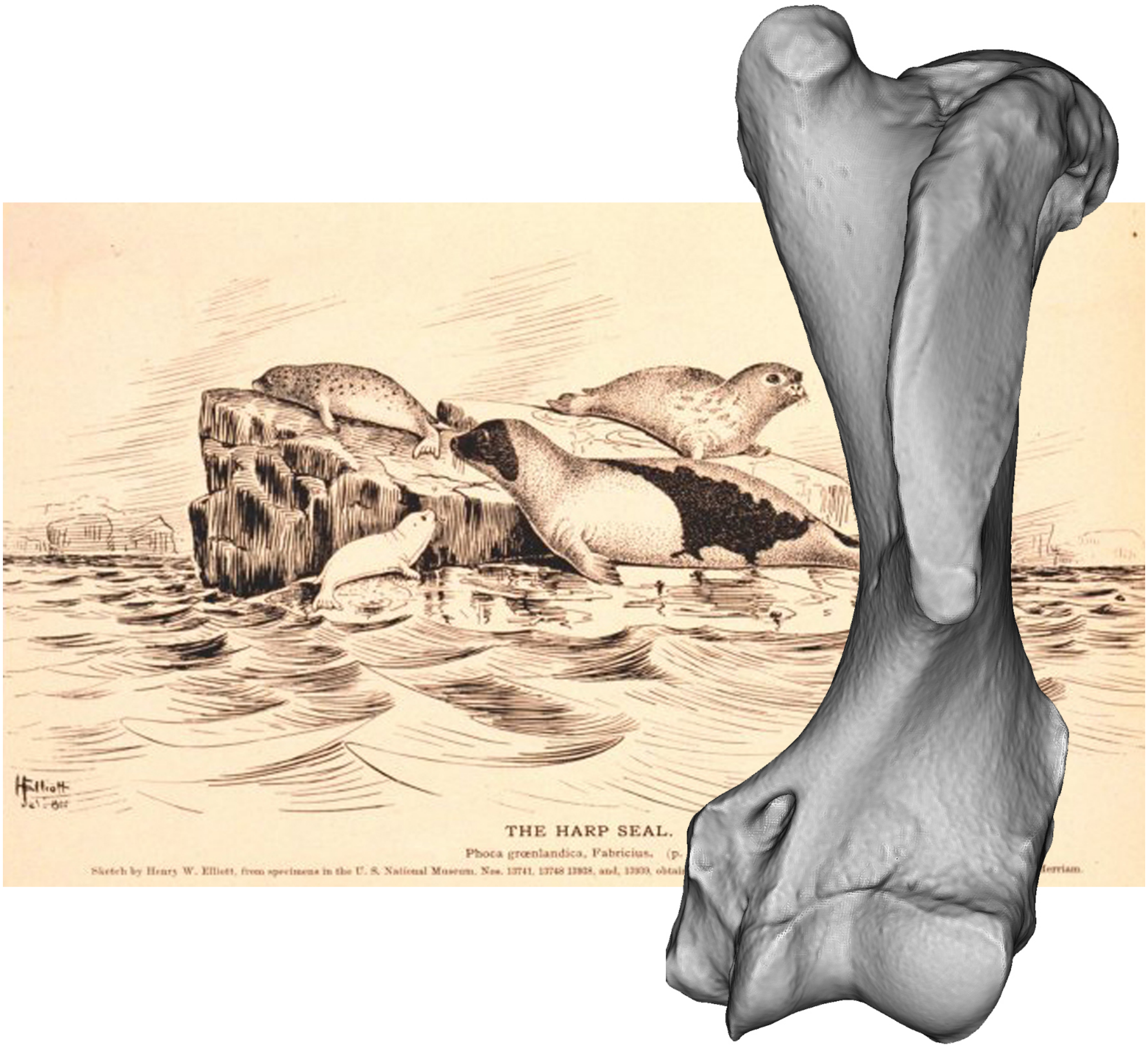
Fusing osteology with virtual reality

Three dimensional morphological differences between harp seal (*Pagophilus groenlandicus*) and ringed seal (*Phoca hispida*)



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Abstract

Seal remains, especially the harp seal is a common find from Stone Age settlements in the Baltic basin. The presence and disappearance of harp seal form the Baltic Sea is an interesting and widely discussed topic. Seal bones are quite easy determined to family (Phocidae), but more difficult to determine to species. Morphological differences between harp seal and ringed seal has been discussed by several researchers and line drawings has been made to illustrate the criteria for species determination. The aim of this study is to improve the ability to identify two species of seals - harp seal and ringed seal based on three dimensional visualisations and create a database with 3D models that could be used in further studies.

The seal bone scanning and 3D modelling was carried out to visualise the morphological differences between these two species. The mandible (*mandibula)*, the shoulder blade (*scapulae*), the upper arm (*humerus*), bones of the lower arm (*radius*/*ulna*), metacarpal I (*metacarpus*), hip bone (*coxae*), the thigh bone (*femora*), os cruris of the lower leg (*tibia*/ *fibula* = os cruris), metatarsal I (*metatarsus*) from left side of an adult, male harp seal and ringed seal were scanned.

The results from this study show the great potential that involve the 3D model use within osteology. The morphological differences between harp seal and ringed seal are clearly visible in 3D models. The open access of 3D models include a considerable scope for different modifications with this material, thereby facilitating zooarchaeological research, as well as serving for educational purposes.

Key words: morphological differences; harp seal; Pagophilus groenlandicus; ringed seal; Phoca hispida; Baltic Sea; 3D models; virtual reality; 3D scanner

Front page: http://commons.wikimedia.org/wiki/File:Phoca_groenlandica_2.jpg

Foreword

This thesis would not have been possible to carry out without help of several people to whom I wish to express gratitude. First of all I have to thank my supervisor prof. Torbjörn Ahlström for his advices, guidance's and support through the writing process. I am very grateful to the Humanities Lab of the Lund University and especially to Carolina Larsson and Stefan Lindgren for the opportunity to use the 3D scanner and computer, and their help during the working process. I owe the most gratitude to Carolina for her assistance guiding me through the world of 3D modelling. I wish to express my thanks also to Mogens Andersen at the Zoological Museum of the University of Copenhagen for the warm reception and providing the favourable conditions for bone scanning.

One of the aims of this thesis was to create a database of 3D models. So far the three dimensional models of seal bones are available at the Lund University server, that is password protected, and in an appendix of the thesis (as a separate pdf file available for downloading). Either way, the question about the possibility to facilitate the accessibility of these models is still under consideration.

For more information about models, please contact the author (aijamacane@inbox.lv).

Contents

Introduction

My first contact with digital bones was at a digital heritage seminar in Lund in the autumn 2011. Already before, I had been thinking about the opportunities to facilitate bone identification during the archaeological fieldwork and use of virtual comparative collections when real ones are not available. For example, in my home country Latvia, there are no comparative collections that could be used for animal bone identification, as well as lack of trained specialists hinders the analysis of zooarchaeological material. Thus part of material is not analysed or specialists from other countries help with bone identification.

The faunal remains often are among the most common finds during the excavations, but usually this find category do not get that much attention as other findings. However, I think that this type of material includes large potential, and can help to understand the environmental conditions, as well as people life in the past. The animal bone assemblages and interpretations of this material are affected by excavation methods and preservation conditions. Usually faunal remains are analysed after the excavation. Although, sometimes it would be important to get this information directly on place in order to understand better the excavation context and relation between the finds. Thus ideas about the use of digital technologies during the archaeological fieldwork, particularly the virtual comparative collections of animal bones, was developed prior to this study.

During my studies in archaeology, I have been especially interested in the Stone Age and issues concerning this period. The environment with the surrounding flora and fauna were an important part of the life of Stone Age peoples. Animals had a significant social and economical value. Human activities, as well as ecological conditions, have been the reasons for disappearance or extinction of some animal species. An interesting phenomena is the large amount of harp seal *(Phoca groenlandica* aka *Phagophilus groenlandicus)* remains from the Stone Age sites around the Baltic Sea (Holmqvist 1912; Winge 1914; Pira 1926; Nihlén 1927; Lepiksaar 1964; Ekman 1972, 1974; Aaris-Sørensen 1978; Lindqvist 1988; Lõugas 1997ab, 1998; Segerberg 1999; Daugnora 2000; Zagorska 2000; Storå 2000, 2002). This fact is of interest, since nowadays this seal species is not encountered in the Baltic Sea basin. The presence of harp seal in the Baltic Sea during the Stone Age has been a subject for discussions over the years (Ericson 1989; Storå 2001; Ukkonen 2002; Storå & Ericson 2004; Storå & Lõugas 2005; Bennike *et al*. 2008; Schmölke 2008).

It is easy to determine seal bones to family (Phocidae), but more difficult to determine to species (Ericson 1989:57). Seal bones are a common find from the Stone Age coastal sites in the Baltic basin and the morphological differences between harp seal and ringed seal have interested several researchers (Leipiksaar 1986, 1991; Storå 2001; Storå & Ericson 2004), who have tried to distinguish the differences between these two species. My interest in the digital technique use within osteology, as well as these interesting aspects concerning the seals in the Baltic Sea during the Stone Age, affected the choice of the topic for this thesis.

Background

Background on harp seal and ringed seal

Harp seal is an Arctic deep-sea animal, and nowadays it is present throughout the Atlantic part of the Arctic Ocean. Three main breeding grounds for harp seal are in the Newfoundland area, the region north of Jan Mayen and in the White Sea (Schmölke 2008:233). All these populations differ from each other, where the Newfoundland population is more isolated from others.

Figure 1. Harp seal pup (Picture from http://www.babble.com/mom/work-family/baby-animals-photos/?page=22).

Harp seals are migrating large distances due to their necessity to stay at the ice-edge throughout the year (Sergeant 1991). That can be a reason why nowadays harp seals cannot survive in the Baltic Sea the whole year (Lõugas 1998:5). Contemporary harp seals only sporadically reach Danish waters and the Baltic Sea (Bennike *et al.* 2008). Harp seal breading season is in the spring and take place mainly on pack ice, drifting pieces of ice that are not attached to land. The young harp seal is a solitary animal in the spring. Their migration seems to be separate from the rest of the herds. The harp seal pups (fig.1) can swim long distances due to their need to stay in the vicinity of the ice belt. During the autumn, harp seals are migrating southwards feeding heavily before whelping period. Male harp seals reach maturity between the ages of 6-8 years, while females between 5-8 years, with a peak at 6 years (Lõugas 1998:6 f.).

Figure 2. Ringed seal (Picture from www.einfopedia.com).

Ringed seal (fig.2) is a circumpolar Arctic species with a very special adaptation to life in the polar region, being able to maintain breathing holes in the ice. In European waters, the largest population exists in the Barents Sea, and only single individuals sometimes occur in southern regions down to France or Portugal. The ringed seals live in the eastern Baltic Sea, and isolated freshwater populations are known from the north-eastern European lakes Ladoga and Saimaa. In the Baltic Sea, it persists north of the line between the cities of Stockholm and Riga(Schmölke 2008:233). In contrast to harp seal, this species is not pelagic but spends the whole time near to the coast and in shallow bays, and they can even swim up rivers. Ringed seal breeding season is in March-April and take place on fast ice, ice attached to the land, mostly near the coastline, where they make snow caves in which the pups are born. This species is solitary and fairly stationary (Ukkonen 2002:190; Schmölke 2008:233).

Appearance of harp seal and ringed seal in the Baltic Sea

The first possibility for the marine species to enter the present - day Baltic Sea was during the Yoldia Sea phase in the history of the Baltic Sea. First finds of harp seals and ringed seal came from Dalsland in western Sweden (Fredén 1975), showing the presence of these two species at the entrance of the Yoldia Sea around 10600 cal. BC. Through the small opening, that connected the Atlantic Ocean and the Yoldia Sea (corresponding to nowadays middle Sweden) during the 9th millennia BC, ringed seal immigrated into the Yoldia Sea and resided in the eastern and northern part of the sea. During the next 3000 years, ringed seal was the only seal species in the Baltic basin (Ukkonen 2002:188; Schmölke 2008:235).

During the early Holocene water salinity decreased and that affected the composition and distribution of ringed seal fish prey. Ringed seal was able to survive because changes occurred at a slow rate, allowing the species to adapt to them and because fast ice areas, that were suitable for breeding, persisted in northern parts of basin (Schmölke 2008:236). Harp seal evidently did not immigrated into the Yoldia Sea, due to the small, island rich and shallow connection between the Baltic basin and the Ocean that was not unsuitable environment for this pelagic, deep-sea species (Lepiksaar 1964, cited in Schmölke 2008:236).

