Finding Moby: Identifying Whales in the Archaeological Record

A study of the vertebral morphology of cetacean species in the North Eastern Atlantic for the purposes of zooarchaeological analysis

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Cetaceans have been a key marine resource for millennia, and their bones and teeth are recovered from archaeological sites from the Paleolithic onward. Present-day populations are a product of past exploitation, and archaeological sites can provide a record of the changing nature and intensity of cetacean procurement as well as information on population distributions and sizes in the past. However, research on the archaeological remains of cetaceans is hampered by difficulties with morphological identification and the absence of adequate identification guides. The Finding Moby project aims to address this gap, to develop a morphometric guide for the identification of cetacean bone, and specifically vertebrae, which is applicable in the North Eastern Atlantic.

Cetacean Bone Identification by Morphometrics: The Issues

Research on the archaeological remains of cetaceans is fraught with difficulties surrounding morphological identification. Whilst biological texts for identifying live, recently dead, or complete cetacean skeletons exist, there is little international expert knowledge available for dealing with fragmented archaeological assemblages. Species identifications are possible for the majority of bones in the cetacean body. Teeth, tympanic bones, and skulls in particular are well suited to species identification and have been used successfully in archaeological studies (e.g., Glassow 2005). Others, including the vertebrae, can also be reliably identified to family and in most cases species. However, while some studies have had success in identifying cetacean bone using morphological methods, others have proved to be inaccurate, and have in some cases led to incorrect identifications (e.g., Cumbaa 1986). These inaccuracies are coming to light in the face of modern techniques of analysis such as DNA and ZooMS (Zooarchaeology by Mass Spectrometry).

Figure 1. Fragmentary cetacean bone being prepared for ZooMS analysis. Photograph courtesy of authors.

Inaccurate identifications are the result of problems faced by those undertaking morphological analysis. The problems stem from the endangered status and rarity of many cetacean species and the large size of others. These factors mean that comprehensive collections of cetacean skeletons are rare. Even rarer are those which contain multiple specimens of the same species, simply due to the constraints of curation, display, and storage. This often leaves comparisons to be based on the morphological traits of a few individuals, which in turn creates difficulties when identifying osteological traits which are true reflectors of species, i.e., those that recur consistently throughout the species and thus do not relate to individual conditions. Research has also shown that museum specimens can be incorrectly labeled, causing further problems (Evans et al. 2016). Moreover, the morphology of cetacean bones from different species can be very similar, while males and females of the same species can exhibit extreme sexual dimorphism, making it challenging to accurately identify bone fragments to species. These issues are compounded by deliberate fragmentation of bone on many archaeological sites, due to human butchery or artifact creation, as well as the overall friability of archaeological whale bone, leading to the loss of distinctive morphological traits (e.g., Figure 1).

Taxonomical uncertainty is another potential underlying difficulty with the study of cetacean bone. It is well acknowledged that the classifications of known species may, and do, change as a result of new information. Current understanding of classifications within the order Cetacea is based on the work of individuals ranging from Flower, working in the nineteenth century, to Rice, working today (Flower 1867; Rice 1998). These classifications make use of morphological data, behavioral information, distributions, diet and, more recently, genetics.

These classifications may therefore be subject to change. Recent genetic, ecological, and morphological studies into *Orcinus orca*, for example, have indicated that this species may actually represent a number of different species, with transient, resident, and offshore populations (noted in the North Pacific) and Type A, B, and C (noted in the Antarctic; Pitman and Ensor 2003). As early as 1870, zoologists such as Gray (1870) also suggested that multiple species lay within the genus *Orcinus*, publishing material showing considerable differences in the morphology and metrics of different specimens, now all grouped under the species *Orcinus orca*. The species-problem with *Orcinus orca* demonstrates the difficulty in identifying whale bone to species, when there are large amounts of variability between individuals today grouped under the same species.

