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The First Stranding Record of Longman's Beaked Whale (*Indopacetus pacificus*) in Okinawa, Japan

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Abstract

Longman's beaked whale (*Indopacetus pacificus*) is one of the least known cetaceans in the world. Since it was first described as its own species in 1926, they have been observed alive at sea only on a few occasions, and stranding has been reported for less than 20 cases worldwide to date. Thus, biological information regarding this species is still very limited compared to other cetaceans. In this study, the external appearance, osteological characters, DNA analysis, and parasitic organisms of a Longman's beaked whale that was stranded on Ukibaru Island in Okinawa, Japan, are reported. The external appearance and the osteological features of the specimen matched the features of the Longman's beaked whale presented in previous studies. MtDNA control-region sequences obtained from the specimen also matched the reference sequences of the species deposited in GenBank. Based on these features, we concluded that the specimen was a Longman's beaked whale. The specimen was estimated as a juvenile male because of its body length (4.78 m), no eruption of teeth on its lower jaw, and no fusion of the vertebral epiphyses of its vertebral bodies. Whale lice collected from the body surface of the specimen were identified as *Isocystamus indopacetus*, which are known to parasitize Longman's beaked whales. This was the first record of a stranded Longman's beaked whale in Okinawa and also the first record of a juvenile male for this species confirmed in Japan. The whole skeleton was cataloged in the collection of the Okinawa Churashima Research Center (Okinawa Churashima Foundation).

Key Words: Longman's beaked whale, *Indopacetus pacificus*, external appearance, osteology, genetic analysis, whale lice, *Isocystamus indopacetus*

Introduction

Longman's beaked whale (*Indopacetus pacificus*) is one of the least known cetaceans in the world. It was first described as a member of the genus *Mesoplodon* by Longman (1926) based on a skull found in Queensland, Australia. With the comprehensive morphological evaluation of the skull (Moore, 1968, 1972) and the discovery of the second skull in Somalia (Azzaroli, 1968), it was elevated to its own genus, *Indopacetus*, in later years. External appearance and genetic information of the species were first presented by Dalebout et al. (2003).

The total number of strandings for this species reported to date is 17 cases, with 24 animals confirmed in the Indian and Pacific Oceans (Yamada et al., 2012; Acebes et al., 2019). Almost all cases of stranding have been singletons, with two exceptions of a mother–calf pair in Taiwan in 2005 (Yao et al., 2012) and seven animals stranded at once in New Caledonia in 2013 (Garrigue et al., 2016). Thus, there is a lack of ecological and life history data, including body size and sex, of this rare cetacean. In previous studies, sex was determined in most of the cases with 12 males and 10 females confirmed, and two of the animals of unknown sex. The largest male (6.08 m) and female (6.50 m) known to date were found in China (Peng et al., 2009) and Japan (Yamada et al., 2004), respectively. Moreover, in Japan, there are two stranding records of this species: (1) a 6.48 m female in Kagoshima in 2002 (Yamada et al., 2004; Yatabe

et al., 2010) and (2) a 6.30 m female in Hokkaido in 2010 (Yamada et al., 2012).

In this study, information of a Longman's beaked whale, which was stranded for the first time in Okinawa in the southern part of Japan, is reported. A 4.78-m toothed whale carcass was found on a beach on Ukibaru Island in Okinawa on 30 July 2011. The Okinawa Churashima Research Center (Okinawa Churashima Foundation) has been conducting research on marine mammals around the Ryukyu archipelago, including stranding research of cetaceans, since 1991. However, the external features of the cetacean carcass found on Ukibaru Island did not match any other species confirmed in the archipelago, including Okinawa. In the present study, external appearance, osteological characterization, and DNA analysis were conducted to identify the specimen. Species identification of parasitic organisms on the body surface of the specimen is also reported in this study.

Methods

Study Site and Data Collection

Samples were collected from a toothed whale carcass found on a beach on Ukibaru Island in Okinawa, Japan ($26^{\circ} 18' N$, $127^{\circ} 59' E$) on 30 July

2011 (Figures 1 & 2). Photos and 72 external measurements were recorded at the study site. A postmortem (except for the head) was conducted at the study site. Skin tissues for DNA analysis and whale lice were also collected. The skin tissues were fixed with 100% ethanol, and the whale lice were desiccated to preserve them. Whale lice (Cyamidae family) found on the body surface of the specimen, especially around the circular scars observed on the dorsal and lateral sides of the body which were probably caused by the bites of a cookiecutter shark (*Isistius* sp.), were also collected (Figure 2A, arrows 1 & 2). The whole body was carried to the Okinawa Churashima Research Center, and a detailed postmortem of the head was conducted on 17 to 19 July 2012 in the facility.

External Appearance

Twenty-five external measurements and the measurement of its beak tip to the anterior end of pelvic bone (Figure 3) were compared to the values for 10 specimens of Longman's beaked whale found in South Africa, Maldives, Taiwan, Hawaii, and New Caledonia, which were presented in Dalebout et al. (2003), Yao et al. (2012), West et al. (2013), and Garrigue et al. (2016), to identify the specimen.

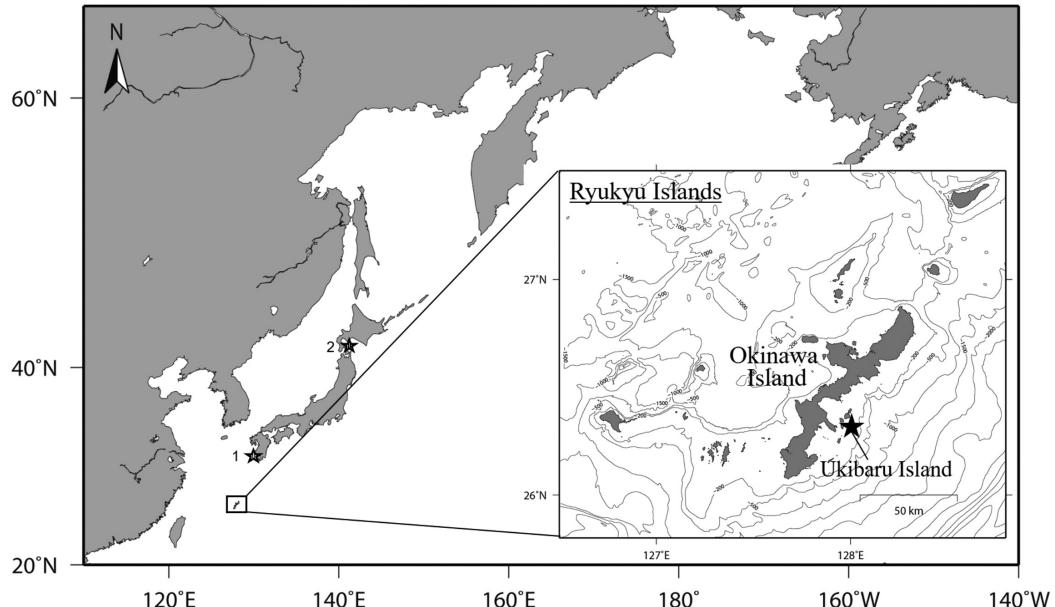


Figure 1. Study site. The black star in the map indicates the location of the stranding of the Longman's beaked whale (*Indopacetus pacificus*) found on Ukibaru Island in Okinawa, Japan. The shaded stars with numbers in the map indicate the stranding locations of Longman's beaked whales in Japan prior to this report: shaded star 1, a 6.48-m adult female found in Kagoshima in 2002 (Yamada et al., 2004; Yatabe et al., 2010); and shaded star 2, a 6.30-m adult female found in Hokkaido in 2010 (Yamada et al., 2012).

