# Are ancient dugong bones useful for analyses?

Osamu Hoson[1*], Go Ogura[2], Noriyuki Ohtaishi[3] and Sen-ichi Oda[1]
[1]*Graduate School of Bio-Agricultural Science, Nagoya University, Nagoya 464-8601, Japan*
[2]*Faculty of Agriculture, University of Ryukyus, Okinawa 903-0213, Japan*
[3]*Hokkaido University Museum, Sapporo 060-0808, Japan*
*E-mail: hoson.osamu@e.mbox.nagoya-u.ac.jp*

***ABSTRACT***
The Ryukyu Archipelago of Japan is the northern limit of the distribution of the dugong (*Dugong dugon*), and populations in Japanese waters are small. Therefore, little biological information is available on local dugong, and new specimens or techniques are necessary to help shed light on the populations of this region. We assessed the suitability of using ancient dugong bones collected from ruins on Shimoji Island, in the Yaeyama Islands, for biological investigations. We collected more than 1,000 fragments of animal bone at the site. From these, we were able to reconstruct 91 dugong skulls, from which we estimated body length (124.2–301.2 cm) and age group compositions (43% adults, 29% adolescents, and 16% juveniles). Our estimation revealed a wide range of age groups, from neonates to mature adults. These results suggest that the ancient dugong population bred and spent all life stages along the coasts of the Yaeyama Islands. Moreover, our study shows that these ancient bones can be used for meaningful biological investigations on dugong, and should help to elucidate their historical distribution and population structure in this area.

**KEYWORDS: dugong, *Dugong dugon*, ancient bone, population structure, historical distribution.**

**INTRODUCTION**

The dugong (*Dugong dugon*) is the only extant species of herbivorous marine mammal belonging to the family Dugongidae in the order Sirenia (Husar, 1978). It occurs in tropical and subtropical coastal areas between latitudes of 26°N and 27°S in 48 countries, from the western coast of Africa to the Red Sea, Arabian Gulf, and Asia (Nishiwaki *et al*., 1979). Most populations are small, except for those in Australian waters, which collectively host about 85,000 dugongs (Marsh *et al*., 2002).

In Japan, the species is restricted to the Ryukyu Archipelago, which represents the northern limit of its distribution (Marsh *et al*., 2002). However, according to the Ministry of the Environment of Japan (2004), it has been documented at Okinawa Island only since the 1990s (Fig. 1). Its historical distribution is based on middens containing dugong bones or products made from dugong bones, excavated from several islands in the archipelago (Morimoto, 2003); documents such as dugong harvest reports (from 1894 to 1916) of the Okinawa Prefectural Government (Uni, 2003); and historical books from the Ryukyu Kingdom period (ca. 1400–1800) and the Meiji period (~100 years ago; Uni, 2003; Ministry of the Environment of Japan, 2004, 2005). Collectively, these sources indicate that dugong inhabited nearly the entire Ryukyu Archipelago and sustained a population there until around 100 years ago. However, there are no specimens to support this inference. Approximately 20 specimens from Japan are preserved in museums, most of which were individuals stranded on Okinawa Island. Thus, there is little biological information on the dugong of the Ryukyu Archipelago, and new specimens or techniques are necessary to shed light on populations of this region.

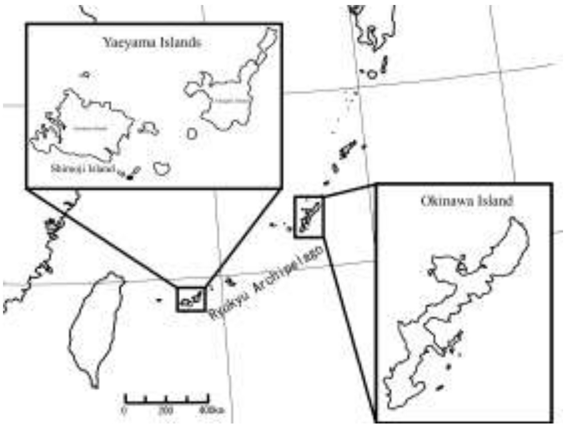


Fig. 1 Location of Okinawa Island and Shimoji Island in the Ryukyu Archipelago. Shimoji Island is about 500 km from Okinawa Island. At present, dugong seem to inhabit only waters to the north of Okinawa Island.

