

Original Article

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Institutional Abbreviations:

CET, Department of Geodynamics and Paleontology, University of Huelva, Spain; GMNH, Gunma Museum of Natural History, Tomioka, Japan; INM, Ibaraki Nature Museum, Bando, Japan; IRSNB, Institut Royal des Sciences Naturelles de Belgique, Brussels, Belgium; MAB, Oertijdmuseum, Boxtel, the Netherlands; MAUL, Museo dell'Ambiente, Università di Lecce, Italy; MTA, Miguel Telles Antunes collection, Departamento de Ciências da Terra, Universidade Nova de Lisboa, Portugal; NMR, Natural History Museum Rotterdam, the Netherlands; NSM, National Science Museum, Tokyo, Japan; YPM, Yamagata Prefectural Museum, Japan





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A Miocene sperm whale (Cetacea, Physeteroidea) tooth from Liessel (Noord-Brabant, the Netherlands)

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Abstract

Here we report a well-preserved isolated physeteroid tooth of Late Miocene age from Liessel, the Netherlands. The presence of several morphological features allows attribution to the macroraptorial physeteroids. Size and morphology are to some extent comparable to *Zygophyseter* and almost identical to the primarily tooth-based Tortonian taxon *Scaldicetus caretii*. However, the genus *Scaldicetus* was declared unutilizable, which is supported here with an overview of modern classifications of *Scaldicetus* species and specimens. Despite the restrictions, the type species *S. caretii* is still valid, although the name is to be restricted to the type material. Based on its morphological resemblance, the tooth is identified as Physeteroidea indet. cf. *Scaldicetus caretii*.

Introduction

Physeteroidea is a monophyletic clade within Odontoceti, the toothed whales (Geisler et al., 2011). Physeteroid origins trace back to the late Oligocene, and the diversity of Physeteroidea peaked during the Middle and Late Miocene (Mchedlidze, 1970; Gol'din & Marareskul, 2013; Lambert et al., 2017; Lambert et al., 2020; Paolucci et al., 2020; Peri et al., 2022). The clade comprises three extant species: giant sperm whale (*Physeter macrocephalus* Linnaeus, 1758), pygmy sperm whale (*Kogia breviceps* (de Blainville, 1838)) and dwarf sperm whale (*Kogia sima* (Owen, 1866)). All of the extant members are specialized deep-diving suction feeders, preying on cephalopods. The extant sperm whales lack their upper dentition or have vestigial teeth positioned in their maxilla (Werth, 2004, 2006). Some extinct physeteroids were probably foraging at great depths as well, but the full shift to a deep-diving ecology likely occurred relatively recently (Lambert, 2008). Most of the Miocene representatives of Physeteroidea still possessed upper dentition and displayed a wide variety in feeding strategies. The largest members with teeth up to 36.2 cm in length were mostly macroraptorial, feeding on fish and possibly on medium-sized cetaceans as well (Lambert et al., 2010b; Lambert et al., 2017; Reumer et al., 2017). Recently, Watmore and Prothero (2023) described a 25 cm long macropredatory physeteroid tooth from California. Other extinct physeteroids with smaller teeth (physeterids and kogiids) were mostly piscivorous, fed on benthic prey or predated on cephalopods through suction feeding (Benites-Palomino et al., 2020; Collareta et al., 2020; Benites-Palomino et al., 2021). All physeteroids are characterized by their remarkable skull structure, which makes room for a supracranial basin containing the spermaceti organ, which plays a role in echolocation (Cranford et al., 1996; Paolucci et al., 2020).

The stem physeteroid genus *Scaldicetus* du Bus, 1867 is mainly based on isolated teeth, which is considered material of limited diagnostic value (Bianucci & Landini, 2006; Toscano et al., 2013; Marra et al., 2016; Lambert et al., 2017; Reumer et al., 2017; Bosselaers & Van Nieulande, 2018). However, studies on physeteroid dentition of the last three decades do show characterizing features in size and morphology for different physeteroid species (Hirota & Barnes, 1994; Kazár, 2002; Bianucci et al., 2004; Bianucci & Landini, 2006; Kimura et al., 2006; Bloodworth & Odell, 2008; Lambert, 2008; Boersma & Pyenson, 2015; Lambert et al., 2017; Collareta et al., 2019; Benites-Palomino et al., 2020; Lambert et al., 2020; Kimura & Hasegawa, 2022; Peri et al., 2022). The genus *Scaldicetus* was introduced by du Bus (1867) based on 45 large physeteroid teeth with rugose enamel-capped crowns from the Upper Miocene of Borgerhout, Antwerp, Belgium. Solely based on the dentition du Bus erected the species *Scaldicetus caretii*. Following this classification, multiple large enamel-capped sperm whale teeth have been assigned to the genus *Scaldicetus* (Table 2). However, Bianucci & Landini (2006) regarded the genus unutilizable due to the low diagnostic value of isolated physeteroid teeth and they restricted the generic and specific name only to the lectotype of *S. caretii* (IRSNB M. 512) from