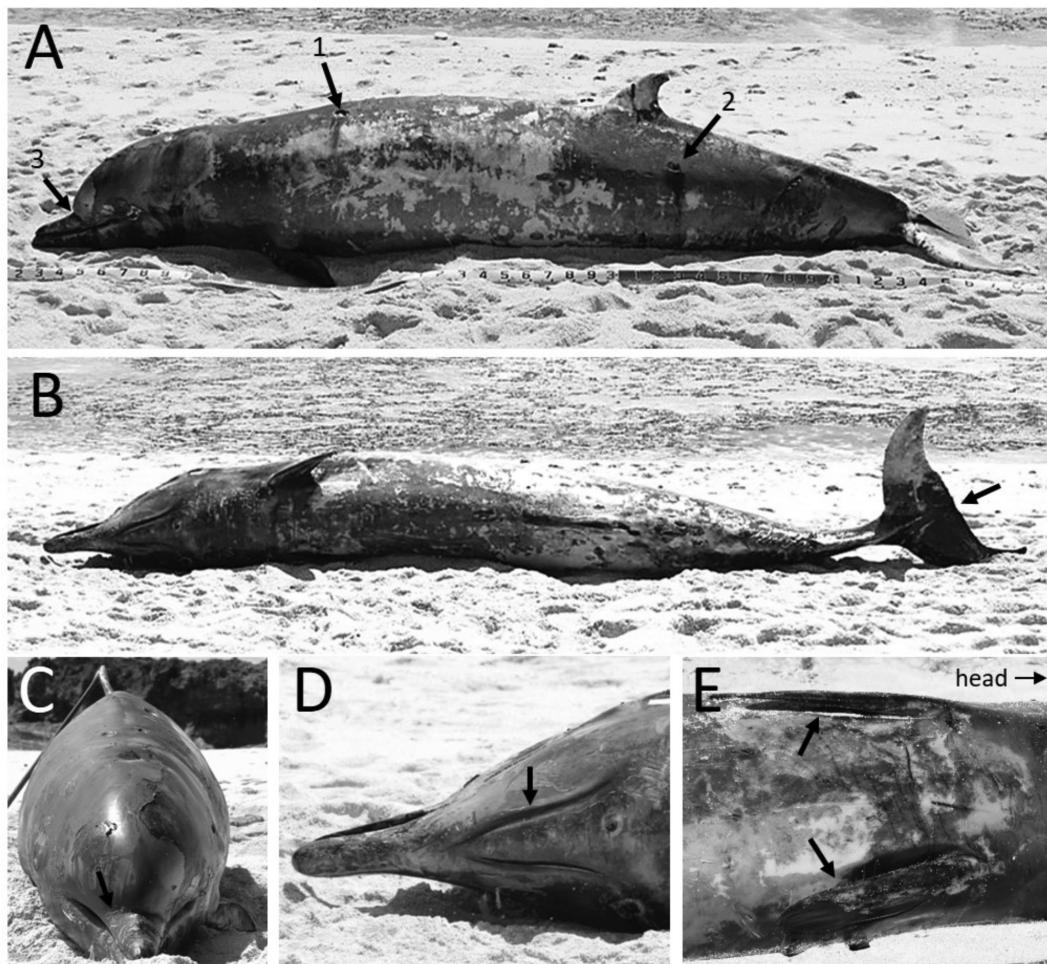


Figure 2. External appearance for the Okinawan specimen of a male Longman's beaked whale: (A) lateral view of body, with arrows 1 and 2 indicating the round-shaped scars possibly caused by cookiecutter sharks (*Isistius brasiliensis*), and arrow 3 indicating the point where the melon and the rostrum meet; (B) ventral view of body, with the arrow indicating the fluke with no notch in the middle; (C) anterior view of head, with the arrow indicating the point where the melon and the rostrum meet; (D) ventral view of head, with the arrows indicating the grooves under the jaw; and (E) ventral view of flippers, with the arrows indicating the “flipper pockets.”

Osteological Analysis

The whole body was immersed in a water tank with free-flowing water for about 2 y after the postmortem to remove the soft tissue from the bones by maceration before osteology. A total of 50 measurements from the cranium, including the mandible and teeth (Figures 4 & 5), were compared to the values for Longman's beaked whale reported in previous studies (Azzaroli, 1968; Dalebout et al., 2003). Radiography (MOBILETT XP Hybrid; Siemens Healthcare GmbH, Erlangen, Germany) and CT scanning (SOMATOM Spirit, Siemens Healthcare GmbH) were also conducted

on the pectoral fins as well as the lower and upper jaws of the specimen before the postmortem to examine the structure of the skeleton and teeth.

Genetic Analysis

MtDNA sequencing was conducted following the methods described in Yoshida et al. (2010). From the skin tissue collected, total cellular DNA was extracted with a Gentra Puregene Mouse Tail Kit (QIAGEN, Hilden, Germany). The MtDNA control region was amplified by polymerase chain reaction (PCR) using the primers ‘t-PRO’ (5'-CCTCCCTAACGACTCAAGGAA-3’) from

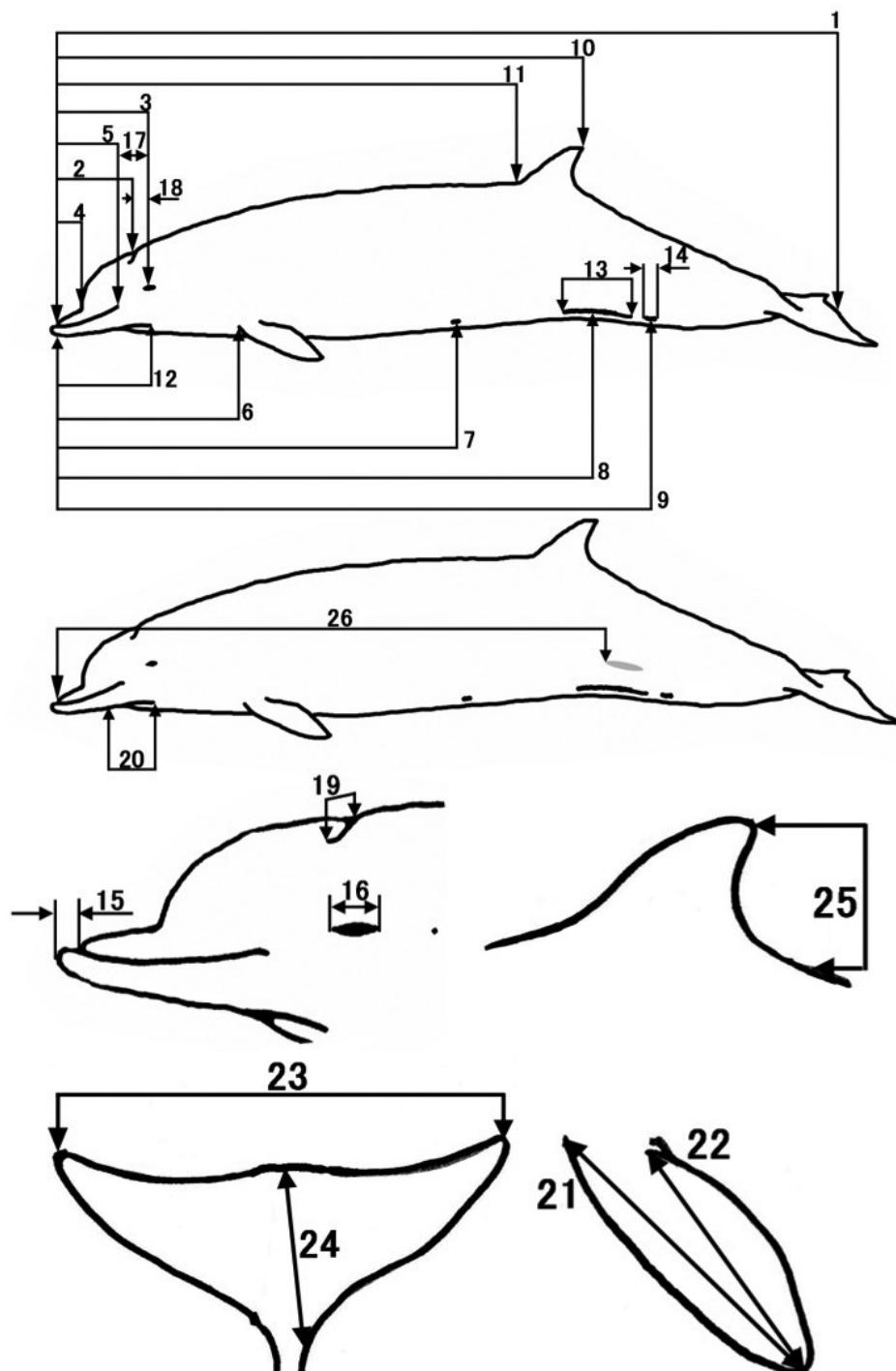


Figure 3. Twenty-six external measurements for the Okinawan Longman's beaked whale specimen. The actual measurements are presented in Table 1.

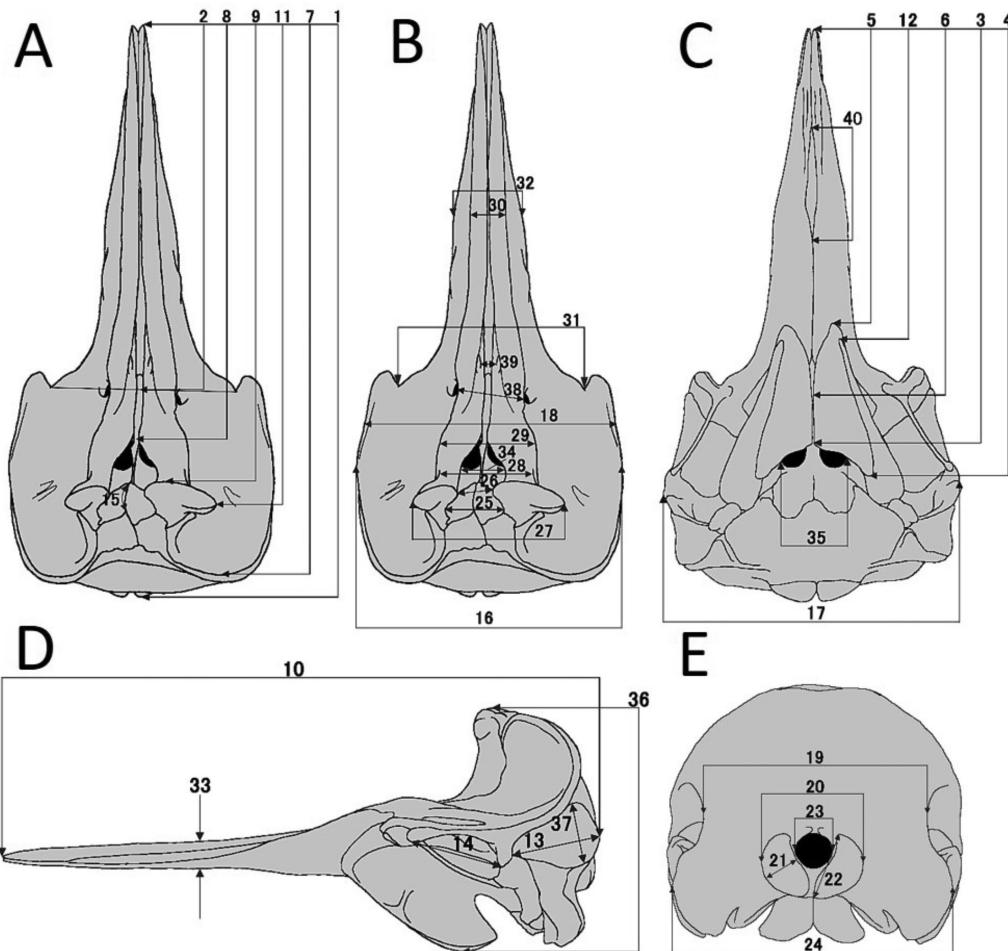


Figure 4. Forty cranial measurement points for the Okinawan Longman's beaked whale specimen: (A) and (B) dorsal view of skull, (C) ventral view of skull, (D) lateral view of skull, and (E) posterior view of skull. The actual measurements for each point are presented as the same numbers in Table 2.