Studies of Cetacean Bone Morphology

The Finding Moby project began by collating all existing data relating to cetacean bone identification. Studies of cetacean bone are widespread, cropping up in the disciplines of marine biology and zoology, biomechanics, paleontology, museum and conservation studies, and archaeology. Each discipline views the bone from different perspectives focusing on different attributes, and all ultimately have the potential to contribute to our understanding of cetacean bone in the archaeological record.

Detailed studies of the osteology of cetaceans were undertaken from the nineteenth century led by authorities such as Van Beneden and Gervais (1868–1879), Flower (1864), True (1904), and Gray (1864, 1868), based at the world's major museums: Paris, London, Washington. This research was continued in the twentieth century by individuals such as Slijper (1936), and by 1948 the Whales Research Institute (later the Institute for Cetacean Research) was also contributing to research in this area. Some of the earlier works cover the order Cetacea while others focus on families or individual species. Studies of individual species are available for many of the species present within the North East Atlantic.

Other studies focus on particular skeletal elements. For example, *Zoology of the Voyage of H.M.S Erebus and Terror, 1839–1843* focuses principally on the crania of cetaceans (Richardson and Gray 1839–1843), while Benke's (1993) study focuses on the cetacean forelimb. Of particular note are the extensive studies of comparative mammalian and cetacean anatomy undertaken by Flower (1885), Slijper (1936), and Yablokov and colleagues (1972), and texts that summarize these German and Russian works (Berta et al. 2015). Mead and Fordyce's (2009) recent work on the skulls of Odontoceti also forms an important reference guide.

Although these studies form important reference material for the identification of cetacean bone, they tend to focus on identifying or classifying cetaceans based on differences across the skeleton, rather than the identification of species from individual bones. This means that areas such as the skull receive much more attention than other bones. Those elements found most frequently on archaeological sites, namely vertebrae, receive little attention.

The Finding Moby Project

The Finding Moby project aims to address deficiencies in existing studies in order to produce a morphological guide specifically focused on the identification of cetacean vertebrae, ultimately allowing vertebrae from archaeological sites to be identified morphologically.

Under the Finding Moby project, we have been working with cetacean skeletal collections and specialists around Europe to share knowledge and develop new integrated datasets that will allow species identification based on the shape and size of archaeologically preserved bone. In addition to the information from pre-existing studies, research undertaken as part of the Finding Moby project has augmented previous investigations of cetacean bone by ourselves and Dr. Vicki Szabo at Museum of Scotland (Granton Research Centre), and the British Museum of Natural History (Wandsworth Research Centre), with cetacean bone held by Cardiff University, the Icelandic Institute of Natural History, Húsavík Whale Museum, and Bergen Museum. We have also examined and included collections held by individuals in Shetland, using measurements following von den Driesch (1976) and classifications following Perrin (1989).

We have combined the results of this research with data from historic publications to provide detailed morphometric infor-

Table 1: Summary of the Number of Specimens of Each Species for which Vertebrae Have Been Recorded for the Identification Dataset.

Name	Scientific name	No. of specimens recorded	Name	Scientific name	No. of specimens recorded
Blue whale	*Balaenoptera musculus*	13	False killer whale	*Pseudorca crassidens*	0
Fin whale	*Balaenoptera physalus*	4	Sowerby's beaked whale	*Mesoplodon bidens*	2
Bowhead whale	*Balaena mysticetus*	1	Beluga	*Delphinapterus leucas*	1
Right whale	*Eubalaena glacialis*	2	True's beaked whale	*Mesoplodon mirus*	0
Sperm whale	*Physeter macrocephalus*	4	Narwhal	*Monodon monoceros*	2
Humpback whale	*Megaptera novaeangliae*	4	Bottlenose dolphin	*Tursiops truncatus*	3
Sei whale	*Balaenoptera borealis*	4	Risso's dolphin	*Grampus griseus*	1
Gray whale	*Eschrichtius robustus*	7	Pygmy sperm whale	*Kogia breviceps*	0
Bottlenose whale	*Hyperoodon ampullatus*	3	Atlantic white-sided dolphin	*Lagenorhynchus acutus*	1
Minke whale	*Balaenoptera acutorostrata*	4	White-beaked dolphin	*Lagenorhynchus albirostris*	2
Killer whale	*Orcinus orca*	3	Melon-headed whale	*Peponocephala electra*	0
Cuvier's beaked whale	*Ziphius cavirostris*	2	Fraser's dolphin	*Lagenodelphis hosei*	0
Gervais' beaked whale	*Mesoplodon europaeus*	0	Striped dolphin	*Stenella coeruleoalba*	1
Pilot whale	*Globicephala melas*	4	Short-beaked common dolphin	*Delphinus delphis*	3
Blainville's beaked whale	*Mesoplodon densirostris*	2	Harbor porpoise	*Phocoena phocoena*	4
Total number of specimens recorded in historic publications and by the Finding Moby project					**77**