Therefore, we collected dugong bones from middens on Shimoji Island (Fig. 1). During the reign of the Ryukyu Kingdom, the people of Shimoji and Kamiji islands were exclusively allowed to hunt dugong, the meat of which they paid as a tax to the kingdom (Ouhama, 1971). Dugong hunters decapitated their catches as a sacrificial offering to the gods to ensure sustainable hunting success and these dugong skulls have remained on the two islands until now (Board of Education of

Taketomi, 1987; Ogura *et al.*, 2005b). However, as no one has lived on Shimoji Island since 1963, the ruins have gradually broken down via erosion (Fig. 2a), and some dugong skulls have been stolen by visitors. Thus, by collecting the remaining skulls and skull fragments, we were able not only to assess their use for scientific investigation but also to preserve them, with the consent of the Shimoji-jima Islander Society and the public office of the town of Taketomi.


Fig. 2 a: Ruins on Shimoji Island. b: Dugong bones on top of a stone wall made of coral. The triangle denotes bones.

## MATERIALS AND METHODS

・Skull preparation

Shimoji Island is located 500 km south of Okinawa Island. Most of the bones were found on the northeast side of the ruins (Fig. 2b), and many skulls were fragmented. Because the bones of West Indian manatees (*Trichecus manatus*), which belong to the same order as the dugong, ossify epiphyses and unite with the diaphysis very late in the developmental process (Fawcett, 1942), and dugong show slow fusion of some sutures in crania (Mitchell, 1973), we primarily distinguished each skull and skull region based on parietal bones, frontal bones, maxilla, premaxilla, sphenoids, temporal bones, occipital bones, tympanici, and mandibles (Fig. 3). We separated and sorted the dugong bones, counted the number of skull fragments, and then matched bones via their structure, e.g., frontal suture (between each side of the frontal bone), coronal suture (between the frontal and parietal bones), intermaxillary suture (between each side of the maxilla), squamous suture (between the parietal and temple bones), shenofrontal suture (between the frontal bone and sphenoid), and sphenoparietal suture (between the parietal and occipital bones). From these skull reconstructions, we estimated the least possible number of dugongs represented at the site.


Fig. 3 Fragmented skulls. a: zygomatic bone, b: temple bone, c: tympanicum, d: occipital bone, e: premaxilla, f: maxilla, g: sphenoid, h: frontal and parietal bone. Bone identifications were based on Karger (1974).

・Analysis

The growth pattern of the skull is less known than that of body length. Thus, we calculated the length of dugong based on two characters: length of the frontal bone to the supraoccipital bone along the midline (LFS), and width of the frontal bone at the junction of the parietal and frontal bones (WJF; Fig. 4). We chose these because of the good preservation state of most specimens, and because they had comparatively little damage due to weathering. Measurements were performed using digital calipers to the nearest 0.1 mm.

The models for body length estimation were based on measurements of museum specimens (Table 1), and the calculations were as follows (The relationship between the body length and two characters investigated by Pearson's correlation coefficient test; Fig. 5):

Body length = 0.312 LFS + 75.564
($R^2 = 0.994$, $p < 0.01$)
Body length = 0.186 WJF + 35.437
($R^2 = 0.928$, $p < 0.01$)

Table 1 The specimens used for the design of the linear model.

| Museum name | F/M | Body length (cm) | LFS (mm) | WJF (mm) |
|---|---|---|---|---|
| Okinawa Prifectual Museum | Unknown | 147 | 120.63 | 64.33 |
| The Museum of University of the Ryukyus | M | 215 | 143.75 | 75.53 |
| | F | 262 | 159.30 | 81.55 |
| Nago Museum | M | 252 | 153.72 | 79.07 |
| Higashi Museum | M | 300 | 167.81 | 95.28 |

