226	70	53	39	
10	3	173	243	61	51	49	
11	4	154	252	59	51	59	
12	5	144	256	59	51	64	
13	6	135	269	69	54	69	
14	7	129	270	69	55	75	
15	8	152	275	74	56	82	
16	9	211	285	88	61	87	
17	L 1	253	290	87	62	91	
18	2	254	293	84	64	96	
19	3	250	302	85	72	99	
20	4	248	315	87	72	101	
21	5	248	323	89	75	106	
22	6	245	328	89	77	109	
23	7	243	331	90	81	111	
24	8	236	335	98	88	119	
25	9	231	329	95	87	124	
26	10	231	324	97	88	127	
27	Ca 1	232	319	98	89	129	
28	2	229	317	101	96	129	
29	3	213	295	103	95	124	
30	4	194	281	104	95	121	
31	5	179	254	102	93	114	
32	6	159	236	103	92	110	
33	7	139	209	101	94	108	
34	8	119	190	103	94	105	Transverse processes imperfectly perforated.

Continued . . .

APPENDIX TABLE. Continued.

Serial no.	Vertebral no.	Greatest breadth	Greatest height	Centrum			Notes
				Breadth	Height	Length	
35	9	101	163	98	94	99	Left transverse process perforated.
36	10	—	138	90	94	94	Transverse processes dis-
37	11	—	112	83	90	84	appear.
38	12	—	82	76	78	65	
39	13	—	—	69	62	48	Spinous process disap-
40	14	—	—	62	51	40	pears.
41	15	—	—	55	45	37	
42	16	—	—	46	38	32	
43	17	—	—	38	31	29	
44	18	—	—	31	23	21	
45	19	—	—	25	15	20	
46	20	—	—	20	10	15	

3. Specimen ZC 12

Serial no.	Vertebral no.	Greatest breadth	Greatest height	Centrum			Notes
				Breadth	Height	Length	
1	C 1	} 300 (C 1–6)	} 220 (C 1–3)	163*	94*	} 135 (C 1–6)	* Articulating face.
2	2			—	—		Adult. All of the epiphyses are completely
3	3				—		fused to their centra.
4	4		162	—	—		First 6 cervicals are united, but the 6th fused
5	5		167	—	—		only at the inferior
6	6		172	81	83		part of the body.
7	7	131	190	115	69	25	Spinous processes are fused in 1–4th, and others free.
8	D 1	219	293	92	69	41	
9	2	236	351	82	66	56	
10	3	242	363	79	63	70	
11	4	230	351+	75	61	82	
12	5	211	340+	75	64	90	
13	6	204	382	75	67	94	
14	7	200	285	81	68	102	
15	8	265	395	88	69	110	
16	9	345	405	94	75	120	Facets for articulation for ribs present.
17	L 1	389	434	95	78	138	Posterior portion of the
18	2	385+	425+	114	109	133	1st and anterior por-
19	3	365	455	100	93	137	tion of the 2nd lum-
20	4	389	453	103	96	143	bar developed extra-
21	5	355+	459	105	98	147	ordinary and a pit
22	6	368	443+	107	104	150	present at the center of
23	7	282+	470	108	106	157	both centra.

Continued . . .

APPENDIX TABLE. Continued.

Serial no.	Vertebral no.	Greatest breadth	Greatest height	Centrum Breadth	Centrum Height	Centrum Length	Notes
24	8	346+	473	110	109	163	
25	9	260+	477	117	116	157+	
26	10	288+	479	119	118	175	
27	11	300	485	115	123	179	
28	Ca 1	305	467	115	118	180	
29	2	292	472	119	126	175	} Centra developed extraordinarily as in the case of the 1st and 2nd lumbars.
30	3	262	431	131	121	158+	}
31	4	215+	401	125	115	160	
32	5	231	375	128	115	151	
33	6	200	332	127	118	140	
34	7	173	295	123	119	135	} Transverse processes imperfectly perforated.
35	8	149	263	118	118	124	}
36	9	125	227	117	120	115	T.p. perforated.
37	10	—	192	106	118	106	T.p. disappear.
38	11	—	144	96	105	83	
39	12	—	101	88	91	62	
40	13	—	—	82	79	53	Spinous process disappears.
41	14	—	—	77	67	51	
42	15	—	—	68	58	43	
43	16	—	—	56	47	39	
44	17	—	—	49	37	35	
45	18	—	—	41	29	31	
46	19	—	—	37	28	28	
47	20	—	—	24	13	22	

4. Specimen ZC 3

Serial no.	Vertebral no.	Greatest breadth	Greatest height	Centrum Breadth	Centrum Height	Centrum Length	Notes
1	C 1	250	} 197 (1–4)	143*	86*	} 81 (1–4)	* Articulating face.
2	2	203		—	—		Adult. All of the epiphyses are fused to their centra but linea epiphysialis are visible up to 7th caudal.
3	3	133		—	—		
4	4	111		80	71		
5	5	90	151	78	71	18	First 4 cervicals united, but the 4th fused only at spinous and left transverse processes.
6	6	97	181	78	73	22	
7	7	107	207	106	76	27	
8	D 1	187	283	73	71	44	
9	2	207	346	76	68	57	
10	3	195	353	66	61	67	
11	4	180	359	64	60	78	
12	5	176	364	64	60	85	
13	6	179	367	66	61	91	
14	7	166	374	69	62	98	

Continued . . .

