# **Short Note**

## First Record of a Fossil Blue Whale in São Paulo State, Brazil

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Knowledge of the actual distribution of blue whales (Balaenoptera musculus; Linnaeus, 1758) is incomplete throughout most of its range (e.g., Mizroch et al., 1984; Mate et al., 1999; Branch et al., 2007). Population numbers have dropped worldwide as a consequence of an intensive harvesting period, and no complete record of the species' distribution previous to commercial whaling exists. Blue whales were one of the main targets of the modern whaling period with the adoption of more intrusive harpoons and faster boats. In the Southern Hemisphere, the population of Antarctic (or true) blue whales was estimated at 239,000 (202,000 to 311,000) before the start of commercial whaling (population estimate in 1905) (Branch et al., 2004), while whaling caused the species' depletion to very low levels. The International Whaling Commission declared a blue whale hunt moratorium in 1966, and the most recent estimate for the Antarctic blue whales is of 1,700 (860 to 2,900) individuals for 1996 (Branch et al., 2004).

Post-whaling studies of living blue whales have been conducted in different areas around the world (e.g., Sears et al., 1990; Fiedler et al., 1998; Palacios, 1999; Hucke-Gaete et al., 2004; Calambokidis et al., 2007). Information regarding distribution patterns is segmented and concentrated during summer months (e.g., Mate et al., 1999). In the South Atlantic Ocean, blue whales have been recorded in Brazil, Namibia (Walvis Bay), Angola, and Gabon (Yochem & Leatherwood, 1985). Hinton (1925) reported a possible sighting off the coast of Rio de Janeiro (22° S) (Yochem & Leatherwood, 1985). Historical records report that two individuals were caught at the whaling station of Costinha, Paraíba, in 1948 and 1965, and one in Cabo Frio (Rio de Janeiro) in 1962 (Zerbini et al., 1997). Additionally, three individuals were sighted off the coast of Paraíba during the period

of commercial whaling between 1966 and 1981 (Da Rocha, 1983). The most recent record of the species in Brazil was of a live stranded female at the village of Chui  $(32^{\circ} 07' \text{ S}, 52^{\circ} 05' \text{ W})$ , Rio Grande do Sul State, on 29 April 1992 (Dalla Rosa & Secchi, 1997).

Herein, we report the discovery of a fossil blue whale at Leste Beach (UTM coordinates 23J 255227 and 7269410) in the City of Iguape, southern coast of São Paulo State (Brazil) (Figure 1). Recent coastal erosion in this area exposed the bones, which were associated with sediments indicating a shallow marine environment. The fossil is the first record of the species for São Paulo State. During the excavation conducted in August 2012, part of the skull with wellpreserved occipital condyles and tympanic bulla, scapula, axis, ribs, an epiphysis of a vertebra, and a chevron were recovered. A detailed description of the discovered material from a paleontological point of view as well as an explanation about the circumstances that allowed the formation of the fossil are provided.

Leste Beach is constituted of sandy sediments that are disposed in spit forms, controlled by microtides, and under the influence of the Ribeira de Iguape River (Suguio & Martin, 1978). The genesis of this spit is associated with variations of sea level during the Holocene (Giannini et al., 2008). The adjacent basement is mainly composed of proterozoic granitoids and migmatite rocks (Almeida & Carneiro, 1998).

The area is characterized by intensive coastal erosion. To characterize the fossil location, a series of aerial photographs (from 1962) and satellite images (between 1984 to 2013) were analyzed to describe the evolution of the coastline around the deposit location over the last 30 y. The satellite images of Leste Beach indicate that the oceanographic conditions (e.g., tides, waves, and currents) of the area removed the sediments, causing cycles of accretion and erosion of the shoreline (Figure 1). Between 1993 and 2000 (7 y), a total of 600 m of accretion was observed with a rate of 85 m/y. Between 2001 and 2013 (12 y), an erosion of 900 m was observed perpendicular to the shoreline, with a rate of 75 m/y. Studies conducted at the mouth of Ribeira de Iguape River, Leste Beach, and Icapara Bar reported an accretion of 220 m, or an average of 37 m/y at



**Figure 1.** Location where the skull and other bones of the blue whale were found at the southern coast of São Paulo State. The dotted rectangle indicates the position of satellite images (*Google Earth*) presented in A and B, and the "x" represents the location of the found bones. A-D: Evidence of recent coastal erosion that exposed the bones. A & B – comparison between the coastline in 2001 and 2013; C – transition of coastline showing the erosion of Leste Beach and the accretion of Ilha Comprida Beach and Icapara Bar; and D – occurrence of the skull.

the northern limit of Ilha Comprida from 1993 to 1999 (Kawakubo & Luchiari, 2002; Nascimento et al., 2008; Guedes et al., 2011; Lima & Oliveira, 2012). Kawakubo (2009) evaluated the evolution of the coastline and reported that in 1976, 1980, 1993, and 2000, the erosion and depositional process were extremely dynamic and that the geomorphic features in the area could change over a very short period of time.

