Skeletal Development of the Striped Dolphin
(Stenella coeruleoalba) in Japanese Waters

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Abstract. Development, sexual dimorphisms and individual differences of the skeleton of the striped dolphin (Stenella coeruleoalba) living off the Pacific coast of Japan were examined. As materials, 38 individuals were used. Cranial skeleton reach adult plateau at the age of 3. Earbone increases little after birth. Most of postcranial skeleton reach adult size at the age of 7–10. Length of thoracic and lumbar vertebrae, thylohyals, stylohyals, ribs and sternals continue to grow at the age of 15–19. Length of the 2nd–the 7th cervical vertebrae reach adult plateau at the age of 3. The front edge of the occipital in adult female overhangs the frontals to form a crest, but in adult males the crest is typically absent. Width of rostrum (except for at base) and length of basyhyal, the 2nd–8th ribs and pelvic bones are larger in male on average than in female. Individual differences are found in the number of vertebrae (77–81), chevron bones (26–31), phalanges of the 1st digit (3–4), the 2nd (5–8), the 3rd (7–10) and the 4th (2–3), teeth in upper left (43–52), upper right (43–52), lower left (41–50) and lower right (42–53). The species reaches physical maturity at ages between 15 and 19.

Key words : Stenella coeruleoalba ; Skeletal development ; Sexual dimorphism ; Individual variation ; Physical maturity

Introduction

The striped dolphin, Stenella coeruleoalba (Meyen, 1833), occurs in most tropical and temperate waters (Sampson, 1970; Hubbs et al., 1973; Perrin, 1975a; Miyazaki et al., 1974). Several thousand striped dolphins (mean of 6 seasons, 1976–1981: 6,718 individuals) were caught annually in past years by the driving method at Taiji, Futo and Kawana on the Pacific coast of Japan (Miyazaki, 1984). They are all considered to have belonged to one population (Miyazaki et al., 1974). In this study skeletons of this population are described. Skeletons are very important characters for taxonomic study. Perrin (1975b) collected large series of spotted and spinner dolphins (genus Stenella) in the eastern tropical Pacific and Hawaii. He described their variation not only in coloration and external morphology but also in osteology of the skeleton owing to development, sexual dimorphism, individual differences within schools and geographical differentiation. Several geographical races of the spotted and spinner dolphins are defined. Schnell et al. (1985) and Douglas et al. (1986) analyzed sexual dimorphism of spotted and spinner dolphins for each.
In the case of the striped dolphin, a method of age determination is established and its life history has been described (Kasuya, 1976; Miyazaki, 1977, 1984).

The present study was undertaken to examine the skeletal development of the striped dolphin in Japanese waters. We describe ossification, growth, sexual dimorphism, and individual variation in the cranial and postcranial skeleton, and address the question of when physical maturity is reached.

**Materials and Methods**

We examined 38 specimens collected from the Pacific coast of Japan. Complete skeletons were available for 19 specimens (Museum nos. M19772–19790) and skulls for 10 additional specimens (M19791 and M21385–21393), all deposited in the National Science Museum of Japan (Miyazaki, 1986). We also examined the skeleton of a newborn calf and the hyoids and dorsal vertebrae of 8 additional specimens. All were captured by the driving method at Taiji on the east coast of Kii Peninsula. Sixteen meristic observations and 63 measurements were employed. (Table 1 and Fig. 1). They comprise some of the characters used by Perrin (1975b) and additional ones devised by us.

Detached flippers were sun-dried and X-rayed. Flipper bones were counted and measured on X-ray photographs. Other bones were boiled to eliminate the soft tissue and then sun-dried. The measurements were taken with calipers to the nearest millimeter. The 31 measurements expressed as a proportions of condylobasal length are shown in Appendix 1.

Dissection of the tip of the rostrum and lower jaws was carefully carried out so that all teeth would be counted. For age determination, teeth were prepared by staining with haematoxylin after decalcification of thin ground sections (10 to 20 μm) in a 5% water solution of formic acid, based on Kasuya’s method (Kasuya, 1976). Although reading of growth layers in the dentine is easier than reading those in the cementum for the younger animals, it becomes more difficult for animals older than the age of 16 because of the formation of osteodentine inside the pulp cavity. In the present study, age was determined mainly by counting the growth layers in the dentine for animals younger than the age of 10 and by counting them in the cementum for animals older than 10. Ages for specimens younger than 2 were estimated by using a published growth curve (Miyazaki, 1977). Differences between males and females were examined with a t-test (95% confidence).

