Deformed Cetacea bones from the southern North Sea

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Abstract: This study describes the occurrence of osteological pathologies in cetacean bones from the North Sea held in the collections of Vonk and Ecomare on the island of Texel, the Netherlands. Bone pathologies are mostly a congenital condition, a result of degeneration or a bacterial infection. More severe bone malformations can have serious consequences for the health of cetaceans. Previous research indicates that lesions in a cetacean skeleton can lead to a decrease in mobility and fitness of the animal. Besides affecting the locomotion, these animals are more exposed to predation as well. In total, 37 whale bones with abnormal conditions were found. The majority originated from the harbour porpoise (*Phocoena phocoena*) and accounted for 15 units. Vertebrae were the most common deformed bones with 24 units, mostly showing features of spondylodiscitis. As the studied collections primarily consist of fished up bone singletons instead of complete skeletons, it proved almost impossible to conclude if the observed pathologies had affected the health of the concerning cetaceans.

Keywords: Cetacea, osteological pathologies, pseudopathology, deformed bones, abnormalities, North Sea.

Introduction

The mammalian infraorder Cetacea comprises baleen and toothed whales, including dolphins and porpoises. These species evolved from quadruped terrestrial animals around 55.8 million years ago, in the early Eocene (Barnes 1984). The adaptation to the marine environment has been accompanied with several physical changes, such as the extension of the skull (also known as telescoping) with one or two dorsal blowholes for breathing, the disappearance of the pelvic limbs, and the transformation of the pectoral limbs into fins for locomotion. Nowadays, cetaceans move through the water by powerful vertical movement developed by their tailstock and the flukes (e.g., Camphuysen & Peet 2006, Cozzi et al. 2009). These movements are generated by very strong muscles, which are located along the spine. Hence the spine and its muscles can be assigned as the main locomotor organ in cetaceans (Cozzi et al. 2009) and the vertebral column of cetaceans is crucial for all their vital activities.

However, several studies have found different types of skeletal lesions (e.g. Kompanje 1995a, 1995b, 1996, 1999, Félix et al. 2007, Van Bressem et al. 2007, Groch et al. 2012, San Martín et al. 2016), raising the question whether these osteological pathologies affect the health of cetacean species. Based on previous studies, bone aberrations can be diagnosed as a consequence of: 1. Degeneration, related to age or as a result of direct damage due to abnormal forces around the joint or

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adjacent supporting structures. 2. Infectious spondylitis, often referred to as spondylo-osteomyelitis and used as an umbrella term for an inflammation of a vertebra as a result of a direct infection. 3. Spondylodiscitis, damage to the vertebral disc due to bacterial infection. 4. Congenital pathology. 5. Pseudopathology due to post-mortem disintegration, which are abnormalities that appear on the bone after the death of the animal, for instance due to the weathering process. Furthermore, osteophytes, which are bony outgrowths, and syndesmophytes occur often on the bones. Syndesmophytes are defined as osteophytes bridging between two vertebrae due to different ossification processes (François et al. 1995)

Here we report on the observed osteological pathologies of cetaceans held in the Vonk and Ecomare bone collections in spring 2021. For over thirty years, the Dutch fisherman Adrie Vonk has been collecting whale bones and other (marine) mammal remains found by fishermen as 'bycatch' at the North Sea. Vonk started this process in 1990 and kept everything he received from his fellow fishermen in his shed, called 'Groenland', on the island of Texel. No selection has been made in the incoming bones and every single bone ended up in Vonk's collection. Most bones are fished up in the period between 1980 and 2016 by beam trawl fishing in the area south of the Newcastle-Limfjord line in the southern half of the North Sea. In 2016, the extensive collection was donated to Ecomare, a nature museum on Texel. The collection consists of fished up recent bones but also fossils of all different parts of the skeleton. Currently, the collection is still being supplemented with new bones. The whole collection of around 5500 fished up bones has been identified, described, and catalogued with the help of a group of volunteers. The assessment of the entire bone collection consisted of the identification of the species, a rough estimate of the age, as well as defining from which part of the skeleton the bone originates, and the corresponding quantity.