APPENDIX TABLE. Continued.

Serial no.	Vertebral no.	Greatest breadth	Greatest height	Centrum Breadth	Centrum Height	Centrum Length	Notes
15	8	210	384	74	64	104	
16	9	279	392	79	65	112	
17	L 1	353	409	82	73	119	
18	2	360	424	84	78	124	
19	3	355	440	85	82	128	
20	4	360	451	86	85	131	
21	5	357	455	89	86	136	
22	6	352	460	91	91	144	
23	7	340	458	94	97	150	
24	8	320	453	98	99	157	
25	9	318	444	102	101	164	
26	10	313	444	103	103	167	
27	Ca 1	321	433	105	106	168	
28	2	322	416	106	106	168	
29	3	302	410	109	104	164	
30	4	267	379	111	107	157	
31	5	242	347	114	104	149	
32	6	212	318	114	105	146	
33	7	187	287	112	105	141	Transverse processes per-
34	8	156	257	111	105	136	forated.
35	9	118	225	108	103	125	
36	10	98	189	96	101	115	
37	11	—	158	90	98	100	Transverse processes dis-
38	12	—	109	80	87	69	appear.
39	13	—	—	78	75	56	Spinous process disap-
40	14	—	—	69	58	51	pears.
41	15	—	—	69	52	47	
42	16	—	—	56	46	43	
43	17	—	—	50	36	38	
44	18	—	—	38	27	32	
45	19	—	—	33	18	29	
46	20	—	—	25	11	21	

5. Specimen ZC 7

Serial no.	Vertebral no.	Greatest breadth	Greatest height	Centrum Breadth	Centrum Height	Centrum Length	Notes
1	C 1	220 (1–3)	206 (1–3)	134*	90*	71 (1–3)	* Articulating face.
2	2			—	—		Juvenile. Epiphyses are
3	3			83	70		only fused to their centra in 4–5 cervicals and 11–17 caudals.
4	4	110	135	77	71	20	First 3 cervicals are unit-
5	5	96	162	74	71	20	ed into a mass as well
6	6	93	155	73	73	22	as their spinous pro-
7	7	138	181	72	71	28	cesses.

Continued . . .

APPENDIX TABLE. Continued.

Serial no.	Vertebral no.	Greatest breadth	Greatest height	Centrum			Notes
				Breadth	Height	Length	
8	D 1	186	263	71	65	45	
9	2	190	316	73	61	58	
10	3	182	328	74	59	69	
11	4	176	333	76	60	79	
12	5	180	331	69	60	84	
13	6	174	349	71	64	91	
14	7	144	347	75	68	96	
15	8	237	356	85	69	106	
16	9	285	358	89	73	111	Articulating facet for rib present.
17	L 1	289	373	91	80	116	
18	2	299	386	93	87	119	
19	3	295	402	96	89	124	
20	4	292+	413	96	90	128	
21	5	298	412	98	93	127	
22	6	290	430	99	99	134	
23	7	281	428	103	99	139	
24	8	267	429	106	102	144	
25	9	268	423	109	99	152	
26	10	265	419	107	102	155	
27	Ca 1	261	409	107	103	157	
28	2	253	384	108	104	155	
29	3	237	381	111	100	150	
30	4	214	359	113	100	143	
31	5	198	327	110	100	137	
32	6	179	304	108	102	131	
33	7	164	274	108	104	128	Transverse processes perforated imperfectly.
34	8	135	244	110	103	123	
35	9	108	240	105	105	119	
36	10	—	181	93	105	108	Transverse processes disappear.
37	11	—	145	86	103	94	
38	12	—	98	84	90	71	
39	13	—	—	77	75	56	Spinous process disappears.
40	14	—	—	70	63	48	
41	15	—	—	65	54	45	
42	16	—	—	58	47	41	
43	17	—	—	48	38	39	
44	18	—	—	39	28	34	
45	19	—	—	32	20	30	
46	20	—	—	26	14	25	
47	21	—	—	20	9	17	

Continued . . .

APPENDIX TABLE. Continued.

6. Specimen ZC 1

Serial no.	Vertebral no.	Greatest breadth	Greatest height	Centrum			Notes
				Breadth	Height	Length	
1	C 1	279		164*	—		* Articulating face.
2	2	240	236	—	—	83	Adult. All of the epi-
3	3	191		—	—		physes are fused to
4	4	124		87	72		their centra complete-ly.
5	5	101	150	81	73	25	First 4 cervicals fused
6	6	99	178	79	73	24	into a mass, including
7	7	170	224	92	76	26	spinous processes.
8	D 1	187	230	87	75	36	
9	2	226	318	78	74	52	
10	3	237	362	74	70	67	
11	4	242	380	71	67	78	
12	5	219	379	72	66	88	
13	6	222	397	76	68	93	
14	7	195+	408	78	69	101	
15	8	174	418	91	71	112	
16	9	282	421	91	73	121	
17	10	328	422	102	82	129	
18	L 1	360	439	100	80	138	
19	2	360	457	101	89	146	
20	3	354	470	103	93	149	
21	4	347	478	107	93	153	
22	5	336	—	108	101	158	
23	6	330	488	109	106	164	
24	7	323	492	113	110	173	
25	8	312	489	118	113	185	
26	9	303	490	121	114	185	
27	10	298	483	125	120	189	
28	Ca 1	300	483	124	119	192	
29	2	298	472	127	122	183	
30	3	285	441	131	118	177	
31	4	261	404	130	117	168	
32	5	239	—	129	114	162	
33	6	220	—	130	118	153	
34	7	195	283	127	123	147	
35	8	161	243	123	117	143	Transverse processes per-
36	9	129	213	115	117	134	forated.
37	10	—	177	108	115	121	Transverse processes
38	11	—	141	100	109	96	disappear.
39	12	—	—	92	93	65	Spinous process disap-
40	13	—	—	80	71	53	pears.
41	14	—	—	72	56	50	
42	15	—	—	65	50	48	
43	16	—	—	47	43	44	

Continued . . .