**Ossification**

*Cranial skeleton*

**Skull.** The progress of ossification is summarized in Table 2.

A newborn calf has large fontanelles at the confluence of the parietal, exoccipital and supraoccipital bones. The bony septum and the partitions between the alveoli are yet ossified. The condyle of the mandible, the coronoid
### Table 1. Skeletal measurements and meristics

<table>
<thead>
<tr>
<th>No.</th>
<th>Measurements and meristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Condylobasal length - from tip of rostrum to hindmost margin of occipital condyles.</td>
</tr>
<tr>
<td>2.</td>
<td>Length of rostrum - from tip to line across hindmost limits of antorbital notches.</td>
</tr>
<tr>
<td>3.</td>
<td>Width of rostrum at base - along line across hindmost limits of antorbital notches.</td>
</tr>
<tr>
<td>4.</td>
<td>Width of rostrum at 60 mm anterior to line across hindmost limits of antorbital notches.</td>
</tr>
<tr>
<td>5.</td>
<td>Width of rostrum at midlength.</td>
</tr>
<tr>
<td>6.</td>
<td>Width of premaxillaries at midlength of rostrum.</td>
</tr>
<tr>
<td>7.</td>
<td>Width of rostrum at 3/4 length, measured from posterior end.</td>
</tr>
<tr>
<td>8.</td>
<td>Distance from tip of rostrum to external nares (to mesial end of anterior transverse margin of right naris).</td>
</tr>
<tr>
<td>9.</td>
<td>Distance from tip of rostrum to internal nares (to mesial end of posterior margin of right pterygoid).</td>
</tr>
<tr>
<td>10.</td>
<td>Greatest preorbital width.</td>
</tr>
<tr>
<td>11.</td>
<td>Greatest postorbital width.</td>
</tr>
<tr>
<td>12.</td>
<td>Least supraorbital width.</td>
</tr>
<tr>
<td>15.</td>
<td>Greatest width of premaxillaries.</td>
</tr>
<tr>
<td>16.</td>
<td>Greatest parietal width, within posttemporal fossae.</td>
</tr>
<tr>
<td>17.</td>
<td>Vertical external height of braincase from midline of basisphenoid to summit of supraoccipital, but not including supraoccipital crest.</td>
</tr>
<tr>
<td>18.</td>
<td>Greatest length of left posttemporal fossa, measured to external margin of raised suture.</td>
</tr>
<tr>
<td>19.</td>
<td>Greatest width of left posttemporal fossa at right angles to greatest length.</td>
</tr>
<tr>
<td>20.</td>
<td>Major diameter of left temporal fossa proper.</td>
</tr>
<tr>
<td>21.</td>
<td>Minor diameter of left temporal fossa proper.</td>
</tr>
<tr>
<td>22.</td>
<td>Projection of premaxillaries beyond maxillaries measured from tip of rostrum to line across foremost tips of maxillaries visible in dorsal view.</td>
</tr>
<tr>
<td>23.</td>
<td>Length of left orbit - from apex of preorbital process of frontal to apex of postorbital process.</td>
</tr>
<tr>
<td>24.</td>
<td>Length of antorbital process of left lacrimal.</td>
</tr>
<tr>
<td>25.</td>
<td>Greatest width of internal nares.</td>
</tr>
<tr>
<td>26.</td>
<td>Greatest length of left pterygoid.</td>
</tr>
<tr>
<td>27.</td>
<td>Greatest length of bulla of tympanoperiatic.</td>
</tr>
<tr>
<td>28.</td>
<td>Greatest width of tympanic bulla.</td>
</tr>
<tr>
<td>29.</td>
<td>Greatest length of periatic of tympanoperiatic.</td>
</tr>
<tr>
<td>30.</td>
<td>Greatest width of periatic bulla.</td>
</tr>
<tr>
<td>31.</td>
<td>Diameter of cochlear portion.</td>
</tr>
<tr>
<td>32.</td>
<td>Length of upper left tooth row - from hindmost margin of hindmost alveolus to tip of rostrum.</td>
</tr>
<tr>
<td>33.</td>
<td>Number of teeth - upper left.</td>
</tr>
<tr>
<td>34.</td>
<td>Number of teeth - upper right.</td>
</tr>
<tr>
<td>35.</td>
<td>Number of teeth - lower left.</td>
</tr>
<tr>
<td>36.</td>
<td>Number of teeth - lower right.</td>
</tr>
<tr>
<td>37.</td>
<td>Length of lower tooth row - From hindmost margin of hindmost alveolus to tip of mandible.</td>
</tr>
<tr>
<td>38.</td>
<td>Greatest length of ramus.</td>
</tr>
<tr>
<td>39.</td>
<td>Greatest height of ramus at right angles to greatest length.</td>
</tr>
<tr>
<td>40.</td>
<td>Length of mandibular fossa, measured to mesial rim of internal surface of condyle.</td>
</tr>
<tr>
<td>41.</td>
<td>Length of basihyal along midline.</td>
</tr>
<tr>
<td>42.</td>
<td>Greatest width of basihyal.</td>
</tr>
<tr>
<td>43.</td>
<td>Greatest width of thyrohyal proximally.</td>
</tr>
<tr>
<td>44.</td>
<td>Greatest length of thyrohyal.</td>
</tr>
</tbody>
</table>
process and the angle of the mandible are not fully developed.