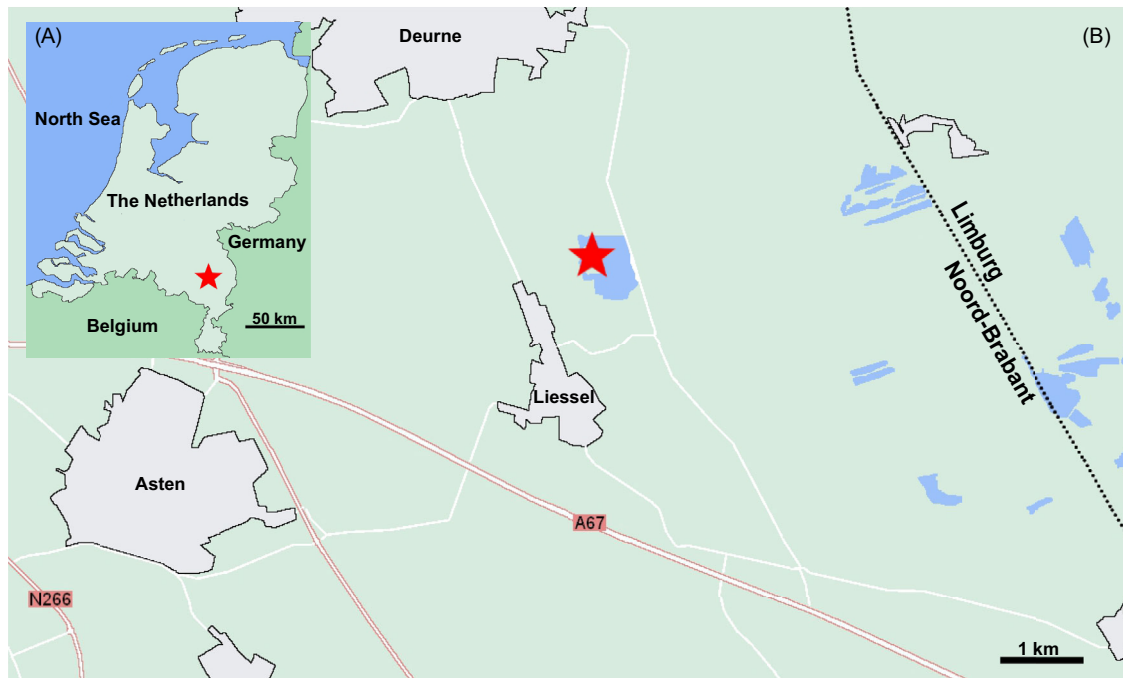


Figure 1. Locality of MAB13159. (A) Map of The Netherlands where the red star indicates the Liessel section. (B) Map of Liessel and surroundings where the red star indicates the exact locality of the discovery: sand-lime brick factory Hoogdonk.

Borgerhout. Lambert & Bianucci (2019) confirmed this conclusion and referred to other isolated physeteroid teeth as *Physeteroidea* indet. Recently, teeth comparable to the type material of *S. caretti* that were collected from the Westerschelde estuary, the Netherlands, were tentatively attributed to the genus *Zygophyseter* Bianucci & Landini, 2006 by Reumer et al. (2017). Despite the conclusions of Bianucci & Landini (2006), several physeteroid findings from across the globe are still attributed to the unutilized *Scaldicetus* genus.

Here we report a large, well-preserved isolated physeteroid tooth similar to the teeth of the type material of *Scaldicetus caretti* (as defined by Bianucci & Landini, 2006 and Lambert & Bianucci, 2019) and resembling *Zygophyseter varolai* (Bianucci & Landini, 2006). It was found in Miocene deposits at Liessel, Noord-Brabant province, the Netherlands. We also provide a list of modern classifications of *Scaldicetus* species/specimens to ensure future adherence to the restrictions set by Bianucci & Landini (2006).

Methods and materials

The Miocene physeteroid tooth from Liessel is in the collection of the Oertijdmuseum in Boxtel (MAB13159). The specimen was impregnated using methyl-methacrylate copolymer dissolved in acetone. Measurements were taken with digital callipers and compared to other physeteroid teeth based on descriptions in the literature.

Systematic palaeontology

Order Cetacea Brisson, 1762

Suborder Odontoceti Flower, 1867

Superfamily Physeteroidea Gray, 1821

Physeteroidea indet. cf. *Scaldicetus caretti*

Locality and stratigraphy

MAB13159 was recovered *ex situ* at Liessel near Eindhoven, Noord-Brabant Province, the Netherlands (Fig. 1). It was dredged by the sand-lime brick factory Hoogdonk and discovered on the sand deposit area. Here terrestrial sediment from the Pleistocene and Pliocene and marine sediment from the Upper Miocene is extracted (Peters, 2009; Bisconti et al., 2020).

Description

MAB13159 (Fig. 2) is heavily mineralized and has a total length of 227 mm. The tooth is distally curved and thickened, in contrast to the relatively flat mesial side (Fig. 2). The lingual/labial side of an isolated physeteroid tooth cannot be determined. The crown is 41.3 mm long and makes up about 18 per cent of the total tooth length. It has a conical shape with a subcircular cross-section. A small part of the apex of the crown is missing due to erosion. The crown is covered in a thick layer of enamel revealing natural wear with a striped (crenulated) pattern showing longitudinal ridges and grooves of approximately 1 mm in width. The margin of the enamel is irregular, but on the mesial side this margin is well-preserved, giving an indication of the actual base of the crown (Fig. 3). At the base of the crown, the mesiodistal diameter measures 31.7 mm and the labiolingual diameter 32.2 mm. Here the enamel forms a continuous surface with the cement of the root.

The robust root has a maximum mesiodistal diameter of 74.2 mm and slightly smaller maximum labiolingual diameter of 67.5 mm. It is subcircular in cross-section throughout the root. The maximum diameter is positioned at about mid-length of the tooth. Approaching the crown, the diameter becomes quickly more slender, with a crown diameter/maximum root diameter ratio of 0.43. A distal view of the root clearly shows the upper boundary of



Figure 2. Different views of tooth. (A) Lingual or labial view with the gingival collar represented with orange dotted lines, the folding indicated by the white arrow. The white rectangle displays the position of Fig. 3. (B) Distal view with the upper boundary of the gingival collar represented with an orange dotted line. (C) Labial or lingual view. (D) Mesial view.



Figure 3. Close-up of the mesial side of the crown.

the gingival collar at about 70 mm below the apex of the crown (measured along the curvature of the tooth) (Fig. 2B). Although the lower boundary is much harder to distinguish, it appears to have

been located at mid-length of the tooth about 20 mm below the upper boundary (Fig. 2A). Anteriorly, the same gingival boundary runs more diagonally, leading to a folding of the gingival collar (Fig. 2A and B). This corresponds to the occlusion of the opposite teeth, indicating the presence of dentition in both the maxilla and mandible (Bianucci & Landini, 2006). However, it is impossible to establish whether the isolated tooth was positioned in the upper or lower jaw. The end of the root is damaged. At the apex of the root, the pulp cavity is present. The pulp cavity has an average diameter of 18.8 mm. This is relatively small and indicates that the tooth belonged to an older individual (Bosselaers & Van Nieulande, 2018).