APPENDIX TABLE. Continued.

Serial no.	Vertebral no.	Greatest breadth	Greatest height	Centrum Breadth	Centrum Height	Centrum Length	Notes
44	17	—	—	42	33	39	
45	18	—	—	37	25	34	
46	19	—	—	31	27	27	
47	20	—	—	27	10	22	

7. Specimen ZC 10

Serial no.	Vertebral no.	Greatest breadth	Greatest height	Centrum Breadth	Centrum Height	Centrum Length	Notes
1	C 1	257 (1–4)	178 (1–4)	163*	100*	87 (1–4)	* Articulating face.
2	2			—	—		Adult. All of the epiphyses are fused to their centra completely.
3	3			—	—		
4	4			90	79		
5	5	95	147+	87	74	18	
6	6	107	209	85	76	19	First 4 cervicals fused into mass.
7	7	120	195	112	80	25	
8	D 1	203	273	94	79	40	
9	2	236	326	94	72	56	
10	3	239	358	93	67	70	
11	4	230	372	73	69	83	
12	5	218	385	74	66	93	
13	6	201	398	76	68	98	
14	7	183	405	81	70	105	
15	8	189	442	92	68	116	
16	9	283	419	95	71	121	
17	10	345	437	100	74	130	
18	L 1	372	449	102	83	136	
19	2	356	459	104	91	142	
20	3	356	469	105	95	144	
21	4	353	477	106	97	147	
22	5	343	484	108	105	153	
23	6	334	486	108	108	158	
24	7	325	491	111	111	167	
25	8	311	489	114	117	175	
26	9	308	485	119	118	179	
27	10	315	479	122	120	180	
28	Ca 1	310	475	130	127	181	
29	2	288	459	134	132	177	
30	3	265	431	131	126	168	
31	4	253	399	137	123	159	
32	5	240	369	136	123	152	
33	6	217	332	135	126	147	
34	7	193	303	136	121	145	
35	8	155	272	135	122	141	

Continued . . .

APPENDIX TABLE. Continued.

Serial no.	Vertebral no.	Greatest breadth	Greatest height	Centrum			Notes
				Breadth	Height	Length	
36	9	128	240	123	124	131	Transverse processes perforated.
37	10	—	207	110	124	123	Transverse processes disappear.
38	11	—	159	102	115	102	
39	12	—	106	93	97	67	
40	13	—	—	82	79	54	Spinous process disappears.
41	14	—	—	75	67	50	
42	15	—	—	69	61	45	
43	16	—	—	61	53	44	
44	17	—	—	55	45	42	
45	18	—	—	46	32	35	
46	19	—	—	40	23	28	
47	20	—	—	31	16	21	

EXPLANATION OF PLATES

PLATE I

Superior view of skulls of *Ziphius cavirostris* in the northwest Pacific.
Fig. 1. Specimen ZC 2. Skull length 590 mm. Very young. Sex unknown.
Fig. 2. Specimen ZC 11. Skull length 707 mm. Juvenile. Sex unknown.
Fig. 3. Specimen ZC 12. Skull length 811 mm. Adult male.
Fig. 4. Specimen ZC 6. Skull length 819 mm. Juvenile. Sex unknown.

PLATE II

Superior view of skulls of *Ziphius cavirostris* in the northwest Pacific.
Fig. 1. Specimen ZC 7. Skull length 826 mm. Juvenile. Sex unknown.
Fig. 2. Specimen ZC 4. Skull length 844 mm. Female.
Fig. 3. Specimen ZC 1. Skull length 891 mm. Adult female.
Fig. 4. Specimen ZC 10. Skull length 921 mm. Adult female.

PLATE III

Fig. 1. Inferior view of skull of *Ziphius cavirostris* in the northwest Pacific. Specimen ZC 11.
Fig. 2. Inferior view of skull of *Ziphius cavirostris* in the northwest Pacific. Specimen ZC 7.
Fig. 3. Posterior view of skull of *Ziphius cavirostris* in the northwest Pacific. Specimen ZC 12.
Fig. 4. Posterior view of skull of *Ziphius cavirostris* in the northwest Pacific. Specimen ZC 3.

PLATE IV

Lateral view of skull of *Ziphius cavirostris* in the northwest Pacific.
Fig. 1. Specimen ZC 6. Skull length 819 mm. Juvenile. Sex unknown.
Fig. 2. Specimen ZC 8. Skull length 886 mm. Adult male.
Fig. 3. Specimen ZC 3. Skull length 823 mm. Adult female.