Within a few months after birth the fontanelles are closed. The basoocipital and exoccipitals fuse and sutures between them become obliterated. The bony septum is ossified. The mandibular condyle, the coronoid process and the angle of the mandible are ossified.

Between ages 1 and 2, ossification in the braincase continues, and the sutures between the supraoccipital and exoccipitals become obliterated. Other bones are yet not fused together. The external margin of the temporal fossa forms a raised suture. The interparietal becomes less visible in dorsal view of the skull. Partitions between the alveoli are undeveloped.

Between ages 2 and 3, distal fusion between the maxillaries and premaxillaries begins, but sutures between them are still clearly visible. The external margin of the temporal fossa and partitions between the alveoli develop.
Between ages 3 and 6, all of the cranial bones except nasals are completely fused together.

By the age of 12, the nasal bones become fused to the skull. Even in the oldest animal examined (36.5 years old), M 19791, the earbones are separate from the skull and the left mandibular ramus is separate from the right.

**Hyoids.** Progress of the fusion between basihyal and thyrohyal can be divided into four classes (A, B, C and D) (Fig. 2). At birth they are not fused each other (A). Fusion begins on the ventral side at the posterior part of the basihyal between ages 11 and 15 (B). Between ages 15 and 17, fusion occurs on the dorsal side of the basihyal, fusion on the ventral side at the anterior part is incomplete (C). Finally, fusion on both sides is complete at the age of 17 or older (D).
Table 2. Degree of ossification of the skull of the striped dolphin

<table>
<thead>
<tr>
<th>Age</th>
<th>Fontanelles</th>
<th>Sutures</th>
<th>Bony septum</th>
<th>Partition between alveoli</th>
<th>Nasal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>occipital</td>
<td>other</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Newborn</td>
<td>open</td>
<td>unfused</td>
<td>unfused</td>
<td>unformed</td>
<td>unfused</td>
</tr>
<tr>
<td>Few months</td>
<td>closed</td>
<td>fused</td>
<td>unfused</td>
<td>formed</td>
<td>unfused</td>
</tr>
<tr>
<td>1-2 yrs.</td>
<td>closed</td>
<td>fused</td>
<td>unfused</td>
<td>formed</td>
<td>unfused</td>
</tr>
<tr>
<td>2-3 yrs.</td>
<td>closed</td>
<td>fused</td>
<td>unfused</td>
<td>formed</td>
<td>unfused</td>
</tr>
<tr>
<td>3-6 yrs.</td>
<td>closed</td>
<td>fused</td>
<td>fused</td>
<td>formed</td>
<td>unfused</td>
</tr>
<tr>
<td>6-12 yrs.</td>
<td>closed</td>
<td>fused</td>
<td>fused</td>
<td>formed</td>
<td>unfused</td>
</tr>
<tr>
<td>&gt;12 yrs.</td>
<td>closed</td>
<td>fused</td>
<td>fused</td>
<td>formed</td>
<td>fused</td>
</tr>
</tbody>
</table>

Postcranial skeleton

Vertebrae. In the newborn calf, the transverse processes are not ossified on any vertebra. The neural arches are not ankylosed to the centra. The left and the right parts of the neural arches of the cervical and thoracic vertebrae are still separate. None of the epiphyses is fused to the centra.

In specimens a few months old, the transverse processes have already ossified. The ventrolateral processes begin to form on the cervicals. Fusion of the neural arches to the centra progresses anteriorly on the caudals and lumbars, and posteriorly on the cervical and thoracic vertebrae until at around age 1.5, all are fused. The epiphyses of the cervical vertebrae have been fused to the centra, but the seams are still clearly visible.

After the age of 1.5 fusion of the epiphyses to the centra progresses anteriorly in the caudal series, from about Ca25-Ca30, and posteriorly in the thoracic series. Fusion comes to completion last in posterior thoracic vertebrae (Fig. 3). The anterior epiphysis has a tendency to fuse to the centrum earlier than the posterior one. The youngest specimen with all epiphyses fused to the centra was 15.5 years old, while the oldest with unfused epiphyses was 18.5.

![Fig. 2. Degree of fusion between basihyal and thyrohyals in the striped dolphin. A: fusion has not occurred. B: fused on the ventral side in the posterior part of basihyal. C: fused on the dorsal side. D: fused completely.](image-url)
Therefore, we estimate that physical maturity is achieved between the ages of 15 and 19.

Comparison between the degree of the fusion of the hyoid bones and physical maturity indicates that physically immature animals have the thyrohyals and basihyals not fused to each other or fused only at the ventral posterior part of the basihyal (class A or B). Physically mature specimens have hyoids, thyrohyals fused to the basihyal. The suture is visible only ventro-anteriorly or obliterated (class C or D) (Table 3).