mation on 24 of the 30 species in the North Eastern Atlantic. Data for over 70 specimens have been examined, from the (relatively) tiny harbor porpoise to the giant blue whale (Table 1).

As the identification guide is developed, we are testing the data on archaeological material held at Cardiff University including the cetacean bone assemblages from the Hebridean sites of Bornais and Cladh Hallan. In order to test the validity of the identifications, we have undertaken ZooMS analysis on a selection of the material identified using the morphological guide. This testing has been undertaken to ensure that features which have been identified as species indicators by the Finding Moby project are robust and replicable. The use of proteomics analysis also allows data from archaeological material to be used in the identification guide. This is particularly important as commercial whaling is known to have had a drastic impact upon cetacean populations. Pre-commercial whaling populations may have included individuals of a larger size than those which survived, and thus by including archaeological material we can effectively begin to remove the filter that commercial whaling has applied to our current dataset. This will ensure that the data produced by the project can be reliably used to identify specimens from assemblages from diverse time periods.

Overview of Findings

The Finding Moby project is building a morphological guide that includes details of the features which can be used to distinguish cetacean bone from the bones of other marine and terrestrial fauna, along with data which makes it possible to distinguish between the bones of different cetacean species. To date, the project has investigated a series of family- and species-specific characteristics in the vertebral morphology of cetaceans (see Figure 2 for visual comparisons). These include the following:

- Size
- Cervical vertebrae fusion
- Relative dimensions of the length of the centrum (CL) compared with centrum height (CH) and width (CW; for determining family). Centrum length relates to flexibility/ rigidity (Long et al. 1997) and the number of vertebrae within the spine.
- Breadth of the neural arch (Rommel et al. 2006)[1]
- Transverse process inclination
- Vertebral height (where complete neural spines exist)
- Vertebral width (where both transverse processes survive intact)
- Height of neural arch and spine
- Shape of neural spine (curved/ squared at distal end)
- Presence and exaggeration of medial ridge/keel on ventral side of vertebral centra
- Presence and location of metapophyses
- Shape of the centrum face (CF)

An extract from an identification table (Table 2) is included below. This table provides data relating to the identification of species from the mid-thoracic vertebrae, and provides an example of the data being developed by the project.

Future Work and How to Get Involved

The project and data are a work in progress, and future research is planned to gather data for more specimens and to refine the identification methodology. In particular, the focus will be on species for which no specimens have yet been studied, including *Mesoplodon mirus* (True's beaked whale), *Kogia breviceps* (Pygmy sperm whale), *Peponocephala electra* (Melon-headed whale), *Lagenodelphis hosei* (Fraser's dolphin), and *Pseudorca crassidens* (False killer whale), and on those species for which few specimens have been recorded.

In order to overcome problems of basing the morphological guide on relatively few specimens, we also plan to begin crowd-sourcing data, and for this we ask for the reader's help[3].

Table 2: Identification of Species from the Mid-Thoracic Vertebrae.