Discussion

MAB13159

The combined presence of several morphological features including the large size of the tooth, the wide and robust root, a thick crenulated enamel cap and the folding of the gingival collar indicates MAB13159 belonged with great certainty to a physeteroid with a macroraptorial feeding strategy (Bianucci & Landini, 2006; Gol'din & Marascul, 2013; Reumer et al., 2017; Bosselaers & Van Nieulande, 2018). According to the most recent phylogenetic analysis of Peri et al. (2022), the macroraptorial sperm whales are identified as a polyphyletic group comprised of the stem physeteroids *Brygmophyseter shigensis* (Kimura et al., 2006), *Zygmophyseter varolai* (Bianucci & Landini, 2006), *Acrophyseter robustus* (Lambert et al., 2017), *Acrophyseter deinodon* (Lambert et al., 2008), *Acrophyseter* sp. (Lambert et al., 2017) and the crown physeteroid *Livyatan melvillei* (Lambert et al., 2010b). In size and morphology, the lectotype of *Scaldicetus caretii* is very comparable with the general characteristics of a macroraptorial physeteroid tooth indicating the inclusion of the *S. caretii* type material in the macroraptorial sperm whales too (Reumer et al., 2017).

Recently described Dutch discoveries (both from the Westerschelde) include NMR999100010227 and NMR999100010228 identified as *cf. Zygmophyseter* sp. (Reumer et al., 2017)

Table 1. Measurements of various physeteroid teeth in millimetres with the size range between brackets

Taxon/specimen	Total tooth length	Crown length	Maximum mesiodistal diameter of root	Maximum labiolingual diameter of root	Mesiodistal diameter at crown base	Labiolingual diameter at crown base
MAB13159	227	41.3	74.2	67.5	31.7	32.2
NMR999100010227 ¹	215	20–35	62	69	22	–
NMR999100010228 ¹	210	–	85	72	–	–
<i>Zygophyseter varolai</i> ²	175.6 (150–205)	20.4 (9–28)	52.4 (47–56)	–	19 (16–25)	–
Physeteroidea tooth ³	282	–	94	91	36	43
<i>Scaldicetus caretii</i> ⁴	207 (128–235)	29.1 (19–39)	62.1 (32.1–72.3)	–	25.9 (16–33)	–
' <i>Scaldicetus grandis</i> ' ⁵	107	16	29	–	14	–
<i>Eudelphis mortezelensis</i> ⁶	88–93	9–11	24	17	10	10
<i>Hoplocetus borgerhoutensis</i> ⁷	160	–	–	–	–	–
<i>Hoplocetus ritzi</i> ⁸	117.7 (92–150)	15–23	40.8 (27–47)	39.2(32–46)	–	–

¹Reumer et al. (2017).²Varola et al. (1988).³Bosselaers & Van Nieulande (2018).⁴Based on Table 1 in Lambert & Bianucci (2019).⁵Based on Figure 16 in Hampe (2006).⁶Based on the teeth description and Figure 6 in Lambert (2008).⁷du Bus (1872).⁸Hampe (2006).

and the massive tooth described by Bosselaers & Van Nieulande (2018) tentatively classified as a Physeteroidea tooth. Other stem physeteroid discoveries from the North Sea area include the *Scaldicetus caretii* type material (du Bus, 1867), '*Scaldicetus grandis*' (du Bus, 1872), *Eudelphis mortezelensis* (du Bus, 1872), *Hoplocetus borgerhoutensis* (du Bus, 1872) and *Hoplocetus ritzi* (Hampe, 2006). Following the reasoning of Bianucci & Landini (2006) and Lambert & Bianucci (2019), the solely tooth-based genus *Hoplocetus* (Gervais, 1848–1852) can also be regarded unutilizable. However, a complete revision of *Hoplocetus* is beyond the scope of this paper.

The sizes of both cf. *Zygophyseter* sp. teeth (NMR999100010227 and NMR999100010228) are very comparable with MAB13159 (Table 1). NMR999100010228 is heavily damaged, which precludes precise comparisons with MAB13159 (Reumer et al., 2017; Fig. 2). The largest difference in dimensions between the specimens is present in the crown. The crown of the better preserved anterior positioned NMR999100010227 is smaller in length and diameter. The crown length/total length ratio of the tooth is smaller as well. Although this ratio from MAB13159 is approximately 18 per cent, the crown of NMR999100010227 makes up about 9–16 per cent of the total tooth length. In addition to this, NMR999100010227 has a crown diameter/maximum root diameter ratio of 32 per cent (Reumer et al., 2017), while MAB13159's ratio is higher with a ratio of 43 per cent. This means that approaching the crown from the greatest diameter of the tooth NMR999100010227 narrows much more compared to MAB13159. *Zygophyseter varolai* has a difference in crown length/total length ratio as well (Varola et al., 1988). The anterior *Zygophyseter varolai* teeth show a ratio of approximately 12 per cent, which is smaller compared to the ratio of MAB13159. In addition to this, the overall size of the *Z. varolai* teeth is smaller

than that of NMR999100010227 and MAB13159, with a mean total tooth length of 176 mm and a maximum mesiodistal diameter of 52 mm (Varola et al., 1988: Table II). The morphology of both NMR999100010227 and *Zygophyseter varolai* are relatively similar to MAB13159, as well (Varola et al., 1988: pl. 1; Reumer et al., 2017: Fig. 1). However, some characteristic differences are noteworthy. The anterior teeth of *Zygophyseter varolai* possess a strong curvature of the external root and both NMR999100010227 and *Z. varolai* have their largest diameter at two-thirds of the height of the tooth. This differs from MAB13159 which has a relatively straight root with a moderately curved upper part and the largest horizontal extension at mid-height of the tooth. Other than the difference in root curvature and largest diameter, both NMR999100010227 and NMR999100010228 and the anterior teeth of *Z. varolai* are to some extent similar in size (Table 1) and morphology.

