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Geo(Im)pulse

Bite marks on early Holocene *Tursiops truncatus* fossils from the North Sea indicate scavenging by rays (Chondrichthyes, Rajidae)

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Abstract

A number of *Tursiops truncatus* mandibles in the collection of fossil marine mammals in the Rotterdam Natural History Museum have marks consisting of several parallel linear grooves. These marks are also found on four atlas complexes, a scapula and on one vertebra. The hypothesis that they are bite marks and were caused by scavenging rays (Rajidae, Chondrichthyes) was tested with a real-life experiment using different shark and ray species, allowing them to scavenge on cow ribs as proxies for the dolphin bones. The bite marks of these animals were compared with the fossil marks and show that the fossil marks are most likely caused by scavenging rays.

Keywords: taphonomy, bite marks, rays, bottlenose dolphin

Introduction

Many fossils of Quaternary terrestrial and marine mammals have been trawled from the North Sea and brought ashore since the late nineteenth century. Several important collections were formed and collections and individual finds were published (i.e. De Man, 1875; Kortenbout van der Sluijs, 1971; Bosscha Erdbrink & Van Bree, 1986; De Vos et al., 1998; Reumer et al., 2003; Post, 2005; Mol et al., 2006, 2008). The Natural History Museum Rotterdam (NMR) houses a large sample of such marine mammals, among which bottlenose dolphin (*Tursiops truncatus*) is a common species. This collection of fossils is not only remarkable for its size or because the objects are in an extremely good condition, but also for a large number of Tursiops bones that show marks. Some of these were previously interpreted as having been made by sharks (K. Post, information on collection label). However, one specific type of scratches remained unidentified. It consists of parallel lines, and is found on twelve mandibles, four atlas complexes, one caudal vertebra and one scapula. Up until now, they were interpreted as either caused by sharks, by rays, by beach-combing hyaenas or even by humans. Of these possible causative agents, we considered rays to be the most likely culprit, which we adopted as our working hypothesis. We tested the hypothesis by performing a real-life experiment with sharks and rays in the Dolfinarium Zoo, Harderwijk.

Material and Methods

Fossil material

The collection of *Tursiops truncatus* fossils in the Natural History Museum Rotterdam (NMR) consists of a total of 202 objects, 18 of which show the specific marks, described below. All objects were trawled from the North Sea using trawl-fishing boats. In this specific method of fishing, a net is trawled across the bottom of the sea, bringing up not only flatfish such as flounder or sole, but also any objects that lie at or near the sediment-water interface (Mol et al., 2008). *Tursiops truncatus* is mentioned to have been part of the Pleistocene marine fauna (Kortenbout van der Sluijs, 1971, see also Post, 2005). However, recent C14 datings of several *Tursiops truncatus* fossils from the North Sea indicate an early Holocene, rather than Pleistocene, age of 7 - 8.1 kyr BP (Post, 2005; Mol et al., 2008).

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The oldest *Tursiops truncatus* fossil found, which was located in the southernmost areas of the North Sea, has an age (8135 yr BP, labno. GrA25851, see Post 2005) that postdates the connection of the English Channel to the North Sea, which is supposed to have occurred at around 8300 cal. yr BP (Waller & Long, 2003). Shennan et al. (2000) concluded a slightly older age of the connection between the North Sea and the English Channel, as they record the union of these two water masses prior to 8,800 cal. yr BP. Independent of which age one uses, this implies, as proposed by Laban in Post (2005), that bottlenose dolphins entered the North Sea from the south, using the English Channel.

The vast majority of the *Tursiops truncatus* fossils in the NMR collection was found in the Southern Bight (most notably on the Brown Bank and in 'Het Gat'), with a few exceptions of bones that were found North of the Dutch Wadden-island of Terschelling ('Kop Borkummer Stenen') or in the Southern Bight ('De Schelpen'; see Fig. 1).