Table 1. Number per pathology type found in the Vonk and Ecomare whale bone collections.
* deformed mandibles and scapulae

Pathology	Number
Congenital	3
Degeneration	1
Pseudopathology	6
Severe weathering	4
Spondyloarthropathy	2
Spondylodiscitis	17
Unknown bacterial infection*	4
Total	37

To further elaborate the research on the Vonk whale bone collection, this study will focus on the occurrence of deformed cetacean bones. The aim of this research is to document pathological aberrations observed in this whale bone collection and to diagnose the potential pathologies. In order to get an impression of how often osteological pathologies occur, which types are involved and whether there is a relationship with the age or the developmental stage of the animal, the Vonk bone collection is subjected to a closer inspection.

Materials and methods

For this research, whale bone collections were assessed to study the occurrence of pathological conditions in cetacean species. We primarily used the Vonk collection, which comprises around 5500 bones. This collection was readily accessible because it was identified, classified, and photographed in the years 2017 and 2018. Moreover, during this identification, easily recognizable abnormal bones had been stored separately. For our study, a closer inspection of the entire Vonk collection was carried out in spring 2021 in order to find more whale bones with abnormalities. Previous research by François et al. (1995), Groch et al. (2012), Kompanje (1995a, b, 1996, 1999), and Nathan (1962) were

Table 2. The number of deformed bones per cetacean species found in the Vonk whale bone collection, and the corresponding percentages with respect to the total amount of bones. The total amount of bone data is retrieved from previous research by Oosterbaan (2018).

Species	Total amount of bones	Amount of deformed bones	Deformed bones (%)
Beluga *(Delphinapterus leucas*)	-	1	-
Bottlenose dolphin *(Tursiops truncatus*)	137	4	2.92%
Minke whale (*Balaenoptera acutorostrata*)	362	4	1.10%
Harbour porpoise (*Phocoena phocoena)*	± 4500	15	0.33%
Killer whale (*Orcinus orca)*	21	2	9.52%
White-beaked dolphin (*Lagenorhynchus albirostris)*	-	1	-
Unidentified	189	5	2.65%
Total	± 5500	32	0.58%

used to recognize pathologies. All deformed bones were representatively photographed using a digital photo camera. For each bone, the characteristics, species name, and object number were noted. As the Vonk collection is still growing, deformed bones added to the collection after 2018 were identified to species level using the cetacean vertebrae identification key from Houwertjes (2020) and with the expertise of Arthur Oosterbaan, Adrie Vonk, and Erwin Kompanje.

Besides the Vonk collection, this study also includes some material from the Ecomare museum on Texel. This museum owns a few complete whale skeletons from locally stranded specimens. While being on display for the public in 2021, these cleaned skeletons of different cetacean species were examined for pathological aberrations. Just as with the Vonk collection, all bones with pathological changes were photographed and characteristics were recorded for further study and elaboration. After a preliminary classification, all pathologies of both collections were revised or identified by Erwin Kompanje on basis of the photographs.

Results

Within the Vonk whale bone collection of approximately 5500 units, we observed 35 whale bones with abnormal conditions (table 1). As follows from spondylodiscitis being the main pathology, vertebrae were the most common deformed bones with 24 units (65%). Furthermore deformations were found in five skulls, two scapulae and two lower jaws. Among the vertebral anomalies, the most frequent occurred in lumbar vertebrae (*n*=11), followed by caudal (*n*=5), thoracic (*n*=4), and unidentified vertebrae fragments (*n*=4). These osteological pathological changes contained mostly fusion of the vertebrae, presence of osteophytes and syndesmophytes, and/or destruction of the vertebral bodies.

The majority of the deformed bones originated from the harbour porpoise (*Phocoena phocoena)* and counted for 15 units (table 2), followed by the white-beaked dolphin (*Lagenorhynchus albirostris*) with five units, the minke whale (*Balaenoptera acutorostrata)* and the bottlenose dolphin (*Tursiops truncates)* with both four units, and the killer whale (*Orcinus orca)* with three units. Other deformations belonged to one beluga (*Delphinapterus leucas)*, and one unidentified species. When the deformations are put into perspective with the total bone number per species according to the previous findings of Oosterbaan (2018) (table 2), the relatively low percentage of deformed bones in harbour porpoise stands out.