The massive tooth from the Westerschelde described by Bosselaers & Van Nieulande (2018) has not enough distinguishable features due to bioerosion for meaningful comparisons to be made with the present specimen. In size, the tooth is similar to the enormous teeth of *Livyatan melvillei* from Peru (Lambert et al., 2010b). Other fossil stem physeteroid teeth from the North Sea basin like '*Scaldicetus grandis*' (Abel, 1905: Figs. 3 & 4; Hampe, 2006: Fig. 16), *Eudelphis mortezelensis* (Lambert, 2008: Fig. 6), *Hoplocetus ritzi* (Hampe, 2006: Figs. 3–5 & Table 1) and *Hoplocetus borgerhoutensis* (Van Beneden & Gervais, 1868–1879: pl. XX: Fig. 28) are very different in morphology and smaller in size when compared to MAB13159 (Table 1).

Just like NMR999100010227 and NMR999100010228, MAB13159 shows resemblance to *Scaldicetus caretii* dentition (Reumer et al., 2017). MAB13159 even seems to be almost identical in size and shape to some teeth of the lectotype of *S. caretii*

(Lambert & Bianucci, 2019; Fig. 1 & Table 1). Aside from *Zygophyseter varolai* and NMR999100010227, teeth of *S. caretii* are relatively straight with a moderately curved external root and have their largest diameter at mid-height, just like MAB13159. This indicates MAB13159 could belong to the same species as the *Scaldicetus caretii* type material. Despite the restrictions of Bianucci & Landini (2006), *Scaldicetus caretii* is still a valid species with an existing type series. Therefore, we here assign MAB13159 to *Physeteroidea* indet. cf. *Scaldicetus caretii*. This indicates probable conspecificity of MAB13159 and the type material of *S. caretii*, within an undetermined taxonomic unit inside the *Physeteroidea*. The better preserved NMR999100010227 shows morphological similarity with *Zygophyseter varolai* and seems justly attributed to *Physeteroidea* indet. cf. *Zygophyseter* sp. However, the heavily damaged NMR999100010228 has little comparable features. Therefore, we would cautiously suggest to just refer to NMR999100010228 as *Physeteroidea* indet. to prevent using *Zygophyseter* as a wastebasket genus. Overall, the dentition of the type material of *S. caretii* is quite similar to the teeth of *Z. varolai*.

Most findings of the superfamily *Physeteroidea* are of Middle and Late Miocene age. All recorded marine fossils from Liessel originate from Upper Miocene strata (Peters, 2009; Jagt et al., 2009; Bisconti et al., 2020; Peters et al., 2021). The lectotype of *Scaldicetus caretii* is considered to be of Tortonian age (early Late Miocene, c. 11.6–7.2 Ma) (Lambert & Bianucci, 2019). The other stem *physeteroid* *Zygophyseter varolai* dates back to approximately 10.5–8.14 Ma (Bianucci & Landini, 2006). These considerations make a Late Miocene age for MAB13159 likely.

Derived from the vertical root and chipping fractures in the *Scaldicetus caretii* type material and the estimation of the bite force of *Zygophyseter varolai*, both sperm whale species probably fed on

other marine vertebrates and likely occupied an ecological niche comparable to that of the recent killer whale (*Orcinus orca* Linnaeus, 1758). The thick and crenulated enamel and thick cementum layer of both extinct sperm whales indicate a diet probably even more macroraptorial than that of *O. orca* (Bianucci & Landini, 2006; Toscano et al., 2013; Lambert & Bianucci, 2019; Peri et al., 2021).

Some remarks on *Scaldicetus* species/specimens

Both mentions of the taxonomic restriction of *Scaldicetus* to the lectotype by Bianucci & Landini (2006) and Lambert & Bianucci (2019) risking being overlooked, we consider it useful to list the only valid *Scaldicetus* taxon, the taxa previously attributed to *Scaldicetus* and the invalid species and incorrectly named specimens assigned to *Scaldicetus* (Table 2).

In line with the conclusions of Bianucci & Landini (2006) and Lambert & Bianucci (2019), former *Scaldicetus* species outside of the type material of *Scaldicetus caretii* solely defined by large isolated teeth are referred to as *Physeteroidea* indet. The specimens described by Hasegawa et al. (2001), Estevens & Antunes (2004), Kimura et al. (2006) and Toscano et al. (2013) all have been assigned to *Scaldicetus*, because these authors consider *Scaldicetus* to be a wastebasket genus for large enamel-capped *physeteroid* teeth or other less complete *physeteroid* fossils such as dentaries. We would suggest to formally refer to these and future isolated dental specimens as *Physeteroidea* indet. Kimura et al. (2006) wrote in their paper: ‘The size and general shape of the teeth GMNH-PV-581 and INM-4-012885 are also similar to the teeth of the holotype of *B. shigensis*, and there are no substantial morphological differences between all of these specimens’ (p. 8). In addition to this, both specimens and