Fig. 1. Map of the North Sea with finding locations.

Fossil marks, material

The fossil marks are mostly found on the smooth, flat surfaces of the mandibles. This was the case for 12 mandibles (coll.nos. NMR2261, NMR2264, NMR2266, NMR2267, NMR2268, NMR2269, NMR2270, NMR2271, NMR2273, NMR2274, NMR2276, NMR3812) However, they have also been found on a vertebra (NMR4310), a scapula (NMR3880) and several atlas complexes (NMR2339, NMR2351, NMR3011 and NMR3013). In one of these latter synostoses, the marks have even been found inside the neural canal (NMR2339).

A common characteristics of these fossil marks is the presence of several linear, smooth grooves, running parallel to each other, and with a near constant width (Fig. 2). Cross-sections of the marks are non-indicative because all fossils were treated prior to acquisition with a solution of velpon ('clear glue') in

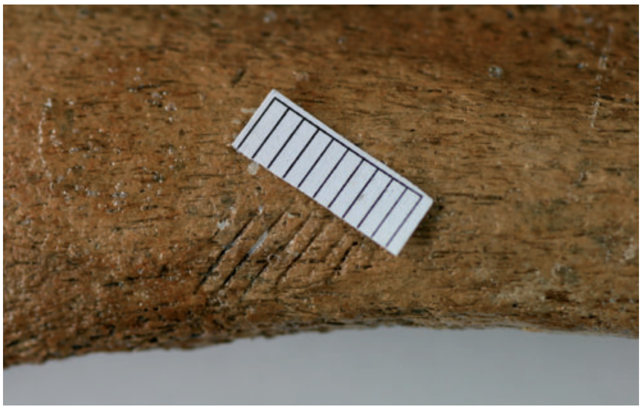

Fig. 2. Fossil marks on NMR 3880 (scapula).

acetone, thus unfortunately obliterating all microscopic characteristics. The length and number of grooves differs greatly. The length can be less than 2 mm (NMR2276) and up to 15 mm (NMR2269 – Figs 3 and 4). In NMR2276, there are 9 grooves that run parallel to each other, whereas in NMR2339, there are only two. The depth of the marks also differs, from extremely shallow (less than 0.5 mm) to clearly visible (more than 1 mm). In most cases, the width of the grooves is between 0.2 to 0.5 mm, except for NMR2269, where the grooves are 0.8 mm wide. The distance between the grooves is always near 1 mm. NMR2310 has marks which differ from the other marks, in that the grooves are not linear and that the sides are much less smooth (Fig. 5). They resemble the marks on NMR2312 (Fig. 6), which were identified as shark-marks (K. Post, unpublished, information on collection label). On this scapula, several singular marks are visible. These are not linear, not parallel and have a more jagged appearance than the usual grooves present on most mandibles.

Experiment, methods

Since the fossils were of marine mammals and were found in a marine setting which has not been dry land since the animals died seven to eight thousand years ago, it can be supposed that the type of animal responsible for the scratches on the fossils was also of a marine nature. The possibility that they were caught at sea, eaten by terrestrial animals or humans, and deposited back in the ocean is extremely unlikely. In order to find out what kind of marine animal made the marks on the fossils, we decided that reference marks made by sharks and rays were needed for comparison. For this reason, we performed an experiment in which an anatomical proxy was to be scavenged by sharks and rays. We used bovine rib fragments (*Bos taurus*) with an approximate length of c. 30 cm each, for two reasons. First, the flat and slightly bent shape was a fairly good approximation of the flat and somewhat curved shape of the *Tursiops* mandibles, which is the type of bone most often marked. A second and more practical reason was that rib fragments from cows were more easily available than fresh *Tursiops* mandibles.