**Chevron bones.** Although ossification of chevron bones was not observed in newborn calves and up to the age of 0.2, it was observed in 0.3-years-old specimens, which has 22 pairs of chevron bones. This suggests that the chevron bones begin to ossify within several months after birth. Adult specimens have 26–31 pairs of chevron bones. The increase of the number of chevron bones with growth seems due to delayed ossification at the posterior end of the series.

**Scapulae.** In the newborn calf, the entire coracoid process is unossified. It begins to ossify within several months after birth.

**Ribs.** Although the heads of the two-headed ribs are undeveloped in the newborn calf, they begin to ossify within several months after birth.

**Sternum.** At birth, the manubrium and 2 mesosternal elements are not yet fused to each other. The manubrium and the first mesosternal element are fused together in one specimen of age 5.5, but in all the other specimens younger than 11.5, no fusion has yet occurred. In specimens older than 11.5, the manubrium and the first and the second mesosternal elements are fused. In the specimen of age 17.5, a third mesosternal element is present but not fused to the second.

**Growth**

**Cranial skeleton**

**Skull.** Condylar length (measurement no. 1 in Table 1) increases rapidly during the first two years and reaches adult size at the age of 3 (Fig. 4). The remaining 30 measurements of the skull and mandible (nos. 2−26, 32, 37−40) show a similar trend. Thus, specimens of age 3 or greater are included in the adult series (Table 4). On the other hand, length of tympanic bulla (no. 27) increases little after birth. The remaining 4 measurements of the earbones (nos. 28−31) show a similar trend.

Comparison of shape of skull between calves and adult specimens indicates that the calf has a shorter beak and wider braincase than the adult does (Fig. 5).

**Hyoids.** The hyoid apparatus composed of a basihyal, a pair of thyrohyals and a pair of stylohyals. The hyoid bones except for the stylohyals (nos. 41−44) reach nearly adult size at the age of 5, while the length of stylohyal (no. 46) continues to increase until the age of 17.

**Vertebrae.** Figure 6 shows the height, width and length of vertebrae (nos. 51−52 and 57) in 3 selected specimens (M 19784: the age of 0.3, M 19774: 5.5, M
Fig. 3. Ossification pattern of the vertebral epiphyses in striped dolphin. □: un-fused both sides. ◀: fused only anteriorly and suture clear. ◇: both epiphyses fused but sutures clear. ▼: fused completely only anteriorly. ◆: both epiphyses fused and suture clear only posteriorly. ■: both epiphyses fused completely.
Table 3. Relationship between physical maturity and degree of ossification in hyoid complex in adult striped dolphins.

<table>
<thead>
<tr>
<th>Specimen no.</th>
<th>Age</th>
<th>Physical maturity</th>
<th>Degree of fusion in hyoids</th>
</tr>
</thead>
<tbody>
<tr>
<td>M19785</td>
<td>8.5</td>
<td>–</td>
<td>A</td>
</tr>
<tr>
<td>23</td>
<td>10.5</td>
<td>–</td>
<td>A</td>
</tr>
<tr>
<td>M19786</td>
<td>11.5</td>
<td>–</td>
<td>B</td>
</tr>
<tr>
<td>M19788</td>
<td>11.5</td>
<td>–</td>
<td>A</td>
</tr>
<tr>
<td>24</td>
<td>14.5</td>
<td>+</td>
<td>C</td>
</tr>
<tr>
<td>M19777</td>
<td>15.5</td>
<td>+</td>
<td>C</td>
</tr>
<tr>
<td>10</td>
<td>15.5</td>
<td>++</td>
<td>C</td>
</tr>
<tr>
<td>M19787</td>
<td>16.5</td>
<td>++</td>
<td>C</td>
</tr>
<tr>
<td>M19790</td>
<td>16.5</td>
<td>++</td>
<td>C</td>
</tr>
<tr>
<td>11</td>
<td>16.5</td>
<td>++</td>
<td>C</td>
</tr>
<tr>
<td>M19789</td>
<td>17.5</td>
<td>++</td>
<td>D</td>
</tr>
<tr>
<td>M19779</td>
<td>17.5</td>
<td>++</td>
<td>D</td>
</tr>
<tr>
<td>M19776</td>
<td>17.5</td>
<td>++</td>
<td>C</td>
</tr>
<tr>
<td>M19780</td>
<td>18.5</td>
<td>+</td>
<td>C</td>
</tr>
<tr>
<td>M19782</td>
<td>18.5</td>
<td>++</td>
<td>D</td>
</tr>
<tr>
<td>25</td>
<td>20.5</td>
<td>++</td>
<td>D</td>
</tr>
<tr>
<td>22</td>
<td>21.5</td>
<td>++</td>
<td>D</td>
</tr>
<tr>
<td>M19781</td>
<td>25.5</td>
<td>++</td>
<td>D</td>
</tr>
<tr>
<td>20</td>
<td>27.5</td>
<td>++</td>
<td>D</td>
</tr>
<tr>
<td>M19778</td>
<td>34.5</td>
<td>++</td>
<td>D</td>
</tr>
</tbody>
</table>

(-) physically immature, (+) epiphyses of dorsal vertebra fused but suture clearly visible or only one side of epiphysis fused to centrum, (++) all epiphyses fused to centrum.