Table 2. Overview of all recorded *Scaldicetus* species and specimens

Species/specimen	Age and locality	References	Modern classification
Valid			
<i>Scaldicetus caretii</i> du Bus, 1867	Late Miocene (Tortonian); Antwerp (Belgium)	du Bus (1867), Abel (1905), Bianucci & Landini (2006), Lambert & Bianucci (2019)	<i>Scaldicetus caretii</i> , generic and specific name restricted to the lectotype, IRSNB M. 512
Previously attributed to <i>Scaldicetus</i>			
<i>Scaldicetus mortselensis</i> (du Bus, 1872) ¹	Middle Miocene; Antwerp (Belgium)	du Bus (1872), Abel (1905), Lambert (2008)	<i>Eudelphis mortzelensis</i> du Bus, 1872
<i>Scaldicetus bolzanensis</i> Dal Piaz, 1916 ²	Early Miocene; Belluno (Italy)	Dal Piaz (1916), Pilleri (1985), Pilleri (1986c), Hampe (2006)	? <i>Idiorophus bolzanensis</i> (Dal Piaz, 1916) ³
<i>Scaldicetus degiorgii</i> Varola et al., 1988; paratype MAUL 229/1	Late Miocene (Tortonian); Lecce (Italy)	Varola et al. (1988), Bianucci & Landini (2006)	<i>Zygophyseter varolai</i> Bianucci & Landini, 2006
<i>Scaldicetus shigensis</i> Hirota & Barnes, 1994	Middle Miocene; Matsumoto (Japan)	Hirota & Barnes (1994), Kimura et al. (2006)	<i>Brygmophyseter shigensis</i> (Hirota & Barnes, 1994)
Invalid			
<i>Scaldicetus grandis</i> (du Bus, 1872) ⁴	Late Miocene; Antwerp (Belgium)	du Bus (1872), Abel (1905), Pilleri (1986b, c), Hampe (2006)	<i>Physeteroidea</i> indet.
<i>Scaldicetus leccense</i> (Gervais, 1872) ⁵	Miocene; Lecce (Italy)	Gervais (1872), Menesini & Tavani (1968), Pilleri (1986a, b, c), Hampe (2006)	<i>Physeteroidea</i> indet.
<i>Scaldicetus minor</i> (Portis, 1885) ⁶	Late Pliocene; Asti (Italy)	Portis (1885), Pilleri (1980), Hampe (2006), Bisconti & Damarco (2022)	<i>Physeteroidea</i> indet.
<i>Scaldicetus macgeei</i> Chapman, 1912	Early Pliocene; Melbourne (Australia)	Chapman (1912, 1917), Fordyce (1982), Hampe (2006)	<i>Physeteroidea</i> indet.

(Continued)

Table 2. (Continued)

Species/specimen	Age and locality	References	Modern classification
<i>Scaldicetus lodgei</i> Chapman, 1917	Unresolved ⁷ ; Hamilton (Australia)	Chapman (1917), Hampe (2006)	Physeteroidea indet.
<i>Scaldicetus perpinguis</i> Pilleri & Pilleri, 1982	Middle Miocene (Serravallian); Turin (Italy)	Pilleri & Pilleri (1982), Pilleri (1986c), Hampe (2006)	Physeteroidea indet. ⁸
<i>Scaldicetus crispus</i> Cigala-Fulgosi & Pilleri, 1985	Middle Miocene (Serravallian); Parma (Italy)	Cigala-Fulgosi & Pilleri (1985), Hampe (2006)	Physeteroidea indet.
<i>Scaldicetus inflatus</i> Cigala-Fulgosi & Pilleri, 1985	Middle Miocene (Serravallian); Parma (Italy)	Cigala-Fulgosi & Pilleri (1985), Pilleri (1986c), Hampe (2006)	Physeteroidea indet.
cf. <i>Scaldicetus</i> sp. INM-4-012885	Middle/Late Miocene; Naka (Japan)	Hasegawa et al., (1987) In: Kimura et al. (2006), Hasegawa et al. (2006), Kimura et al. (2006)	Physeteroidea indet. aff. <i>Brygmophyseter shigensis</i>
? <i>Scaldicetus</i> sp. NSM-PV 2219	Middle Miocene; Mito (Japan)	Hasegawa et al., (1987) In: Kimura et al. (2006), Kimura et al. (2006)	Physeteroidea indet.
<i>Scaldicetus degiorgii</i> Varola et al., 1988; holotype	Late Miocene; Lecce (Italy)	Varola et al. (1988), Bianucci & Landini (2006)	Physeteroidea indet.
cf. <i>Scaldicetus</i> sp. GMNH-PV-581 ⁹	Middle Miocene; Annaka (Japan)	Hasegawa et al. (2001), Kimura et al. (2003), Kimura et al. (2006)	Physeteroidea indet. aff. <i>Brygmophyseter shigensis</i>
<i>Scaldicetus</i> sp. YPM 7923	Late Miocene; Mamurogawa (Japan)	Nagasawa & Oba, (2002) In: Kimura et al. (2006), Kimura et al. (2006)	Physeteroidea indet.
<i>Scaldicetus</i> sp. MTA-CO-10	Middle Miocene (Serravallian); Peninsula de Setúbal (Portugal)	Estevens & Antunes (2004), Toscano et al. (2013)	Physeteroidea indet.
<i>Scaldicetus</i> sp. MTA-CO-13	Late Miocene (Tortonian); Peninsula de Setúbal (Portugal)	Estevens & Antunes (2004), Toscano et al. (2013)	Physeteroidea indet.
<i>Scaldicetus</i> sp. MTA-CO-18	Late Miocene (Tortonian); Peninsula de Setúbal (Portugal)	Estevens & Antunes (2004), Toscano et al. (2013)	Physeteroidea indet.
<i>Scaldicetus</i> sp. CET-AG-1	Late Miocene (Messinian); Gibrleón (Spain)	Toscano et al. (2013)	Physeteroidea indet.
<i>Scaldicetus</i> sp. CET-LR-1	Late Miocene (Tortonian); Lora del Río (Spain)	Toscano et al. (2013)	Physeteroidea indet.

¹du Bus (1872) originally named the holotype (IRSNB M.523) *E. mortzeleensis*, after which Abel (1905) referred to the specimen as *S. mortzeleensis*. Lambert (2008) restored the original name.

²Also referred to as *Scaldicetus bellunensis* (Pilleri, 1985; Pilleri, 1986c).

³Solely based on remains of a maxillary and mandible and some isolated teeth (Dal Piaz, 1916: pl. I).

⁴The holotype of *S. grandis* (IRSNB M.518) was referred to as *Paleodelphis grandis* (du Bus, 1872).

⁵Originally named *Physodon leccense* (Gervais, 1872), but the location of the holotype is unknown (Pilleri, 1986b, 1986c).

⁶Originally named *Hoplocetus minor* (Portis, 1885).

⁷Chapman (1917) mentioned a Balcombian (Middle Miocene) or Oligocene age for *S. lodgei*.

⁸The possibility cannot be excluded that the single tooth described as *S. perpinguis* is in fact the tusk of a ziphiid (Lambert et al., 2010a: Fig. 3).