Fig. 3. Fossil marks on NMR 2269 (mandible)

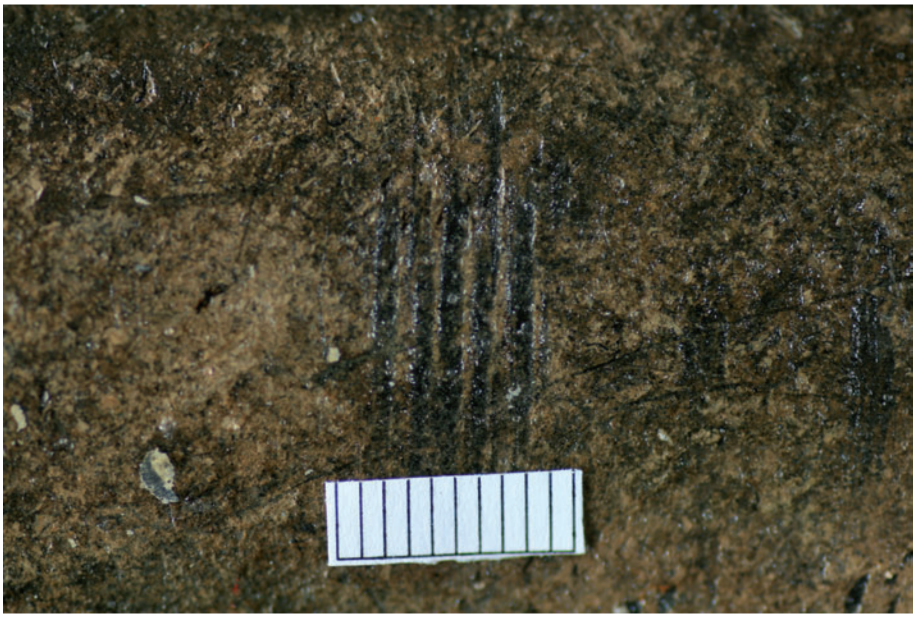

Fig. 4. Detail of Figure 3: fossil marks on NMR 2269 (mandible).

The bones were not completely clean, but were covered by a small layer of tissue (connective tissue and some muscular material).

The rib fragments were made available to us by butcher mr. Hoff, in Hardenberg, the Netherlands, a week before the experiment. They were kept frozen until 24 h prior to the experiment, and then defrosted and kept in a refrigerator in order to make them more appealing to the animals. The rib fragments were then deposited in the basin with sharks and rays at the Dolfinarium Zoo in Harderwijk, Gelderland, the Netherlands. The chondrichthyan species thus involved in the experiment were two species of shark (the dogfish *Scyliorhinus canicula* and the starry smooth-hound *Mustelus asterias*) and three rays (the thornback ray *Raja clavata*, the undulate ray *Raja undulata* and the smalleyed ray *Raja microocellata*). All species are known from the North Sea. Of the undulate ray *Raja undulata*, only a juvenile specimen was available for the experiment. Although more chondrichthyans are found living in the region, this sample can be considered a representative one.

Both the sharks and the rays used in this experiment have jaws in which the teeth are aligned linearly. The direction and spacing of the alignment differs between species. Where the starry smooth-hound (*Mustelus asterias*, Fig. 7) has rather small, broad-rounded teeth placed in diagonal rows of 1.5 mm wide, the smalleyed ray (*Raja microocellata*, Fig. 8) has extremely sharp, pointy teeth arranged in 2 mm wide longitudinal rows. The undulate ray (*Raja undulata*) has its pointy teeth aligned in transverse lines, with 1.5 to 2.0 mm between the teeth.