Árnason et al. (1993) and 'P2' (5'-TCTCGAGAT TTTCAGTGTCTTGCTTT-3') described by Hoelzel et al. (1991). The PCR product was purified using EXOSAP-IT (USB Corporation, Cleveland, OH, USA) and sequenced with an Applied Biosystems 3130xl Genetic Analyzer (Thermo Fisher Scientific, Waltham, MA, USA). The MtDNA control-region sequences of beaked whale species (Ziphiidae) were downloaded from GenBank and used as reference sequences for species identification. Sequences were aligned using the multiple sequence alignment program *CLUSTAL W* according to the method of Thompson et al. (1994).

Parasitic Organisms

Identification and terminology of whale lice (Amphipoda: Cyamidae) followed Iwasa-Arai et al. (2017) and Iwasa-Arai & Serejo (2018). Specimens of whale louse were cataloged and included in the collection at the Okinawa Churashima Research Center (Okinawa Churashima Foundation).

Results

External Appearance

The unidentified cetacean found stranded was a male specimen with a body length of 4.78 m. Carcass condition was determined as "early decomposition (Code 3)." Although the original body color is uncertain, possibly due to the

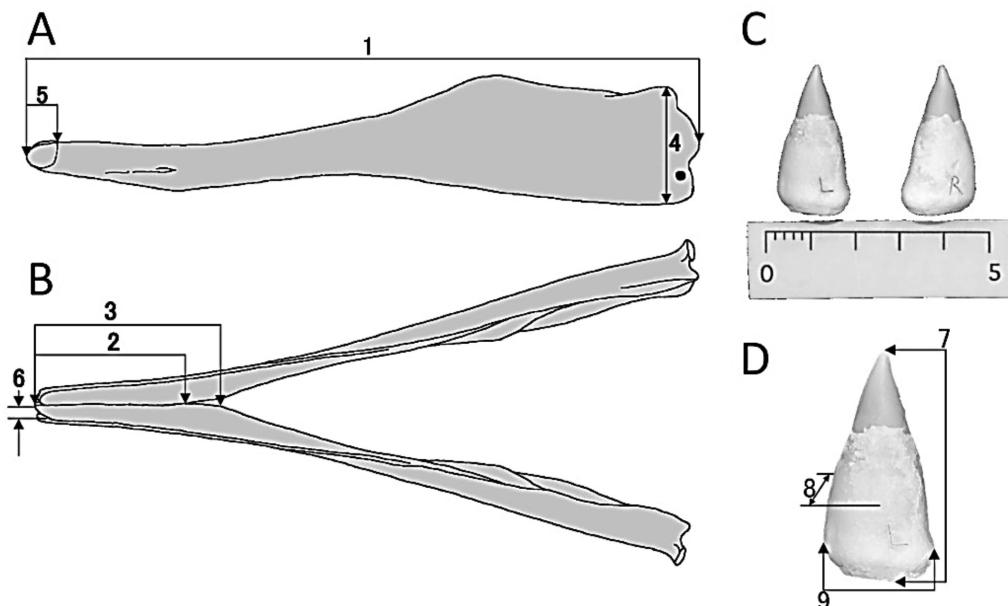


Figure 5. Nine points of mandibular and tooth measurements for the Okinawan Longman's beaked whale specimen: (A) lateral view of lower jaw, (B) dorsal view of lower jaw, (C) both left and right teeth found at the front edge of lower jaw, and (D) three measurement points for the left tooth. The actual measurements for each point are presented as the same numbers in Table 3.

postmortem color change, it was dark gray overall and some parts of the skin were already peeled off when it was found (Figure 2A & B). It had a rounded body with a large melon and long beak. The boundary between the beak and the melon was very clear with the steep angle of the anterior edge of the melon, which meets the rostrum at around 73° (Figure 2A, arrow 3 & Figure 2C, arrow). The oral fissure was rectilinear, and the lower jaw extended beyond the upper jaw when no teeth were observed. There was a pair of v-shaped grooves on the ventral side of the head (Figure 2D, arrow). The pectoral fins were small and fitted in flipper pockets (Figure 2E, arrows; as termed by Mead et al., 1982) on both sides of the body. No notch was present in the middle of its tail fin (Figure 2B, arrow). The dorsal fin was falcate-shaped and relatively small, and was set far back on the body (Figure 2A). The 26 external measurements as a proportion of the body length (Figure 3) are presented in Table 1.

Osteological Characters

A total of 50 measurements were taken for the cranial skeleton (Figure 4A-E), mandible (Figure 5A & B), and teeth (Figure 5C & D) as given in Tables 2, 3 & 4.

All four of the following distinctive cranial features observed for the holotype of Longman's

beaked whale presented by Moore (1968) and Dalebout et al. (2003) were observed in the skull of the Okinawan specimen: (1) the frontal bones occupy an area of the vertex of the skull approximating or exceeding that occupied by the nasal bones (Figure 6A & E); (2) there is minimal extension of the premaxillary crest on the vertex between the nasal and maxillary bones or between the frontal and maxillary bones (Figure 6A & E); (3) a deep groove about half the length of the orbit is present on the dorso-lateral margin of the maxillary bone above the orbit (Figure 6F, arrow); and (4) as seen in the dorsal view, the premaxillae retain an even width to about the mid-length of the rostrum where they may expand slightly before converging again towards the tip of the rostrum (Figure 6A, arrow).

Teeth were not erupted, but a pair of teeth was confirmed at the tip of both mandibles by radiography (Figure 7B, arrow). On the other hand, no teeth were confirmed in the upper jaw (Figure 7A). The hyoid consisted of five bones—left and right stylohyals, a basihyal, and left and right thyrohyals—and none of them were fused (Figure 8A). A pair of periotic and tympanic bulla are shown in Figure 8B.

All parts of the postcranial skeleton were examined (Table 5). Of the seven cervical vertebrae, the anterior five vertebral bodies were fused while the sixth and seventh were separated from each other (Figure 9). Thoracic, lumbar, and caudal vertebrae

Table 1. External measurements of the Okinawan Longman's beaked whale (*Indopacetus pacificus*) specimen and other specimens reported in previous studies. Measurements by the authors are indicated in the table. % TL = percentage of total length.

Sex/age class	Male/juvenile measurement in the past cm % TL (% TL)	Male/inconclusive			Female/adult			Male/juvenile			Male/adult			Female/adult			Female/adult				
		South Africa PEM292 (Dalebout et al., 2003)	South Africa PEM1960 (Dalebout et al., 2003)	Maldives — (Dalebout et al., 2003)	Taiwan IL20050723-1 (Yao et al., 2012)	Taiwan IL20050723-2 (Yao et al., 2012)	Hawaii West et al., (2013)	Maui, Hawaii (West et al., 2013)	New Caledonia #2 (Garrigue et al., 2014)	New Caledonia #A (Garrigue et al., 2014)	New Caledonia #B (Garrigue et al., 2014)	New Caledonia #C (Garrigue et al., 2014)	New Caledonia #2 (Garrigue et al., 2014)	New Caledonia #A (Garrigue et al., 2014)	New Caledonia #B (Garrigue et al., 2014)	New Caledonia #C (Garrigue et al., 2014)					
1 Total length	478.0	100.0	Min	Max	291.0	100.0	363.0	596.0 ^a	100.0	565.0	100.0	420.0	100.0	370.8	100.0	590.0	100.0	590.0	100.0		
2 Beak tip to centre of blowhole	80.0	16.7	12.3	16.1	41.0	14.1	50.0	13.8	--	75.0	13.3	58.0	13.8	45.7	12.3	--	90.0	16.0	95.0	16.1	
3 Beak tip to centre of eye	75.0	15.7	12.3	16.8	43.0	14.8	54.5	15.0	100.0 ^a	16.8	80.0	14.2	63.0	15.0	45.7	12.3	--	92.0	16.3	99.0	16.8
4 Beak tip to apex of melon	23.0	4.8	3.3	4.8	9.5	3.3	--	--	--	27.0	4.8	15.0	3.6	NA	--	--	--	--	--	--	
5 Beak tip to angle of mouth	41.0	8.6	6.9	10.8	26.0	8.9	34.0	9.4	--	52.0	9.2	41.0	9.8	25.4	6.9	64.0	10.8	60.0	10.6	63.0	10.7
6 Beak tip to anterior insertion of flipper	120.0	25.1	20.6	26.0	71.0	24.4	--	--	--	131.0	23.2	109.0	26.0	76.2	20.6	--	137.0	24.3	140.0	23.7	
7 Beak tip to centre of umbilicus	230.0	48.1	46.6	49.8	145.0	49.8	175.0	48.2	--	265.0	46.9	196.0	46.7	172.7	46.6	--	--	--	--	--	
8 Beak tip to genital slit (centre)	295.0	61.7	58.6	72.7	178.0	61.2	220.0	60.6	--	351.0	62.1	246.0	58.6	218.4	58.9	--	410.0	72.7	427.0	72.4	
9 Beak tip to anus	334.0	69.9	67.1	71.1	203.0	69.8	258.0	71.1	--	393.0	69.6	287.0	68.3	248.9	67.1	--	--	--	--	--	
10 Beak tip to tip of dorsal fin	330.0	69.0	54.2	69.4	202.0	69.4	249.0	68.6	--	380.0	67.3	287.0	68.3	246.4	66.5	402.0	68.1	350.0	62.1	320.0	54.2
11 Beak tip to anterior insertion of dorsal fin	294.0	61.5	60.3	64.6	182.0	62.5	224.0	61.7	385.0	64.6	--	--	--	--	223.5	60.3	358.0	60.7	--	--	
12 Beak tip to posterior end of throat creases	70.0	14.6	13.2	13.4	39.0	13.4	48.0	13.2	--	--	--	--	--	--	--	--	--	--	--		
13 Length of genital slit	39.0	8.2	4.1	9.0	17.0	5.8	15.0	4.1	--	--	--	31.0	7.4	--	--	44.0	7.8	53.0	9.0	53.0	--