During the Ancylus lake phase, the winter temperature was 1 degree lower than today, probably creating a large pack ice fields. However, the finds of the ringed seals comes from the northern parts of the Baltic Sea, modern day Finland. Due to the geological processes new separate lakes developed in the north-east part of the Baltic and two new ringed seal populations *(P.hispida saimensis and P.h. ladogensis*) become separated from the ancestral Ancylus Lake population. Trapped in the emerging Lakes Saimaa and Ladoga, they differ today from their maternal population not only genetically but also in colouration, morphology and even behaviour (Schmölke 2008:236).

Between 6900 and 6300 cal. BC, global sea level rise during the Holocene climatic optimum broke the Cimbrian-Scanian land bridge and the Baltic basin become flooded by marine water. That is known as the Littorina Transgression and during this time the main seal migratory period began. Ringed seal immigrated into the Baltic basin for a second time, along the other seal species, such as grey seal (*Halichoerus grypus*), harbour seal (*Phoca vitulina*) and harp seal. Even though it seems unlikely that during this time the Arctic species should have migrated southwards and into the Baltic Sea, because during this time climate reached its Holocene temperature maximum with summer temperatures in north-western Europe approximately 1.9 °C warmer than today. However, a short but hard cooling event influenced the northern Hemisphere during the Littorina Transgression around 6200 cal. BC and lasted for approximately 300 years. It was caused by a giant cold water pulse into the Atlantic Ocean that shut-down the North Atlantic thermohaline. Thus water and atmosphere got cooler affecting the marine Arctic fauna. The Baltic Sea offered suitable conditions for the Arctic species and pack ice areas for breeding would have accumulated during the cold winters, as a consequence of the North Atlantic cooling event (Schmölke 2008:236 f.)

Concerning the harp seal occurrence in the Baltic Sea, three hypotheses have been stated. One of them supports the "relict" theory, that harp seal population in the Baltic was isolated from the Arctic species. Another hypothesis considers that the Baltic breeding stock may have established during the Littorina Transgression by migrants from the Arctic. The third supposes that harp seals made yearly (feeding) migrations into the Baltic and did not form a local population (Lepiksaar 1986, cited in Lõugas 1998:1).

The earliest date of the harp seal reported from the Baltic Sea is 4450 - 4260 cal. BC (Ukkonen 2002:192). Bennike *et al*. (2008:268) consider that harp seal population have been established in the Baltic Sea due to the migrations caused by starvation in the late Atlantic around 4000 cal. BC. The radiocarbon data from the Danish material show two concentrations of harp seal. The first one correspond to the late phase of Ertebølle and beginning of Funnel beaker culture (4100 - 3800 cal. BC), but other fall within the Pitted Ware Culture phase (3000 - 2400 cal. BC) (Bennike *et al*. 2008:268). These two periods are explained with favourable hydrographic conditions for the prey of the species, such as oysters. Archaeological evidences of intensive oyster kitchen middens from the Denmark correspond to these two phases with occurrence of harp seal in the Baltic Sea during the mid - Holocene. The salinity of water was enhanced during these two periods. According to Bennike *et al*. (2008:269) these two periods reflects the environmental changes rather than exploitation patterns.

However, the faunal remains from the Stone Age sites indicate a diminution in size of mid-Holocene harp seal in the Baltic Sea. Storå and Ericson (2004:122 ff.) study about the size and age structure of Baltic harp seals confirms the smaller size of Subboreal seals, as well as supports the hypothesis that harp seals were present in the Baltic throughout the year.

Schmölke (2008:239 f.) considers that diminution of harp seal size was influenced by the combination of several factors. Ecosystem productivity is one of them. Small inflow of the salty water into the Baltic Sea and the input of fresh water through many rivers caused a continuous decrease of salinity in the mid-Holocene Baltic Sea, especially between 3000 and 1100 cal. BC. This caused marked shifts in the distribution and quantity of plankton and therefore changes in the distribution and abundance of fish. In some species, low salinity makes animals more vulnerable to different forms of environmental stress. The most important prey of harp seal, the cod (*Gadus morhua)*, decreased in size following its immigration into the Baltic Sea during the Littorina Transgression.

Density dependent factors represents another aspect. The presence of three or four seal species in a more or less closed system, like the Baltic Sea, increased interspecific competition, since important resources, such as breeding places or food, were very limited. It is likely that increasing population density, reflected in the increasing number of subfossil records after 3800 cal. BC, may also have caused decreasing body size in harp seals. The third factor is Bergmann´s rule, that in many mammal species, body size varies with latitude as individuals tend to be larger in cooler environments. In the Baltic basin, this selection may also have worked for smaller animals because of thermodynamic reasons. Individuals with thick blubber were at a disadvantage here, since blubber accumulations is energetically demanding and quite unnecessary in warmer climates. The last factor is reduced predation, due to the absence of the polar bear (*Ursus marinus*) - the only carnivore, except man, which threatens harp seals (Schmölke 2008:240).

The harp seal population decreases in the end of Neolithic, but archaeozoological data shows that seal breeding populations existed in the Baltic Sea during the Bronze Age and Iron Age (Lõugas 1999:189 ff.; Storå & Ericson 2004:116). The disappearance of harp seal from the Baltic has been explained by environmental changes (Holmqvist 1912; Ekman 1922; Pira 1926; Lepiksaar 1986; Lõugas 1998), such as salinity and production decline which could cause starvation or extinction, winter ice condition changes in the Baltic Sea, as well as low genetic diversity (Storå & Ericson 2004), competition with other seal species (Sergeant 1991) and over-hunting (Storå 2001).

Seal hunting methods

Zooarchaeological evidences from Stone Age settlements around the Baltic Sea leave no doubt that seals were considered as an important resource providing meat, fur and blubber. Seal hunting strategies have been affected by behavioural characteristics of different seals, environmental conditions and appropriate hunting methods. Although the use of ethnographic analogies in the studies of prehistoric seal hunting strategies have been questioned, Storå (2001:9) considers them valuable as a frame of reference for these interpretations.

Harpoons and nets have been the main seal hunting methods during the Stone Age. Even though the most of researchers agree about the hunting methods, various opinions occur concerning the seal hunting seasons. Lõugas (1998:5 f.) considers that sealing probably took place during autumn and early winter, when the sea was not covered by ice and nets have been mainly used in narrow inlets where seals often stayed during this period. Whereas Ericson (1989:59 ff.) believes that seals were hunted during the winter season, on the ice covered sea. According to Storås´ (2001:46) study, the main harp seal hunting period have been during the summer.

Storå (2001:27 ff.) has observed that seal hunting strategies differ between regions and seal species. Ice conditions and the migrating behaviour of harp seal affected the hunting strategies of this species. Thus harp seals were hunted earlier around Gotland, due to the fact that Gotland probably represented breeding grounds. That also explains the scanty amount of young individual finds on Åland islands and Estonian coast. The hunting of harp seals in Swedish west coast took place later than in the Baltic Sea, indicating the seal migration from the Baltic sea and not vice versa. Although the harp seals are migrating in herds, mass hunting strategy seems unlikely. Harp seal population was affected the most because of the long hunting season when large part of yearlings were captured during their migrations.

The hunting of ringed seals seems to be more uniform and don’t differ between the regions. The main hunting period covered late winter and early spring, probably at the breathing holes and birth lairs. Ringed seals were hunted individually, few were hunted off season in open waters (Storå 2001:46).

Background on digital technology use in zooarchaeology

The bone identification is the first step in the zooarchaeological research. The correct identification of bones form the solid ground for the interpretations and further studies of material. O´Connor (2000:36 ff.) has discussed these issues and mentions the lack of comparative collections as a hindering condition working with bones. Good reference material is essential, but comprehensive reference collections are few. Atlases or compendiums with descriptions and illustrations have been a great help in bone identification process. The combination of the use of comparative collections and illustrated atlases have been the main tools for the bone identification during many years. Driver (1992:40) has pointed out the importance of visual materials in the zooarchaeological identifications. Recently researchers worldwide have work to develop the spread of the zooarchaeological illustrative materials. Thus have appeared the web-pages, such as Bone Commons[1] or ZooBook[2] with photos of bone elements to facilitate the bone analysis and identifications, as well as serving as a network where researchers can communicate and share their work.

The creation of a reference collection is time and resources demanding process. Often collections lack the broad range of species or multiple individuals per taxon, since it is not possible to access some species because of their rarity or some have already extinct. During the last decade technologies have developed rapidly contributing to archaeological and zooarchaeological research. More actual have become discussions abut digital, virtual and cyber-archaeology. Forte (2010:9 ff.) discusses the affordance created by cyber-archaeology through which it is possible to generate virtual worlds by interactions and inter-connections. The past cannot be reconstructed but simulated. The cybernetic simulation develops affordances and there relations constitute the potentiality of the interpretation process. This difference between virtual and cyber archaeology is very important, since now we are able to transmit and distribute much more digital-cyber knowledge than in the past (Forte 2010:13).

Thereby during the last years have occurred the attempts to create virtual reference collections. For example, such attempts have been made at the Department of Human Evolution, Max Planck Institute for Evolutionary Anthropology, Germany[3] (Niven *et al.*

1. http://www.alexandriaarchive.org/bonecommons/
2. http://zooarchaeology.ning.com/main/authorization/signIn?target=http%3A%2F%2Fzooarchaeology.ning.com%2F
3. http://www.eva.mpg.de/evolution/files/faunal_comparative_collection.htm

2009), in College of the Holy Cross (the Harvard Museum of Comparative Zoology, the Peabody Museum of Natural History at Yale University) where a three dimensional database of avian skeletal morphology has been created[4]. At the University of Austin, Texas, have been made a virtual collection, primarily of skulls of vertebrate taxa[5]. The 3D models of fossil specimens had been created at the Marshall university[6] (Strait & Smith 2006; Smith & Strait 2008), but at the University of California, Davis, has been developed a virtual museum of 3D natural objects and animal skeletons[7]. Especially actual the problem with comparative collections is in the Arctic zooarchaeology and thus *The Virtual Zooarchaeology of the Arctic Project* (VZAP) have worked to develop a comprehensive virtual comparative assemblage for the skeletons of northern vertebrates[8] (Betts *et al*. 2011).

Theoretical perspective

Interactions between animal and human worlds can be traced through a very long time period. However, not always these relations and interactions reflect a peaceful coexistence. Especially during the Stone Age, animal and human relations have been closely related, in material as well as in spiritual aspects. Harp seal was a common species in the Baltic Sea during the Neolithic. The reason for the appearance, as well as the disappearance of this species in the Baltic Sea at the end of the Neolithic has been widely discussed among scholars and is still not resolved (Storå 2001; Ukkonen 2002; Storå & Ericson 2004; Bennike *et al*. 2008; Schmölke 2008).

Recently, Lyman (2006) has raised the question about the use of paleozoological data as a source material discussing the modern conservative biology issues. Paleozoological data includes information about past conditions created by anthropogenic and natural processes. This information reveals human and animal relations, their coexistence through the time and can contribute with knowledge about the presence or disappearance of some species from a certain territory and help to identify the causes of ecological conditions in the past (Lyman

4. http://aves3d.org/
5. http://digimorph.org/
6. http://paleoview3d.marshall.edu/
7. http://3dmuseum.org/
8. http://vzap.iri.isu.edu

2006). The conservative biology perspective helps to put the research questions of this thesis into wider context. By studying the animal remains from the archaeological context, we gain the knowledge about the species and overall ecology in the Baltic Sea in the past. The varied knowledge of fauna, environmental conditions and human activities in the past can help to better understand the ecological situation in the present-day Baltic Sea.

Aim and research questions

Even though the discussions concerning the harp seal population in the Baltic Sea during the Holocene are very interesting and relevant, this work will not go into the detail of these issues. Instead, these discussions and the theoretical framework of the conservative biology helps to put this particular study within the wider perspective and reveal its contribution to the species' history that have been closely interconnected with people within the Baltic Sea basin during the Stone Age.

The aim of this paper is to try to improve the ability to determine the two species of seals - harp seal and ringed seal based on three dimensional visualisations. An important aspect of this thesis is to create an atlas/database with 3D models of harp seal and ringed seal. This database could be used in further studies and could be supplemented, including complete skeleton and larger variation of individuals and species.

An important aim for me is to get acquainted with digital technology use within osteology. This thesis is a pioneering work in an attempt to see if and how three dimensional visualisations can contribute to the species determination, and if this method could be useful for further studies.

Thus, through this work I will try to get answers to the following questions:

- Is it possible to clarify the morphological differences indicated in Lepiksaar´s (1991) and Storå´s (2001) line drawings with a help of 3 dimensional visualisation?
- Is it possible to see additional characteristics in 3D models that can help in species determination?