* See Fig. 2

19789: 17.5). Comparison of the growth patterns in these three specimens suggests that the height, width and length of vertebrae increase rapidly in the dorsal, lumbar and the first half of the caudal series between the ages of 0.3 and 5.5. Then they continue to grow slowly until physical maturity. In the cervical series and the last half of the caudal series, growth is very slow. The height of lumber vertebrae is greater than in the other series. Width is greatest in the posterior parts of the thoracic and in the lumbar series. Length is greatest in the thoracic series. Figure 7 shows the growth pattern of the dimensions of the 4th cervical (C4), the 7th thoracic (T7), the 11th lumbar (L11) and the 10th caudal vertebra (Ca10). Vertebral height of C4 reaches adult size at age 10, but both width and length reach adult size at age 3. Height, width and length of T7 and L11 increase rapidly for several years after birth and reach nearly adult size at age 7, and then they continue to grow gradually until the onset of physical maturity (age 15). Height, width and length of Ca10 reach adult size at age 10. Sizes of centrum and neural arch in these three specimens (nos. 53–58) reach adult size by age 7. Chevron bones. Length of the longest chevron bone (no. 66) reaches adult size at age 7. Scapulae. Length and width of scapula (nos. 67 and 68) reach nearly adult size
Fig. 4. Development of skull of the striped dolphin: scatterplot of condylobasal length on age. Solid symbols represent males and open symbols females.

at age 5, and then they continue to increase gradually until physical maturity. **Vertebral and sternal ribs.** Although the anterior 13–14 pairs of ribs, being joined by cartilage to the thoracic vertebrae, are almost same in shape and robustness on the right and left sides, the last 1–2 pairs of vertebral ribs (floating ribs), not being connected to the vertebrae, show different shape between the sides. Similarly, the last 1–2 pairs of sternal ribs are not always the same in size on both sides.

Lengths of the first vertebral rib and sternal rib, (nos. 60 and 61) increase after birth and reach nearly adult size at age 7 and continue to grow gradually until the onset of physical maturity. **Sternum.** Length and width of manubrium (nos. 62 and 63) increase rapidly after birth and reach adult size at age 7. **Foerimb.** Length and width of humerus (nos. 69 and 70) increase rapidly after birth and reach adult size by age 10. The other measurements of the flipper (nos. 71–73) show the same trend. **Pelvic bones.** In the specimens younger than age 2, there are no clear differences in shape or length of pelvic bones between the right and left sides. In older specimens the shape of pelvic bones are not always the same on both sides. Length of pelvic bone (no. 79) reaches adult size in both sexes at age 7.

**Sexual dimorphism**

Obvious sexual difference can be observed in the shape of the front edge of the occipital bone (Fig. 8). In the specimens older than age 3–6, females have a developed crest above the frontals. In male specimens however, such a crest is not typical, and a pitted area develops on the anterior part of the occipital. The formation of the crest at the front of the occipital begins at age of 1–2.

Some measurements for the male sample are on the average greater than those for the females. (1) rostrum width (at 60 mm from base, at mid length and at 3/4 length of rostrum) (nos. 3–5 and 7), (2) width of premaxillaries at midlength of rostrum (no. 6), (3) length of basihyal (no. 41), (4) length of ribs (the 2 nd-8 th) (no. 60) and length of pelvic bone (no. 79) (Tables 4 and 5).

In the specimens older than age 7, the male has a rod-shaped and slightly
curved pelvic bone, compared with the female bone which is L shaped and more flattened.

Table 4. Skull measurements of the striped dolphins age 3 years or older.