Three deformed vertebrae units were found

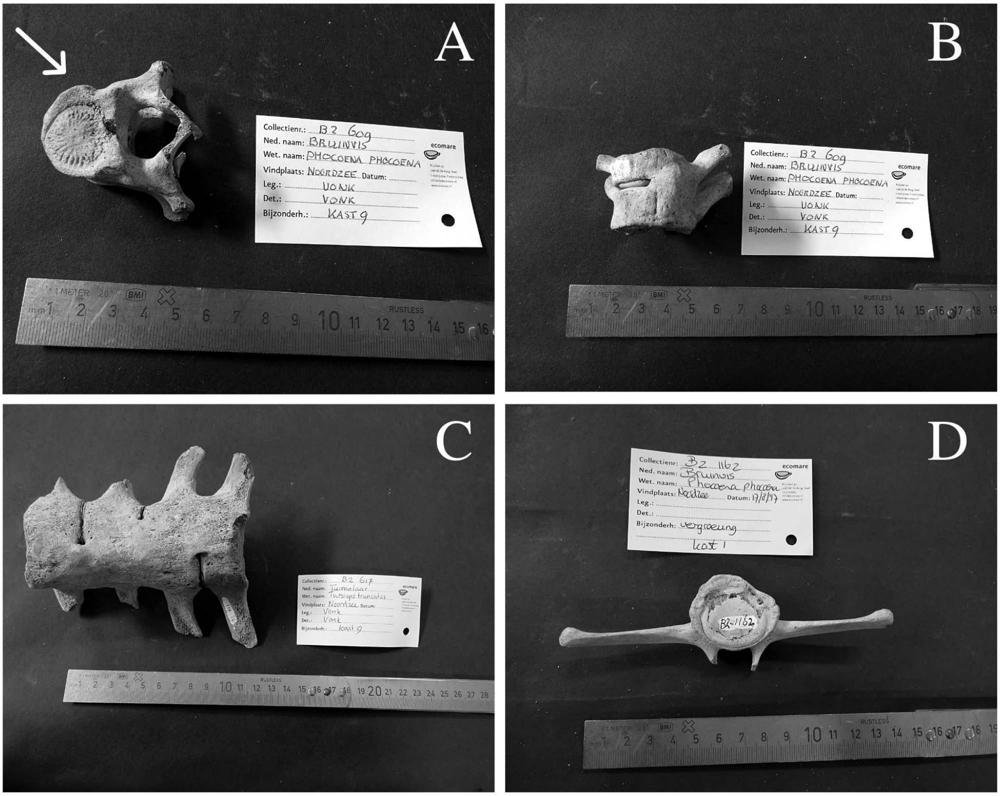

Figure 1. Deformed vertebral units of cetaceans. A: *Phocoena phocoena* (B2-0609), anterior view of two partly fused thoracic vertebrae. The arrow indicates the presence of marginal osteophytes. B: *Phocoena phocoena* (B2-0609), ventral view of two partly fused thoracic vertebrae with a syndesmophyte. C: *Tursiops truncatus* (B2-0617), ventral view of four partly fused thoracic vertebrae by new bone formation. D: *Phocoena phocoena* (B2-1162), posterior view of a lumbar vertebra, showing the growth of marginal osteophytes and pathological perforations of the intervertebral disc. *Photos: Maja Raemakers.*

with unfused growth plates (figure 1). Traditionally the extent of fusion of growth plates has been used as a coarse measure for age and specimens with unfused growth plates were commonly designated as juveniles. However, although this fusion is of course age related, the variation in timing of the process appears large and therefore does not enable a certain determination of life stage (Galatius & Kinze 2003). Figures 1A (anterior view) and 1B (ventral view) show a fusion of two thoracic vertebrae of a harbour porpoise (B2-0609). Furthermore, osteophytes on the margin of the vertebral body and the formation of a syndesmophyte have been observed. Figure 1C shows a fusion of four thoracic vertebrae of a bottlenose dolphin (B2-0617). These fused vertebrae have been developed through smooth new bone formation, which is not a typical sign of osteomyelitis. The last figure, 1D, shows a single lumbar vertebra originated from a harbour porpoise (B2-1162) with irregular thick osteophytes on the margins and an eroded/destructed vertebral endplate. These marginal osteophytes, and thereby the destruction of the vertebral body in immature cetaceans, are the results of an infection. The cavities, or so-called cloacae, found on the vertebral endplate are most likely caused by bacterial infection followed by the forma-

Figure 2. Deformed crania of *Lagenorhynchus albirostris* (B2-0259). Arrows indicate the cloacae. *Photo: Maja Raemakers.*

tion of pus. Therefore, it is likely that this harbour porpoise (B2-1162) suffered from a bacterial infection. This bacterial infection could be originated by penetrating a wound, and spreading from the urinary tract or by bacteremia, which are viable bacteria present in the bloodstream (Félix et al. 2007).