Material and method

Material

The osteological material for analysis comes from the Zoological Museum of the University of Copenhagen. The amount of study material depended on the availability of seal skeletons at the Zoological Museum, as well as the limited time. The choice of skeletal elements for scanning did not include entire skeleton, just certain bones that have most characteristic features for species determination according to Lepiksaar´s (1991) and Storå´s (2001) studies. Thus the bone from lower jaw (*mandibula)*, the shoulder blade (*scapulae*), the upper arm (*humerus*), bones of the lower arm (*radius/ulna*), metacarpal I (*metacarpus*), hip bone (*coxae*), the thigh bone (*femora*), os cruris of the lower leg (*tibia/fibula = os cruris*), metatarsal I (*metatarsus*) from the left side of an adult, male harp seal and ringed seal were scanned. To avoid the sexual dimorphism, the choice of material have been limited to a male specimens. The 3D models of just two individuals cannot give information about variations, but that is considered more detailed in the discussion.

The choice of material turned out to be not that easy. It was difficult to obtain a skeleton where all bone elements would be present. Problems raised incomplete skeletons, specimens where the epiphyses were not yet fused, or bones were originating from a female specimen. Thus for the research an adult (around 8-10 years old), male specimen marked *Phoca groenlandica* (CN 961) that came from Saqaq, Umanak, West Greenland was used. More difficult was to find an appropriate specimen from ringed seal. Most of the bone elements used in 3D scanning came from *Phoca hispida* (K.73), which was collected at Zackenberg in North East Greenland. However, this specimen lack the metacarpal I and metatarsal I, that were replaced by bone elements from the adult, female individual (CN 783) which came from Sarqaq, Nugsuak, Greenland.

Method

My thesis is based on extensive practical work, which includes seal bone scanning with 3D scanner and processing of scans with NextEngine ScanStudio HD[9] and MeshLab V.1.3.0a[10].

9. http://www.nextengine.com/
10. http://meshlab.sourceforge.net/

The practical work included sequence of several steps. First step of this work, after the selection of material, was to scan every skeletal element from both seal species with NextEngine ScanStudio HD scanner (fig.3).

Figure 3. Scanning of bones with NextEngine ScanStudio HD at the Zoological Museum of the University of Copenhagen (Photo: Carolina Larsson).

To scan one bone took approximately one hour. Every bone was first scanned in 360 degrees (10 scans) that took around 32 minutes, and for two bracket scans of distal and proximal sides of the bone (3 scans of each side) took around 20 minutes. Altogether, 20 bones elements were scanned. Afterwards these scans were processed with NextEngine ScanStudio software aligning the scans and creating the models. The aligning process was time consuming, since often it needed to be done manually, putting together every single scan.

The next step was to fuse the alignments and create the 3D models. The NextEngine ScanStudio HD and MeshLab programs were both used in order to create the 3D models. After the 3D models were processed in MeshLab using Radiance Scaling tool, that turned out to be very useful, working with bones. This rendering technique allows the depiction of shapes shading via the modification of light intensities around specific features. The major idea of this technique is to correlate the shading with surface feature variations in order to enhance shape details like concavities and convexities. Recently, the Radiance Scaling technique has received major interest in the French Archaeology research community, in particular for enhancing details in carved stones and thus improving their legibility (Reuter, in press).

After the modification with Radiance Scaling tool snapshots were taken from an angle that depicts the certain characteristics for the species determination. These pictures were processed in the Adobe Photoshop CS[11], creating the visual material for the analysis of morphological differences between harp seal and ringed seal, in attempt to answer the research questions.

11. http://www.adobe.com/products/photoshopfamily.html? promoid=JOLIW

Results

The morphological characteristics between harp seal and ringed seal represented here has been based on Lepiksaar´s (1991) and Storå´s (2001) studies. The description of the morphological criteria is mainly based on Storå´s (2001) and Lepiksaar´s (1991) terminology with small modifications by author in cases when additional characteristics has been described. The capital letters in the parenthesis reflects the morphological characteristics that were marked in Storå´s (2001) line drawings.

A. Mandibula

A1. In ringed seal *Procesuss coronoideus* has straight outline, while in harp seal it is bent caudally (A) (fig. 4).

A2. *Processus supraangularis* is more prominent in harp seal than ringed seal (B) (fig. 4). In ringed seal it is not visible in lateral view, but it is more pronounced in the medial view.

A3. *Procesus angularis* is more marked in ringed seal than in harp seal (C) (fig.4), while in this case it was marked for both species.

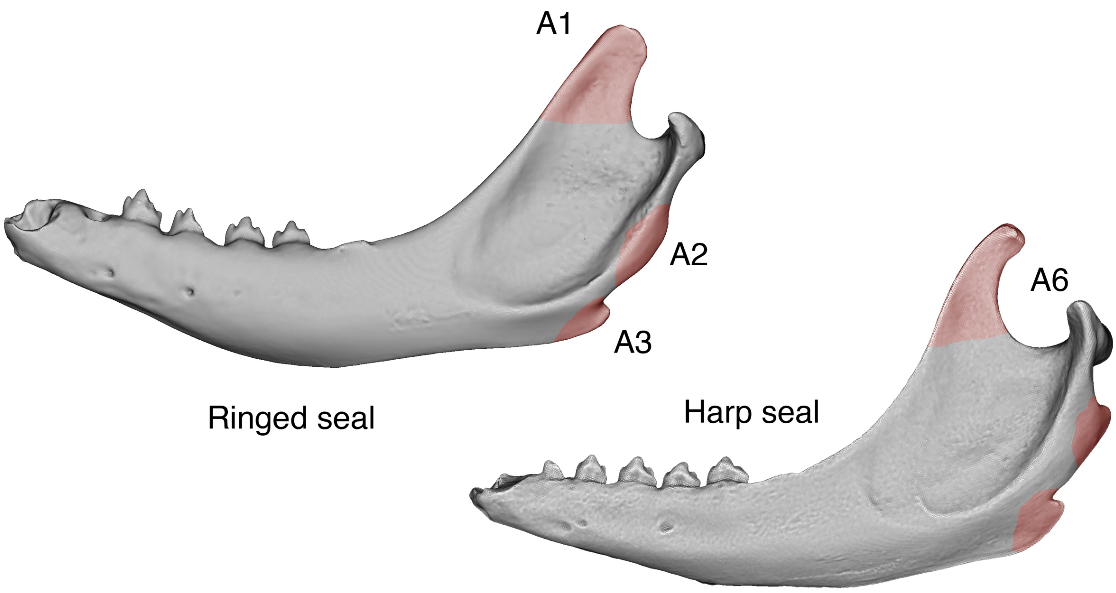


Figure 4. Lateral view of mandibula.

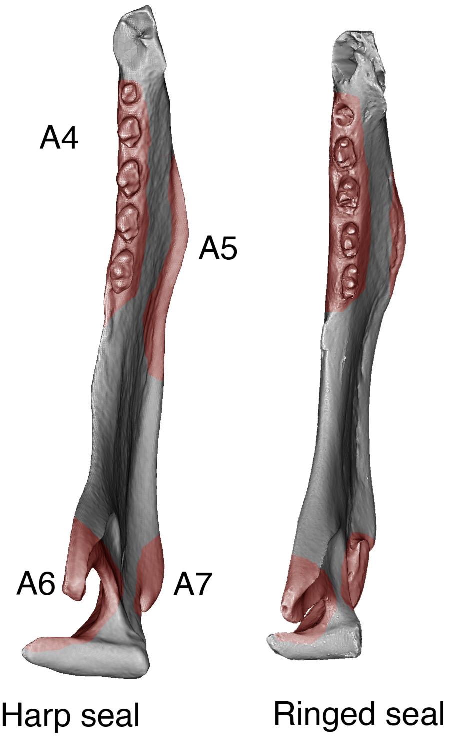


Figure 5. Mandibula from dorsal view.

A4. *Margo alveolaris* is more flattened in adult ringed seals than in harp seals (fig. 5).

A5. There is a sharp edge, strongly concave visible in the medial view for harp seal while this edge is not so pronounced for ringed seal (fig. 5).

A6. *Incisura mandibulae* between *Processus coronoidus* and *Processus articularis* is more rounded and has a wider angle for harp seal than ringed seal (fig. 4; 5).

Teeth are mentioned also as a criteria for identification of seals. Incisors and canins are larger in harp seal, although I did not have material to study this issue. The premolars and molars from harp seal has a larger central cusp, than others, while in ringed seal the cusps are more evenly sized (Storå 2001:68).

B. Scapula

B.1. Harp seal often has a marked ridge *Impressio muscularis* caudally of *Spina scapulae* (B). In ringed seal this ridge is discernible, but it is not as clearly marked (fig. 6).

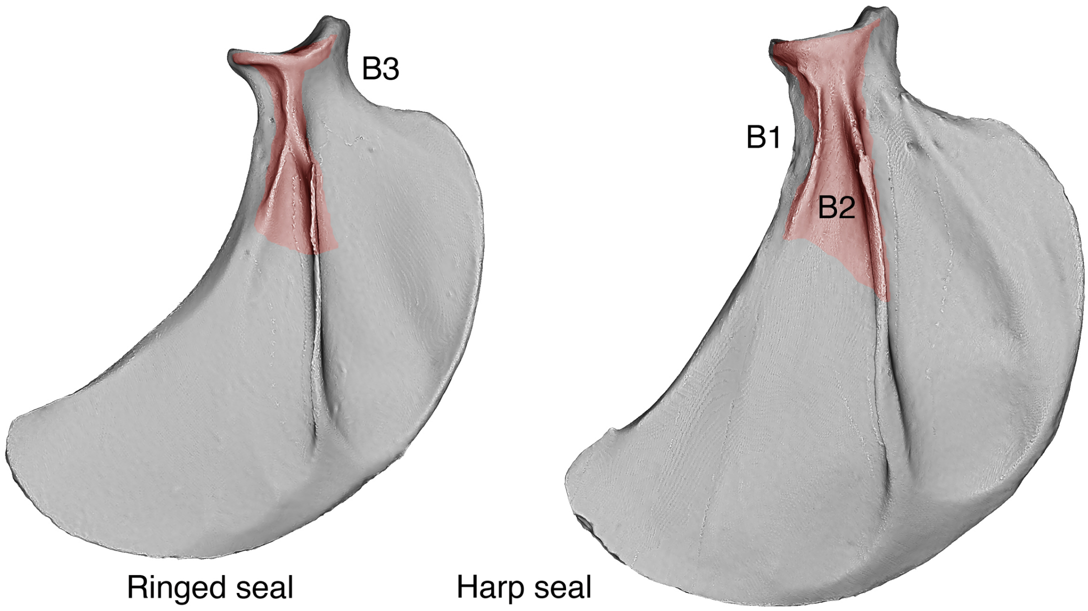


Figure 6. Scapula, lateral view.

B2. The distance between *Impressio muscularis* and *Spina scapulae* is often greater in harp seal than ringed seal (fig. 6). In this example, *Impressio muscularis* and *Spina scapulae* joins together for ringed seal.

B3. The *Collum scapulae* is more narrow in ringed seal than in harp seal (fig. 6).

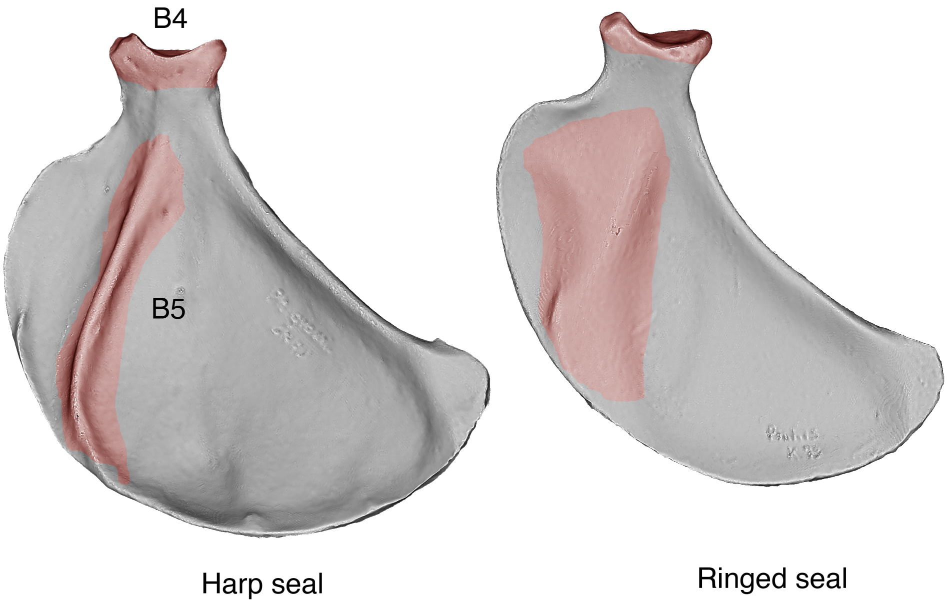


Figure 7. Scapula, medial view.

B4. The *Tuberculum glenoidalis* in harp seal has a blunt appearance while in ringed seal it protrudes further distally (fig. 7).
B5. In this example, muscle attachment *Lineae musculares* is more pronounced in harp seal than ringed seal (fig. 7).