⁹Originally referred to as *Physeteroidea* gen. et sp. indet. (Hasegawa et al., 2001).

B. shigensis were found in Middle/Upper Miocene deposits. Therefore, we would cautiously suggest to classify GMNH-PV-581 and INM-4-012885 as *Physeteroidea* indet. aff. *Brygmophyseter shigensis*. This indicates that both specimens have affinity to *B. shigensis*, but are not from the same species and probably belonged to a close relative.

Conclusions

MAB13159 belonged to a macroraptorial sperm whale with a Late Miocene age. Based on the great resemblance to the type series of *Scaldicetus caretii*, we prefer to assign this physeteroid tooth to *Physeteroidea* indet. cf. *Scaldicetus caretii*.

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References

- Abel, O., 1905. Les odontocètes du Boldérien (Miocène supérieur) d'Anvers. Polleunis & Ceuterick, imprimeurs (Brussels): 155 pp.
- Benites-Palomino, A., Vélez-Juarbe, J., Collareta, A., Ochoa, D., Altamirano, A., Carré, M., Laime, M.J., Urbina, M. & Salas-Gismondi, R., 2021. Nasal compartmentalization in Kogiidae (Cetacea, Physeteroidea):

- insights from a new late Miocene dwarf sperm whale from the Pisco Formation. *Papers in Palaeontology* 7: 1507–1524.
- Benites-Palomino, A., Vélez-Juarbe, J., Salas-Gismond, R. & Urbina, M.**, 2020. *Scaphokogia totajpe*, sp. nov., a new bulky-faced pygmy sperm whale (Kogiidae) from the late Miocene of Peru. *Journal of Vertebrate Paleontology* 39(6): e1728538. DOI: [10.1080/02724634.2019.1728538](https://doi.org/10.1080/02724634.2019.1728538).
- Bianucci, G. & Landini, W.**, 2006. Killer sperm whale: a new basal physeteroid (Mammalia, Cetacea) from the Late Miocene of Italy. *Zoological Journal of the Linnean Society* 148: 103–131.
- Bianucci, G., Landini, W. & Varola, A.**, 2004. First discovery of the Miocene northern Atlantic sperm whale *Orycterocetus* in the Mediterranean. *Geobios* 37: 569–573.
- Bisconti, M. & Damarco, P.**, 2022. The paleontological and cultural heritage of the fossil cetaceans from the Pliocene of Valleandona. In: Marramà G. & Carnevale G. (eds): *Paleodays 2022, XXII Edizione delle Giornate di Paleontologia della Società Paleontologica Italiana*: 167–186.
- Bisconti, M., Munsterman, D.K., Fraaije, R.H.B., Bosselaers, M.E.J. & Post, K.**, 2020. A new species of rorqual whale (Cetacea, Mysticeti, Balaenopteridae) from the Late Miocene of the Southern North Sea Basin and the role of the North Atlantic in the paleobiogeography of *Archaeobalaenoptera*. *PeerJ* 8: e8315. DOI: [10.7717/peerj.8315](https://doi.org/10.7717/peerj.8315).
- Bloodworth, B.E. & Odell, D.K.**, 2008. *Kogia breviceps* (Cetacea: Kogiidae). *Mammalian Species* 819: 1–12.
- Boersma, A.T. & Pyenson, N.D.**, 2015. *Albicetus oxymycterus*, a New Generic Name and Redescription of a Basal Physeteroid (Mammalia, Cetacea) from the Miocene of California, and the Evolution of Body Size in Sperm Whales. *PLOS ONE* 10(12): e0135551. DOI: [10.1371/journal.pone.0135551](https://doi.org/10.1371/journal.pone.0135551).
- Bosselaers, M. & Van Nieulande, F.**, 2018. Een reuzenroofpotvis uit de Westerschelde. *Cranium* 35: 12–17.
- Brisson, M.J.**, 1762. *Regnum Animale in classes IX. distributum, sive synopsis methodical*. Theodorum Haak (Leiden): 296 pp.
- Chapman, F.**, 1912. On the occurrence of *Scaldicetus* in Victoria. Record of the Geological Survey of Victoria 3: 236–238.
- Chapman, F.**, 1917. New or little-known Victorian fossils in the National Museum. Part XXI. Some Tertiary cetacean remains. *Proceedings of the Royal Society of Victoria* 30: 32–43.
- Cigala-Fulgosi, F. & Pilleri, G.**, 1985. The lower Serravallian cetacean fauna of Visiano (Northern Apennines, Parma, Italy). *Investigations on Cetacea* 17: 55–113.
- Collareta, A., Fulgosi, F. & Bianucci, G.**, 2019. A new kogiid sperm whale from northern Italy supports psychrospheric conditions in the early Pliocene Mediterranean Sea. *Acta Palaeontologica Polonica* 64: 609–626.
- Collareta, A., Lambert, O., de Muizon, C., Benites Palomino, A.M., Urbina, M. & Bianucci, G.**, 2020. A new physeteroid from the late Miocene of Peru expands the diversity of extinct dwarf and pygmy sperm whales (Cetacea: Odontoceti: Kogiidae). *Comptes Rendus Palevol* 19: 79–100.
- Cranford, T.W., Amundin, M. & Norris, K.S.**, 1996. Functional morphology and homology in the odontocete nasal complex: implications for sound generation. *Journal of Morphology* 228(3): 223–285.
- Dal Piaz, G.**, 1916. Gli Odontoceti del Miocene Bellunense. Parte Nona: *Scaldicetus bolzanensis*. *Memorie dell'Istituto Geologico della Università di Padova* 4: 87–92.
- de Blainville, H.**, 1838. Sur les cachalots. *Annales françaises et étrangères d'anatomie et de physiologie* 2: 335–337.
- du Bus, B.A.L.**, 1867. Sur quelques Mammifères du Crag d'Anvers. *Bulletins de l'Académie Royale des Sciences, des Lettres et des Beaux-Arts de Belgique* 24: 562–577.