In the Vonk whale bone collection, five skulls originated from two minke whales, one white-beaked dolphin, one killer whale, and one unidentified skull fragment, which probably originates from a long-finned pilot whale (*Globicephala melas)*. The skulls from a white-beaked dolphin and an unidentified cetacean showed deformations. However, due to the severe weathering features on these two crania it was difficult to identify the pathological cause. Although a few cloacae on the cranium of the white-beaked dolphin (B2-0259, figure 2) may have been the result of a bacterial infection, yet the very atypical location of these cloacae made it more plausible to diagnose these as pseudopathology.

Each of the other three skulls showed two remarkable holes on the posterior side right above the foramen occipital magnum, which consists of an oval or circular opening and passes through the spinal cord. In addition, two more skulls, originated from minke whales, with two similar holes on the back of the crania were found in the museum collection of Ecomare. This made a total of five cetacean skulls showing two additional holes around the same place on the skull. It seemed very plausible that these holes were located on fragile parts of the skull resulting in an increased chance of fracturing during the weathering process on the bottom of the seafloor. Although this phenomenon can be diagnosed as a pseudopathology, it is remarkable we found five nearly identical examples of this deformation. Because of the multiple occurrences, we used to call it the 'smiley phenomenon', since it resembles a little face (figure 3).

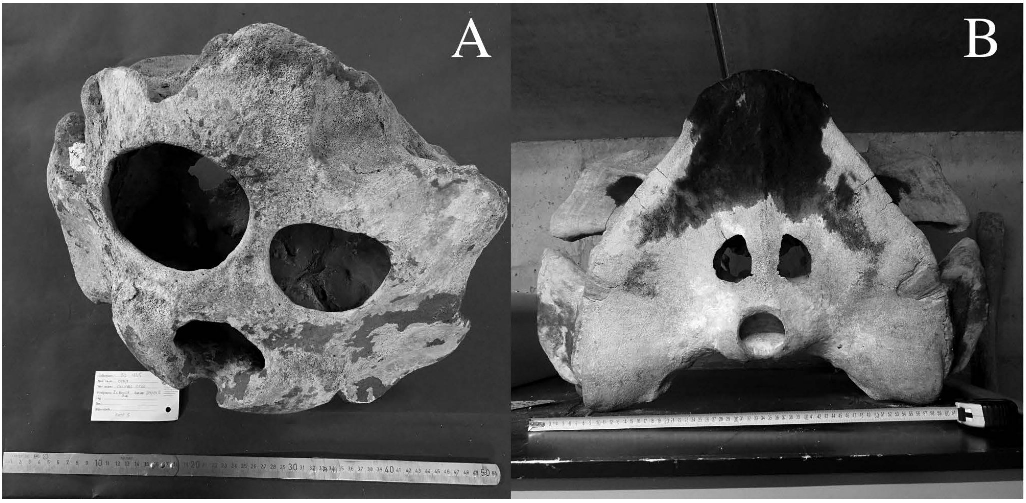

Figure 3. "Smiley" skulls of *Orcinus orca* (A) and *Balaenoptera acutorostrata* (B), posterior view. *Photos: Maja Raemakers.*

Figure 4. Deformed scapulae B2-1469 (A) and B2-1321 (B): osteolysis, resulting in complete loss of bone. *Photos: Maja Raemakers.*

Two deformed scapulae (figure 4) were also found. These scapulae were labelled as belonging to bottlenose dolphins (respectively B2-1469 & B2-1321), but after comparison with an intact skeleton, the latter one, B2-1321, was reidentified as a white-beaked dolphin. Both scapular blades showed deformations, however, only the fracture in object B2-1321 is diagnosed with a pathological cause due to the presence of several cloacae (figure 4B). It seems very plausible that this deformed scapula is the result of a bacterial infection. On the other hand, the fracture on the scapula with object number B2-1469 can be diagnosed as a post-mortem disintegration. Two deformed mandibles were identified as a white-beaked dolphin (B2-0634) and a bottlenose dolphin (B2-0618). The lower jaw of the white-beaked dolphin (figure 5A) showed an inner lesion at the top, possibly caused by a bacterial infec-