		Centrum characteristics				
Species	**No of TV***	**CL**	**CH**	**CW**	**CL/CH**	**CF shape**
B. musculus	15–16	149–215	184–240	250–304	0.77–0.96	Heart with rounded base
B. physalus	15–16	141–203	160–208	215–294	0.88–1.02	Heart with rounded base
B. mysticetus	13					
B. borealis	14	127–159	126–150	175–229	0.98–1.01	Heart with rounded base
P. macrocephalus	11	127–160	226–275	235–380	0.51– 0.59	U-shaped with flat top
E. glacialis	14–15	110	229	284	0.48	Triangle with rounded corners
M. novaeangliae	14	99–137	178–186	216–228	0.53– 0.77	Heart with V-shaped base
E. robustus	14	148	162	213	0.87	
B. acutorostrata	11	61–128	82–100	101–144	0.77–0.96	Oval, long axis horizontal and V-shaped base
H. ampullatus	8–9	89–95	129–136	150–163	0.65–0.74	Heart with rounded base
O. orca	11–12	45–94	91–135	100–145	0.49–0.76	Rounded shield-shape, slightly flat-topped
Z. cavirostris	9–10[1]	84	72	82	1.17	
M. europaeus	9–11					
G. melas	11	41–83	51–82	55–87	0.80–1.01	Rounded, slightly flat-topped
P. crassidens	9–10					
M. bidens	10	74	47	69	1.57	
M. mirus	10					
M. densirostris	10–11	60				
D. leucas	11	61	60	63	1.01	
M. monoceros	11	73	58	66	1.26	
M. grayi	10					
G. griseus	12	42	49	55	0.86	
T. truncatus	10–12	45	48–53	46–53	0.85–0.96	Rounded
K. breviceps	12–14					
L. albirostris	13–14	31–43	42–44	46–50	0.70–1.02	Sub-square to rounded CW> CH
L. acutus	13–14	22	32	36	0.69	Sub-square to rounded CW> CH
P. electra	12					
D. delphis	13	17–24	23–29	25–29	0.74–0.88	Rounded
S. coeruleoalba	14					
P. phocoena	12–13	17–22	20–23	21–24	0.85–1.05	Circular to teardrop shape (V at ventral side).