14 Length of anal opening	10.5	2.2	2.7	2.8	8.0	2.7	10.0	2.8	--	--	--	--	--	--	--	--	--	--	--	--	
15 Projection of lowerjaw beyond rostrum tip	2.0	0.4	0.3	1.2	1.2	0.4	--	--	--	2.7	0.5	1.6	0.4	--	--	4.0	0.7	7.0	1.2	4.0	
16 Length of eye opening	4.0	0.8	0.8	0.9	2.7	0.9	--	--	5.0	0.8	--	--	--	--	--	--	--	--	--	--	
17 Centre of eye to angle of mouth	34.0	7.1	5.0	6.5	19.0	6.5	--	--	--	28.0	5.0	22.0	5.2	--	--	--	--	--	--	--	
18 Centre of eye to centre of blowhole	5.0	1.0	0.9	1.2	27/23	8.6 ^b	--	--	--	5.0	0.9	5.0	1.2	--	--	--	--	--	--	--	
19 Blowhole width	15.0	3.1	2.6	3.1	8.5	2.9	--	--	--	16.0	2.8	13.0	3.1	--	--	16.0	2.8	16.5	2.8	16.0	
20 Length of throat grooves	38.5	8.1	7.0	8.6	25.0	8.6	29.0	8.0	--	--	39.5	7.0	--	--	--	--	--	--	--	--	
21 Flipper length, anterior	45.0	9.4	7.2	10.5	29.0	10.0	26.0	7.2	55.0	9.2	55.0	9.7	44.0	10.5	NA	--	50.0	8.5	50.0	8.9	
22 Flipper length, posterior	28.0	5.9	5.7	6.7	17.5	6.0	22.0	6.1	--	--	32.0	5.7	28.0	6.7	--	--	--	--	--	--	
23 Fluke width	93.0	19.5	20.2	25.4	62.0	21.3	78.0	21.5	--	136.0	24.1	92.5	22.0	74.9	20.2	150.0	25.4	130.0	23.0	128.0	
24 Fluke depth	43.0	9.0	6.1	7.8	20.5	7.0	22.0	6.1	--	--	--	--	--	--	--	--	44.0	7.8	43.0	7.3	43.0
25 Dorsal fin height	22.0	4.6	4.5	5.7	13.0	4.5	18.0	5.0	--	--	31.0	5.5	20.0	4.8	17.8	4.8	31.0	5.3	27.0	4.8	31.0
26 Beak tip to anterior end of pelvic vestige	315.0	65.9	66.2	66.7	--	--	--	--	--	--	374.0	66.2	280.0	66.7	--	--	--	--	--	--	--

^aCurvilinear length^bTaken from mean of left- and right-hand measurements

Table 2. Cranial measurements for the Okinawan Longman's beaked whale specimen and other specimens reported in former studies. Measurements were made by the authors indicated in the table. % CBL = percentage of condylobasal length.

Sex/age class	Male/juvenile	Measurements in the past (% CBL)				Male/adult				Female/adult				Male/subadult			
		cm	% CBL	Min	Max	cm	% CBL	cm	% CBL	cm	% CBL	cm	% CBL	cm	% CBL	cm	% CBL
1	Condyllobasal length	104.0	100.0	69.0	66.3	61.8	69.5	119.4	100.0	111.6 ^a	100.0	123.0	100.0	113.0 ^b	100.0	70.4	100.0
2	Length of rostrum; tip of beak to line connecting apices of antorbital notches							81.5	68.3	75.2	67.4	85.5	69.5	77.5	68.6	43.5	61.8
3	Tip of rostrum to posterior margin of pterygoid near mid-line	80.5	77.4	68.6	81.2	96.9	81.2	88.8	79.6	98.5	80.1	104.5	85.0	—	—	54.0	72.0
4	Tip of rostrum to most posterior extension of wing of pterygoid	85.2	81.9	76.7	85.0	101.1	84.7	91.2	81.7	104.5	85.0	—	—	—	—	54.0	76.7
5	Tip of rostrum to most anterior extension of pterygoid	59.5	57.2	58.1	91.6	70.3	58.9	64.8	58.1	76.5	62.2	—	—	—	—	64.5	91.6
6	Tip of rostrum to most posterior extension of maxillaries between pterygoids on the palatal maxillary plate	66.0	63.5	60.1	70.7	80.7	67.6	78.6	70.4	87.0	70.7	—	—	—	—	42.3	60.1
7	Tip of rostrum to most posterior extension of maxillary plate	97.5	93.8	92.2	98.2	111.7	93.6	105.6	94.6	116.0	94.3	111.0	98.2	108.2	64.9	92.2	
8	Tip of rostrum to anterior margin of superior nares	78.0	75.0	58.0	78.8	92.1	77.1	85.1	76.3	95.5	77.6	89.0	78.8	80.8	40.8	58.0	
9	Tip of rostrum to most anterior point on premaxillary crest	82.5	79.3	74.1	83.2	97.9	82.0	89.4	80.1	99.5	80.9	94.0	83.2	83.2	52.2	74.1	
10	Tip of rostrum to most posterior extension of temporal fossa	102.0	98.1	95.5	99.6	115.2	96.5	108.9	97.6	117.5	95.5	112.5	99.6	109.6	67.8	96.3	
11	Tip of rostrum to most posterior extension of lateral tip of premaxillary crest	87.0	83.7	81.0	99.8	101.0	84.6	95.0	85.1	122.7	99.8	—	—	—	—	57.0	81.0
12	Tip of rostrum to most anterior extension of pterygoid sinus	63.0	60.6	53.0	62.7	74.9	62.7	67.9	60.8	—	—	—	—	—	—	37.3	53.0
13	Length of temporal fossa	16.5	15.9	13.0	16.8	18.0	15.1	18.6	16.7	16.0	13.0	15.5	13.7	11.8	11.8	16.8	
14	Length of orbit	13.5	13.0	10.1	14.5	12.0	10.1	12.7	11.4	14.0	11.4	13.5	11.9	10.2	10.2	14.5	
15	Length of nasal suture	7.0	6.7	4.1	6.5	6.8	5.7	7.2	6.5	—	—	6.5	5.8	2.9	2.9	4.1	
16	Breadth of skull across postorbital process of frontals	46.8	45.0	41.1	48.2	52.8	44.2	53.8	48.2	50.5	41.1	48.0	42.5	33.7	33.7	47.9	
17	Breadth of skull across zygomatic processes of squamosals	46.0	44.2	39.8	45.3	52.4	43.9	50.6	45.3	49.0	39.8	47.5	42.0	31.4	31.4	44.6	
18	Breadth of skull across centers of orbits	44.4	42.7	37.4	45.7	50.4	42.2	50.2	45.0	46.0	37.4	47.0	41.6	32.2	32.2	45.7	