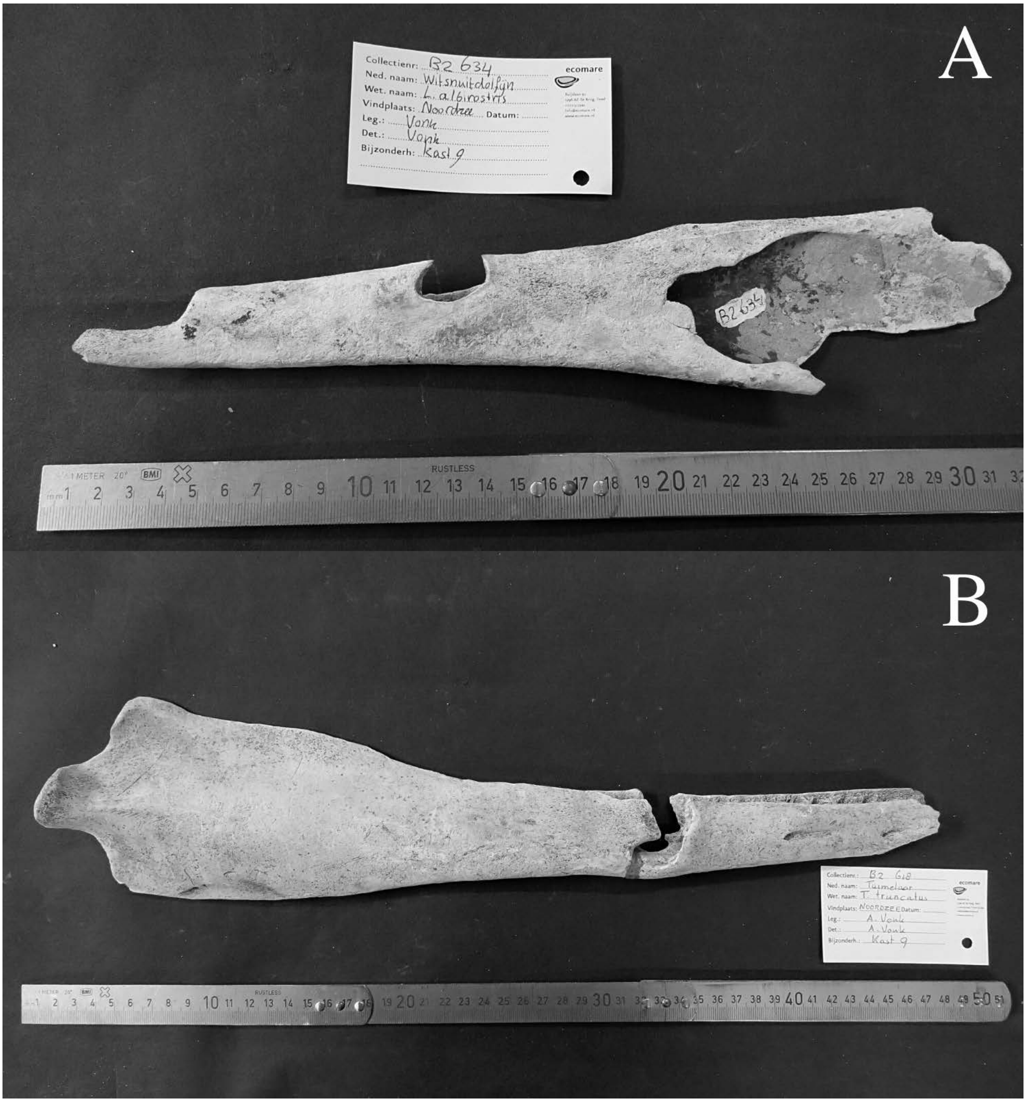

Figure 5. Deformed mandibles caused by a bacterial infection in the dental alveoli. A: white-beaked dolphin (B2-0634). B: common bottlenose dolphin (B2-0618). *Photos: Maja Raemakers.*

tion in the dental alveoli. Figure 5B shows a lesion in the mandible of the bottlenose dolphin, which almost reaches to the bottom of the mandible as a result of an infection. Note that the dark line at the bottom of the lesion is glued since the mandible has been broken during the identification process. Both mandibles were missing the tip, which is probably again no pathological cause, but is related with post-mortem disintegration.

In the collection of Ecomare, five other osteological deformations have been found. Of the cleaned skeletons, the specimens of one white-beaked dolphin and one killer whale showed both several skeletal abnormalities.