<table>
<thead>
<tr>
<th>No.</th>
<th>Measurement</th>
<th>Mean (mm)</th>
<th>S.D. (mm)</th>
<th>Max. (mm)</th>
<th>Min. (mm)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Condylar length</td>
<td>458</td>
<td>16.1</td>
<td>485</td>
<td>434</td>
<td>22</td>
</tr>
<tr>
<td>2</td>
<td>Length of rostrum</td>
<td>274</td>
<td>12.9</td>
<td>297</td>
<td>251</td>
<td>22</td>
</tr>
<tr>
<td>3</td>
<td>Width of rostrum at base</td>
<td>112</td>
<td>5.8</td>
<td>126</td>
<td>101</td>
<td>22</td>
</tr>
<tr>
<td>4</td>
<td>Width of rostrum at 60 mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>78.1</td>
<td>4.0</td>
<td>83</td>
<td>71</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>73.6</td>
<td>4.6</td>
<td>83</td>
<td>67</td>
<td>10</td>
</tr>
<tr>
<td>5</td>
<td>Width of rostrum at 1/2 length</td>
<td>64.7</td>
<td>2.6</td>
<td>69</td>
<td>56</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>59.6</td>
<td>3.1</td>
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<td>327</td>
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<td>4.3</td>
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<td>20</td>
<td>Major diameter of temporal fossa</td>
<td>34.3</td>
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<td>Minor diameter of temporal fossa</td>
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<td>Projection of pmx's</td>
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<td>25</td>
<td>Width of internal nares</td>
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<td>Length of pterygoid</td>
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<td>7.3</td>
<td>98</td>
<td>73</td>
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<tr>
<td>27</td>
<td>Length of tympanic bulla</td>
<td>31.8</td>
<td>0.8</td>
<td>32</td>
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<td>22</td>
</tr>
<tr>
<td>28</td>
<td>Width of tympanic bulla</td>
<td>18.3</td>
<td>0.7</td>
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<tr>
<td>29</td>
<td>Length of periotic bulla</td>
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<td>0.5</td>
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<tr>
<td>30</td>
<td>Width of periotic bulla</td>
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<tr>
<td>31</td>
<td>Diameter of cochlear portion</td>
<td>17.3</td>
<td>0.7</td>
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<td>32</td>
<td>Length of upper tooth row</td>
<td>239</td>
<td>10.2</td>
<td>256</td>
<td>222</td>
<td>22</td>
</tr>
<tr>
<td>37</td>
<td>Length of lower tooth row</td>
<td>233</td>
<td>11.6</td>
<td>255</td>
<td>215</td>
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<tr>
<td>38</td>
<td>Length of ramus</td>
<td>392</td>
<td>14.8</td>
<td>419</td>
<td>367</td>
<td>22</td>
</tr>
<tr>
<td>39</td>
<td>Height of ramus</td>
<td>71.2</td>
<td>2.9</td>
<td>77</td>
<td>65</td>
<td>22</td>
</tr>
<tr>
<td>40</td>
<td>Length of mandibular fossa</td>
<td>130</td>
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<td>145</td>
<td>117</td>
<td>22</td>
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</tbody>
</table>
Fig. 5. Comparison of skull proportions of the striped dolphin as newborn as adult.

Fig. 6. Height, width and length of each vertebra in three striped dolphins.
Skeletal Development of Striped Dolphins

Fig. 7. Development of vertebrae of the striped dolphin. Scatterplots of height, width and length of fourth cervical, seventh thoracic, eleventh lumbar and tenth caudal on age.

Fig. 8. Sexual difference in the shape of the front edge of the occipital bone between adult male and female of the striped dolphin.

Individual variation

The number of phalanges in digits I–V is affected by ossification for the first year after birth. However, after that the numbers become stable within the range of individual variation (Table 6). The numbers of phalanges are 2–
3 in the 1st digit, 8-10 in the 2nd, 6-8 in the 3rd, 3-4 in the 4th, and 2 in the 5th. In most cases, the number of phalanges is the same in both right and left sides. However, some specimens have one more phalanx on the right side than on the left, and vice versa.

Table 7 shows meristic variation. Individual variation is also observed in fusion of the cervical vertebrae. Although among 19 specimens examined, specimens (N = 13, 68% of total) have C1-2 fused, there are 2 specimens having C1-3 fused and one specimen each having C1-4 fused, C4-6 fused, C4-5 fused and C5-6 fused. In one specimen (M 19782), there is an exceptional fusion between the 7th cervical and 1st dorsal vertebrae. Various types of combinations of fusion are observed in the first 1-5 chevron.