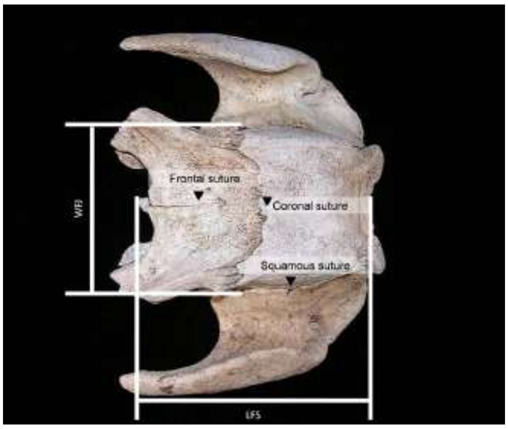


Fig. 4 Neural cranium of a reconstructed skull. The triangles denote the structures used to reconstruct the skull. The two white lines indicate the length of the frontal bone to the supraoccipital bone along the midline (LFS) and the width of the frontal bone at the junction of the parietal and the frontal bone (WJF).

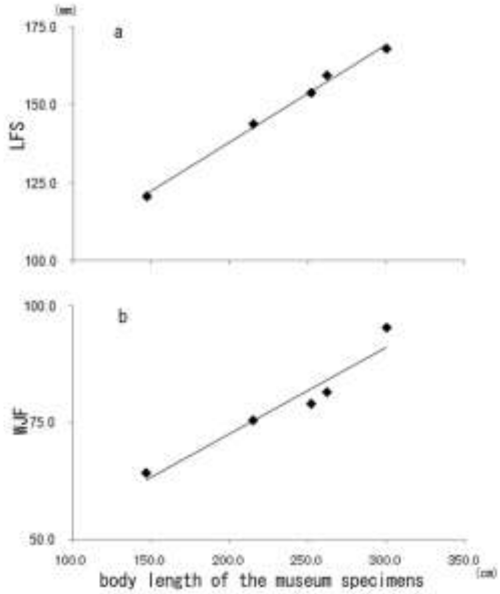


Fig. 5 Linear models for estimating body length. a: regression line between body length and LFS; b: regression line between body length and WJF.

We also estimated age groups, which are typically calculated based on the number of growth layers of tusks. However, because we did not collect any tusks (they were likely stolen), we followed the method of Mitchell (1973), who estimated age groups based on the number and position of molar sockets, as follows: 1) juveniles have five molar and $P^2$ teeth located at the aboral part of the maxillary process; 2) adolescents have four or five molar, $P^3$, and $M^1$ teeth located at the aboral part of the maxillary process; and 3) adults have two or three molar and $M^2$ teeth located at the aboral part of the maxillary process.

## RESULTS

・Restoration of the skull

We collected more than 1,000 fragments of animal bone, nearly all of which, except for one dugong atlas and two sea turtle beaks, were dugong skull fragments. The total numbers of bone fragments (798) were sorted into 10 bone types (Table 2). The temple bone was most abundant (122 pieces; Left: 65, Right: 57), followed by the premaxilla (118; L: 51, R: 67), frontal bone (115; L: 52, R: 63), maxilla (98; L: 48, R: 50), mandible (87; L: 43, R: 44), parietal bone (58), sphenoid (56), occipital bone (52), zygomatic bone (51; L: 21, R: 30), and tympanicum (41; L; 23, R: 18).