19 Least breadth of skull across posterior margins of temporal fossae	31.3	30.1	26.0	36.5	31.7	26.5	32.3	28.9	32.0	26.0	31.5	27.9	25.7	36.5
20 Greatest span of occipital condyles	14.1	13.6	12.6	17.9	16.1	13.5	16.5	14.8	15.5	12.6	15.4	13.6	12.6	17.9
21 Greatest width of an occipital condyle	5.7	5.5	4.5	7.1	6.7	5.6	5.0	4.5	6.9	5.6	7.5	6.6	5.0	7.1
22 Greatest length of an occipital condyle	9.0	8.7	8.2	10.8	10.0	8.4	9.2	8.2	10.8	8.8	9.9	8.8	7.6	10.8
23 Greatest breadth of foramen magnum	5.1	4.9	4.2	8.1	5.4	4.5	5.4	4.8	5.2	4.2	5.4	4.8	5.7	8.1
24 Breadth of skull across exoccipitals	41.1	39.5	35.4	42.2	45.8	38.4	40.4	36.2	43.5	35.4	42.5	37.6	29.7	42.2
25 Breadth of nasals on vertex	8.5	8.2	7.5	10.2	9.3	7.8	9.7	8.7	--	--	8.5	7.5	7.2	10.2
26 Least distance between premaxillary crests	5.5	5.3	4.7	16.1	5.6	4.7	6.0	5.4	--	--	--	--	11.3	16.1
27 Greatest span of premaxillary crests	23.0	22.1	18.3	24.4	24.0	20.1	23.6	21.1	22.5	18.3	22.7	20.1	17.2	24.4
28 Least width (strictly transverse) of premaxilla where they narrow opposite superior nares	15.5	14.9	13.0	14.4	16.3	13.7	16.1	14.4	16.0	13.0	--	--	--	--
29 Greatest width of premaxillae anterior to place of previous measurement	16.0	15.4	14.1	14.5	16.8	14.1	16.2	14.5	--	--	--	--	--	--
30 Width of premaxilla at mid-length of rostrum	6.5	6.3	5.9	8.0	8.9	7.5	8.9	8.0	7.3	5.9	7.6	6.7	5.2	7.4
31 Width of rostrum in apices of antorbital notches	31.8	30.6	26.8	32.4	34.4	28.8	35.8	32.1	33.0	26.8	33.0	29.2	22.8	32.4
32 Greatest width of rostrum at mid-length of rostrum	11.2	10.8	9.4	14.1	12.5	10.5	14.4	12.9	11.6	9.4	12.8	11.3	9.9	14.1
33 Greatest depth of rostrum at mid-length of rostrum	4.8	4.6	4.6	6.8	5.5	4.6	5.5	4.9	6.1	5.0	5.8	5.1	4.8	6.8
34 Greatest transverse width of superior nares	7.7	7.4	6.7	10.2	9.0	7.5	8.1	7.3	8.2	6.7	8.9	7.9	7.2	10.2
35 Greatest inside width of inferior nares; at apices of pterygoid notches, on the pterygoids	13.2	12.7	10.4	13.6	--	--	--	--	12.8	10.4	12.5	11.1	9.6	13.6
36 Height of skull; distance between vertex of skull and most ventral point of pterygoids	41.0	39.4	36.3	39.2	43.3	36.3	42.5	38.1	45.0	36.6	42.0	37.2	27.6	39.2
37 Greatest width of temporal fossa approximately at right angles to greatest length	9.8	9.4	9.2	9.9	11.5	9.6	11.1	9.9	--	--	11.2	9.9	6.5	9.2
38 Least distance between (main or anterior) maxillary foramina	11.2	10.8	9.8	11.1	11.9	10.0	11.9	10.7	12.0	9.8	11.8	10.4	7.8	11.1
39 Least distance between premaxillary foramina	3.5	3.4	2.0	3.6	4.3	3.6	3.6	3.2	2.5	2.0	3.7	3.3	2.3	3.3
40 Greatest length of vomer visible at surface of palate	22.8	21.9	20.2	29.1	34.7	29.1	28.9	25.9	--	--	--	--	14.2	20.2

^aNo adjustment made for the 25 to 50 mm broken off the tip of the rostrum
^bBroken fragment of rostrum included in measurements (Azzaroli, 1968)

^cTip of rostrum broken but restored

Table 3. Width/depth ratio of rostrum at mid-length for Longman's beaked whale. Measurements were made by the authors indicated in the table.

	Okinawa, Japan Ukibaru Island specimen (This publication)	Minimum and maximum of measurements in the past (1/2 ratio)		Queensland QM-J2106 (Dalebout et al., 2003)		Kenya OM7622 ^a (Dalebout et al., 2003)		Maldives -- (Dalebout et al., 2003)		Somalia MZUF 1956 ^b (Azzaroli, 1968)		South Africa PEM1960 ^c (Dalebout et al., 2003)		
Sex/age class	Male/juvenile	1/2 ratio	Min	Max	cm	1/2 ratio	cm	1/2 ratio	cm	1/2 ratio	cm	1/2 ratio	Female/ subadult	Male/juvenile
Measurement	cm				cm		cm		cm		cm		cm	1/2 ratio
1 Greatest width of rostrum at mid-length of rostrum	11.2	2.3	1.9	2.6	12.5	2.3	14.4	2.6	11.6	1.9	12.8	2.2	9.9	2.1
2 Greatest depth of rostrum at mid-length of rostrum	4.8	--			5.5		5.5		6.1		5.8		4.8	

^aNo adjustment made for the 25 to 50 mm broken off the tip of the rostrum^bBroken fragment of rostrum included in measurements (Azzaroli, 1968)^cTip of rostrum broken but restored**Table 4.** Mandibular and tooth measurements for Longman's beaked whale. Measurements were made by the authors indicated in the table. % ML = percentage of mandible length (based on mean where two measurements are given).

	Okinawa, Japan Ukibaru Island specimen (This publication)	Minimum and maximum of measurements in the past (% ML)		Queensland QM-J2106 (Dalebout et al., 2003)		Maldives -- (Dalebout et al., 2003)		Somalia MZUF 1956 (Azzaroli, 1968)		South Africa PEM1960 ^a (Dalebout et al., 2003)		South Africa PEM292 ^b (Dalebout et al., 2003)		
Sex/age class	Male/juvenile	Male/adult	Female/adult	Female/subadult	Male/juvenile	Male/neonate	cm	% ML	cm	% ML	cm	% ML	cm	% ML
Measurement	cm	% ML	Min	Max	cm	% ML	cm	% ML	cm	% ML	cm	% ML	cm	% ML
1 Length of mandible	90.5	100.0	--	--	108.7	100.0	107.5	100.0	101.0	100.0	62.6	100.0	--	--
2 Length of symphysis (fused length)	20.0	22.1	27.4	28.7	30.0	27.6	29.5	27.4	29.0	28.7	--	--	--	--
3 Length of symphysis (including unfused posterior part)	26.0	28.7	22.1	31.6	32.7	30.1	34.0	31.6	29.0	28.7	13.9	22.1	--	--
4 Height mandible at coronoid process	15.7	17.3	15.3	19.8	16.6	15.3	17.4	16.2	17.0	16.8	12.4	19.8	--	--
5 Length of alveolus	2.3	2.5	2.7	3.5	3.0	2.8	2.9	2.7	--	--	2.2	3.5	--	--
6 Width of alveolus	1.0	1.1	1.6	1.7	1.8	1.7	1.7	1.6	--	--	1.1	1.7	--	--
7 Greatest (vertical) length of tooth	3.5	3.9	3.3	4.3	--	--	3.6	3.3	--	--	2.7	4.3	2.0	--
8 Greatest anterior/ posterior width of tooth perpendicular to greatest length	1.3	1.4	1.4	1.4	--	--	1.5	1.4	--	--	--	--	1.6	--
9 Greatest breadth of tooth	1.6	1.8	1.8	2.1	--	--	1.9	1.8	--	--	1.3	2.1	--	--
10 Depth of alveolus (This part is not indicated in Figure 5.)	2.0	2.2	2.4	2.4	2.6	2.4	--	--	--	--	--	--	--	--

^aTips of mandibular rami broken but restored^bBased on x-ray of tooth *in situ*

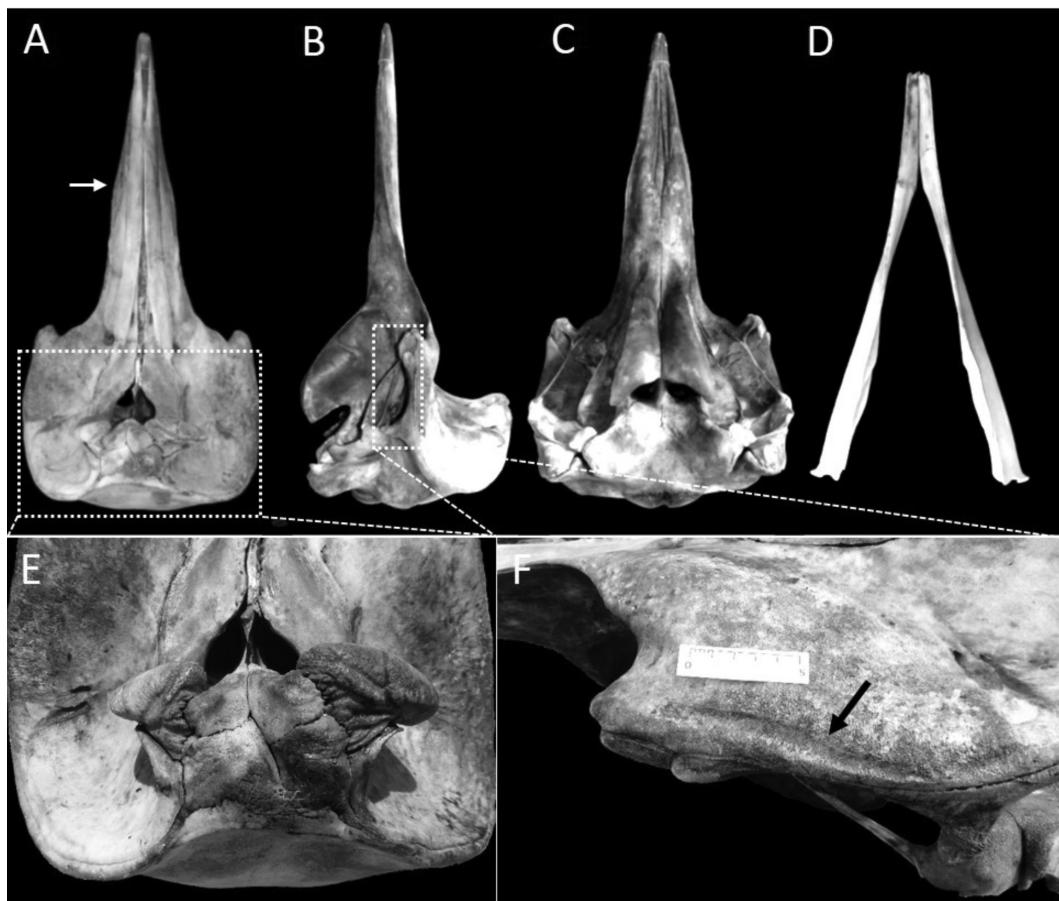


Figure 6. Skull of the Okinawan Longman's beaked whale specimen: (A) dorsal view, (B) lateral view, (C) ventral view, (D) dorsal view of lower jaw, (E) close-up of cranial vertex, and (F) close-up of lateral view of skull. Arrows highlight diagnostic cranial features discussed by Moore (1968) and Dalebout et al. (2003).