PLATE V

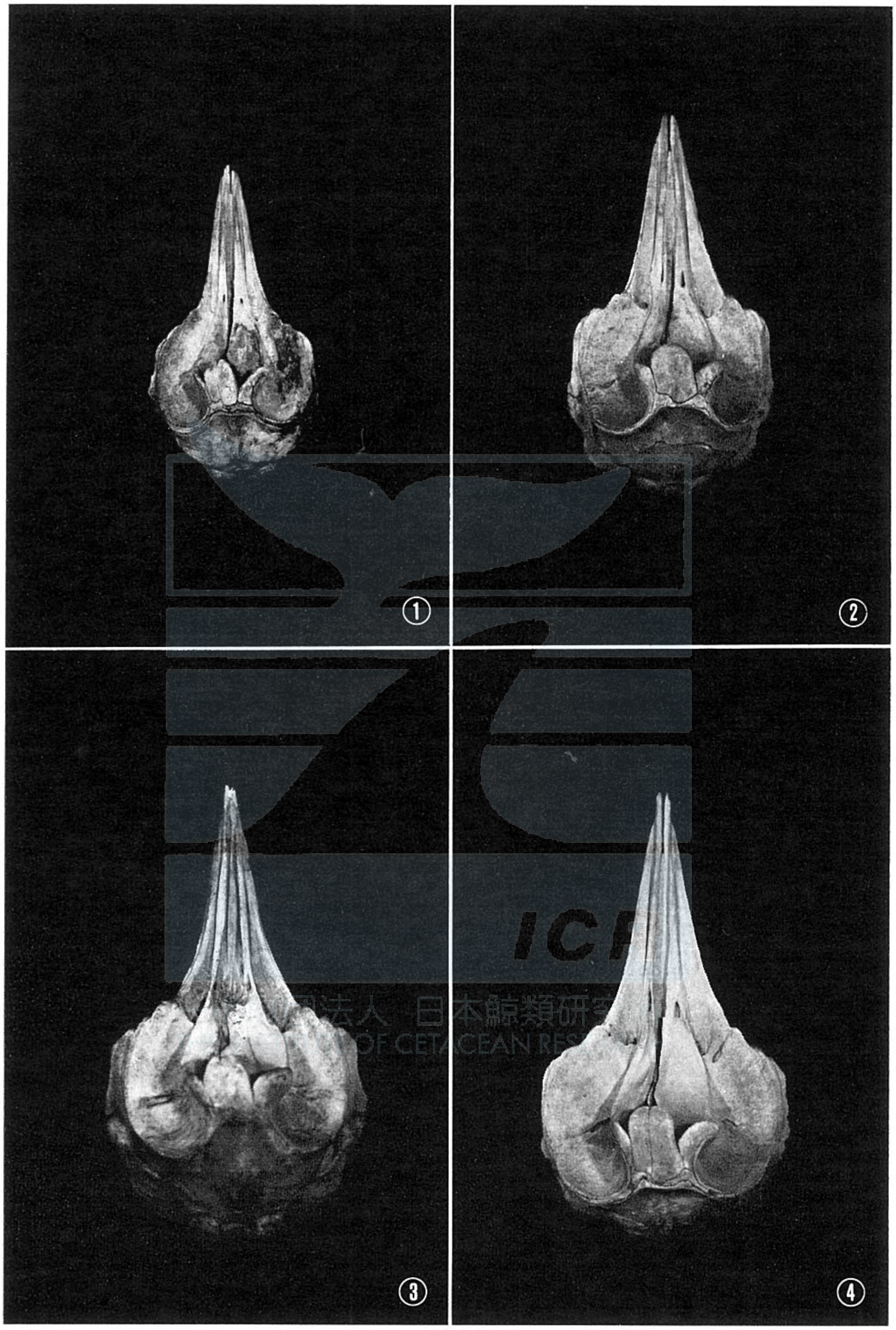
Skull of *Ziphius cavirostris* in the northwest Pacific. Specimen TWM 1. Skull length 837 mm. Old adult male.
Fig. 1. Lateral view.
Fig. 2. Anterior view, showing prenarial basin and a part of mesorostral bone.

PLATE VI

Vertebrae of *Ziphius cavirostris* in the northwest Pacific. Specimen ZC 3.
Fig. 1. Cervical and dorsal vertebrae.
Fig. 2. Lumbar vertebrae.
Fig. 3. Caudal vertebrae.