In the white-beaked dolphin skeleton, a congenital pathological change in the ribcage was observed (figure 6). Its sternum was asymmetrical and the proximal ends of two sternal ribs were fused leading to one attach-

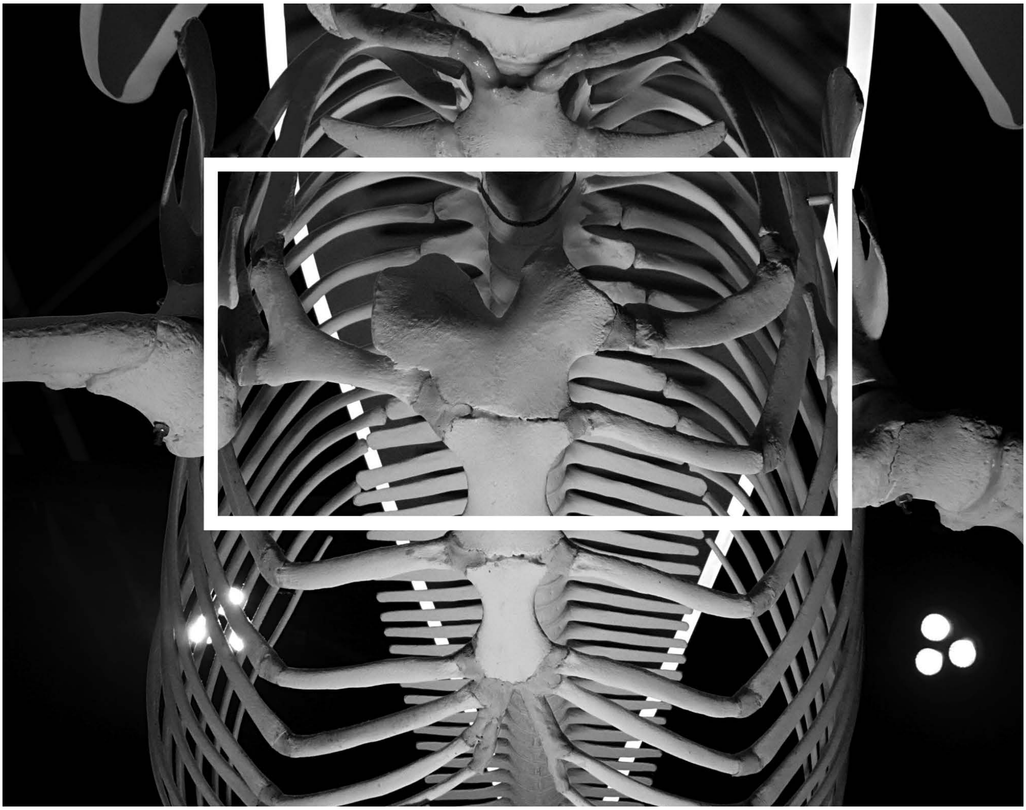

Figure 6. A skeleton of a white-beaked dolphin, *Lagenorhynchus albirostris*, stranded in 1996 on Texel with malformations of sternal ribs. The box indicates the pathological change in the upper part of the ribcage area: an asymmetric sternum and on the left side a fusion of the first and second sternal ribs. *Photo: Maja Raemakers.*

ments site on the sternum.

The killer whale showed a severe lesion in the fourth and fifth caudal vertebrae, which is caused by spondylodiscitis (figure 7A). The ankylosing spondylitis resulted in total loss of movement between these vertebrae. Furthermore, a congenital anomaly was found in the attachment of the last sternal rib on the sternum on the right side of the skeleton (figure 7B).

Discussion and conclusions

The goal of this research was to document the pathological observations that could be found in the whale bone collections of Vonk and Ecomare. A total of 37 osteological deformations were observed in the Vonk and Ecomare whale bone collections. The majority of the deformed bones originated from the harbour porpoise, which is in accordance with previous research on the Vonk whale bone collection (Oosterbaan 2018, 2020). As mentioned by Camphuysen & Peet (2006), the harbour porpoise is by far the most common cetacean species in the (Dutch part of) North Sea, which may explain its high occurrence in the Vonk collection. Moreover, spondylodiscitis occurred quite often in this study, especially in *P. phocoena* individuals, which can be explained by the aforementioned reason. Furthermore, vertebrae represent the majority of deformed bones in this investigation. A properly functioning spine is vital for the survival of cetaceans as the spine is crucial for loco-

