# Remarkable mandibular fracture healing in an early Holocene bottlenose dolphin (*Tursiops truncatus*)

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**Abstract:** The Natural History Museum Rotterdam (the Netherlands) holds a large osteological collection of fossil and recent cetaceans. A right mandible of a bottlenose dolphin (*Tursiops truncatus*) shows signs of perfect healing of a severe traumatic fracture. Its size, colour, state of preservation and the collection site (Southern North Sea bed) point to an estimated age of ca. 8000-7000 years BP (early Holocene). We describe this remarkable fossil mandible and hypothesise about possible causes of the injury.

*Keywords*: bottlenose dolphin, *Tursiops truncatus*, injury, North Sea, Holocene, fossil.

## Introduction

The bottlenose dolphin (*Tursiops truncatus*) is, nowadays, a rare visitor of the Dutch coastal waters and, on a larger scale, of the entire North Sea (Camphuysen & Peet 2006, Aaris-Sørensen et al. 2010). However, during the warmer periods of the early Holocene the bottlenose dolphin was a common species of the Dutch marine mammal fauna (Post 2005), which is supported by an abundant collection of skeletal remains of early Holocene bottlenose dolphins kept in the Natural History Museum of Rotterdam, the Netherlands (NMR) (287 specimens including 25 mandibles). All specimens were collected from the North Sea bed by commercial trawlers.

One of the isolated mandibles kept in this collection (coll. no. NMR 9991-12149) shows signs of perfect healing of a severe traumatic fracture. The dolphin endured a complete fracture of the right mandible, but somehow managed to survive the serious accident. This article describes the remarkable fossil mandible and hypothesises about possible causes of the injury.

## Material

NMR 12149 is an almost complete right mandible of an adult bottlenose dolphin dredged by a commercial trawler in the Southern North Sea in 2005. Apart from some missing fragments of the apex and alveolar bone tissue, the mandible is fairly well preserved. Nine alveoli are still recognisable, and two mental foramina can be observed. The total length of the bone is 418 mm, the length of the precoronoid crest is 196 mm and the distance between the two mental foramina is 56 mm. The height of the mandible at the fracture line measured 84 mm and the height at the symphyseal surface is 35 mm. The greatest height of the mandibular fossa is 92 mm and the length of the mandibular foramen at least 144 mm. The breadth of one of the middle tooth alveoli measures 11 mm. These measurements point clearly to an adult bottlenose dolphin, excluding other common dolphins of the Holocene of the North Sea like the common dolphin (*Delphinus delphis*) and dolphins of the genus *Lagenorhynchus*. Size, color, state of preservation and site (Southern North Sea bed) indicate an estimated age of ca. 8000-7000 years BP (early Holocene) (table 1).

Table 1. Published 14C dates of fossils of bottlenose dolphin (*Tursiops truncatus*) from the North Sea. GrA: University of Groningen; UtC: University of Utrecht

| Fossil | Site | Code | Age |
|---|---|---|---|
| Mandible, No 3920 | Smiths Knoll | GrA 25851 | 8135 +/- 45 BP |
| Mandible, NMR 2273 | Smiths Knoll | GrA 25850 | 7390 +/- 50 BP |
| Vertebra, No 2683 | Brown Bank | UtC 7885 | 7270 +/- 60 BP |

### Description

On the buccal side of the mandible – from the location of the precoronoid crest downwards, a large healed fracture line extends vertically over the complete ramus of the mandible. On both sides of the healed fracture, the bone tissue is marginally swollen and rounded, and shows an uneven surface.

A small V-shaped scar is located in the middle of the fracture itself. About 4 cm towards posterior another, smaller, straight scar is visible. This scar is covered partly with secondary bone growth. On the lingual side of the mandible the fracture line can also be observed over the complete surface of the inside of the mandibular ramus. If viewed dorsally and ventrally it becomes clear that the main body of the mandible was broken in two fully separated parts. During the subsequent healing process the two bone surfaces fused again, however not in the same plane because the posterior part shifted laterally over 5-7 mm (figure 1).

## Discussion

### Possible causes of the fracture

The fracture of the NMR 12149 mandible is clearly not the result of a secondary disease or a pathological condition (pathological fracture), but is obviously caused by a sudden traumatic impact. Fractures of mandibles (and other bones) of extant odontocetes can hypothetically result from: 1. Collision with a vessel. 2. A traumatic blow by a snout or tail of another cetacean. 3. A high jump from the water surface with the dolphin landing on a drifting object or other cetacean. 4. An attack by a large shark.

(1) For the early Holocene (the timeframe in which the bottlenose dolphin of the described mandible supposedly lived), motorised human activity (on the seas) did not exist and can be disregarded as the potential cause.