The fossilized material was deposited with the Stratigraphy and Paleontology Laboratory of Universidade Estadual Paulista (UNESP) Campus do Litoral Paulista (PV-2012-01 up to PV-2012-09). The discovered material occurred in situ, associated with sandy facies with plane-parallel bedding, indicating a shallow marine environment. The skeleton was permineralized (i.e., the empty spaces of the bones were filled with minerals from the groundwater), showing a brown color (iron oxide). The animal, probably stranded on an old beach, was later buried by the accretion of the coastline, which began the process of fossilization in a freshwater environment saturated (iron oxide) beneath the streets and houses. Subsequently, erosion of the shoreline again exposed the bones to a saltwater environment. During excavation, several bones were recovered (Figure 2), and the skull was found upside down. The bones were found

in close proximity to each other, except for one of the ribs, which was approximately 10 m away, suggesting a small reworking by waves during the sedimentation/fossilization process.

The discovered material was identified to the species level. The size and morphology of the skull allowed the identification of the material as a representative of *B. musculus*. Because of its large size, it could also be the skull of a fin whale (Balaenoptera physalus). As the material was incomplete, it was not possible to compare the degree of contact between the palatine and the pterygoid process (Omura et al., 1970). The palatine and the vomer, which are diagnostic features for the identification of cetaceans from the skull, were missing. However, the morphology and arrangement of the occipital fit the description of a blue whale, as well as the tympanic bulla, which was essential to confirm identification. Figure 2 shows the tympanic bulla from different angles.

The ages of samples were determined by radiocarbon dating of AMS Lab Beta Analysis. The age of the skull and associated sedimentary deposit were estimated to between 1.9 kya  $\pm$  40 (Beta337197) and 1.7 kya  $\pm$  40 (Beta337198).

Three models of simple linear regression were applied to estimate the total length of the individual. The models use the extent of the bizigomatic



**Figure 2.** Discovered parts of the blue whale: (A) left scapula in medial view (PV-2012-01), (B) epiphysis of vertebra (PV-2012-02), (C) left tympanic bulla (PV-2012-03), (D) axis (PV-2012-04), (E) ribs (PV-2012-05, PV-2012-06, and PV-2012-07), (F) chevron (PV-2012-08), (G) posterior portion of the skull in ventral view (PV-2012-09), and (H) skull detail.

(maximum distance between the zygomatic processes of the squamosals) as a proxy to estimate the total length of the animal (Pyenson & Sponberg, 2011). Each model uses a taxon as reference. The data used as baseline for each taxa were obtained in museums and universities in Italy, the United States, Australia, and Canada (MSN-UNIPI-Pisa-Italy, NMNH-Smithsonian-USA, SBMNH-California-USA, LML-California-USA, NHM-California-USA, WAM-Australia, and CMN-Canada). The reference taxa adopted were the Neoceti group, the family Balaenopteridae, and *B. musculus*.

The linear regression analysis showed that the discovered fossil measured 22 m based on data of the Neoceti group ( $R^2 = 89\%$ ; n = 45), 25 m based on data of the family Balaenopteridae (R<sup>2</sup> = 81%; n = 53), and 23 m based on the available measures of B. musculus ( $\mathbb{R}^2 = 89.7\%$ ; n = 6). Total length of adult blue whales is usually ~27 to 30 m (Lodi & Borobia, 2013). The animals of the Southern Hemisphere (SH) are bigger than those of the Northern Hemisphere (NH); the maximum recorded size of the former was 33.6 m (Lodi & Borobia, 2013), while the later was 29.9 m (Rice, 1978); and females are larger than males. Sexual maturity (5 to 15 y of age) is reached at a length of 21 to 23 m for the NH females and of 20 to 21 m for males; while for the SH, it is reached at a length of 23 to 24 m for females and 22 m for males (Yochem & Leatherwood, 1985). If our estimates are correct, the discovered fossil was a young animal. Occurrence of the epiphysis of a vertebra among the discovered material is another piece of evidence of an animal that had not completed its longitudinal growth. In some cetacean species, some epiphysis fuse after sexual maturity (see Moran et al., 2015, for an overview).

This is the first record of the species for the State of São Paulo, suggesting the area was probably part of the past distribution of this species. Paleontological studies are of great contribution for knowledge of species' past distribution. This is not the first paleontological record of a cetacean species in Brazil, but it is the first of a blue whale. In 1980, excavations to install sewage outfall in the beaches of Praia Grande, São Paulo State, revealed some fragmented whale bones. The recovered bones consisted of a skull (posterior part with condyle), and cervical and caudal vertebrae; the material was compared to the skeleton of a fin whale, providing evidence it pertained to the genus Balaenoptera but to a species smaller than B. physalus (Mezzalira, 1982). Other registers of fossil vertebrae belonging to the family Balaenopteridae and Balaenidae were discovered in the City of Santa Vitoria do Palmar, Rio Grande do Sul State (Cunha & Nunan, 1980; Cunha, 1982, 1985; Cunha et al., 1992). In the

same area, skulls of Franciscana (*Pontoporia bla-invillei*) were also found from the Pleistocene strata (Buchmann & Rincón, 1997; Ribeiro et al., 1998). The present note contributes to a broader knowledge of blue whale distribution in the southwestern Atlantic Ocean.

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