PLATE VII

Fig. 1. Mandible of *Ziphius cavirostris* in the northwest Pacific. Specimen ZC 10. Adult female. Lateral view.
Fig. 2. Mandibles of *Ziphius cavirostris* in the northwest Pacific.
Left: Specimen ZC 8. Adult male.
Right: Specimen ZC 10. Adult female.
Fig. 3. Scapulae of *Ziphius cavirostris* in the northwest Pacific. Specimen ZC 3.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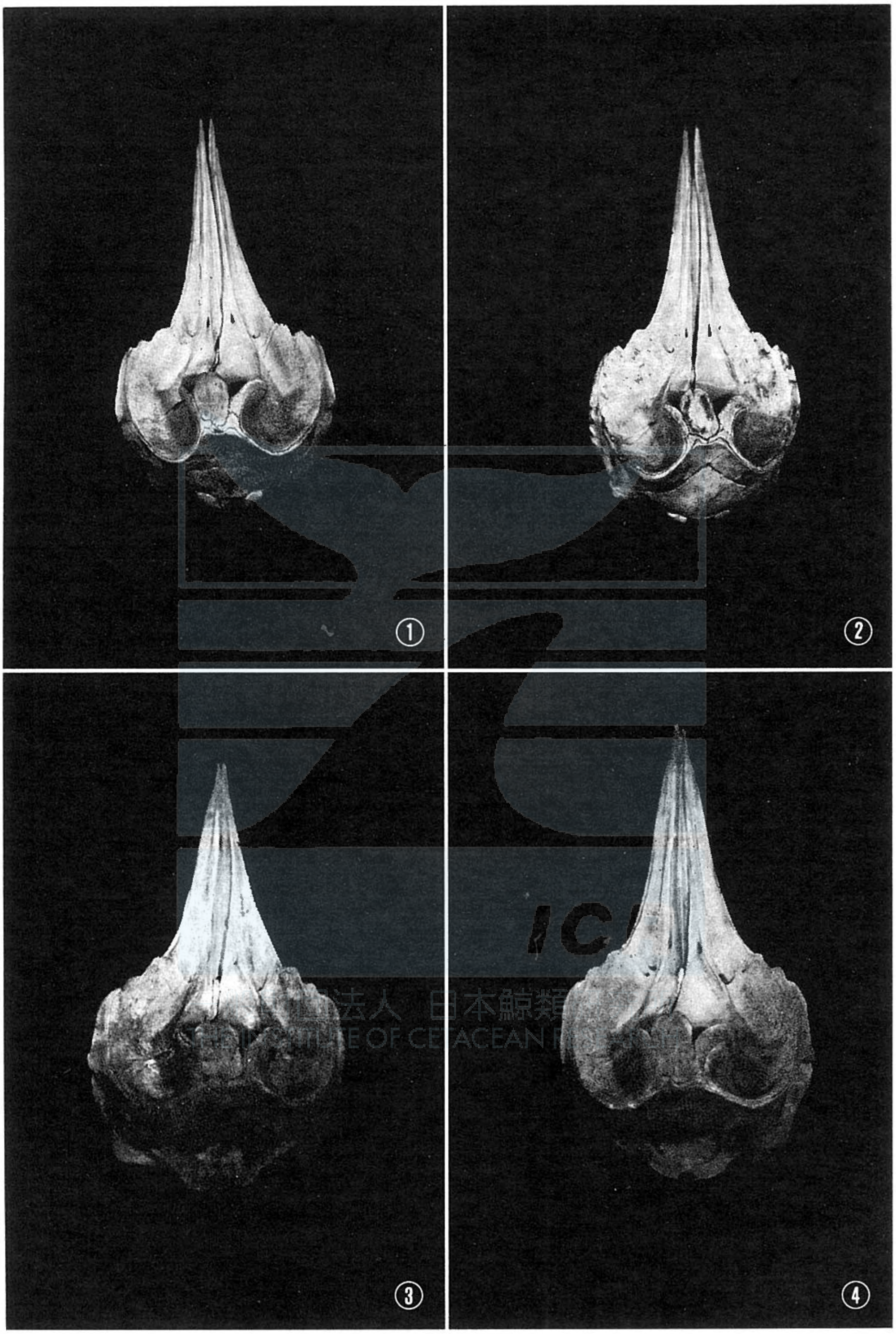
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