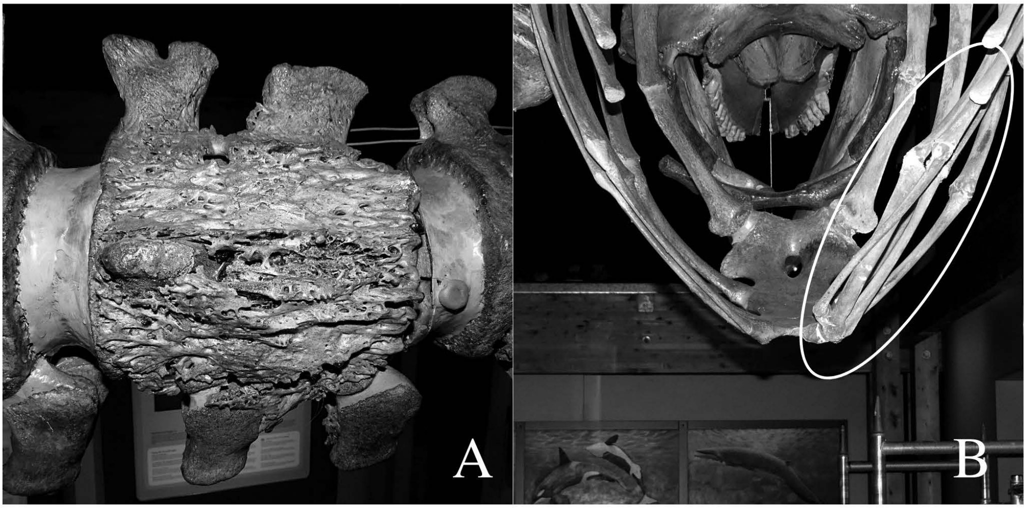

Figure 7. A killer whale (*Orcinus orca*) in the museum collection of Ecomare. A: a severe ankylosis between the two caudal vertebrae. The bizarre and extreme appearance indicates a spondylodiscitis. B: a congenital anomaly. The oval shape indicates the abnormality in the attachment of the last sternal rib on the sternum. *Photos: Maja Raemakers.*

motion (Cozzi 2009). Damage or fusion of vertebrae in particular can lead to a decrease in mobility in the spine. The eventual effect of this on vitality depends on the part of the spine affected and the severity of the damage. But it is clear that normal unobstructed locomotion is crucial for foraging and catching food, reaching the water surface for breathing, as well as for mating behaviour and avoiding danger. With regard to the latter, it is also important to mention that a damaged spine can also lead to a reduction in both manoeuvrability and tail mobility. Both these movement mechanisms are important in defence against predators, like larger sharks and, in the case of smaller species, other cetaceans, especially killer whales (Félix et al. 2007). Therefore, severe deformed bones are likely to lead to premature death of the animal, but the effect of limited osteological deformations is less clear. Probably many cetaceans will experience little hindrance of small lesions, but as lesions often indicate a chronical disease, with for instance the occurrence of bacterial sepsis, they can result in a lower fitness and higher predation risk as well. The deformations found in the Vonk and Ecomare collections are mainly small and can be assigned to the slight hinderance category. Interestingly, the percentage of deformed bones is remarkably lower in harbour porpoise than in the other species. Harbour porpoise is by far the most common and abundant cetacean in the North Sea, while it is rather unattractive to other cetaceans due to its shallowness. Therefore it might be hypothesized that less fit individuals of these other cetaceans (e.g. by illness or bone deformations) are more likely to turn up in the north sea, as more vital specimens prefer other sites. However, it should be noted that harbour porpoise has a low life expectancy (8-10 years) (Galatius & Kinze, 2003), which potentially could mean less time is available for the formation of obvious bone pathologies. It is not possible to estimate whether there is any relationship with the age or the developmental stage of the animal. Furthermore, it is unknown if these pathological aberrations have led to premature death.