Table 2 The number of bones collected at ruins on Shimoji Island.

| | Number of pieces |
|---|---|
| Premaxilla | 118 (L: 51, R: 67) |
| Maxilla | 98 (L: 48, R: 50) |
| Zygomatic bone | 51 (L: 21, R: 30) |
| Frontal bone | 115 (L: 52, R: 63) |
| Parietal bone | 58 |
| Sphenoid | 56 |
| Temple bone | 122 (L: 65, R:57) |
| Tympanicum | 41 (L: 23, R:18) |
| Occipital bone | 52 |
| Mandible | 87 (L: 43, R: 44) |

Table 3 shows the results of skull reconstruction. The estimated minimum numbers of dugongs represented at the site based on matching the frontal, coronal, squamous, shenofrontal, or sphenoparietal sutures were as follows: 71 (matching frontal bone pairs, 44; single frontal bones, 27); 76 (parietal bone pairs with frontal bones, 38; single parietal bones, 18; frontal bones, 20); 91 (R: parietal bones with temporal

Table 3 Estimated number of individuals based on skull reconstructions.

| Structure | A | B | A + B | A | B | Total |
|---|---|---|---|---|---|---|
| Frontal suture | Frontal bone (Right) | Frontal bone (Left) | 44 | 19 | 8 | 71 |
| Coronal suture | Parietal bone | Frontal bone | 38 | 18 | 20 | 76 |
| Squamous suture | Parietal bone | Temporal bone (Right) | 12 | 43 | 36 | 91 |
| | Parietal bone | Temporal bone (Left) | 11 | 46 | 34 | 91 |
| Shenofrontal suture | Frontal bone | Sphenoid | 15 | 25 | 16 | 56 |
| Sphenoparietal suture | Parietal bone | Occipital bone | 2 | 53 | 17 | 72 |

bones, 12; single parietal bones, 43; temporal bones, 36; L: parietal bones with temporal bones, 11; single parietal bones, 46; temporal bones, 34), 56 (frontal bone pairs with sphenoid, 15; single frontal bones, 25; sphenoid, 16); and 72 (parietal bone pairs with occipital bones, 2; single parietal bones; 53, occipital bones, 17), respectively. This result indicates at least 91 dugong skulls at this site.

・Estimation of body length

Figure 6 shows the distribution of estimated body length, which varied widely.

We used LFS to estimate the length of 37 individuals, which ranged from 124.2 to 299.8 cm. We used WJF to estimate the length of 61 individuals, which ranged from
157.5 to 301.2 cm.

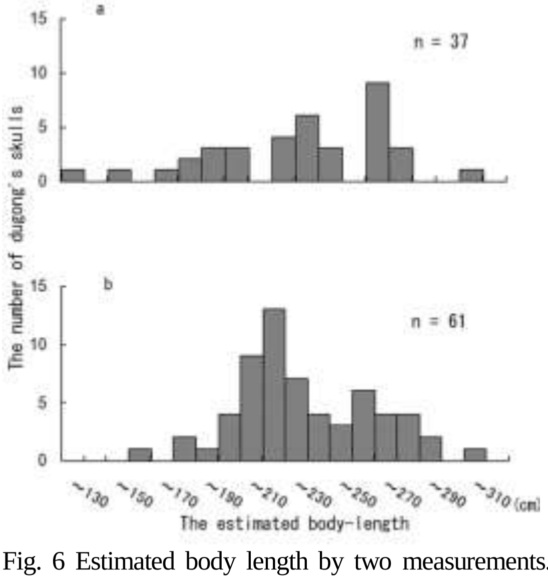


Fig. 6 Estimated body length by two measurements. a: LFS, b: WJF.

・Composition of age group

We collected 98 maxilla fragments, and identified 56 individuals. The results of age-group estimation are shown in Figure 7. Adults made up the largest proportion of the sample (43% of skulls), followed by adolescents (29%) and juveniles (16%).

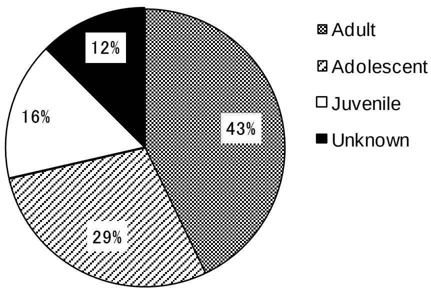


Fig. 7 Proportion of each age class.