- du Bus, B.A.L.**, 1872. Mammifères nouveaux du Crag d'Anvers. *Bulletins de l'Académie Royale des Sciences, des Lettres et des Beaux-Arts de Belgique* 34: 491–509.
- Esteves, M. & Antunes, M.T.**, 2004. Fragmentary remains of Odontocetes (Cetacea, Mammalia) from the Miocene of the Lower Tagus Basin (Portugal). *Spanish Journal of Palaeontology* 19: 93–108.
- Flower, W.H.**, 1867. Description of the skeleton of *Inia geoffrensis* and the skull of *Pontoporia blainvillii*, with remarks on the systematic position of these animals in the Order Cetacea. *Transactions of the Zoological Society of London* 6: 87–116.
- Fordyce, R.E.**, 1982. A review of the Australian fossil Cetacea. *Memoirs of the National Museum of Victoria* 43: 43–58.
- Geisler, J.H., McGowen, M.R., Yang, G. & Gatesy, J.**, 2011. A supermatrix analysis of genomic, morphological, and paleontological data from crown Cetacea. *BMC Evolutionary Biology* 11(112): 33. DOI: [10.1186/1471-2148-11-112](https://doi.org/10.1186/1471-2148-11-112).
- Gervais, P.**, 1848-1852. *Zoologie et Paléontologie Françaises (animaux vertébrés) ou nouvelles recherches sur les animaux vivants et fossiles de la France*. A. Bertrand (Paris): 271 pp.
- Gervais, P.**, 1872. Coup d'œil sur les Mammifères fossiles de l'Italie. *Bulletin de la Société Géologique de France 2me série* 29: 92–102.
- Gol'din, P. & Marakeskul, V.**, 2013. Miocene Toothed Whales (Cetacea, Odontoceti) from the Dniester Valley: The First Record of Sperm Whales (Physeteroidea) from The Eastern Europe. *Vestnik Zoologii* 47(5): 409–414.
- Gray, J.E.**, 1821. On the natural arrangement of vertebrate animals. *The London Medical Repository* 15: 296–310.
- Hampe, O.**, 2006. Middle/late Miocene hoplocetine sperm whale remains (Odontoceti: Physeteridae) of North Germany with an emended classification of the Hoplocetinae. *Fossil Record* 9(1): 61–86.
- Hasegawa, Y., Kimura, T. & Koda, Y.**, 2006. Fossil physeterid from the Miocene Urizura Formation, Taga Group, Ibaraki, Japan. *Bulletin of Gunma Museum of Natural History* 10: 25–36, (in Japanese, with English abstract).
- Hasegawa, Y., Takakuwa, Y. & Nakajima, H.**, 2001. First discovery of Physeterid fossil from the Haraichi Formation (Middle Miocene), Tomioka Group, Gunma, Japan. *Bulletin of Gunma Museum of Natural History* 5: 31–38, (in Japanese, with English abstract).
- Hirota, K. & Barnes, L.G.**, 1994. A new species of Middle Miocene sperm whale of the genus *Scaldicetus* (Cetacea; Physeteridae) from Shiga-mura, Japan. *Island Arc* 3: 453–472.
- Jagt, J.W.M., Fraaije, R.H.B. & Van Bakel, B.W.M.**, 2009. A late Miocene astropectinid (Echinodermata, Asteroidea) and associated ichnofossils from Liessel, province of Noord-Brabant, the Netherlands. *Netherlands Journal of Geosciences* 88: 127–131.
- Kazár, E.**, 2002. Revised phylogeny of the Physeteridae (Mammalia: Cetacea) in the light of *Placoziphius* Van Beneden, 1869 and *Aulophyseter* Kellogg, 1927. *Bulletin de l'Institut Royal des Sciences Naturelles de Belgique, Sciences de la Terre* 72: 151–170.
- Kimura, T., Hasegawa, Y. & Barnes, L.**, 2006. Fossil sperm whales (Cetacea, Physeteridae) from Gunma and Ibaraki prefectures, Japan; with observations on the Miocene fossil sperm whale *Scaldicetus shigensis* Hirota and Barnes, 1995. *Bulletin of the Gunma Museum of Natural History* 10: 1–23.
- Kimura, T. & Hasegawa, Y.**, 2022. A new physeteroid from the Lower Miocene of Japan. *Paleontological Research* 26(1): 87–101.
- Kimura, T., Takakuwa, Y. & Hasegawa, Y.**, 2003. Cetacean fossils in the Nakajima collection. *Bulletin of the Gunma Museum of Natural History* 7: 19–33, (in Japanese, with English abstract).
- Lambert, O.**, 2008. Sperm whales from the Miocene of the North Sea: a re-appraisal. *Bulletin de l'Institut Royal Des Sciences Naturelles de Belgique, Sciences de La Terre* 78: 277–316.
- Lambert, O. & Bianucci, G.**, 2019. How to break a sperm whale's teeth: dental damage in a large Miocene physeteroid from the North Sea basin. *Journal of Vertebrate Paleontology* 39(4): e1660987. DOI: [10.1080/02724634.2019.1660987](https://doi.org/10.1080/02724634.2019.1660987).
- Lambert, O., Bianucci, G. & de Muizon, C.**, 2008. A new stem-sperm whale (Cetacea, Odontoceti, Physeteroidea) from the Latest Miocene of Peru. *Académie des sciences* 7(6): 361–369.
- Lambert, O., Bianucci, G. & de Muizon, C.**, 2017. Macroraptorial sperm whales (Cetacea, Odontoceti, Physeteroidea) from the Miocene of Peru. *Zoological Journal of the Linnean Society* 179: 404–474.
- Lambert, O., Bianucci, G. & Post, K.**, 2010a. Tusk-bearing beaked whales from the Miocene of Peru: sexual dimorphism in fossil ziphiids? *Journal of Mammalogy* 91(1): 19–26.
- Lambert, O., Bianucci, G., Post, K., de Muizon, C., Salas-Gismondí, R., Urbina, M. & Reumer, J.**, 2010b. The giant bite of a new raptorial sperm whale from the Miocene epoch of Peru. *Nature* 466(7302): 105–108.