<table>
<thead>
<tr>
<th>Skeleton</th>
<th>Males Mean (cm)</th>
<th>Males S.D. (cm)</th>
<th>Males N</th>
<th>Females Mean (cm)</th>
<th>Females S.D. (cm)</th>
<th>Females N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of basihyal (5 years)</td>
<td>5.1</td>
<td>0.38</td>
<td>6</td>
<td>4.3</td>
<td>0.35</td>
<td>9</td>
</tr>
<tr>
<td>Length of rib 2nd (physically mature)</td>
<td>22.7</td>
<td>0.36</td>
<td>3</td>
<td>20.6</td>
<td>0.35</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>27.8</td>
<td>0.92</td>
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<td>25.2</td>
<td>1.45</td>
<td>7</td>
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<tr>
<td></td>
<td>30.6</td>
<td>0.74</td>
<td>3</td>
<td>27.9</td>
<td>1.37</td>
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</tr>
<tr>
<td></td>
<td>31.7</td>
<td>0.94</td>
<td>3</td>
<td>29.2</td>
<td>0.85</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>32.2</td>
<td>0.50</td>
<td>3</td>
<td>29.9</td>
<td>0.90</td>
<td>7</td>
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<tr>
<td></td>
<td>32.3</td>
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<td>3</td>
<td>30.3</td>
<td>0.84</td>
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<tr>
<td></td>
<td>32.4</td>
<td>0.56</td>
<td>3</td>
<td>30.4</td>
<td>1.05</td>
<td>7</td>
</tr>
<tr>
<td>Length of pelvic bone (&gt; 7 years)</td>
<td>8.1</td>
<td>1.00</td>
<td>6</td>
<td>6.4</td>
<td>1.19</td>
<td>8</td>
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</tbody>
</table>

**Discussion**

The pattern of fusion of the vertebral epiphyses to the centra in Odontoceti has been little studied. Two types of ossification patterns have been reported for the Mystacoeti: in fin whale epiphyseal fusion starts from both ends of the vertebral column (Wheeler, 1930; Ohsumi et al. 1958), whereas in the minke whale fusion starts at the anterior cervicals and, then occurs at posterior caudals, and is completed at the middle or posterior dorsal vertebrae (Kato, 1988). The present study indicates that the fusion pattern in S. coeruleoalba is similar to that of the minke whale.

According to Perrin (1975b), in S. attenuata from the eastern Pacific and Hawaii, complete fusion of the thyrohyals and basihyal occurs quite late in development and does not appear to be correlated with the attainment of physical maturity as adjudged by fusion of the vertebral epiphyses, because some individuals with unfused epiphyses have completely fused hyals, and vice
versa. However, in the present study, complete fusion of the hyoid bones in *S. coeruleoalba* has good agreement with the attainment of physical maturity. Therefore, in *S. coeruleoalba* complete fusion of the hyoid bones is a good indication of its physical maturity. Comparing the process of fusion of the hyals in three species of *Stenella* (Perrin, 1975b), complete fusion is much more

### Table 6. The number of phalanges in each digit of the striped dolphin.

<table>
<thead>
<tr>
<th>Museum no.</th>
<th>Age</th>
<th>Age</th>
<th>Digit</th>
<th>Digit</th>
<th>Digit</th>
<th>Digit</th>
</tr>
</thead>
<tbody>
<tr>
<td>M 19783</td>
<td>0.2</td>
<td>2</td>
<td>L:7</td>
<td>R:6</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>M 19784</td>
<td>0.3</td>
<td>2</td>
<td>8</td>
<td>6</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>M 19772</td>
<td>1.6</td>
<td>2</td>
<td>9</td>
<td>6</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>M 19773</td>
<td>1.8</td>
<td>2</td>
<td>9</td>
<td>L:7</td>
<td>R:6</td>
<td>3</td>
</tr>
<tr>
<td>M 19774</td>
<td>5.5</td>
<td>2</td>
<td>9</td>
<td>7</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
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<td>8</td>
<td>6</td>
<td>3</td>
<td>2</td>
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<td>M 19785</td>
<td>8.5</td>
<td>2</td>
<td>L:7</td>
<td>R:8</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>M 19786</td>
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<td>2</td>
<td>9</td>
<td>7</td>
<td>4</td>
<td></td>
</tr>
<tr>
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<td>L:2</td>
<td>R:3</td>
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<tr>
<td>M 19777</td>
<td>15.5</td>
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<td>9</td>
<td>7</td>
<td>4</td>
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<tr>
<td>M 19787</td>
<td>16.5</td>
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<td>R:9</td>
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<tr>
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<td>7</td>
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</tr>
<tr>
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<td>7</td>
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<td></td>
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<td>8</td>
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<td>9</td>
<td>7</td>
<td>4</td>
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</tr>
<tr>
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<td>9</td>
<td>6</td>
<td>4</td>
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<td>9</td>
<td>7</td>
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</table>

### Table 7. Individual meristic variation in the striped dolphin.

<table>
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<tr>
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<td>Teeth lower</td>
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<tr>
<td>Teeth left</td>
<td>42-53</td>
</tr>
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<td>Vertebral total</td>
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</tr>
<tr>
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<td>14-16</td>
</tr>
<tr>
<td>Vertebral lumbar</td>
<td>19-24</td>
</tr>
<tr>
<td>Vertebral caudal</td>
<td>34-38</td>
</tr>
<tr>
<td>Chevron bones</td>
<td>26-31 pairs</td>
</tr>
<tr>
<td>Sternal</td>
<td>8-10</td>
</tr>
<tr>
<td>Phalanges</td>
<td></td>
</tr>
<tr>
<td>I</td>
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<tr>
<td>II</td>
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<tr>
<td>III</td>
<td>5-8</td>
</tr>
<tr>
<td>IV</td>
<td>3-4</td>
</tr>
<tr>
<td>Mesosternal elements of sternum</td>
<td>2-3</td>
</tr>
</tbody>
</table>
rapidly attained in *S. longirostris* than in either *S. attenuata* or *S. coeruleoalba*.