**DISCUSSION**

The present distribution of dugong in Japan is confined to around Okinawa Island (Kasuya *et al.*, 1999; Kasuya *et al.*, 2000; Ministry of the Environment of Japan, 2004; Ogura *et al.*, 2005a), although previous reports have suggested a historical distribution including the entire Ryukyu Archipelago, as described in the Introduction. In addition, the presence of dugong around Amami Island, Okinawa Island, and the Yaeyama Islands was reported in an interview survey of 1888 (Uni, 2003). Kuroiwa (1895) reported that the people of the Yaeyama Islands hunted dugong around Iriomote Island. While there is no direct evidence of dugong anywhere other than on Okinawa Island, this species migrates up to 600 km in Australian waters (Preen, 2001), and thus it is possible that previous reports were of incidental migrants from neighboring regions; Okinawa Island is only about 400 km from the Yaeyama Islands and Taiwan is just 200 km west of Iriomote Island.

Our results partly support the historical distribution of dugong. Most of the bones were from the cranium and mandibles (Fig. 2b), and we could not reconstruct complete skulls in most cases, similar to previous reports (e.g., Ogura *et al*., 2005b). This was due to missing skull fragments, such as the zygomatic and tympanicum bones, which are relatively small and easily lost. However, we were able to extract useful biological information from the incomplete skulls.

In Australia, newborn dugongs are about 100–150 cm long (Marsh *et al*., 1984). The linear model based on five specimens deposited at the Okinawa Prefectural Museum, the Museum of the University of the Ryukyus, Nago Museum, and Higashi Museum estimated that the smallest specimen in our sample was 124.19 cm (based on LSN) or 157.19 cm (based on WCS; Fig. 6). Therefore, we considered those specimens to be newborns. Juveniles accounted for 16% of the examined specimens (Fig. 7), but there were representatives of all age classes, from neonates to mature adults, which suggest that historically some groups of dugong bred in the Yaeyama Islands, and therefore were native to the area, not migrants from the Okinawa Islands, Taiwan, or the Philippines. In other words, there was likely a local population in the Yaeyama Islands.

Dugongs were also hunted in the Torres Strait, between Australia and Papua New Guinea (McNiven and Feldman, 2003), and possibly in other regions. If ancient bones could be located, identified, and categorized, as in the present paper (perhaps combined with written records or interviews with local people), further useful information regarding the historical distribution of dugong could be obtained. By reconstructing its historical distribution, we could better understand population structure.

The samples of our study were limited to the Yaeyama Islands. Future studies should examine other parts of the Ryukyu Archipelago. We are planning to extract mtDNA from some of the bones collected for this study. The control region produced reasonable phylogenies and is thus useful as a marker for phylogeographic and population studies on the dugong (McDonald, 2005). We hope to use the data to clarify the phylogenetic relationships among the populations of the region.

**ACKNOWLEDGMENTS**

We thank the Shimoji-jima Islander Society for their cooperation. We are particularly grateful to Mr. Soukichi Nosoko and Mr. Kinsei Ishigaki. We thank Mr. Masanao Toyama, Mr. Athushi Nakamori, and Ms. Ayano Shimabukuro for their help in negotiations and fieldwork. We are grateful for the cooperation of the Board of Education of Taketomi and the Board of Education of Isigaki. We thank the Okinawa Prefectural Museum, the Museum of the University of the Ryukyus, Nago Museum, and Higashi Museum for providing measurement data for their specimens. We thank Dr. Shin-ichiro Kawada and Dr. Nozomi Kurihara for advice on writing this report. This research was supported by a Grant-in-Aid for Scientific Research (A) from the Ministry of Education, Culture, Sports, Science and Technology.

**REFERENCES**

Board of Education of Taketomi. (in Japanese, 1987). Remains of Shimoji, Aragusuku Islands: report of their distribution. 23 pp.

Fawcett, D. W. (1942). The amedullary bones of the Florida manatee (*Trichechus latirostris*). *American Journal of Anatomy* **71**: 271–309.

Husar, L. S. (1978). Dugong dugon. *Mammalian Species*, **88**: 1－7.