(2) The possibility that the trauma was indeed caused by a lateral blow from the snout or tail of a larger odontocete (such as a killer whale – *Orcinus orca*), or another bottlenose dolphin of the pod to which the dolphin belonged, is real. Documentation of aggressive non-predatory interactions between sympatric odontocete species exists (Shane 1995, Orr & Harwood 1998, Wedekin et al. 2004, Scott et al. 2005). Bottlenose dolphins establish and maintain dominance within the pod by biting, chasing and smacking their tails on the water. Male dolphins are observed to be more aggressive than females. The aggressive behaviour is mostly limited to raking and scathing one another with their teeth, resulting in tooth rake marks that cause superficial lacerations which heal as white scars (Scott et al. 2005). The patterns of tooth rake presence and prevalence likely result from offensive sexual coercion of adult females by adult males and intra-sexual male competition (Scott et al. 2005). Male bottlenose dolphins are known to fight and kill rivals and offspring. It has also been observed that they participate in non-predatory aggressive interactions with smaller harbour porpoises (*Phocoena phocoena*) and even commit interspecies infanticide (Patterson et al. 1998). Bottlenose dolphins have been observed to ‘sandwich’ a porpoise between two dolphins,

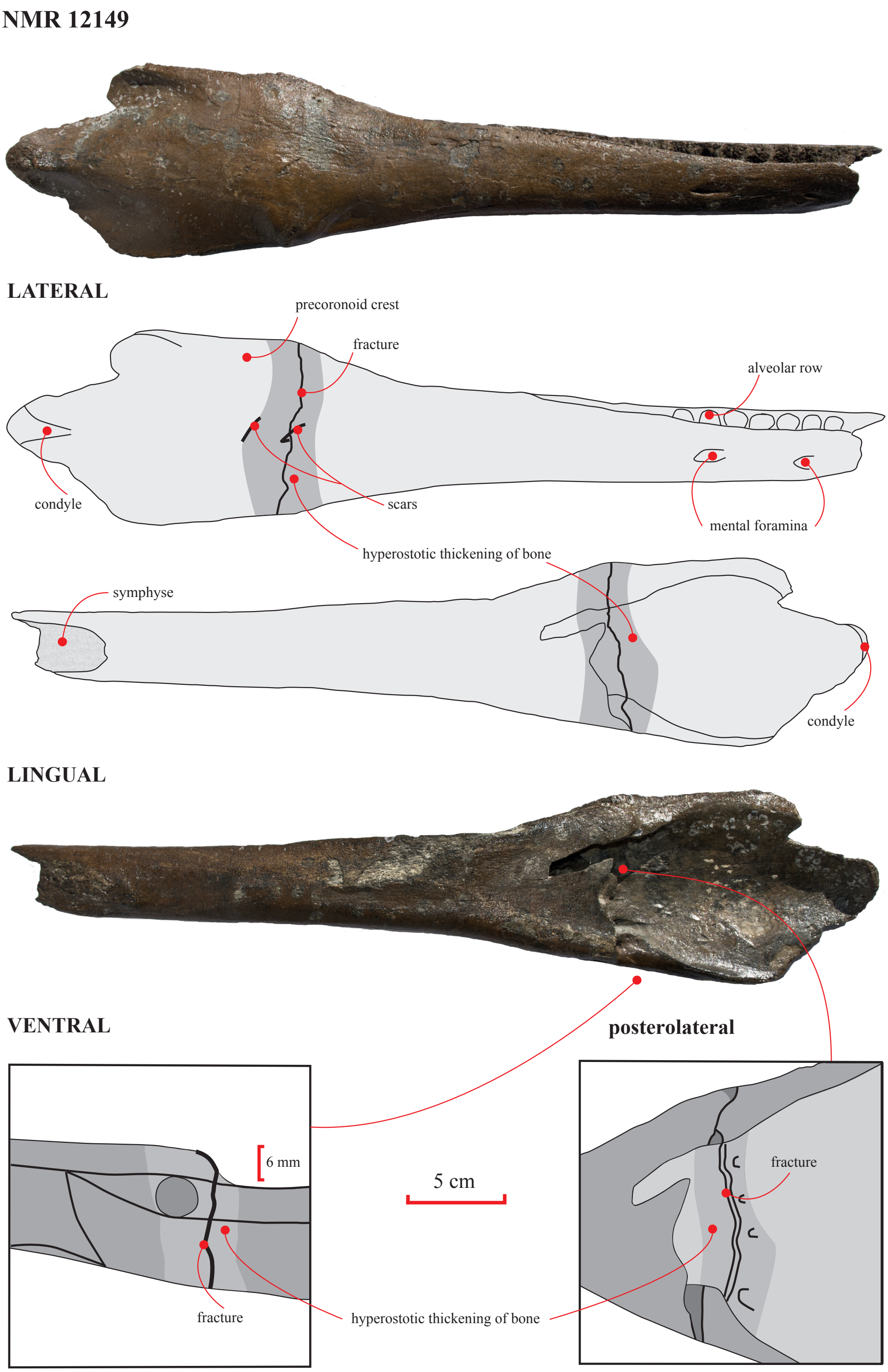


Figure 1. Mandible of bottlenose dolphin (*Tursiops truncatus*) NMR 9991-12149.