- Lambert, O., de Muizon, C., Urbina, M. & Bianucci, G.**, 2020. A new longirostrine sperm whale (Cetacea, Physeteroidea) from the lower Miocene of the Pisco Basin (southern coast of Peru). *Journal of Systematic Palaeontology* **18**(20): 1707–1742.
- Linnaeus, C.**, 1758. *Systema naturae, per regna tria naturae, secundum classes, ordines, genera, species, cum characteribus, differentiis, synonymis, locis*. Tomus I. Editio decima, reformata. Holmiae (Stockholm): 824.
- Marra, A., Carone, G. & Bianucci, G.**, 2016. Sperm whale teeth from the late Miocene of Cessaniti (Southern Italy). *Bollettino della Società Paleontologica Italiana* **55**: 223–225.
- Mchedlidze, G.A.**, 1970. Some general characteristics of the evolution of cetaceans, part 1. *Akademia Nauk Gruzinskoi S.S.R. Institut Paleobiologii (Tbilisi)*: 112 pp.
- Menesini, E. & Tavani, G.**, 1968. Resti de *Scaldicetus* (Cetacea) nel Miocene della Puglia. *Bollettino della Società Paleontologica Italiana* **7**: 87–93.
- Owen, R.**, 1866. On some Indian Cetacea collected by Walter Elliot, Esq. *Transactions of the Zoological Society of London* **6**: 17–47.
- Paolucci, F., Buono, M.R., Fernández, M.S., Marx, F.G. & Cuitiño, J.I.**, 2020. *Diaphorocetus poucheti* (Cetacea, Odontoceti, Physeteroidea) from Patagonia, Argentina: one of the earliest sperm whales. *Journal of Systematic Palaeontology* **18**: 335–355.
- Peri, E., Collareta, A., Aringhieri, G., Caramella, D., Foresi, L.M. & Bianucci, G.**, 2022. A new physeteroid cetacean from the Lower Miocene of southern Italy: CT imaging, retrodeformation, systematics and palaeobiology of a sperm whale from the Pietra leccese. *Bollettino della Società Paleontologica Italiana* **61**: 187–206.
- Peri, E., Falkingham, P., Collareta, A. & Bianucci, G.**, 2021. Biting in the Miocene seas: estimation of the bite force of the macroraptorial sperm whale *Zygophyseter varolai* using finite element analysis. *Historical Biology* **34**: 1916–1927.
- Peters, N.**, 2009. Brabant tussen walvissen en mastodonten. Nationaal Beiaard- en Natuurmuseum (Asten). Oertijdmuseum De Groene Poort (Boxtel): 110 pp.
- Peters, N., Munsterman, D. & Post, K.**, 2021. A late Miocene balaenopterid petrotympanic from Liessel (The Netherlands). *Cainozoic Research* **21**: 165–172.
- Pilleri, G.**, 1980. The fossil odontocetes (Cetacea) in the Museum of Paleontology of the University of Turin. *Investigations on Cetacea* **11**: 39–53.
- Pilleri, G.**, 1985. The Miocene Cetacea of the Belluno Sandstones (Eastern Southern Alps). *Memorie di Scienze Geologiche* **37**: 1–87.
- Pilleri, G.**, 1986a. The Cetacea of the Western Paratethys (Upper Marine Molasse of Baltringen). *Brain Anatomy Institute (Berne)*: 70 pp.
- Pilleri, G.**, 1986b. The Miocene Cetacea of the Pietra Leccese. *Brain Anatomy Institute (Berne)*: 27 pp.
- Pilleri, G.**, 1986c. The Oligo-Miocene Cetacea of the Italian waters with a bibliography of the fossil Cetacea of Italy (1670-1986). *Brain Anatomy Institute (Berne)*: 81 pp.
- Pilleri, G. & Pilleri, O.**, 1982. Catalogue of the fossil odontocetes (Cetacea) in the Bologna Giovanni Capellini Museum of Palaeontology with description of a new species of *Hoplocetus* (Physeteridae). *Memorie di Scienze Geologiche* **35**: 293–317.
- Portis, A.**, 1885. *Catalogo descrittivo dei Talassoterii rinvenuti nei terreni terziarii del Piemonte e della Liguria*. E. Loescher (Torino): 121 pp.
- Reumer, J.W.F., Mens, T.H. & Post, K.**, 2017. New finds of giant raptorial sperm whale teeth (Cetacea, Physeteroidea) from the Westerschelde Estuary (province of Zeeland, the Netherlands). *Deinsea* **17**: 32–38.
- Toscano, A., Abad, M., Ruiz, F., Muñiz, F., Álvarez, G., García, E.X.-M. & Caro, J.A.**, 2013. Nuevos restos de *Scaldicetus* (Cetacea, Odontoceti, Physeteridae) del Mioceno superior, sector occidental de la Cuenca del Guadalquivir (sur de España). *Revista mexicana de ciencias geológicas* **30**: 436–445.
- Van Beneden, P.J. & Gervais, P.**, 1868-1879. *Ostéographie des Cétacés vivants et fossiles comprenant la description et l'Iconographie du squelette et du système dentaire de ces animaux ainsi que des documents relatifs à leur histoire naturelle*. A. Bertrand (Paris): 634 pp.
- Varola, A., Landini, W. & Pilleri, G.**, 1988. A new *Scaldicetus* (Cetacea: Physeteridae) from the Pietra Leccese. Late Miocene. *Investigations on Cetacea* **21**: 16–38.
- Watmore, K.I. & Prothero, D.R.** Gigantic macroraptorial sperm whale tooth (cf. *Livyatan*) from the Miocene of Orange County, California, 2023. bioRxiv, in press. doi: [10.1101/2023.01.25.525567](https://doi.org/10.1101/2023.01.25.525567).
- Werth, A.J.**, 2004. Functional morphology of the sperm whale tongue, with reference to suction feeding. *Aquatic Mammals* **30**: 405–418.
- Werth, A.J.**, 2006. Mandibular and dental variation and the evolution of suction feeding in Odontoceti. *Journal of Mammalogy* **87**: 579–588.