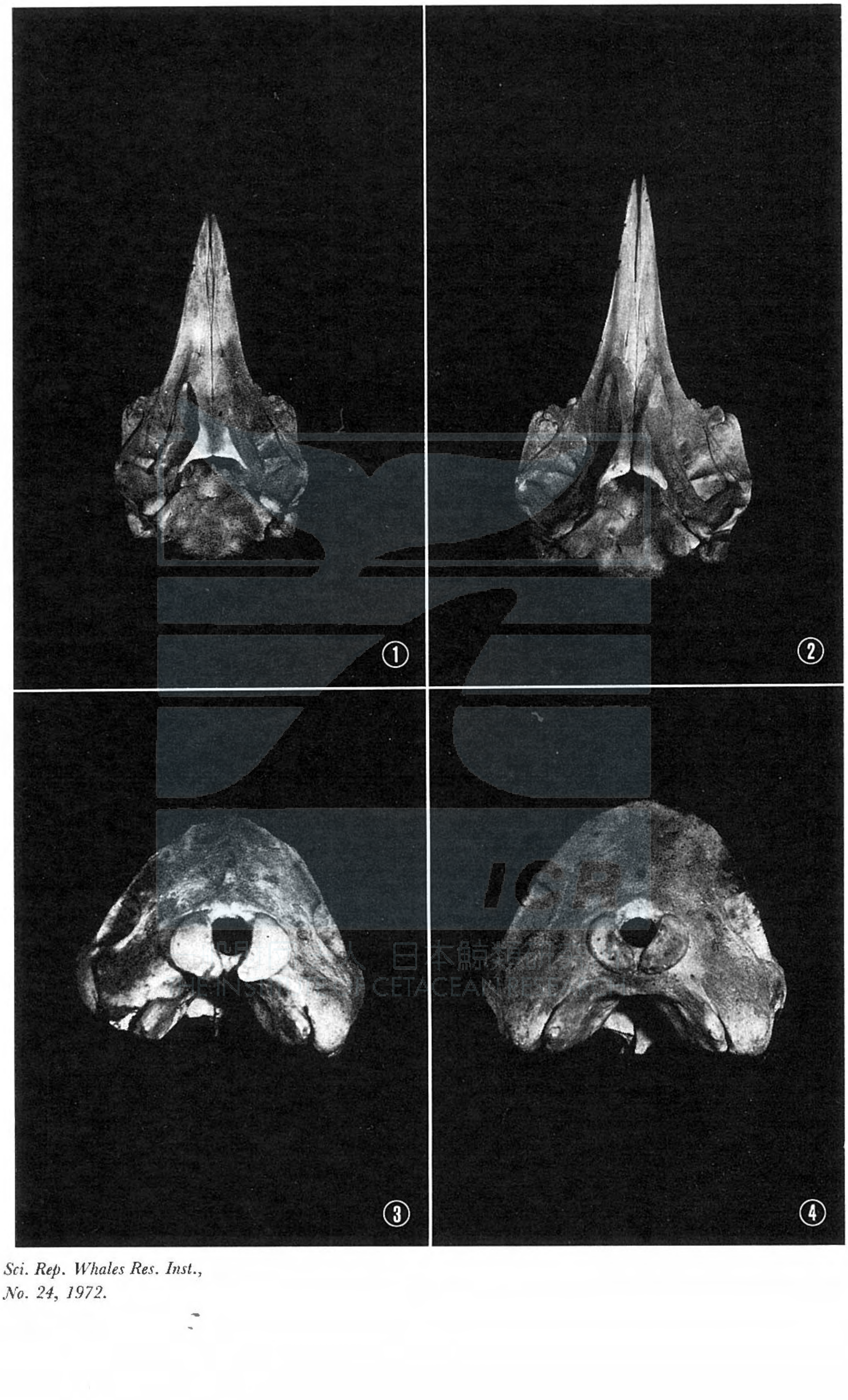
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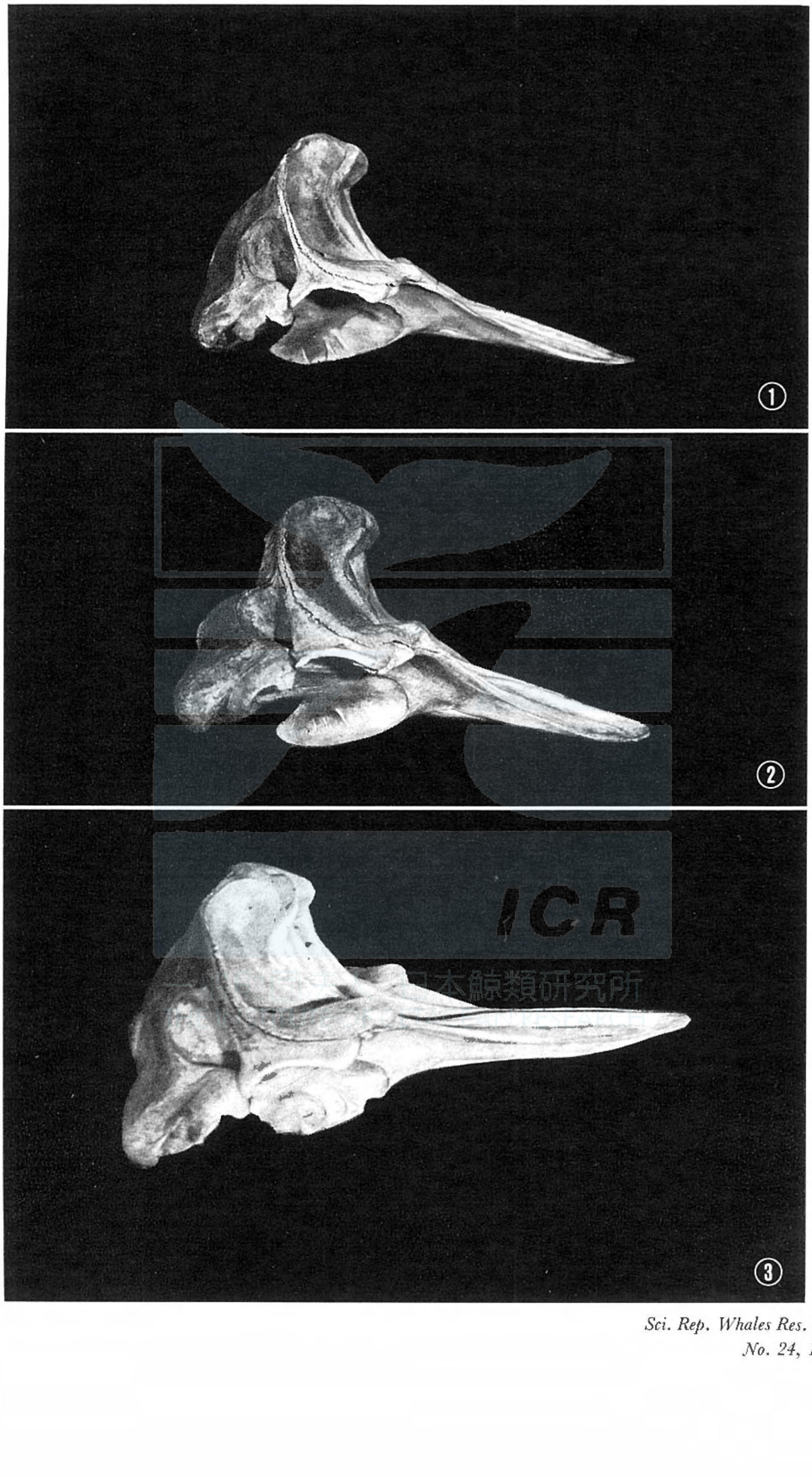
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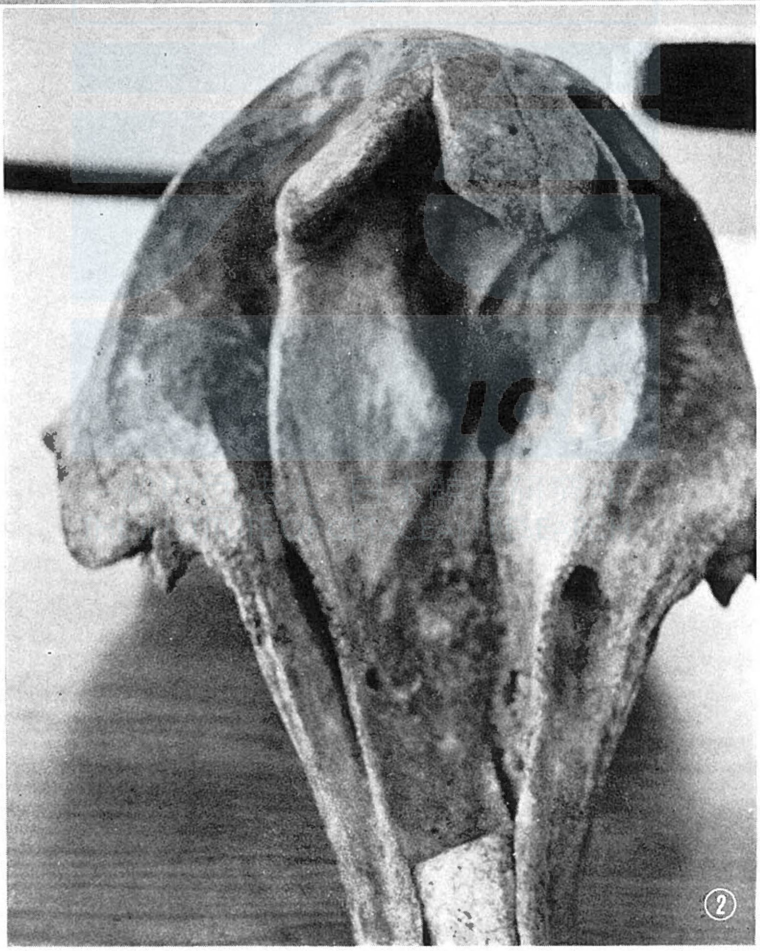