consisted of 10, 10, and 19 bones, respectively (Figure 10A-C). Nine chevron bones were confirmed (Figure 10C). Vertebral epiphyses were not fused and were fully separated from the vertebral bodies between the posterior side of the 5th cervical vertebrae and the anterior side of the 17th caudal vertebrae. There were nine ribs on each side of the body (Figure 11), which included seven double-headed ribs. There were no ossified sternal ribs, and the sternum consisted of four bones (Figure 12A). Scapula on both sides of the body are presented in Figure 12B. Ossified pelvic bones were confirmed on each side of the body (Figure 13A). Forelimbs consisted of the following bones: a humerus, radius, ulna, six carpal, five metacarpals, and phalanges (Figure 13B). Phalanges were classified as follows: I (0/0), II (5/5), III (5/5), IV (4/4), and V (3/3). None of the carpals in the forelimbs were fused, including between the intermedium and ulnare.

Genetic Analysis

A total of 272 bp of the mtDNA control region of the Okinawan specimen could be sequenced. For species identification, mtDNA control-region sequences of 17 beaked whale species (Ziphiidae) were downloaded from GenBank (Table 6). When the sequence of the Okinawan specimen was compared with these reference sequences, it matched two sequences from the *I. pacificus* (KP892561 and KY0364702), whereas it differed by more than 20 nucleotide substitutions from the sequences in the other species. The genetic analysis, thus, indicates that the Okinawan specimen is a Longman's beaked whale. The sequenced 272 bp of the Okinawan specimen spanned the nucleotide positions 38 and 309 of the mtDNA control region of KY0364702 (Yao et al., 2012).

Table 5. Postcranial osteology for Longman's beaked whale. Measurements were made by the authors indicated in the table.

	Okinawa, Japan Ukibaru Island specimen (This publication)	South Africa PEM292 (Dalebout et al., 2003)	Maldives -- (Dalebout et al., 2003)	IL20050723-1 (Watson et al., 2008)	IL20050723-2 (Watson et al., 2008)
Sex/age class	Male/juvenile	Male/neonate	Female/adult	Female/adult	Male/juvenile
Cervical vertebrae	5 + 2	5 + 2	5 + 2	--	--
Thoracic vertebrae	10	10	10	--	--
Lumbar vertebrae	10	12	9	--	--
Caudal vertebrae	19	7+	15+	--	--
Chevron bones	9	--	-	--	--
Double-headed ribs	7	7	7	--	--
Flipper bones (L/R)	I (0/0) II (5/5) III (5/5) IV (4/4) V (3/3)	-- -- -- -- --	-- -- -- -- --	I (0/0) II (6/6) III (5/5) IV (4/4) V (3/3)	I (0/0) II (6/5) III (6/5) IV (4/4) V (3/3)

**Figure 7.** Radiographs of upper and lower jaw of the Okinawan Longman's beaked whale specimen: (A) dorsal view of upper jaw and (B) lateral view of lower jaw. Arrow indicates the teeth in the lower jaw.

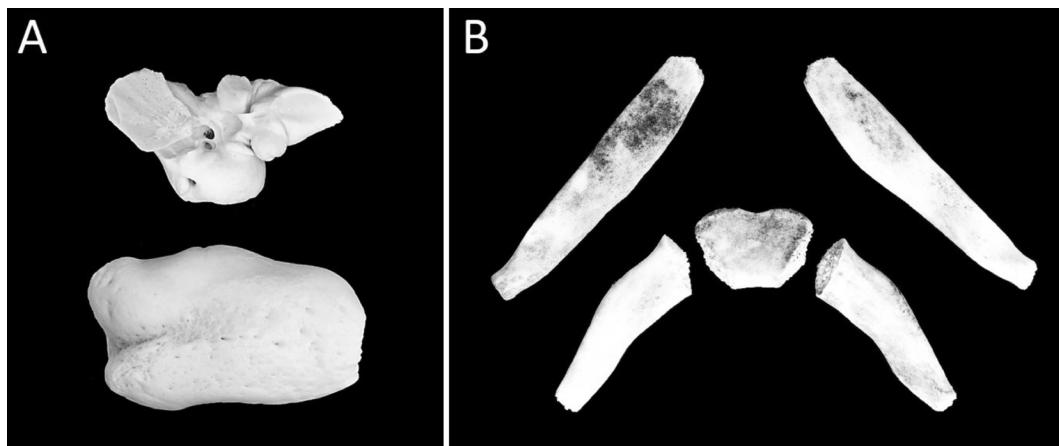


Figure 8. Periotic, tympanic bulla, and hyoid of the Okinawan Longman's beaked whale specimen: (A) Upper: medial view of right periotic; Lower: lateral view of right tympanic bulla; and (B) medial view of hyoid bones.

Parasitic Organisms

Over hundreds of whale lice (cyamids) were found around the mouth, mammary slits, and circular scars on the body surface of the specimen (Figure 14A). These cyamids were identified by Kei Miyamoto as *Isocyamus indopacetus* (Iwasara-Arai & Serejo, 2017) by having the following combination of characters: terminal articulate of antenna 1 with a continuous band of seta; accessory gills present in males; one pair of ventral acute processes present on segments 5 to 7; pereonite 2 with anterodorsal epaulet-like cuticular infoldings; and two spine-like processes present on the base of the lateral gills (Figure 14B & C).

Osteological and Parasitic Organism Material Held

The skeleton of the Okinawan specimen was cataloged in the Okinawa Churashima Research Center's (Okinawa Churashima Foundation) marine mammal collection as OCF-MM20110730. The whole skeleton was constructed as a skeletal preparation by Nishio Biological Models Co., LTD (Yamashina-ku, Kyoto, Japan) and is presently displayed in Ocean Expo Park in Okinawa (Figure 15). The skeleton was constructed without any damage to any part of the bones (such as making holes or gluing), and all the bones are demountable at any time to meet the needs and uses of any future osteological studies. The specimens of cyamids were cataloged in the Okinawa Churashima Research Center's collection as follows: OCF-Cr00054, nine males (body size range: 8.2 to 11.2 mm), four females (8.6 to 10.3 mm), and five juveniles (2.4 to 3.5 mm).

Discussion

To the best of our knowledge, less than 20 cases of Longman's beaked whale have been reported as stranded to date. The first specimen was found in Australia, which was reported by Longman (1926), and the external appearance and genetic information of the species were first presented by Dalebout et al. (2003). In the current study, the external measurements and general appearance of the Okinawan specimen were similar to the values for Longman's beaked whales presented in previous studies (Dalebout et al., 2003; Yao et al., 2012; West et al., 2013; Garrigue et al., 2016). Characteristic features for the external appearance of the Okinawan specimen also matched the features of the Longman's beaked whale presented by Dalebout et al. (2003), especially in the following parts: (1) relatively small pectoral fins fit in the flipper pockets on both sides of the body; (2) there was no notch confirmed in the middle of its tail fin; (3) the dorsal fin was falcate shaped and relatively small, and was set far back on the body; (4) there was a pair of grooves on the ventral side of its head; and (5) the large and round melon met its rostrum at ~75°. These features are commonly found in many beaked whales, while *Hyperoodon* and *Berardius* spp. also share similar external characteristics with the Okinawan specimen; however, the form in the dorsal surface of the vertex of these two genera presented in Moore (1968) were different from those of the Okinawan specimen.

The cranial features, especially those of the dorsal surface of the vertex of the Okinawan specimen, showed distinctive features of the Longman's beaked whale presented in Moore (1968), Azzaroli (1968), and Dalebout et al. (2003). Both the general cranial features and external appearance observed for the Okinawan specimen were also similar to



Figure 9. Lateral view of the cervical vertebrae and the first thoracic vertebra of the Okinawan Longman's beaked whale specimen

Shepherd's beaked whale (*Tasmacetus shepherdi*). However, neither the small teeth nor the many mandibular and maxillary alveoli present in Shepherd's beaked whale were observed in the Okinawan specimen. The position, shape, and size of the teeth confirmed on the lower jaw of the Okinawan specimen were similar to those of the Longman's beaked whale as reported in previous studies.