C. Humerus

C1. The *Tuberculum lateralis* in harp seal is not divided as for other species (fig.8). Due to that the margin of the *Crista deltoidea-Tuberculum lateralis* is more rounded for harp seal than other species (see fig.10:C1).
C2. On the cranial side of the distal diaphysis (D), the medial margin forms as sharper ridge (above *Condylus medialis*) in harp seal in comparison to other species where the margin is more smoothly rounded (fig. 8).

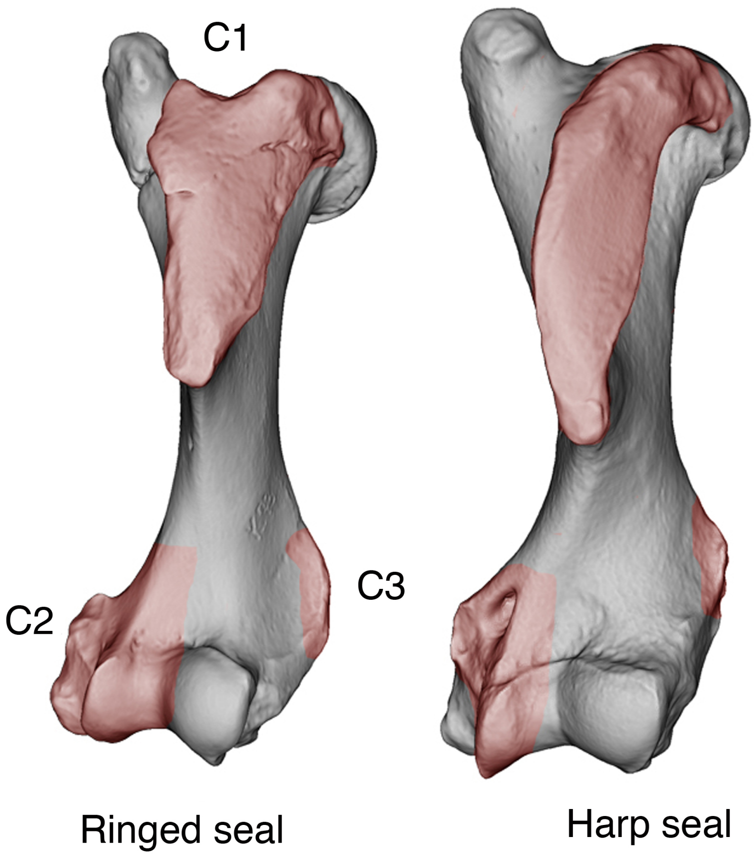


Figure 8. Humerus, cranial view.

C3. In harp seal, the *Crista epicondylus lateralis* does not project as far laterally as in the other species (F) (fig. 8).

C4. The *Tuberculum medialis* (B) in the harp seal does not project over the caput as far as in the ringed seal (fig. 9), but in this example characteristic was not that obvious.

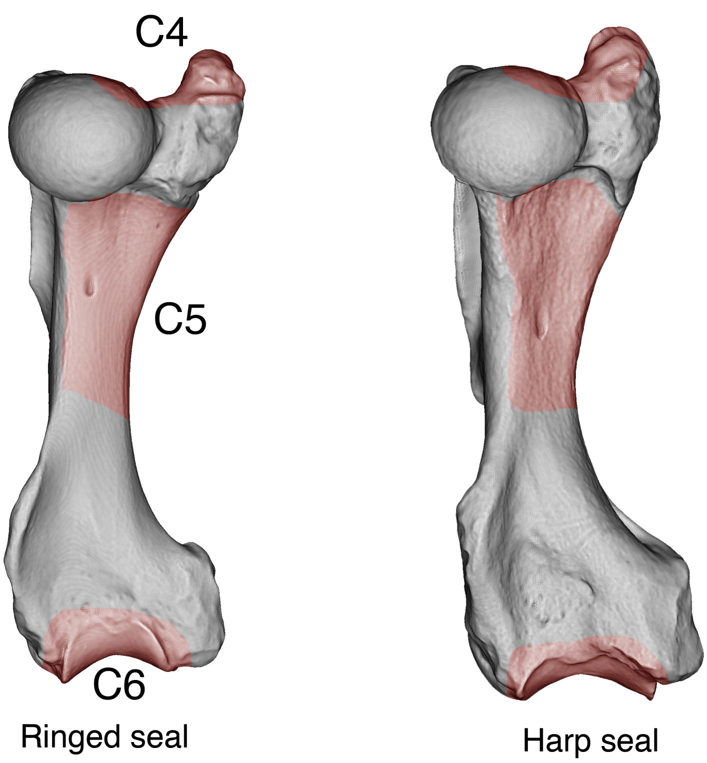


Figure 9. Humerus, caudal view.

C5. In general the middle part of the diaphsysis in harp seal is more robust and has “wider” appearance (fig. 9) than in the in the other species (H). That together with morphological differences (D, F) can be used in the identification of humerus where the epiphyses have not fused to the diaphysis.

C6. Distally, the *Facies articularis* (C) in harp seal does not continue as far up (proximally) towards the diaphysis as in the other species. In harp seal the medial part of *facies articularis* does not continue above the level of the *Epicondylus medialis* (fig. 9).

C7. The *Tuberculum lateralis* is clearly visible in ringed seal (fig.10).

C8. The *Facies lateralis* is more pronounced in harp seal than ringed seal (fig.11).

C9. Caudal peak of *Crista deltoidea* is more pronounced and concave in harp seal than ringed seal (fig.11).

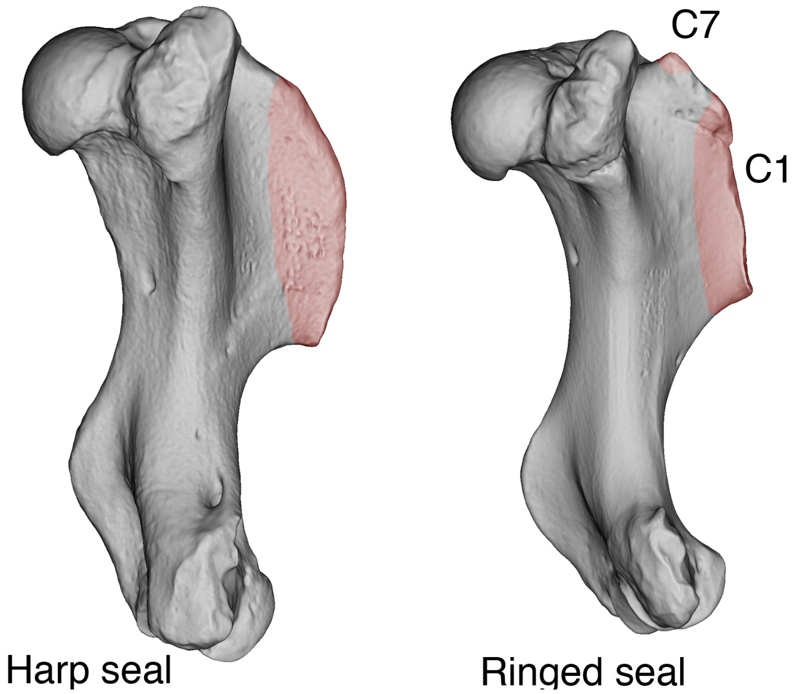


Figure 10. Humerus, medial view.

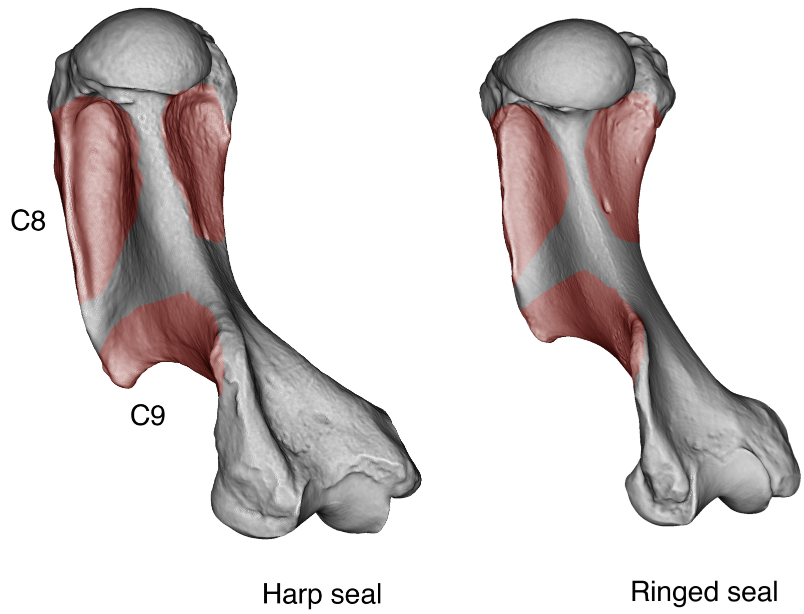


Figure 11. Humerus, caudal - lateral view.

C10. In cross section the caudal side of the midpart of the diaphysis in harp seal has an almost flat or sometimes even slightly concave outline (G), while it is more convex and rounded in other species.

C11. Cross section of diaphysis in the harp seal has a sharper border between the cranial and medial sides of the diaphysis (fig.12) (E).

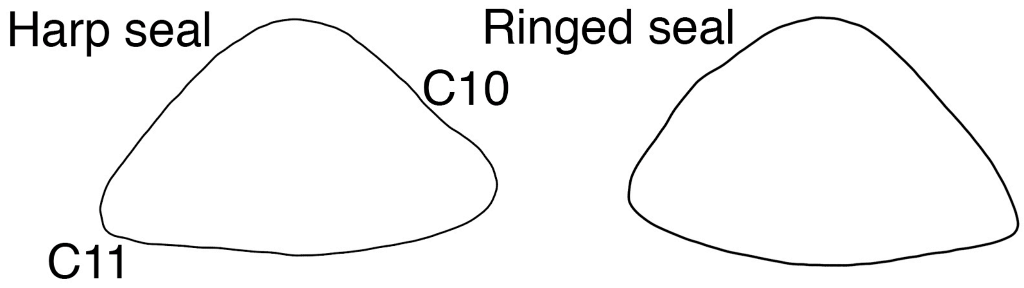


Figure 12. Cross sections of humerus.

The cross section of the distal metaphysis of an unfused diaphysis from harp seal normally appears to be more rectangular than in the other species, although I could not study this criteria. This is mostly due to the contour of the medial margin which in harp seal is oriented more closely in cranial-caudal direction than seen in the other species (Storå 2001:70).

D. Radius

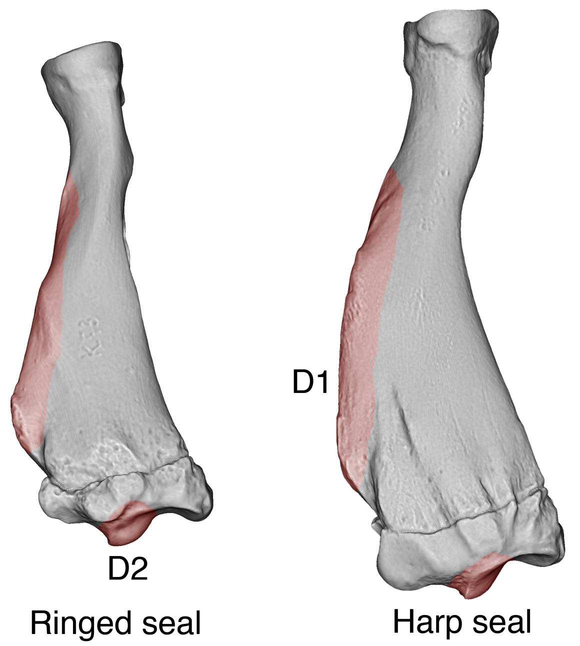


Figure 13. Radius, dorsal view.

D1. In harp seal the diaphysis of the radius has a more marked flexure compared with ringed seal. Harp seal has in distal part greater diagonal depth than ringed seal (fig.13; 14).

D2. *Processus styloideus* is more pronounced in harp seal than in ringed seal (fig.13; 14) (B).

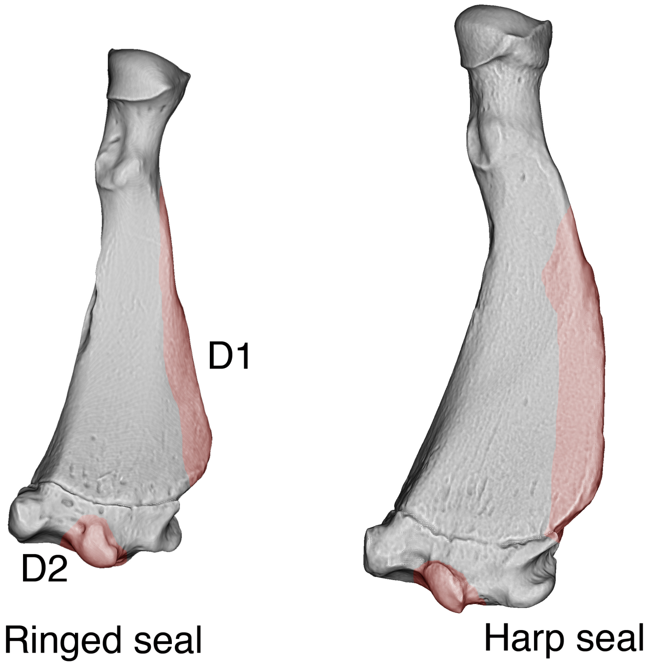


Figure 14. Radius, volar view.