In order to ensure the interest of the animals, they were kept unfed during eighteen hours prior to the experiment. As

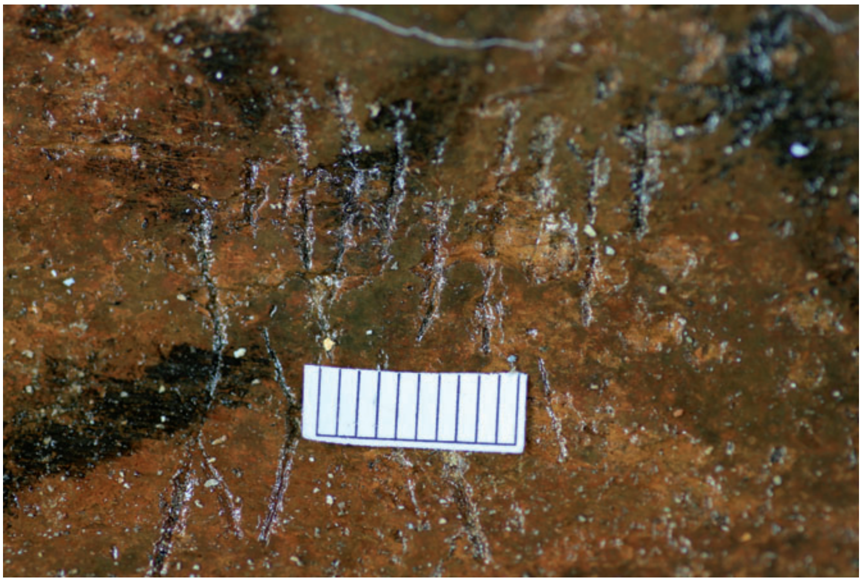

Fig. 5. Fossil marks on NMR 2310 (mandible), probably caused by a shark.

an extra lure, shrimp juice was poured over the ribs, as it was known by the trainers that the animals react strongly to the juice. Active luring by hand was also performed by the trainers, who are working daily with the animals and know their habits well. This was done by holding the bone while keeping it partly submerged and also by attracting animals and actively putting the bone between the jaws of the animal. This last method proved to give the best visible results. This did indeed attract the animals, and as a consequence many animals were observed scraping or nibbling from the tissue attached to the bone. The disadvantage of this method was that the gnawing-marks were to some extent made in the tissue, rather than on the bone itself, thereby making them less easily to observe and harder to preserve. Nevertheless, several clearly visible marks were made even on the tissue. After the experiment, the bones were kept frozen, while covered with cellophane, to wait for further study.

Results

Raja clavata *(Thornback ray)*

The bite marks of the thornback ray are near-linear grooves up to 30 mm long. The grooves (Fig. 9) are located parallel to each other and have a width that in the tissue varies between 0.5 and 1.5 mm. The distance between the individual grooves is 2.5 to 3.0 mm. The grooves were made by scraping the teeth across the tissue on the rib parts. Other marks (Fig. 10) were made by simple biting without a scraping movement. This occurred when the bone was actively put inside the jaws of a thornback ray. This produced elliptical shaped marks, each mark representing one tooth. These marks show the linear alignment of the teeth typical of the rays used in this experiment, with a distance of 2 mm between the midpoints of each row.

Fig. 6. Fossil marks on NMR 2312 (scapula), identified as shark marks by mr K. Post (personal communication).

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*Fig. 7. Dentition of a starry smooth-hound (*Mustelus asterias*).*

*Fig. 8. Dentition of a small-eyed ray (*Raja microocellata*).*

Raja undulata *(undulate ray)*

The juvenile undulate ray made superficial grooves, hardly penetrating the tissue (Fig. 11). The grooves were linear and parallel and had a width of approximately 1.5 mm and a length of 10 mm. The distance between the grooves is similar to the width of the grooves.

Raja microocellata *(smalleyed ray)*

The only available marks made by a smalleyed ray were small (less than 3 mm in length), thin, parallel lines with a width of up to 0.5 mm and a similar distance between the grooves.

Mustelus asterias *(starry smooth-hound)*

The bite marks of the starry smooth-hound were superficial and small. They are non linear grooves, approximately 0.5 mm long, which are almost parallel to each other.

There are 5 grooves within approximately 10 mm, indicating that the width of each groove, which is slightly smaller than the distance between the grooves, is around 0.5 - 1.0 mm.