The Okinawan specimen had 10 thoracic vertebrae and 10 ribs, including seven double-headed ribs, which were the same numbers observed in the

South African and Maldivian specimens (Dalebout et al., 2003). The numbers were slightly different in the lumbar and caudal vertebrae between the Okinawan specimen and Longman's beaked whales in a previous study (Dalebout et al., 2003). The number of lumbar vertebrae for the Okinawan specimen was 10, which was well within the nine to 12 range of previously reported specimens. The numbers of these parts presented in Table 5 varied in the specimens of the previous study as well (Dalebout et al., 2003), indicating that this feature

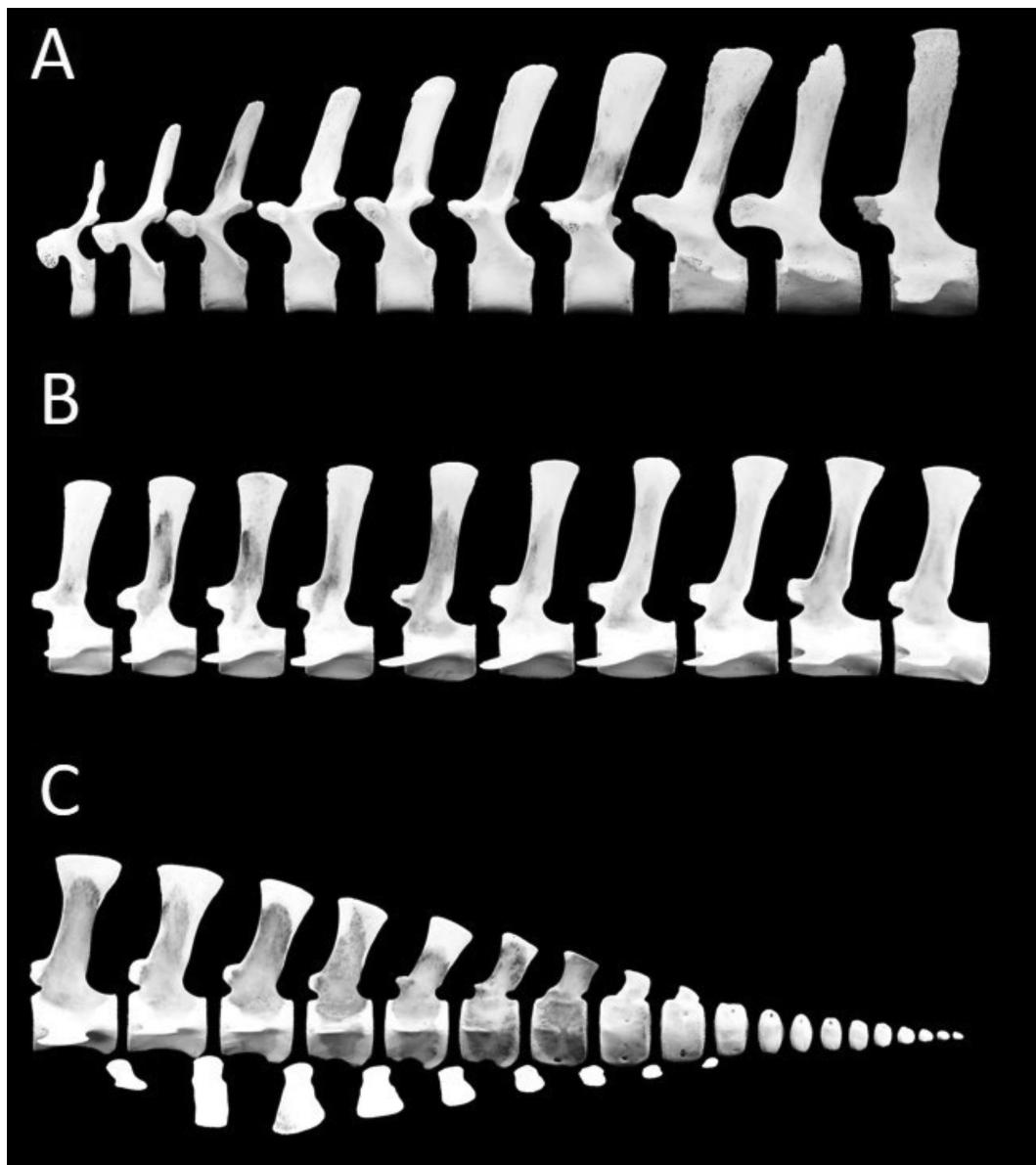


Figure 10. Lateral view of the vertebrae (without epiphyses) of the Okinawan Longman's beaked whale specimen: (A) thoracic vertebrae, (B) lumbar vertebrae, and (C) caudal vertebrae.

varies between individuals. According to Perrin (1975) and Ito & Miyazaki (1990), the vertebral epiphyses for physically immature cetaceans are by definition not fused to the vertebral bodies observed in most vertebrae of the Okinawan specimen. The number of the phalanges in the forelimbs matched the adult female specimen found in Kagoshima, Japan (Watson et al., 2008). The numbers also matched an adult and juvenile specimen found in Taiwan (Watson et al., 2008),

except for phalange II (Table 5). Phalange II for the Taiwan specimens was six when it was five for the Okinawan specimen. Watson et al. (2008) also reported that the intermedium and ulnare of forelimbs of the adult specimen were in robust contact and coalesced over their proximal halves while in the juvenile they were separate. Moreover, there were wider intercarpal, cartilaginous spaces (3 to 6 mm), and the edges of the carpal bones were more rounded in the juvenile specimen in

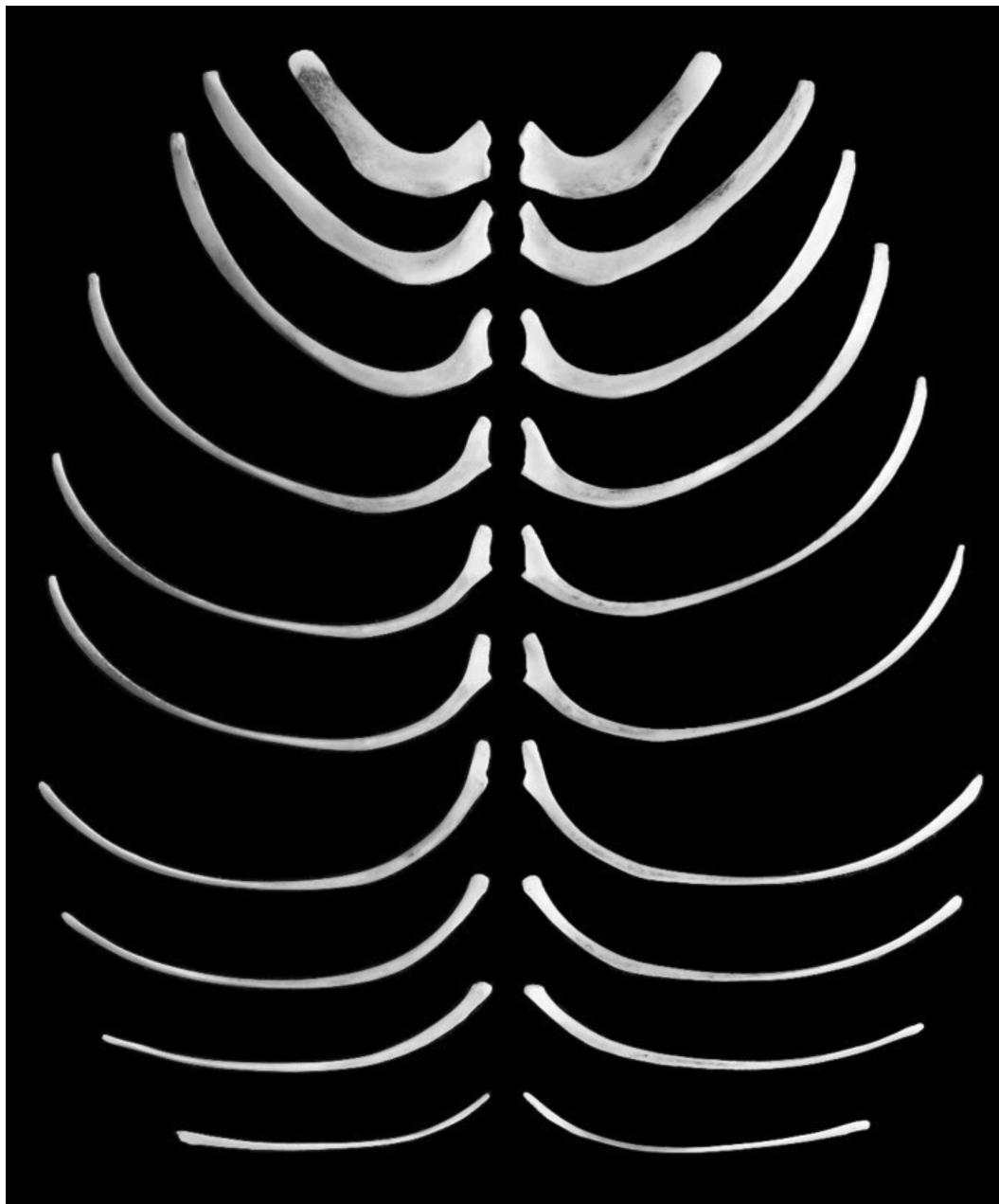


Figure 11. Left and right ribs of the Okinawan Longman's beaked whale specimen. The upper side is the cranial side of the specimen.

Taiwan, confirming that the Okinawan specimen was indeed an immature cetacean (Watson et al., 2008). The intermedium and ulnare of forelimbs for the Okinawan specimen were separate, the intercarpal spaces were wider, and the edges of the carpal bones were rounder than those of the adult specimen in Taiwan.

Whale lice (*Isocyamus indopacetus*) was originally described based only on the male holotype, which parasitized Longman's beaked whales stranded in southern New Caledonia (Iwasa-Arai et al., 2017), and no additional specimens had been recorded before. This is the second record of the species and the first distributional record from the



Figure 12. Sternum and scapula of the Okinawan Longman's beaked whale specimen: (A) medial view of sternum and (B) lateral views of the left and right scapula.

northwestern Pacific region. In addition, females were observed for the first time. This species is likely to have high host-specificity to Longman's beaked whales because it has only been discovered in these whales.

Based on the result of the DNA analysis of this species identification, and with these results and the characteristic features observed especially in the cranial figures of the Okinawan specimen, it was concluded that the Okinawan specimen was a Longman's beaked whale.