D3. The distal articular surface is rectangular in outline in ringed seal while in harp seal the articular surface is widening towards the volar margin (fig.15) (C).

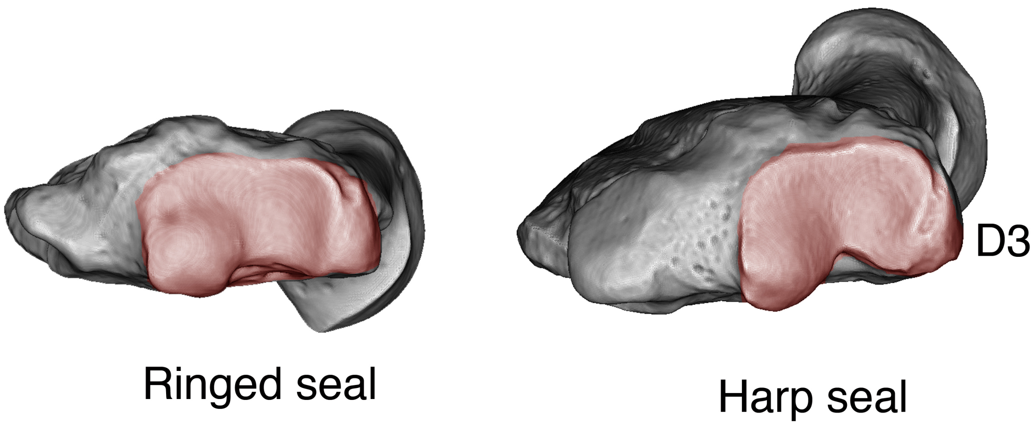


Figure 15. Radius, distal view.

D4. Cross section of ringed seal diaphysis show more round contour than harp seal, which contour is more angular (fig.16) (A).

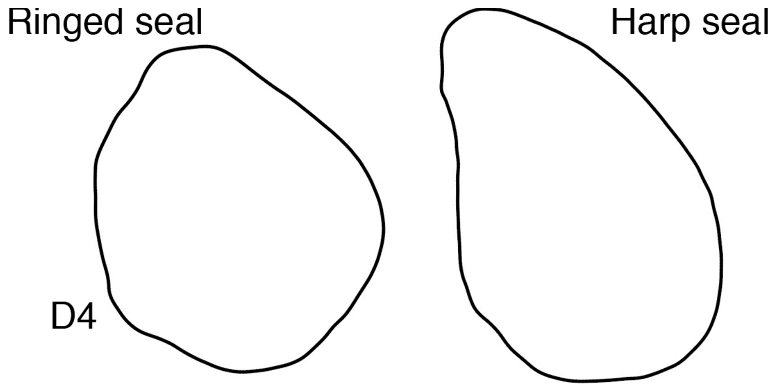


Figure 16. Cross sections of proximal diaphysis of radius.

E. Ulna

E1. In harp seal the shape of *Olecranon* is different from all other species of seals. *Facies anterior* in harp seal is wider and has a bent appearance (A), while in the other species *Facies anterior* is straight (in volar view) (fig.17; 18).

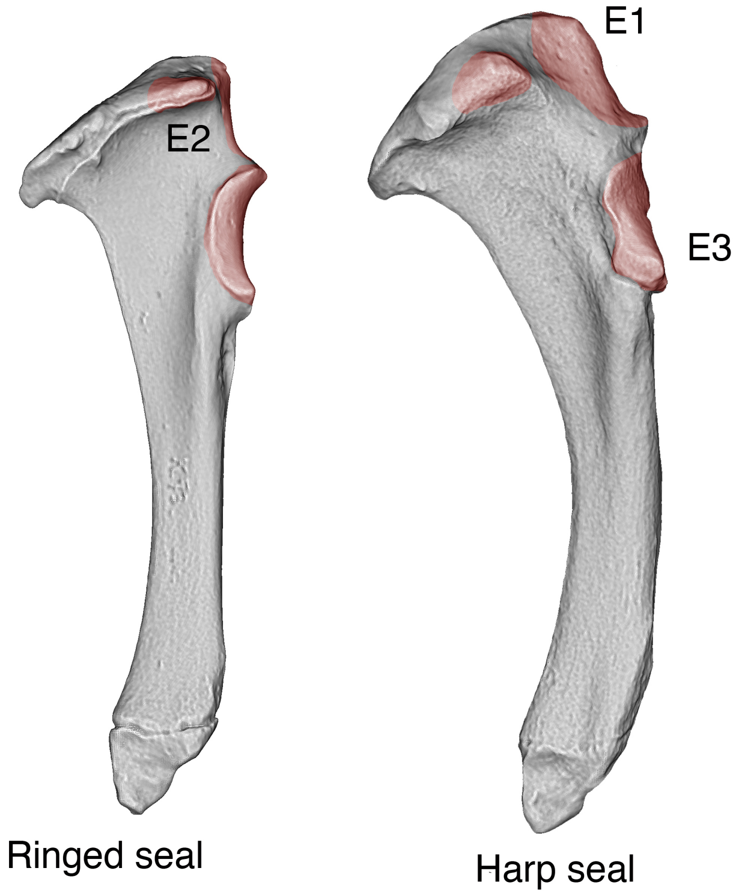


Figure 17. Ulna, volar view.

E2. On the volar side *Tuber olecranon* forms a prominent process in ringed seal (fig.18) (B).
E3. At least in this example, the *Facies articularis* of harp seal is hourglass-shaped, while in ringed seal the *Facies articularis* in volar view reminiscent a crescent (fig.17).
Compared to ringed seal the diaphysis of ulna in harp seal is thicker and more robust and has straighter appearance.

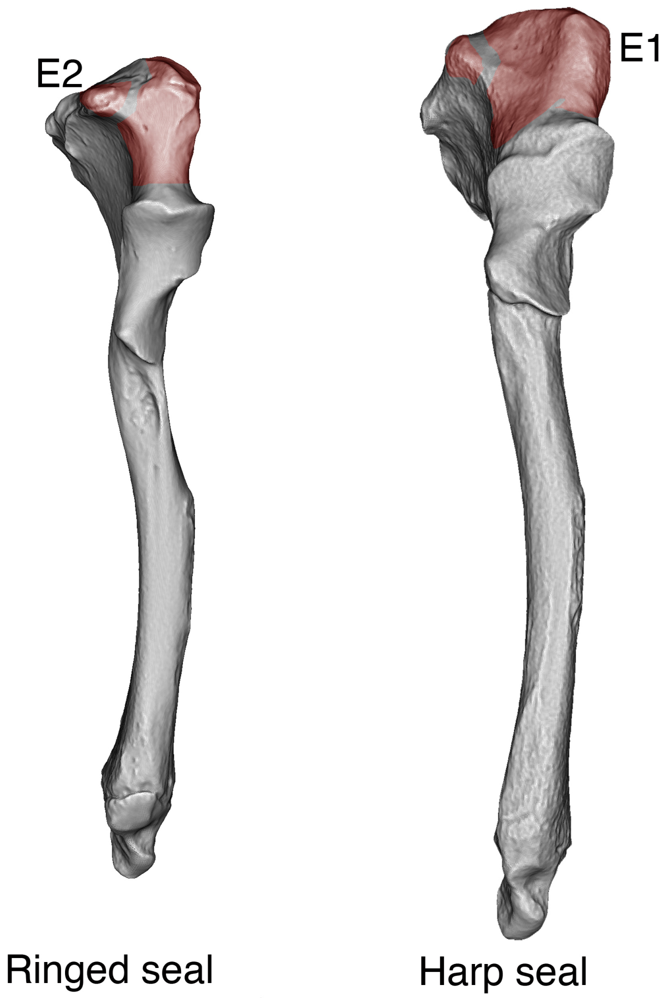


Figure 18. Ulna, medial view.

F. Metacarpus I

Size differences are fairly good criteria in the separation of harp seal and ringed seal, as this element is clearly larger in harp seal.

F1. The medial margin of the distal diaphysis shows a more marked flexure in harp seal than ringed seal (A), however in this example it seems to be vice versa (fig.19).

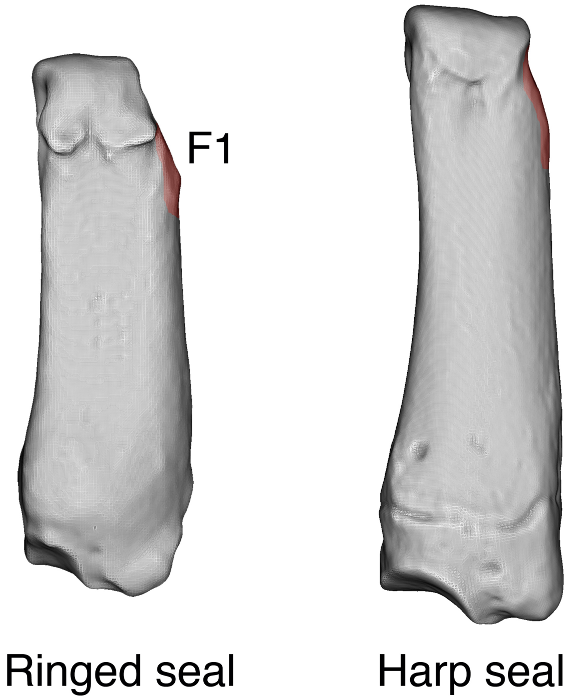


Figure 19. Metacarpus I, dorsal view.

F2. Ringed seal has a more distinct *Verticillus* on the distal epiphysis which is visible both in palmar and distal view (fig.20; 21) (B, C). The distal epiphysis may appear flatter in outline (distal view) in harp seal than in ringed seal.

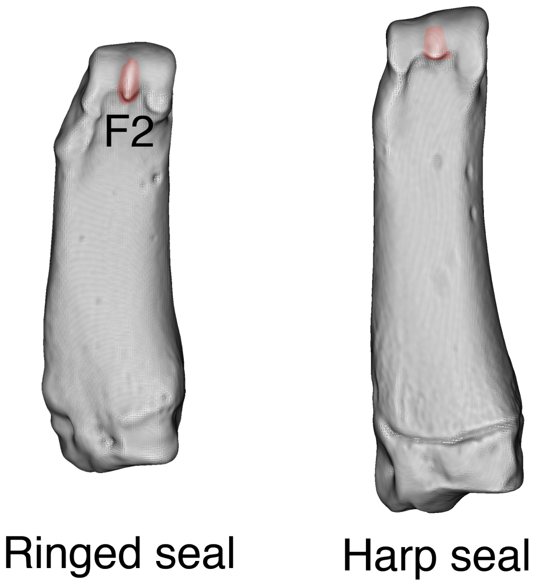


Figure 20. Metacarpus I, volar view.

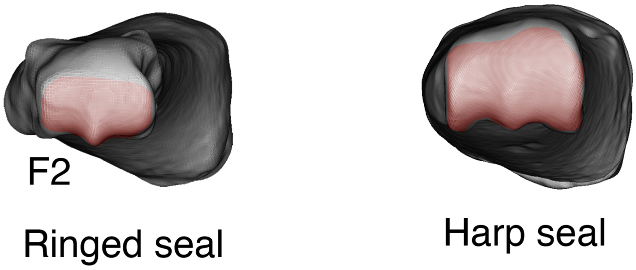


Figure 21. Metacarpus I, distal view.

G. Coxae

G1. Generally, in harp seal, the ridges on the Illium - mainly the dorsal ridge - tend to be slightly more defined than in ringed seal (fig.22) (D).

G2. In harp seal the caudal border of *Foramen obturatum* has a more narrow contour than seen in ringed seal, where the contour is wider (fig.22) (C).