Scyliorhinus canicula *(dogfish)*

The dogfish were among the most active species during the experiment, especially the juveniles. They were nibbling on the tissue on many occasions. However, the only evidence for their eating of the tissue is a small area with visibly less tissue than the surrounding area. Dogfish did not leave any tooth marks on this area.

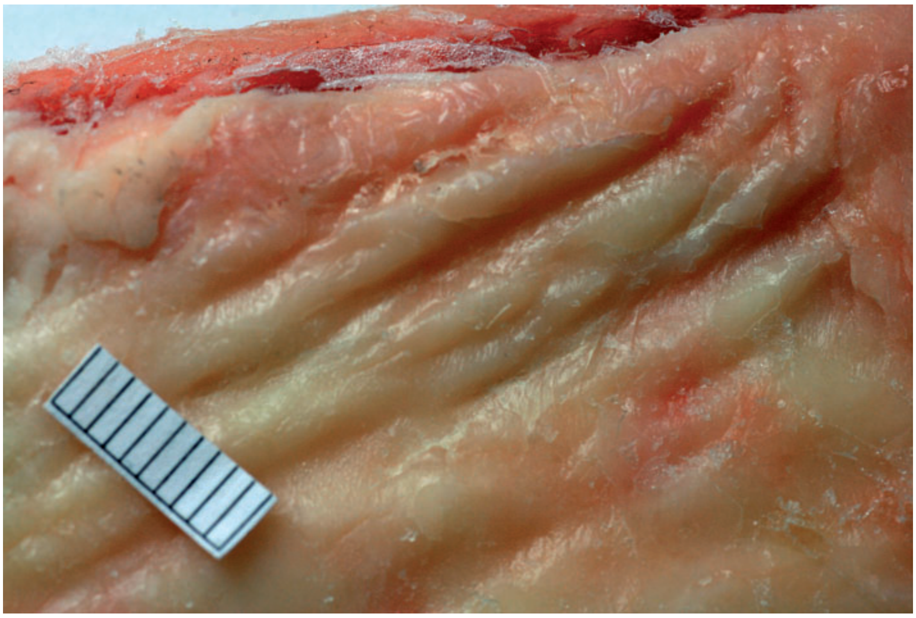

*Fig. 9. Scraping marks left by a thornback ray (*Raja clavata*).*

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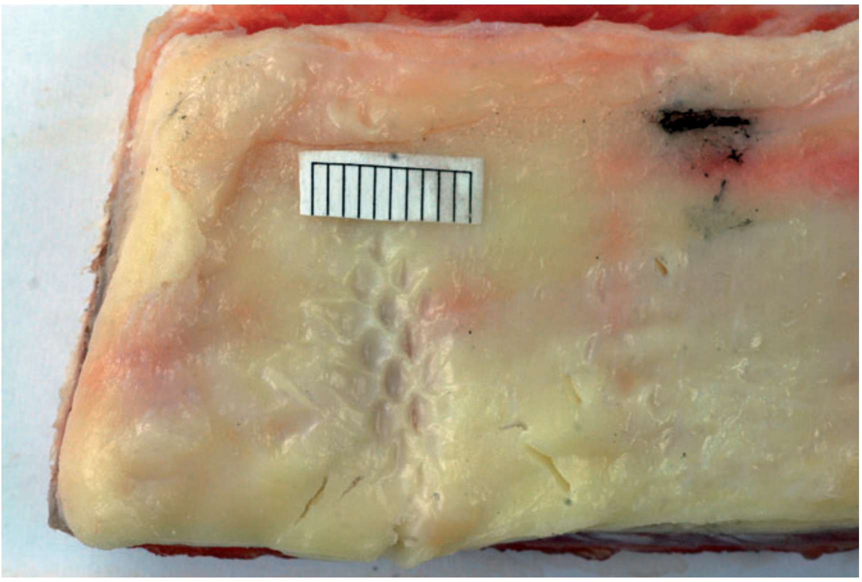