Unfortunately it proved hardly possible to elaborate on the results due to usage of fished up separate bones instead of analysing the whole cetacean skeleton. This major diagnostic deficiency is an inherent characteristic of this method. The results are therefore a mere conservative estimate of the type of osteological pathology, since the condition of the entire animal is unknown. This leads to an absence of important information about the life history of the individual cetacean. Furthermore, the occurrence of pseudopathologies has been observed several times due to weathering and corroding. The weathering process on the seafloor results in the disappearance of characteristic features of certain osteological anomalies. This can make it difficult to indicate the type of pathological deformation and its accompanying inducement. Moreover, there are some uncertainties in the identifications of the species name and the type of bone, especially with the vertebrae series.

Besides that, there could be a bias in the Vonk whale bone collection since the size of the bones determines the chance of slipping through the fishing nets and the decision of fishermen if the bones are worth to collect. This can lead to a higher presence of certain bone types. As a result, it is not possible to determine with certainty the influence of deformities in the skeleton on the general health of cetaceans in the North Sea with the observations in the Vonk and Ecomare whale bone collections. A extrapolation to population effects of cetaceans in the North Sea is similarly impossible with these data. In conclusion, using whale bone collection for scientific analyses gives strongly limited information due to absence of the whole skeleton, weathering and corroding processes and a bias in the type of bones. Despite these drawbacks, the observations made in this study give an insight in the occurrence of osteological pathologies and their potential consequences for cetaceans in the North Sea. Without the impressive collecting effort of Adrie Vonk, this would not have been possible.

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Samenvatting

Afwijkingen bij walvisbotten uit de zuidelijke Noordzee

Afwijkende botten worden wel vaker gezien bij walvisskeletten, maar in sommige gevallen lijkt er meer aan de hand te zijn. Zo bevinden zich in de walvisbottencollectie Vonk op Texel botten die vreemde uitstulpingen hebben of aan elkaar vastgegroeid zijn. Om de bottencollectie Vonk verder te analyseren, heeft dit onderzoek zich gericht op het voorkomen van misvormde walvisbotten. Het doel van dit onderzoek was om de afwijkende observaties te documenteren en de bijbehorende mogelijke pathologieën te bepalen. In totaal werden 37 vervormde walvisbotten gevonden, waarvan de meerderheid afkomstig is van de bruinvis (*Phocoena phocoena*; *n*=15). Het overgrote deel van de gevonden aandoeningen heeft een infectieuze oorzaak. Daarnaast representeren de wervels de meerderheid van de misvormde botten (*n*=24), waarbij spondylodiscitis het vaakst is geïdentificeerd. Dit is een aandoening waarbij de wervelschijf is aangetast als gevolg van een bacteriële infectie. Verder werden zeven schedels, twee schouderbladen en twee onderkaken gevonden met pathologische kenmerken. Hiervan werden de meeste vervormingen geïdentificeerd als pseudopathologie, waarbij de afwijkingen op het bot zijn ontstaan na de dood van het dier door verwering. Bij de schedels werd een ander opmerkelijk verschijnsel herhaaldelijk waargenomen. Aan de achterzijde, net boven de foramen occipitale magnum, werden twee extra gaten gevonden in de schedel. Het resulterende beeld was zo typisch dat we dit het 'smiley-fenomeen' genoemd hebben. Botaantastingen kunnen van grote invloed zijn op de overlevingskansen van de betreffende dieren. Met name een goed functionerende ruggengraat is van groot belang voor het overleven van walvisachtigen. Ernstige botvergroeiingen leiden daardoor hoogstwaarschijnlijk tot (vroegtijdige) sterfte. Bij beperkte vergroeiingen zullen de meeste walvisachtigen weinig hinder ondervinden, maar omdat het vaak om een chronische infectie gaat, kunnen bijkomende effecten, zoals bijvoorbeeld bacteriële sepsis, de overlevingskansen toch sterk reduceren. De aangetroffen vergroeiingen in de

collecties Vonk en Ecomare zijn over het algemeen minder ernstig en vallen daardoor in de beperkt hinderlijke categorie. Bij de beschreven resultaten moet er natuurlijk rekening mee worden gehouden dat onderzoek naar botafwijkingen in de walvisbottencollecties Vonk en Ecomare behoorlijke beperkingen heeft. Het gebruik maken van afzonderlijke opgeviste skeletdelen in plaats van het analyseren van het complete dier leidt tot verlies van veel waardevolle informatie. De resultaten geven dan ook slechts een grove schatting over het type botaandoening en de mogelijke bijbehorende oorzaak. Het heeft echter wel geleid tot een beeld van de botvervormingen die kunnen optreden bij walvisachtigen en de potentiële gevolgen ervan.

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