Karger. H. E. (1974). Morphology of the Sirenia. Graphische Betriebe Coop Schweiz, *Basel*, 75 pp.

Kasuya, K., M. Shirakihara, H. Yoshida, K. Ogawa, Y. Yokochi, S. Uchida and K. Shirakihara. (in Japanese, 1999). Status of the dugong and its protection in Japan. *Report of the 8th Pro Natura Fund* **8**: 6–13.

Kasuya, K., K. Ogawa, Y. Yokochi, T. Hosokawa, M. Shirakihara and N. Higashi. (in Japanese, 2000). Status of the dugong and its protection in Japan. *Report of the 9th Pro Natura Fund* **9**: 29–36.

Kuroiwa, H. (in Japanese, 1895). Hunting grounds for the dugong. *Zoological Magazine* **7(85)** .

Marsh, H., G. E. Heinsohn, and L. M. Marsh. (1984). Breeding cycle, life history and population dynamics of the dugong (*Dugong dugon*) (Sirenia: Dugongidae). *Australian Journal of Zoology* **32**: 767–788.

Marsh, H., H. Penrose, C. Eros and J. Hugues. (2002). *The Dugong(Dugong dugon) Status Reports and Action Plans for Countries and Territories*. UNEP(W)/EAS WG.1/2. 162pp.

McDonald, B. (2005). Population genetics of dugongs around Australia: implications of gene flow and migration. PhD Dissertation, Department of Zoology and Tropical Ecology and the Department of Tropical Environment Studies and Geography, James Cook University of North Queensland, Townsville.

McNiven, I. J. and R. Feldman. (2003). Ritually orchestrated seascapes: hunting magic and dugong bone mounds in Torres Strait, NE Australia. *Cambridge Archaeological Journal* **13(2)**: 169–94.

Ministry of the Environment of Japan. (in Japanese, 2004). *Reports of surveys of dugong and seagrasses in Japan in FY 2003*. 255 pp.

Ministry of the Environment of Japan. (in Japanese, 2005). *Reports of surveys of dugong and seagrasses in Japan in FY 2004*. 374 pp.

Mitchell, J. (1973). Determination of relative age in the dugong *Dugong dugon* (Müller) from a study of skulls and teeth. *Zoological Journal of the Linnaean Society* **53**: 1–23.

Morimoto, I. (in Japanese, 2003). List of faunal remains in prehistoric Nansei Islands, Japan. The prehistoric cultures of the circum East China Sea area Part 2 supplement. edited by Komoto. M. 88–163.

Nishwaki, M., T. Kasuya, N. Miyazaki, T. Tobayama And T. Kataoka. (1979). Present distribution of the dugong in the world. *The Scientific Reports of The Whales Research Institute*, 31: 133－141.

Ogura, G., T. Hirayama, K. Sudo, N. Otaishi, H. Mukai and Y. Kawashima. (in Japanese, 2005a). Investigation of the northern limit of dugong habitat in the Tokara Islands and Amami-Oshima in the Ryukyu Archipelago, Japan. *Wildlife Conservation of Japan* **9(2)**: 49–58.

Ogura, G., N. Ohtaishi, Y. Kawashima, K. Sudou, M. Uchimura and S. Ohthuka. (in Japanese, 2005b). Survey of the Dugong Ruin, Nanazou, Utaki, on the island of Shimoji in the Ryukyu Archipelago, Japan. Biostory 5: 95–105.

Ouhama, S. (in Japanese, 1971). Taxes of the Yaeyama Islands. *San-ichi Syobou*, Tokyo, 278 pp.

Preen, A. (2001). Dugongs, boats, dolphins and turtles in the Townsville-Cardwell region and recommendations for a boat-traffic management plan for the Hinchinbrook Dugong Protection Area. *Great Barrier Reef Marine Park Authority Research Publication* No. 67, Townsville, Australia.

Uni, K. (in Japanese, 2003). Harvest report of dugong (*Dugong dugon*) in Okinawa Prefecture. Bulletin of Nago Museum 11: 1–14.