Fig. 10. *Bite marks left by a thornback ray (*Raja clavata*).*

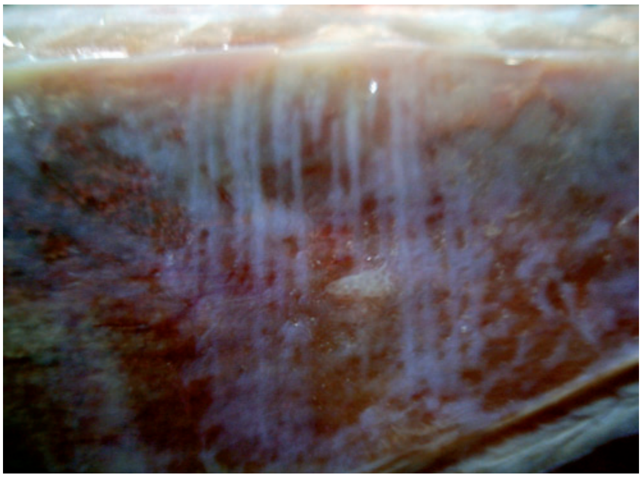

Fig. 10. Bite marks left by a (juvenile) undulate ray (total width of the marks approx. 1 cm).

Conclusion and discussion

The results of the experiment show that scavenging by rays is a possibility for explaining the parallel marks. The width of the grooves and of the interspacing between the grooves of the fossil marks and those made during the experiment correspond to the spacing between the individual teeth in the dental plates of the rays, and thus to differences in age and size of the rays. The fact that in the experiment the rays did not reach the bone with their teeth is not relevant. The zoo rays included in our experiment were generally well-fed and they were not given sufficient time to scrape enough tissue from the ribs in order to reach the bone surface. It is entirely feasible that the combination of a better exposed (better defleshed) bone and a more hungry ray would result in marks that enter the bone.

The marks produced by the sharks used in the experiment share the non-linearity with the shark marks on the fossils. Such lines that are not mathematically parallel are typical for sharks; see for example Shimada & Hooks (2004) who described shark bite marks on turtle bones and carapax. Therefore, it is exactly the linearity of placement of teeth in the dental plates of the rays and the parallel structure of the marks left by the rays in the experiment that lead to the conclusion that the fossil marks are most likely the result of scavenging by rays.

Although it is often hard to prove whether bite marks are the result of a successful kill or of scavenging (i.e. Fischer, 1995; Schwimmer et al., 1997; Rothschild et al., 2005), the placement of the marks on the fossils, together with the shallow depth, clearly indicate that they were the result of post-mortem activity. Several *Tursiops* lower jaws have several groups of marks with different orientations, that are unlikely to be the result of an attack on the dolphin. Also, the marks inside the atlas complexes (especially the ones on NMR2339) are impossible to have originated as the result of an attack, since they would have needed a separation of the atlas complex from the rest of the skeleton before the marked area became within reach of any animal (predator or scavenger). Together, this is good evidence for the idea that the marks were made as a result of scavenging and not predation. In our specific case this conclusion seems more credible as these rays or sharks do not kill dolphins. The shape of the marks, several thin grooves that run parallel to each other, indicates that they were made by scraping tissue from the bone, rather than biting into it.

The idea initially proposed that the marks could be the result of human activity can be disregarded for several reasons. As mr Jan Glimmerveen (pers. comm. 2008) indicated, the lines are too nicely parallel to be made by humans, except if they would have been made by some sort of fork or comb. The marks also bear no resemblance to any of the standard human bone modifications described by Fischer (1995). The age and location of the fossils also excludes human interference with the objects, since the North Sea has not been dry land since it became connected with the English Channel, approximately 8.3 - 8.8 kyr BP.

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