Kasuya (1976) reported that males and females in *S. coeruleoalba* attain asymptotic length at ages of about 17 and 21, respectively. These ages are close to the age when *S. coeruleoalba* attains physical maturity (15–19 years). If more data on epiphyseal fusion were available, a male/females difference in age at physical maturity parallel to that in asymptotic length might be discovered.

To summarize the pattern of skeletal growth, : (1) most cranial bones attain adult size at age 3, (2) the earbones at the neonatal stage are the same size as in adults, and (3) most postcranial bones attain adult size at age 7 which is close to the age of sexual maturity (female: 7.1 years, male: 8.8 years) (Miyazaki, 1977) and then gradually increase until physical maturity (15–19 years).

In the present specimens, most cranial bones reach adult size at age 3. According to Miyazaki and Nishiwaki (1978), this age coincides with the age when the juvenile dolphin moves from the adult school to the juvenile school. Perrin (1975b) reported that cranial bones in *Stenella attenuata* and *Stenella longirostris* in the eastern Pacific and Hawaii reach adult size at 5 or more layers and 4 or more layers in the postnatal dentine, respectively. Thus, it is possible that *S. coeruleoalba* is the most precocious in cranial features among the three species of *Stenella* and *S. longirostris* more precocious than *S. attenuata*. An alternative explanation is that age determination is in error for one or more of the 3 species.

Perrin (1975b) reported that in the spotted dolphins (*S. attenuata*) from the eastern Pacific and Hawaii, males have the larger braincases, the shorter and broader rostra, the broader first ribs and the larger pelvic bones than females do, and also have the rod-shaped pelvic bones which are different from the L-shaped pelvic bones of females. While Schnell et. al. (1985) analyzed 36 cranial traits of 612 adult specimens of spotted dolphins for sexual dimorphism. They reported, “In general, our results suggest that the rostrum is elongate in females relative to males, but that overall skull length is about the same. The finding that 64 percent of our measurements exhibited significant sexual dimorphism extends information on this phenomenon for *S. attenuata*,” and “A discriminant function involving a combination of 10 characters enabled us to identify correctly the sex of more than 75 percent of the specimens.” Perrin (1975b) also concluded the sexual dimorphism of *S. longirostris* from the eastern Pacific and Hawaii is negligible except for the pelvics. But, Schnell et. al. (1986) reported that sexual dimorphism was significant in 13 of 36 cranial characters, and they could correctly identify 67% to 69% of the specimens to sex based on a discriminant function involving six characters. In both cases, sexual dimorphism they found was relatively minor.

Although, in our analysis, relatively few specimens were available, *S. coeruleoalba* shows obvious sexual dimorphism in the shape of the front edge of the occipital (see Fig. 8), and in the other several characters. Thus, it is considered that the degree of sexual dimorphism in striped dolphins is greater
than in spotted and spinner dolphins.

Acknowledgments

The samples were collected through the cooperation of the fishermen's cooperative unions at Taiji. Dr. W. F. Perrin, National Marine Fisheries Service who read the draft critically and provided us the useful suggestions. Dr. M. Nakagawa, Tohoku University who kindly read our first draft and gave us useful comments. We had the help of Mr. S. Shiraga in collecting and preparing samples. Professor I. Hanyu, University of Tokyo who gave us constant encouragement. These persons are deeply acknowledged.

References

Appendix 1. Ratio of the skull measurements to condylobasal length (%) in the striped dolphin, age 3 and older.

<table>
<thead>
<tr>
<th>No.</th>
<th>Measurement</th>
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<th>S.D.</th>
<th>Max.</th>
<th>Min.</th>
<th>N</th>
</tr>
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<tr>
<td>2</td>
<td>Length of rostrum</td>
<td>59.8</td>
<td>1.1</td>
<td>61.8</td>
<td>57.8</td>
<td>22</td>
</tr>
<tr>
<td>3</td>
<td>Width of rostrum at base</td>
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<td>26.2</td>
<td>22.9</td>
<td>22</td>
</tr>
<tr>
<td>4</td>
<td>Width of rostrum at 60 mm</td>
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<td></td>
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<td></td>
</tr>
<tr>
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<td>M</td>
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<td>0.50</td>
<td>17.5</td>
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<td>17.1</td>
<td>15.2</td>
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<tr>
<td>5</td>
<td>Width of rostrum at 1/2 length</td>
<td></td>
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<td></td>
<td></td>
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