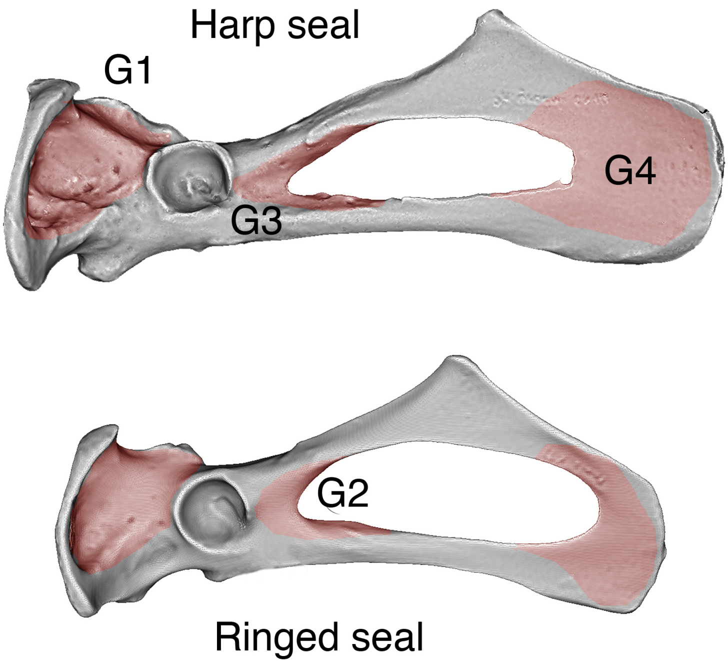


Figure 22. Coxae, lateral view.

G3. Distance between the *Acetabulum* and the caudal border of *Foramen obturatum* is longer in harp seal than in ringed seal (fig.22) (B).

G4. The coxae is more elongate in harp seal than in ringed seal (fig.22).

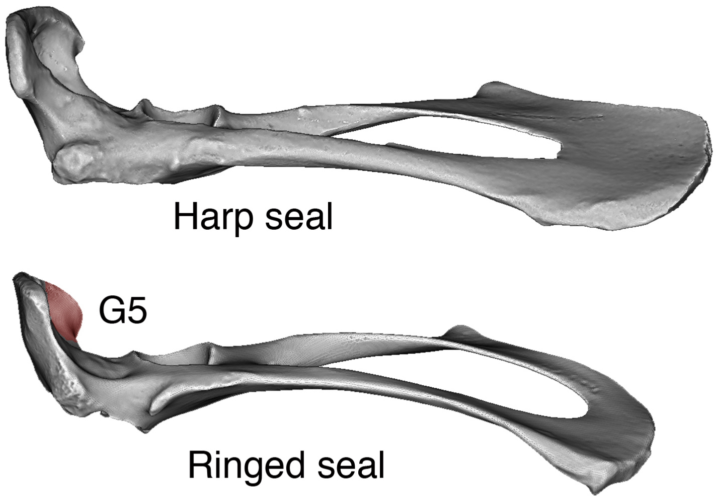


Figure 23. Coxae, ventral view.

G5. *Illium* in ringed seal has a more pronounced lateral texture than the other seal species (fig.23).

H. Femur

The general morphology of the diaphysis is useful for distinguishing femur of harp seal from other species of seals.

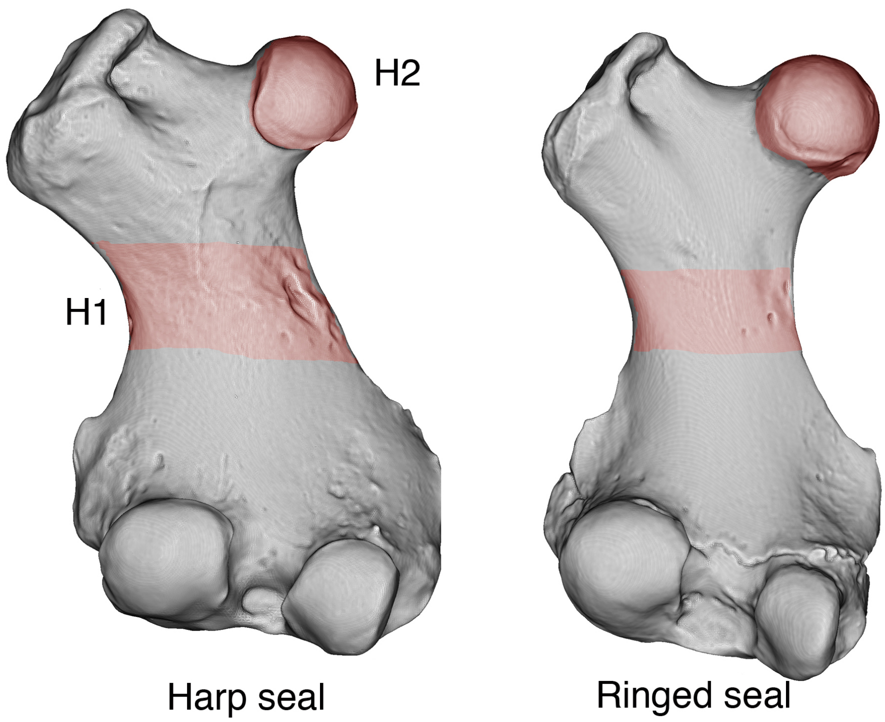


Figure 24. Femur, caudal view.

H1. The midpart of diaphysis is relatively wide for harp seal and smaller for ringed seal (fig.24) (A).

H2. Normally the size of the *Caput* is markedly larger, compared with the overall size of the bone, in other species than in harp seal (fig.24).

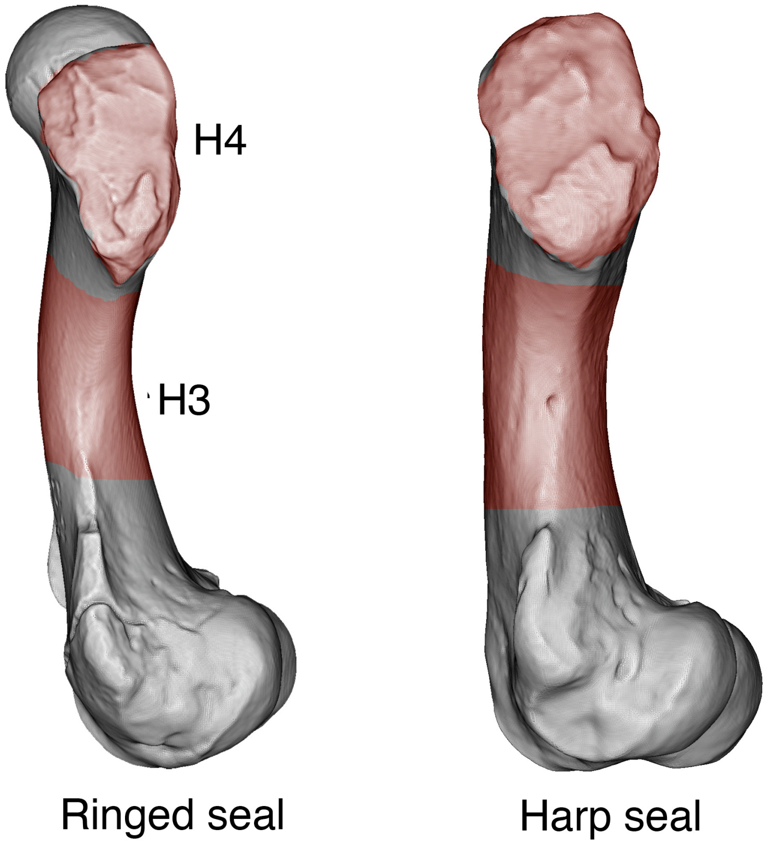


Figure 25. Femur, lateral view.

H3. In lateral (and medial) view, the midpart is almost straight in outline for harp seal. In the ringed seal the midpart is relatively narrower and in a lateral view the diaphysis is bowed (fig.25) (B).

H4. *Trochanter major* in harp seal appears to be more wider and rounded than in ringed seal, where it narrows towards the diaphysis (fig.25).

H5. *Trochlea patellaris* is wider and more concave in ringed seal than in harp seal (fig.26).

H6. *Fossa suprapatellaris* is sharper allocated in harp seal than in ringed seal. However, Lepiksaar (1991) mentions that *Fossa suprapatellaris* is strongly marked in ringed seal as well, while in this example that was not so obvious (fig.26).

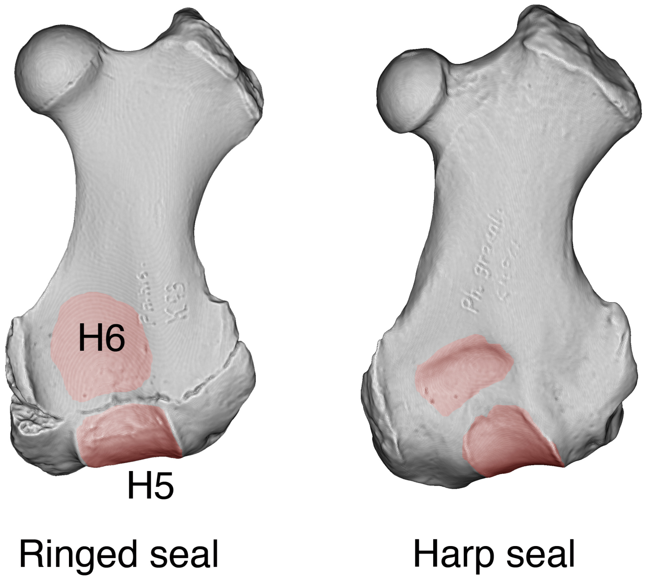


Figure 26. Femur, cranial view.

Storå (2001:72) also mentions that in unfused femora the outline of *Fossa trochanterica* in harp seal is often wider than in the ringed seal (C), but I could not analyse this criteria.

I. Os Cruris

Sometimes size can be used as a criteria in separating bone fragments. Adults of harp seal are in general larger than those of ringed seal.

I1. The margin of the *Crista tibiae* at the proximal end of diaphysis is in general straighter and more pronounced in harp seal than ringed seal (fig.27) (A).

These criteria may (with caution) be used in the identification of diaphyses from juvenile seals. In general, the ridges and the margins on the diaphysis maybe more sharply defined in ringed seal but these criteria should not be used on their own for species identification.

I2. The epiphysis show better criteria for species identification. In a distal view the epiphysis from harp seal has more pronounced *Incisura* on the plantar side (fig.28) (C).

I3. The distal epiphysis of the fibula in harp seal has a more pronounced *Malleolus fibularis* than ringed seal (fig.28) (E). In harp seal *Malleolus fibularis* forms a ridge which continues up to the margin of the epiphysis. Because of this there is in harp seal a more pronounced ridge on the lateral margin of the metaphysis (fig.30) (F).

I4. On the dorsal side the distance is longer between the lateral margin of the diaphysis to the ridge in harp seal than in ringed seal (fig.28) (D).

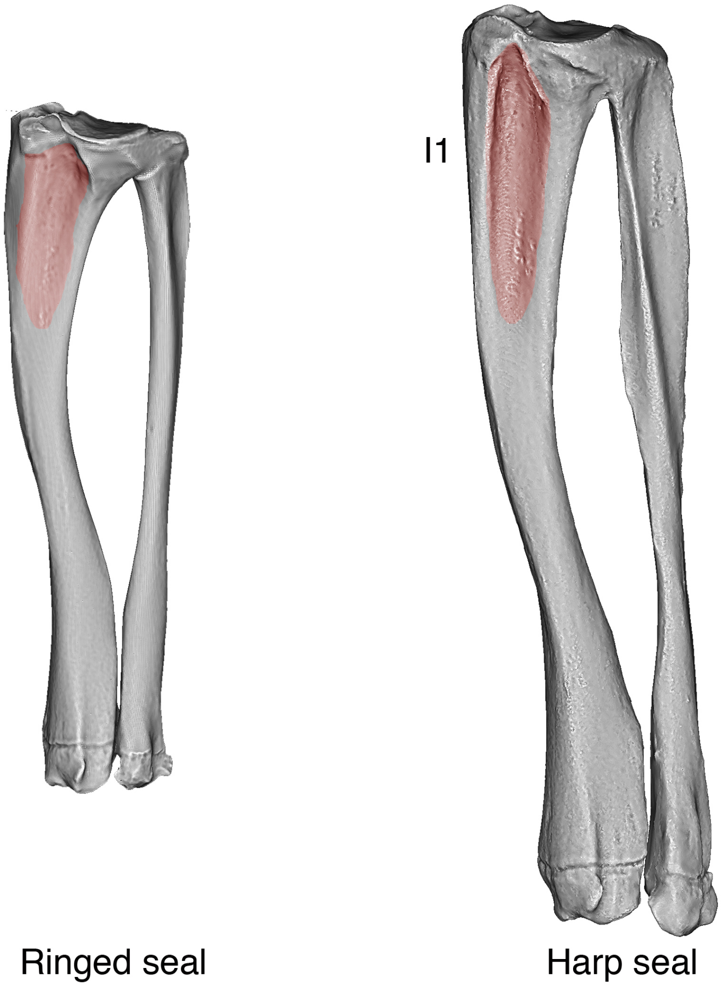


Figure 27. Os Cruris, dorsal view.