but also to drown, toss and ram smaller cetaceans. Between 1991 and 2011, at least 137 harbour porpoises died as the result of attacks by bottlenose dolphins in Cardigan Bay, Wales, United Kingdom (Cotter et al. 2012).

(3) Bottlenose dolphins have been observed to jump as high as six metres (20 feet) above the water surface and to land on their bellies or sides. If the dolphin of the described mandible jumped out of the water and landed on a floating object or another dolphin, the fractured mandible could have been the painful result of the acrobatic action.

(4) The least likely possibility is an attack by a large shark. Although not frequently observed, large sharks have been known to prey on dolphins, and fatal attacks by large white sharks (*Carcharodon carcharias*) and tiger sharks (*Galeocerdo cuvier*) on fully grown bottlenose dolphins have occasionally been observed (Heithaus 2001, Celona et al. 2006, Fallows et al. 2013). However, the two small superficial scars on the surface of the fracture were not involved in the initial healing process of the fracture, making it totally unlikely that they were part of the same trauma. One of the scars is on the surface of the healed fracture. Hypothetically they could have been caused by a second injury or even post mortal scavenging, in any case after the fracture had healed. We conclude that the scars are most likely unrelated to the initial trauma.

### Survival

Depending on the hunting environment and available prey, most dolphins use raptorial feeding strategies, suction feeding strategies, and/or a combination of both methods (Hocking et al. 2017). The bottlenose dolphin survived despite the obvious fact that the completely fractured mandible must have caused the dolphin substantial discomfort with eating and hearing. However the masseter muscle, if not fully severed, may have covered the fracture and kept the fractured jaw parts in position. The jaw fat in the mandible may also have been disrupted, causing disturbance of sound passing to the inner ear through the sound conducting tissue of the jaw fat. However as this tissue is solid but also flexible, it may have served as an inner splint for the fractured bone. Therefore two possible scenarios for the survival of the dolphin may be envisioned:

a. The animal was still able to eat in its normal way because of the support of the fractured bone by the massive masseter muscle and the inner jaw fat.
b. The animal managed to survive by suction feeding only with minimal movements of beak and tissues. In this way it could collect the basic energy necessary for the long healing process. Suction feeding (catching and swallowing of prey – fish and/or squid – by oral pressure without active mandible movements and oral processing) is noted in most extant odontocetes. Some families depend for their food intake almost exclusively on suction feeding (e.g. beaked whales - Ziphiidae, sperm whales - Physeteridae), others (like the dolphins - Delphinidae) combine various feeding methods subject to the available prey (Werth 2006). Sperm whales use for the process only the most posterior part of the mouth and their short tongue as a piston and are reported to survive and live with a healed and grotesquely curved mandible (Werth 2004). It is observed that bottlenose dolphins and porpoises are able to eat by suction feeding (Ito et al. 2002).

## Conclusion

It appears most likely that the traumatic fracture of the mandible in the described specimen was caused by sexual coercion of an adult female by adult males, or by intra-sexual male competition. The fact that the mandible healed proves that (bottlenose) dolphins with a completely fractured mandible are able to survive until the injury has completely healed.

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## Samenvatting

### Een opmerkelijke, herstelde, onderkaakfractuur van een tuimelaar uit het vroeg-Holoceen

Het Natuurhistorisch museum Rotterdam beheert een uitgebreide collectie skeletmateriaal van fossiele en recente Cetacea. Een van de collectiestukken, een rechter onderkaak van een tuimelaar (*Tursiops truncatus*) laat een

perfect geheelde, ernstige traumatische fractuur zien. De kleur en fossilisatiegraad van het fossiel en de vindplaats (Zuidelijke Noordzee) wijzen in de richting van een leeftijd van circa 8000-7000 jaar oud (vroeg Holoceen). Ondanks het feit dat de onderkaak compleet gebroken was, heeft de tuimelaar kunnen overleven en kon de fractuur perfect genezen. In dit artikel beschrijven wij deze opmerkelijke onderkaak en geven onze hypothese over de mogelijke oorzaak van de fractuur.

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