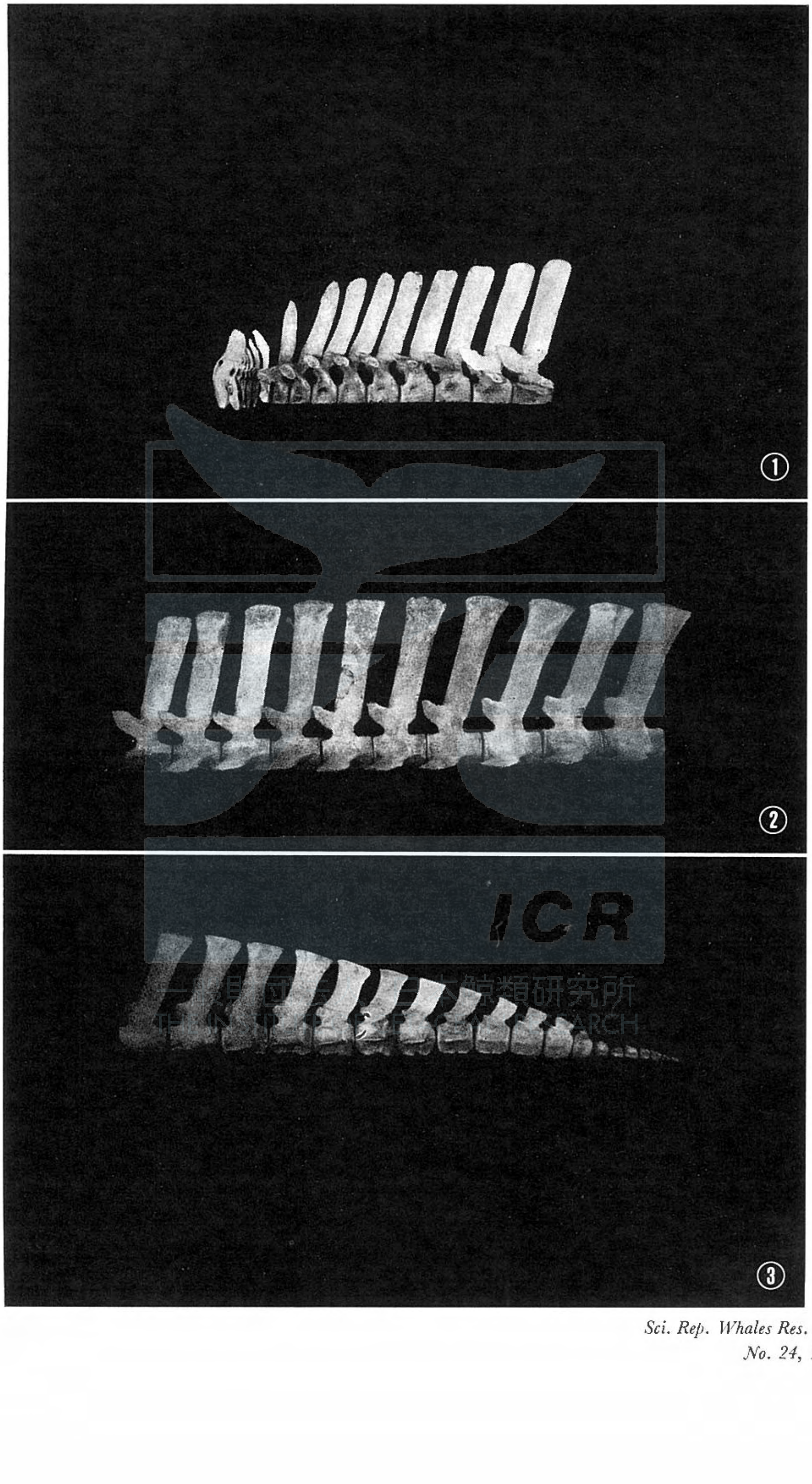
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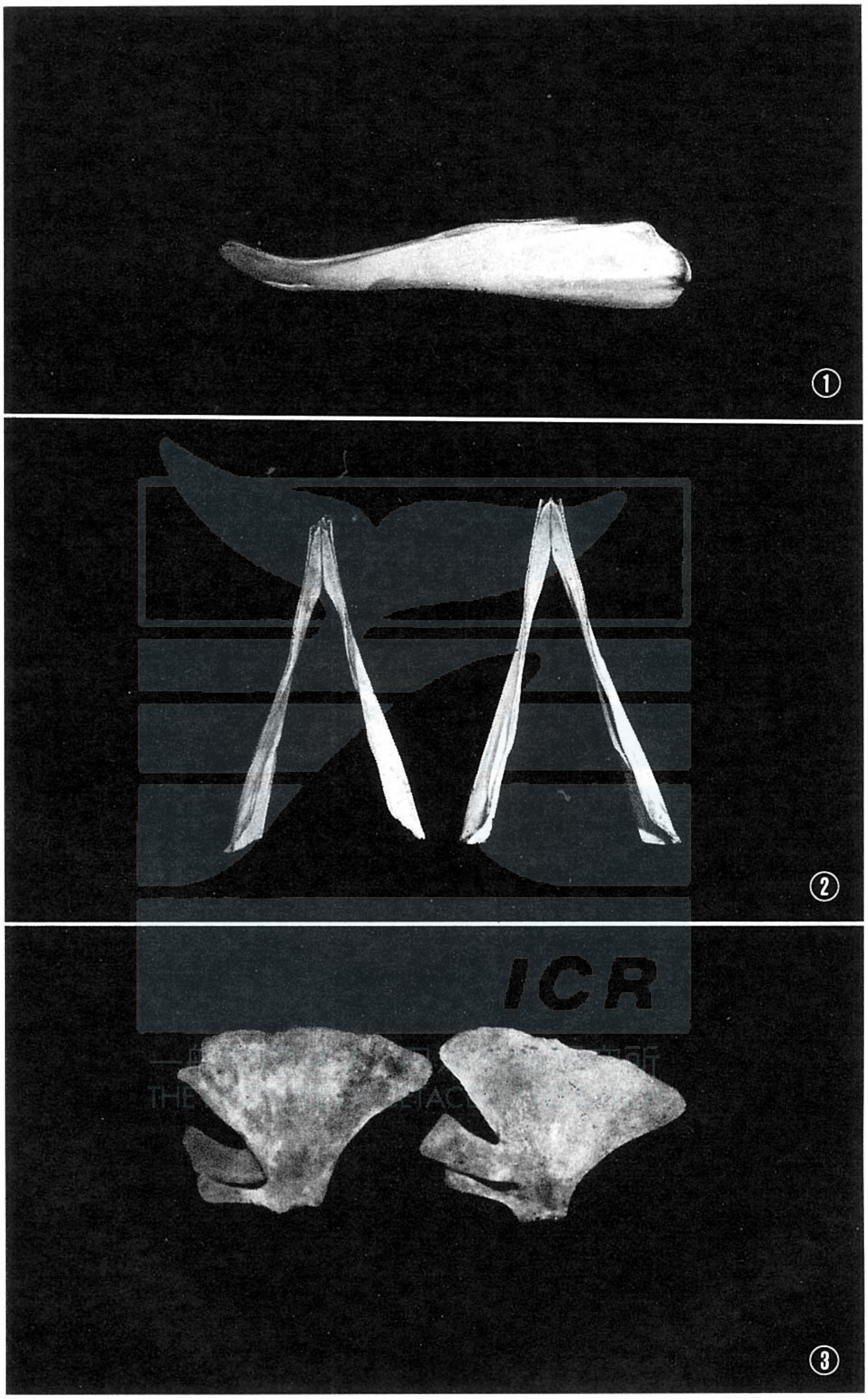
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