The body length of Longman's beaked whales reported stranded in the world to date ranged between 2.91 and 6.50 m. The largest female was 6.50 m in Japan (Yamada et al., 2004), and the largest male was 6.08 m in China (Peng et al., 2009). The body length of the Okinawan specimen was 4.78 m, which was slightly larger than the juvenile male specimens found in South Africa (Dalebout et al., 2003), the United States (Jensen et al., 2011), and Taiwan (Yang et al., 2008), but it was relatively

smaller than any subadult or adult specimens found and reported before (Yamada et al., 2012; Garrigue et al., 2016; Acebes et al., 2019). These results also indicate that the Okinawan specimen was physically immature (juvenile)—an estimation which was supported by no eruption of its teeth on its lower jaw as well as the condition of the fusion confirmed for the vertebral epiphyses or the carpal for the forelimbs.

In Japan, two cases of stranded Longman's beaked whale have been reported prior to the Okinawan specimen: the first record was an adult female found in Kagoshima in 2002, and the second one was also an adult female found in Hokkaido in 2010 (Yamada et al., 2012). Thus, the specimen found in Okinawa was the 3rd and the most southern record of the discovery of this species in Japan. Moreover, this is the first record of a male juvenile Longman's beaked whale in Japan. However, the distribution and habitat use of this species in Okinawa, Japan, is still poorly understood. According to previous studies, sightings of the species at sea were reported in

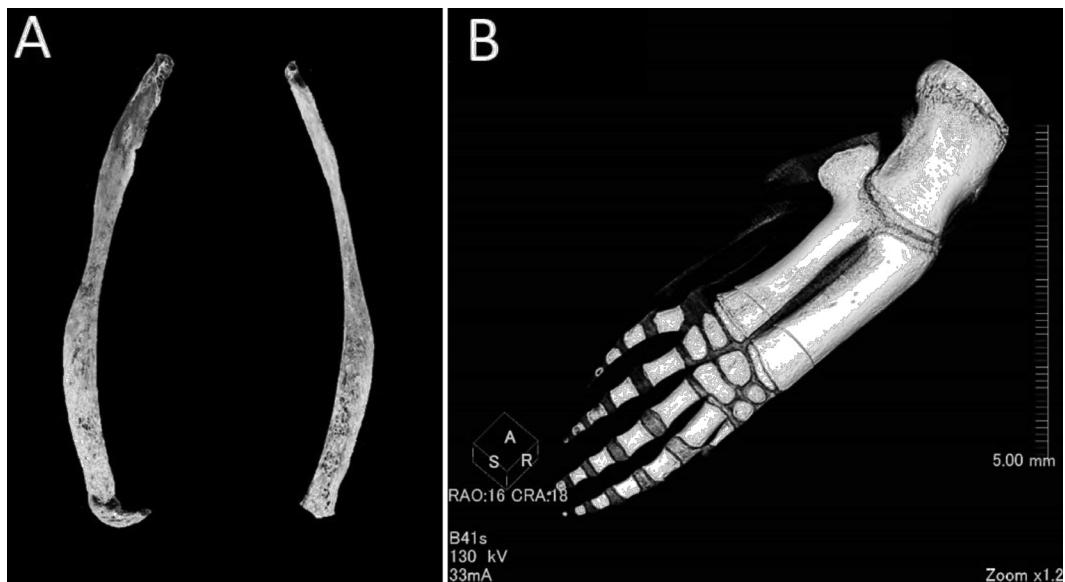


Figure 13. Pelvic bones and right forelimb of the Okinawan Longman's beaked whale specimen: (A) lateral views of left (length: 8.0 cm; maximum width: 8.5 mm) and right pelvic bones; and (B) CT scanned image of the lateral view of the right forelimb of the Okinawan specimen.

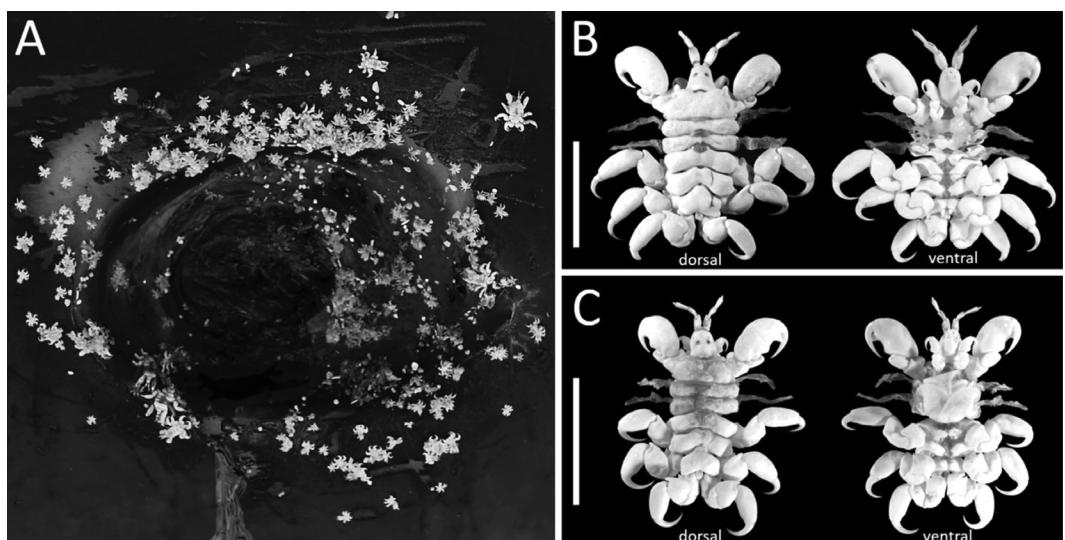


Figure 14. Cyamids (whale lice) collected from the body surface of the Okinawan Longman's beaked whale specimen: (A) whale lice found especially around the circular scars on the body surface of the specimen; (B) dorsal and ventral views of a dry specimen of male *Isocyamus indopacetus*; and (C) dorsal and ventral views of a dry specimen of female *Isocyamus indopacetus*. Scale bars = 5 mm.

the Indian and Pacific Oceans (Pitman et al., 1999; Anderson et al., 2006; Yamada et al., 2012). Thus, it is not clear whether the Longman's beaked whale is distributed around Japan, including the Okinawan area, throughout the year or only on some occasions.

Therefore, it is essential to conduct boat and/or aerial surveys to obtain more information on the distribution of Longman's beaked whale around Japan. The discovery of this specimen has extended the known range of the Longman's beaked whale.

Table 6. GenBank accession numbers of 17 species in the family Ziphiidae, including *Indopacetus pacificus*, used for comparisons in this study

Species (Ziphiidae)	GenBank accession number	Reference
<i>Indopacetus pacificus</i>	KP892561 KY364702	Garrigue et al., 2016 Yao et al., 2012
<i>Mesoplodon bidens</i>	AY579508	Dalebout et al., 2004
<i>Mesoplodon bowdonini</i>	AY579509	Dalebout et al., 2004
<i>Mesoplodon carlhubbsi</i>	AY579511	Dalebout et al., 2004
<i>Mesoplodon densirostris</i>	AY579514	Dalebout et al., 2004
<i>Mesoplodon europaeus</i>	AY579516	Dalebout et al., 2004
<i>Mesoplodon ginkgodens</i>	AY579517	Dalebout et al., 2004
<i>Mesoplodon grayi</i>	AY579519	Dalebout et al., 2004
<i>Mesoplodon hectori</i>	AY579522	Dalebout et al., 2004
<i>Mesoplodon hotaula</i>	JX470543	Dalebout et al., 2004
<i>Mesoplodon layardii</i>	AY579523	Dalebout et al., 2004
<i>Mesoplodon mirus</i>	AY579525	Dalebout et al., 2004
<i>Mesoplodon perrini</i>	AF441254	Dalebout et al., 2004
<i>Mesoplodon peruvianus</i>	AY579526	Dalebout et al., 2004
<i>Mesoplodon stejnegeri</i>	AY579528	Dalebout et al., 2004
<i>Mesoplodon traversii</i>	AF439992	van Helden et al., 2002
<i>Tasmacetus shepherdi</i>	AF036226	Dalebout et al., 2004

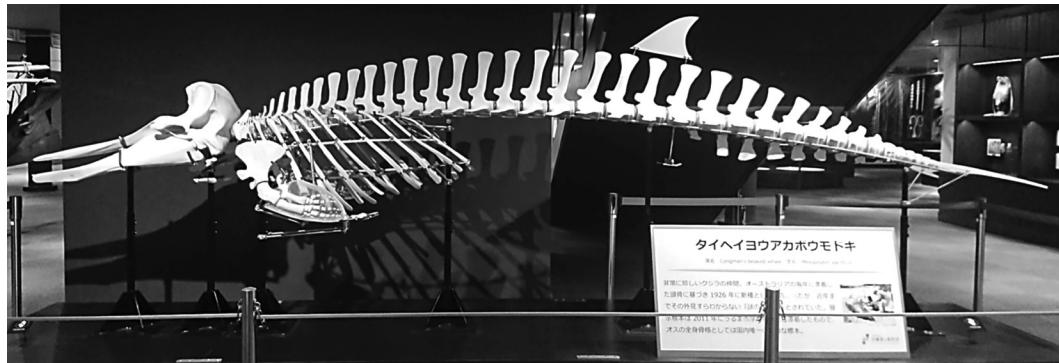


Figure 15. Whole skeleton of the male Okinawan Longman's beaked whale as displayed in Ocean Expo Park in Okinawa

Acknowledgments

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