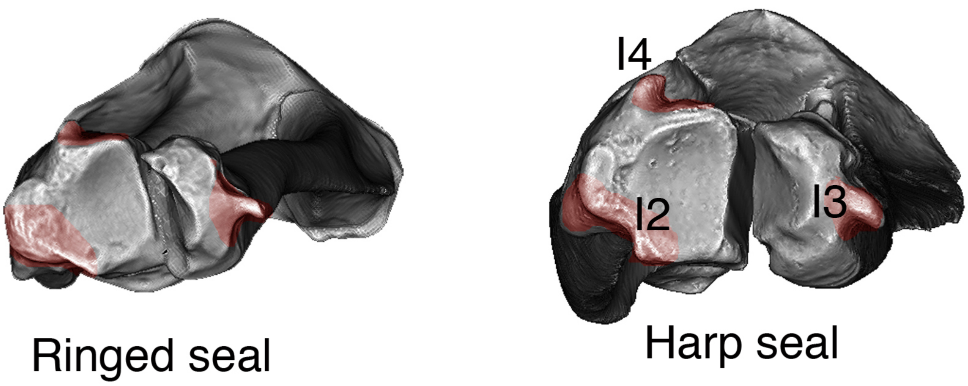
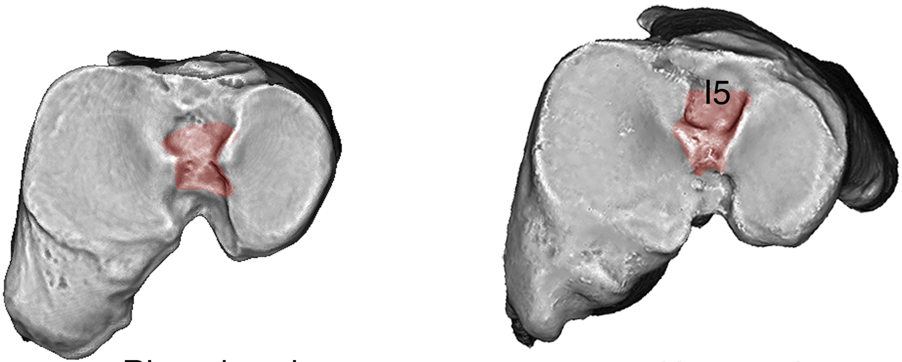


Figure 28. Os Cruris, distal view.

I5. The proximal epiphysis in harp seal has, in general, a larger *Fossula intercondylica* than other species. The outline of *Fossa intercondylica* may, however, show considerable variation (fig.29) (B).

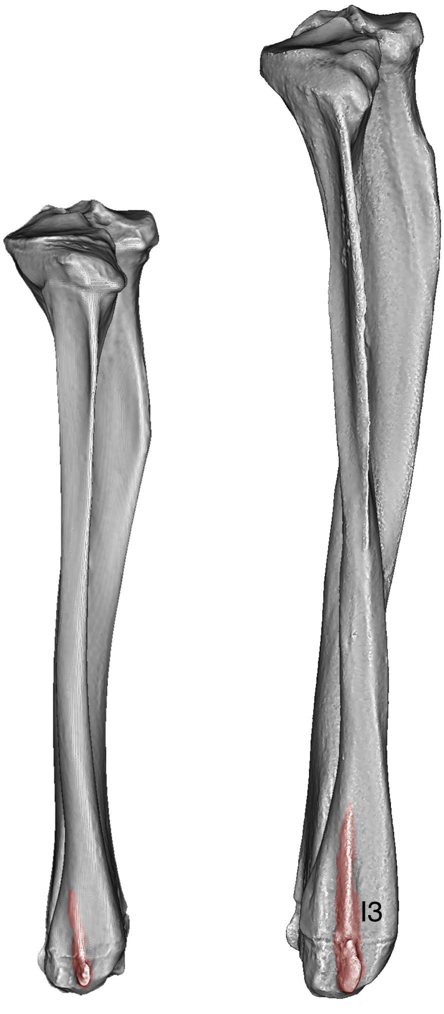


Ringed seal

Harp seal

Figure 29. Cruris, proximal view.

These characteristics (B, C) can be used for species identification also of epiphysis from juvenile seals, even they are more prominent in adult seals. In general the outline of the metaphysis (and epiphysis) appears rectangular in ringed seal, but more rounded in harp seal.



Ringed seal

Harp seal

Figure 30. Os Cruris, lateral view.

J. Metatarsus I

Size differences can help in species identification, since the metatarsus of harp seal is larger than ringed seal.

J1. The diaphysis of harp seal in most cases is straighter than in ringed seal. This is best observed on the plantar margin in lateral view (fig.31) (A).

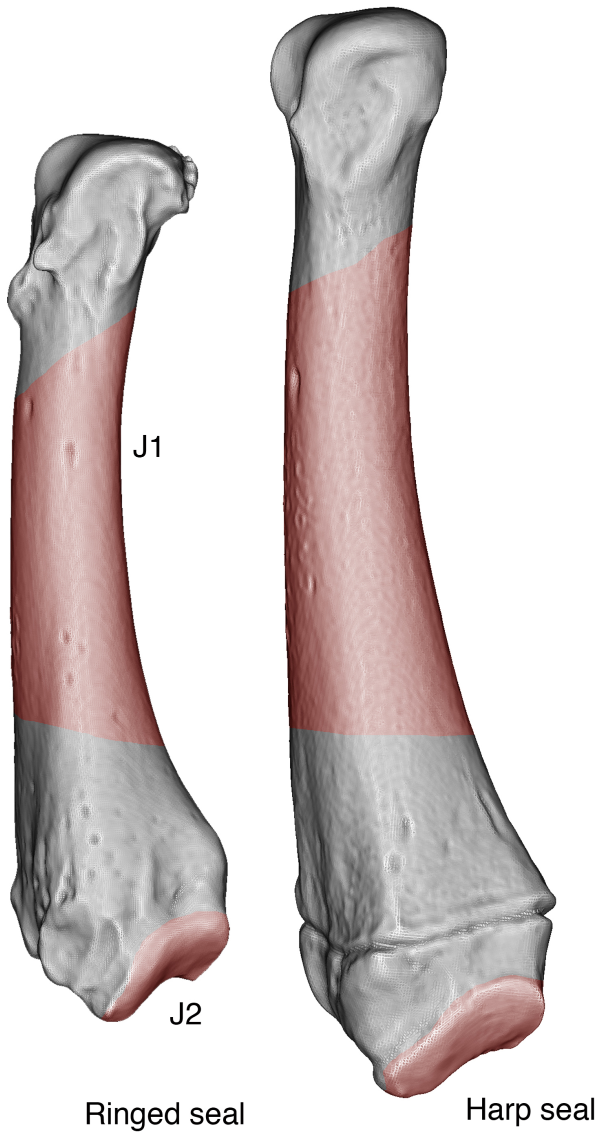


Figure 31. Metatarsus I, lateral view.

J2. Proximally the lateral articular surface continues further distally towards the diaphysis in ringed seal than in harp seal (fig.31) (B).

J3. The proximal articular surface may be more concave in ringed seal than in harp seal (fig.32) (C). Due to this the breadth of the articular surface appears shorter in ringed seal than in harp seal. In plantar view the margin of the articular surface appears wider in harp seal than in ringed seal.

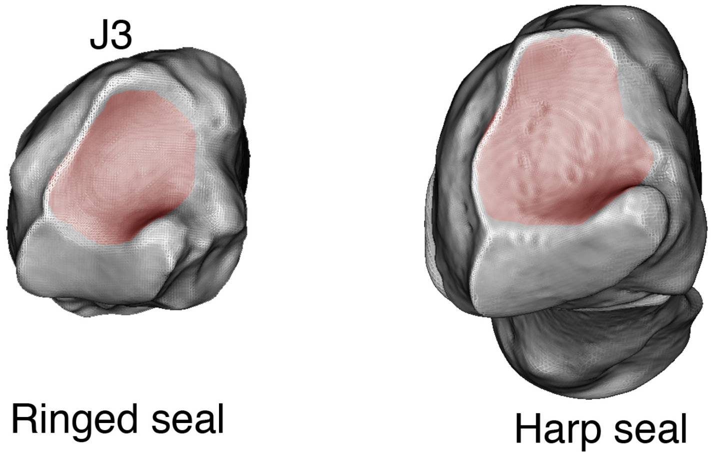


Figure 32. Metatarsus I, proximal view.

Discussion

This discussion will concentrate on the stated research questions, the use of 3D technologies in zooarchaeological context and the advantages and disadvantages of this method. Another part of discussion will be devoted to the reflections of performed 3D modelling, taking up the aspects that could have been done differently and which difficulties I encountered creating the 3D models, and identifying morphological characteristics of harp seal and ringed seal in the models. The discussion will conclude with perspectives for further studies.

Use of three dimensional visualisations in osteology

The aim of this paper was to try to improve the ability to identify the two species of seals - based on three dimensional visualisations and create a database with 3D models of harp seal and ringed seal. This study approved that three dimensional visualisations have a great potential to clarify the morphological differences between harp seal and ringed seal in line marked drawings by Lepiksaar (1991) and Storå (2001). The 3D models include more bone details than line drawings, where usually just the main morphological features are represented. The three dimensional models offer large variety of modifications, for example, to turn the bone in different angles, change colours, use shaders etc. to emphasize the morphological characteristics. These aspects can facilitate the search for other features that could help to identify the species. That leads to the second research question about the possibility to see additional characteristics in 3D models that could help in species determination. In this case the answer is not affirmative. Even though there are differences between harp seal and ringed seal within the created 3D models, one must be aware of a considerable morphological intraspecific variation that exist between species (Storå & Ericson 2004:118). Thus it is not possible to point out some additional characteristics for species determination without analysing larger variation of individuals from both species.

The development of technologies helps to transmit and distribute much more digital-cyber knowledge than in the past (Forte 2010:13). Betts *et al.* (2011) have pointed out the affordance and accessibility of technologies that create the possibility to develop new methods in zooarchaeological research, for example, to create a virtual faunal comparative collections.

This study was also carried out due to the affordances and possibilities. First of all, the digital archaeology course though at the Institution of Archaeology and Ancient History at Lund University have created the knowledge about the potential of the digital technology use within archaeological field. Secondly, the available technique at the Humanities Lab of the Lund University has supported the possibility to carry out this research. There are no similar zooarchaeological projects carried out in Sweden so far.

Although the digital comparative collections cannot and probably never will replace the real ones, this method can serve as a good complement or alternative in the bone identification process, as well as during education and training, when comprehensive comparative collections are not possible to access (Niven *et al*. 2009:2022). Betts *et al*. (2011:757) believe that the high resolution 2D photographs and 3D models, delivered over a web-platform, provide four critical benefits over traditional paper-based illustrated guides: 1) in resolution and detail, they are superior to traditional paper-based photographs and drawings; 2) they are easily updated and corrected; 3) they are easily accessed via the Internet (and for free); 4) they provide obvious teaching possibilities both for personal study and in digitally equipped classrooms. Properly designed, a virtual collection can both enhance an existing collection, by filling in taxonomic deficiencies and providing additional individuals, and can provide researchers with a comprehensive resource to be used in the field or other locations where no comparative collection exists (Betts *et al*. 2011:757).

The use of digital technologies can help to democratize osteology. Sharing the knowledge is an essential aspect of the scientific world. The high-speed internet makes it much more easier to access and share such knowledge (Betts *et al*. 2011:757). Open access to the 3D models, articles and research project materials makes science more available both for researchers and other interested. The accessibility makes it easier to compare different materials and researchers do not need to travel over the world, for example, to take measurement of bones, but can do that virtually thus simplifying the research process. Digital technologies also provide the possibilities to simulate taphonomy thus helping to understand the world and processes via virtual reality.

The 3D modelling offers a new way to visualize osteological information (Betts *et al*. 2011:758), include great possibilities to work with them in future and process the models in different programs. The 3D models also can be an alternative for working with fragile or rare specimens, that is difficult or impossible to access.

However, the virtual comparative collections cannot replace the feeling of a real bone in your hand. The osteology in a way is tactile science, since the analysis of material mostly is carried out by hands. This is a significant disadvantage, since often the zooarchaeological material is very fragmented and shape or thickness of a real bone could help in the identification process. For example, the shape or cross section of diaphyses sometimes can be an important morphologic characteristic, but through the digital model it is difficult to gain this information. Although *The Virtual Zooarchaeology of the Arctic Project* (VZAP) has worked to improve this deficiency by implementing unique 3D scanning protocols to increase the realism of 3D models, and delivers them on a platform that allows for point to point measurements, cross-sections, morphological labels, and anatomical orientations (Betts *et al.* 2011:761), it still cannot replace a feeling of a real bone.

Reflections

This research has been very educative and interesting. Long hours of work have resulted in an interesting result and have create ideas for the further research. This study has shown the great potential of digital technology use within osteology and has raised the wish to continue to explore the possibilities that offer 3D modelling within zooarchaeology.

One of the aims with this study was to make the 3D models available for everyone. The created models are available at the Lund University server, which is password protected, and can be accessed in the appendix of this work. The pdf fail with the 3D models contains possibilities for modifications of the models, for example, rotating them, changing lights and shadows. However, the question of making the 3D models more available and possible to download, is still under consideration.