** TV= Thoracic Vertebrae; CL= Centrum Length; CH = Centrum Height; CW = Centrum Width; CF= Centrum Face*

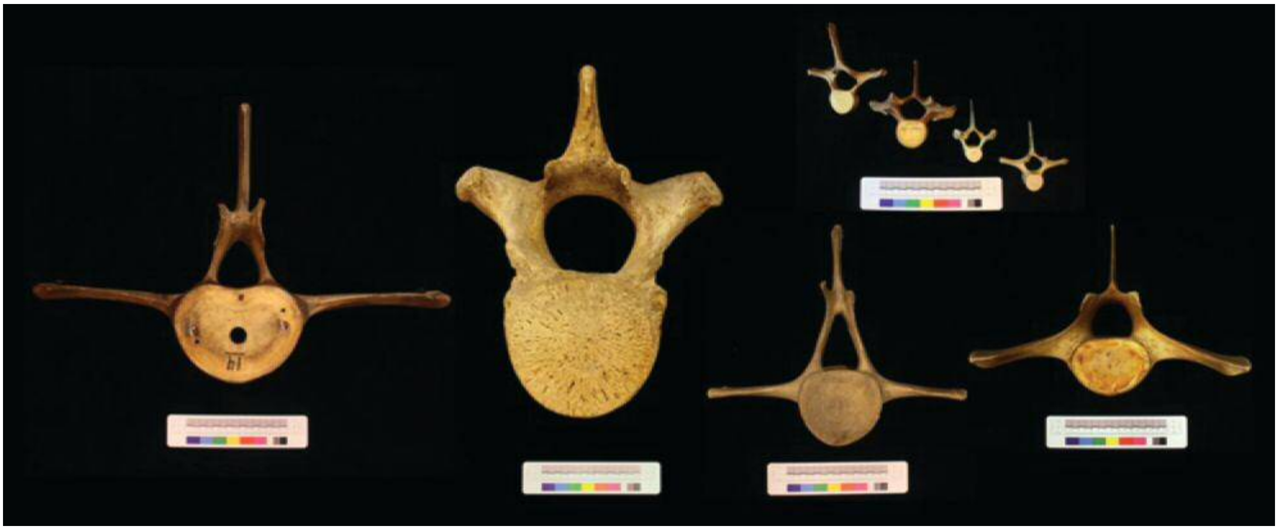

Figure 2. Comparative image showing thoracic vertebrae from left to right, large species: Sei whale, Sperm whale, Orca, Minke whale; and from left to right, small species: Atlantic white-sided dolphin, White-beaked dolphin, Harbor porpoise, and Common dolphin. Photograph courtesy of authors.

We are collecting measurements of the centrum width (CW) and centrum height (CH), front and back, as well as the centrum length (CL), overall height from the base of the keel to the top of the neural process (H), the greatest width of the transverse processes (GLPT), and the breadth of the neural arch (BNA) at its widest point (see Figure 3). We are also collecting images with a scale, showing the bones recorded, along with notes relating in particular to the shape of the centrum, inclination of processes, strength or exaggeration of the keel, and presence, number, and location of foramen. On vertebrae these include foramen present along the dorsal side of the vertebra in the neural arch area, or along the sides of the vertebra, or its ventral aspect. Where full specimens are present, we hope to collect data relating to every other vertebra along the spine in order to build a robust dataset.

As the project progresses we plan to make the morphological guide available via the web to allow researchers across the North Eastern Atlantic to identify their own cetacean bones, and to test the guide and comment on their own findings. This will allow improvements in the interpretation of cetacean remains on archaeological sites, providing insights into past patterns of exploitation with implications for current whale populations.

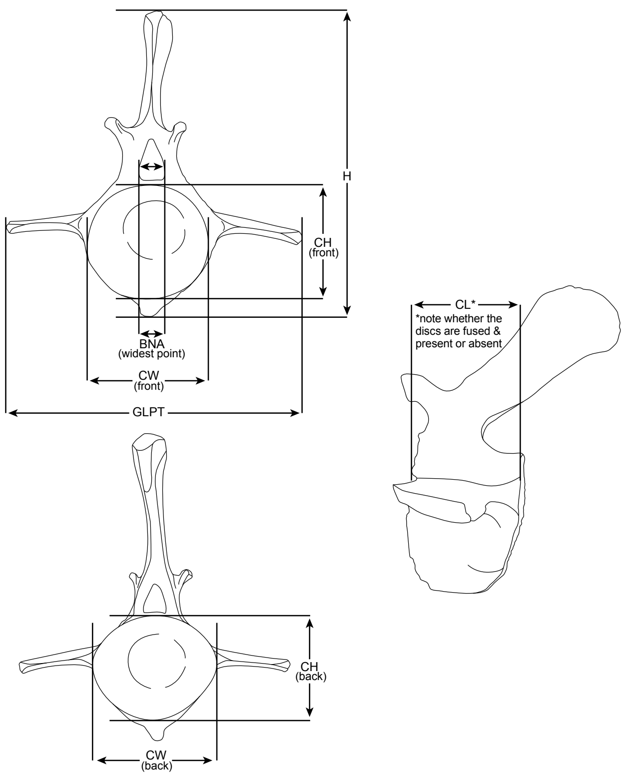

Figure 3. Recording dimensions of cetacean vertebrae. Illustration by Kirsty Harding and Ian Dennis.

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Note:

1. The neural canal has been found to be largest in the deepest diving species (beaked whales and *P. macrocephalus*) by Rommel and colleagues (2006). However, comparison of Minke and Sperm whale lumbar vertebrae as part of the Finding Moby project does not seem to support this statement. This requires further investigation.
2. From True 1910.
3. Please contact Sally Evans at evanssj15@cardiff.ac.uk