After the practical work of bone scanning and 3D modelling, I must mention some aspects that could have been done differently or should be kept in mind for the further studies. The careful choice of material is very important to facilitate this job. For example, to check if the bone from the right individual and the right side have been scanned, since it happens that bone elements can be mixed between boxes etc. Of course, it is possible to make changes, such as reversing the models, but it takes time and thus the careful material selection is crucial.

It would have been very interesting to check the usability of the 3D models on actual archaeological material. The time limit and lack of an appropriate material restricted this opportunity. However, it would be important to prove this methods reliability and determine the advantages and disadvantages of the 3D model use within zooarchaeology.

Another aspect concerns the snapshot capturing of the models. I was trying to take them from all sides, or at least the sides where the morphological characteristics were located. During the work with pictures in Photoshop CS and marking the morphological characteristics, it appears that some pictures could have been taken from another angle to provide the best view of the differences between harp seal and ringed seal.

Problems also appeared when creating the cross sections of the bones. Such an option was not possible to choose in MeshLab v.1.3.0. and thus older version of MeshLab was used. Probably the other program could have been more useful in this case. However, *The Virtual Zooarchaeology of the Arctic Project* (VZAP) mentions the possibility of cross-sectioning the bones (Betts *et al*. 2011:761). The same problem was raised concerning the shape of diaphysis, since it was not possible to take the bone in hand and feel if it is more rounded or more rectangular. Since the seal bones from adult individuals were scanned, I also could not analyse the morphological differences in the unfused diaphysis or shape of epiphysis.

Niven *et al*. (2009:2022) have pointed out the advantage of coloured 3D models and its benefits in bone identification. The colour provides better defined details on surface features or markings such as muscle attachments, nutrient foramina and suture lines. In this study the necessity of colour information was not prioritized, since the aim was to represent morphological differences between harp seal and ringed seal. The colour information can sometimes be a distractive characteristic during the bone identification process. It is more important to enhance shape details like concavities and convexities in bone analysis. That can be achieved by use of different shaders and rendering techniques, for example Radiance Scaling tool in MeshLab.

Perspectives

This study clearly reflects the potential of digital technology use within zooarchaeology. During this study only certain bone elements from one harp seal and one ringed seal were scanned. This database could be supplemented with 3D models of an entire skeleton of seal and include larger variation of species and individuals of different age and both sexes.

This method offers a wide range of modifications with created 3D models that can lead to a new knowledge or research aspects. It could be very interesting to find out how useful the use of the virtual comparative collections is during the archaeological fieldwork. For example, to see if an archaeologist using the 3D models of the bones could be able to identify the excavated material. After this information could be compared with analysis of the same bones carried out by osteologist in the laboratory, using the real comparative collection. Probably with time, the method and technology could develop so far, that it could be possible to identify bones during the fieldwork. For example, to take a photo or scan the bone fragment and program would automatically determine or offer the possible variants for bones identification from the virtual comparative collection.

The virtual comparative collection includes great potential of different modifications and could be complemented with various information, that could be useful during the research. The accessibility of such a resource has a great value not only for researchers, but also for other interested. Thus the spread and accessibility of this knowledge should be increased in the future.

Conclusions

This study has shown that the three dimensional modelling of bones involve a good possibilities to clarify the morphological differences between harp seal and ringed seal. The created database with 3D models (available in appendix or Lund University server) can be used in further studies and as a supplement for bone identification using comparative collections and/or illustrative atlases with line drawings. The three dimensional models can be modified, improving the research process and gaining new knowledge. The carried study can serve as a base for the further research and has the opportunities to be extended, including the entire skeleton and larger variation of species and individuals of different ages and sexes. It also could be complemented with various information useful during the bone analysis. The virtual comparative collections cannot replace the real ones, but can help to preserve them, and spread the information much faster and easier. Thus it involves not only a great research potential, but also can serve for educative aims.

Bibliography

Published sources:

Aaris-Sørensen, K. 1978. Knoglematerialet fra den mellemneolitiske boplads ved Korsnäs. *Riksantikvarieämbetet och Statens Historiska Museer Rapport 8*.

Bennike, O., Rasmussen, P. & Aaris-Sørensen, K. 2008. The harp seal (Phoca groenlandica Erxleben) in Denmark, southern Scandinavia, during the Holocene. *Boreas*, Vol.37: 263–272.

Betts, M. W., Maschner H. D.G., Schou C. D., Schlader R., Holmes J., Clement N., Smuin M. 2011. Virtual zooarchaeology: building a web-based reference collection of northern vertebrates for archaeofaunal research and education. *Journal of Archaeological Science* 38: 755-762.

Daugnora, L. 2000. Fish and seal osteological data at Sventoji sites. *Lietuvos Archeologija* 19:85–101.

Driver, J.C. 1992. Identification, classification and zooarchaeology. *Circaea* 9:35-47.

Ekman, J. 1972. Genomgång av benmaterialet från Hasslingehult. In: Cullberg, C. *Boplats Hasslingehult Göteborg*. FYNDrapporter 1972:571–577.

-1974. Djurbensmaterialet från stenålderslokalen Ire, Hangvar sn, Gotland. In: Janzon, G. O. *Gotlands mellanneolitiska gravar*. Studies in North-European Archaeology 6. Almqvist and Wiksell, Stockholm, 212–246.

Ekman, S. 1922. *Djurväldens Utbredingshistoria På Skandinaviska Hälvon*. A. Bonniers, Stockholm, Sweden.

Ericson, P.G.P. 1989. Säljakt och fiskafänge I Östersjö området under stenåldern. *University of Lund, Institut of Archaeology Report Series*, 33:57–64.

Forte, M. (ed). 2010. Cyber archaeology. BAR international series, 2177. Oxford, England: Archaeopress.

Fredén, C. 1975. Subfossil finds of Arctic whales and seals in Sweden. Sveriges geologiska undersökning ser C710 69:(2). Stockholm, Sweden.

Holmqvist, O. 1912. Tierknochen aus den steinzeitlichen Wohnplätzen in Visby und

Hemmor sowie aus einem Öländischen Ganggrabe. Kungliga Vetenskaps Akademiens Handlingar 49:71–75.

Lepiksaar, J. 1964. Subfossile Robbenfunde von der schwedischen Westküste. *Zeitschrift für Säugetierkunde*, 29, 257–266.

- 1986. The Holocene history of the theriofauna in Fennoscandia and Baltic countries. *Striae* 24:51–70.

-1991. Unpublished manuscript. Osteologia III. Phocidae.

Lindqvist, C. 1988. A carbonized cereal grain (Hordeum sp.) and faunal remains of e.g. harp seal (Phoca groenlandica), cod (Gadus morhua) and herring (Clupea harengus), from the Kolsvidja upper Stone Age habitation site on Åland. *Finskt Museum* 95:5–40.

Lõugas, L. 1997a. Post-glacial development of vertebrate fauna in Estonian water bodies. A palaeozoological study. Dissertationes Biologicae Universitatis Tartuensis 32. Tartu University Press, Tartu, Estonia.

-1997b. Subfossil seal finds from archaeological coastal sites in Estonia, east part of the Baltic Sea. *Anthropozoologica* 25–26:699–706.

-1998. Postglacial invasions of the Harp Seal (Pagophilus groenlandicus Erxl. 1777) into the Baltic Sea. *Proceedings of the Latvian Academy of Sciences*. B. Natural, Exact, and Applied Sciences 52:63–69.

-1999. Postglacial development of fish and seal faunas in the Eastern Baltic water system. In: Benecke N. (ed) *The Holocene History of the European Vertebrate Fauna. Modern Aspects of Research*, 185–200.

Lyman, R. L. 2006. Paleozoology in the Service of Conservation Biology. *Evolutionary Anthropology* 15:11–19.

Møhl, U. 1971. Fangstdyrene ved de danske strande. Den zoologiske baggrund for harpunerne. *KUML, Arbog for Jysk Arkaeologisk Selskab*, 1970, 297–329.

Nihlén, J. 1927. Gotlands stenäldersboplatser. Kungliga Vitterhets Historie och Antikvitetsakademiens Handlingar 36:3.

Niven, L., Steele, T.E., Finke, H., Gernat, T., Hublin, J.-J. 2009. Virtual skeletons: using a structured light scanner to create a 3D faunal comparative collection. *Journal of Archaeological Science* 36:2018-2023.

O´Connor, T. 2000. The archaeology of animal bones. Texas A&M University Press: College Station.

Pira, A. 1926. On bone deposits in the cave ''Stora Förvar'' on the isle of Stora Karlsö , Sweden. A contribution to the knowledge of prehistoric domestic animals. *Acta Zoologica* 7:123–217.

Schmölke, U. 2008. Holocene environmental changes and the seal (Phocidae) fauna of the Baltic Sea: coming, going and staying. *Mammal Rev*iew 38, (4), 231–246.

Segerberg, A. 1999. Bälinge mossar. Kustbor i Uppland under yngre stenåldern. Aun 26. Uppsala Universitet, Uppsala, Sweden.

Sergeant, D. E. 1991. Harp seals, man and ice. *Canadian Special Publication of Fisheries and Aquatic Sciences* 114.

Smith, N.E., Strait, S.G., 2008. PaleoView3D: from specimen to online digital model. *Palaeontologia Electronica* 11, 11A.

Storå, J. 2000. Sealing and animal husbandry in the Ålandic Middle and Late Neolithic. *Fennoscandia Archaeologica* XVII:57–81.

- 2001. Reading bones. Stone Age hunters and seals in the Baltic. *Stockholm Studies in Archaeology* 21.

-2002. Seal hunting on Ajvide. A taphonomic study of seal remains from a Pitted Ware Culture site on Gotland. In Burenhult, G. (ed) Remote sensing. Volume II. Archaeological investigations, remote sensing case studies and osteoanthropological studies. Theses and Papers in North-European Archaeology 13b, Hässleholm, Sweden, 387–428

Storå, J. & Ericson, P. G. P. 2004. A prehistoric breeding population of harp seals (Phoca groenlandica) in the Baltic Sea. *Marine Mammal Science* 20:115–133.

Storå, J. & Lõugas, L. 2005. Human exploitation and history of seals in the Baltic during the Late Holocene. In: Monks, G. G. (ed.) *The Exploitation and Cultural Importance of Sea Mammals*. Proceedings of the 9th Conference of the International Council of Archaeozoology, Durham, August 2002. Oxbow Books, Oxford. 95–106.

Strait, S.G., Smith, N.E., 2006. PaleoView3D: an interactive database of mammals from the Paleocene/Eocene boundary. *Journal of Vertebrate Paleontology* 26, 129A.

Ukkonen, P. 2002. The early history of seals in the northern Baltic. *Annals Zoologica Fennici* 39:187–207.

Winge, H. 1914. Knogler fra en stenalderbopladts vid Jettböle, Åland. Unpublished report in the archives of the Bureau of Antiquities, FIN-22101 Mariehamn, Finland.

Zagorska, I. 2000. Sea mammal hunting strategy in eastern Baltic. *Lietuvos Archeologija* 19:275–285.

Internet sources:

3D museum http://3dmuseum.org/ (visited 03.03.2012).

Aves 3D, A three dimensional database of avian skeletal morphology http://aves3d.org/ (visited 17.01.2012).

Department of Human Evolution (Max Planck Institute for Evolutionary Anthropology) http://www.eva.mpg.de/evolution/files/faunal_comparative_collection.htm (visited 03.03.2012).

Digital Morphology http://digimorph.org/ (visited 03.03.2012).

Front page picture from http://commons.wikimedia.org/wiki/File:Phoca_groenlandica_2.jpg (visited 05.03.2012).

Harp seal pup picture from http://www.babble.com/mom/work-family/baby-animals-photos/?page=22 (visited 05.03.2012).

Paleoview 3D http://paleoview3d.marshall.edu/ (visited 03.03.2012).

Reuter, P., in press. Enhancing surface features with the Radiance Scaling Meshlab Plugin https://www.ocs.soton.ac.uk/index.php/CAA/2012/paper/view/594 (visited 07.03.2012).

Ringed seal picture from *www.einfopedia.com* (visited 05.03.2012).

Software Adobe Photoshop CS http://www.adobe.com/products/photoshopfamily.html?promoid=JOLIW (visited 01.03.2012).

Software NextEngine ScanStudio HD http://www.nextengine.com/ (visited 01.03.2012).

Software MeshLab v1.3.0. http://meshlab.sourceforge.net/ (visited 01.03.2012).

The Virtual Zooarchaeology of the Arctic Project (VZAP) http://vzap.iri.isu.edu (visited 17.01.2012).

Bone Commons http://www.alexandriaarchive.org/bonecommons/ (visited 03.03.2012.)

ZooBook http://zooarchaeology.ning.com/main/authorization/signIn?target=http%3A%2F%2Fzooarchaeology.ning.com%2F (visited 03.03.2012).