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Whaling in Iron Age to post-medieval Scotland: a zooarchaeological and biomolecular study of cetacean remains from selected sites in Caithness, the Orkney Islands and the Shetland Islands

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ABSTRACT

Cetacean remains have been recovered from archaeological sites all over Europe, but are especially abundant in Scotland. These remains originate from all periods and have often been worked into artefacts or tools, including chopping blocks, plaques, combs, pegs, snecks and perforated vertebral epiphyseal discs. It still remains unclear which species were exploited and to what extent active whaling was undertaken in the region. To address these questions Zooarchaeology by Mass Spectrometry (ZooMS) was undertaken on 35 cetacean specimens from five sites in Scotland (Jarlshof, Brough of Birsay, Quoygrew, Deerness and Freswick Links), dating from the Iron Age to the post-medieval period. Furthermore, morphological analysis was performed on the material in order to optimise the ZooMS identifications.

*A large variety of species were identified, including high numbers of Balaenidae sp and Globicephalinae sp. Comparison with other ZooMS studies in north-western Europe revealed equally high specimen numbers for these species, but also fin whale (*Balaenoptera physalus*), sperm whale (*Physeter macrocephalus*) and humpback whale (*Megaptera novaeangliae*). Moreover, one grey whale (*Eschrichtius robustus*) was identified in the Scottish specimens, adding to an increasing number of specimens indicating that the grey whale was once abundant in European waters. Furthermore, only one specimen of the common minke whale (*Balaenoptera acutorostrata*) was identified, despite modern stranding data which suggests this is the most common large whale species in Scottish waters.*

The large variety of species identified suggests that opportunistic scavenging was likely the primary method of acquiring cetaceans, though historical and ethnographic sources suggest that two distinct forms of active whaling may have occasionally been undertaken. The high number of Globicephalinae specimens from Jarlshof raise the possibility that drive-hunting might have already been undertaken at the site during the Iron Age.

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INTRODUCTION

Cetacean material is recovered from archaeological sites all over Scotland, but is found especially frequently in the northern regions. Research on cetacean exploitation in the region from an archaeological perspective has previously been conducted by Clark (1947) and, more recently and thoroughly, by Mulville (2002). The questions most frequently asked are to what extent active whaling was undertaken and which species were exploited.

Historical and ethnographic sources have been used to argue that active whaling was indeed undertaken in Scotland from at least the Norse period (Lindquist 1995: 29). From these sources it appears that two forms of active whaling, designed to target different species, may have been employed: 'spear-whaling' targeting larger whales, and 'drive-hunting' primarily targeting dolphin species.

Drive-hunting has been argued to be of Norse origin. Norse culture originates in Scandinavia, but from the late 8th century onwards, the Norse expanded their territory and sphere of influence in the direction of Scotland, colonising the Shetland and Orkney Islands around AD 800, the Faroe Islands around AD 820, and the Scottish Western Islands, Sutherland and Caithness around AD 870 (Fitzhugh 2000: 19; Laist 2017: 88). With them, the Norse brought their culture and traditions which likely included whaling practices, such as drive-hunting (Lindquist 1995). This technique is still practised in the modern Faroe Islands where it is known as the *Grind*. It entails a number of boats that 'drive' dolphins or whales into a bay where they are subsequently killed by the hunters in shallow waters (Illus 1). Most frequently, the long-finned pilot whale (*Globicephala melas*) is targeted, but the common bottlenose dolphin (*Tursiops truncates*), white-beaked dolphin (*Lagenorhynchus albirostris*), Atlantic white-sided dolphin (*Lagenorhynchus acutus*), Risso's

Illus 1 Whaling in the Faroe Islands as observed in 1854. Image extracted from page 107 of *A Narrative of the Cruise of the Yacht Maria among the Feroe Islands in the Summer of 1854*. (Courtesy of the British Library Mechanical Curator Collection / Wikimedia Commons / Public Domain)

dolphin (*Grampus griseus*) and the northern bottlenose whale *(Hyperoodon ampullatus*) are also occasionally taken (Fielding 2018: 92). This form of whaling is known to have been practised in Iceland, the Shetland Islands, the Orkney Islands, the Hebrides and Ireland during the 17th to early 19th centuries in some coastal areas with suitable bays, but might have been practised far earlier than that (Lindquist 1995: 29).

Besides drive-hunting practices, another form of whaling is described by the Muwallad geographer al-ʹUdhri when he visited the Norse-Gaelic regions in AD 1058. He mentions that during the months of October to January, the Norse-Gaelic hunted whales using iron-tipped spears with large rings attached, to which ropes were tied. Calves especially were targeted and when killed the carcasses were dragged ashore and the meat preserved with salt (Laist 2017: 95). Though this is the only mention of this type of whaling in the area, it is clear that this is a completely different practice than drive-whaling and suggests that multiple whaling practices were mastered by the Norse in northern Scotland. This second technique was probably more adapted to target larger whales, most likely the North Atlantic right whale (*Eubalaena glacialis*), and potentially also the humpback whale (*Megaptera novaeangliae*) and the grey whale (*Eschrichtius robustus*), which are all relatively slow coastal species (Laist 2017: 95). This technique described by al-ʹUdhri bears close analogies to the whaling techniques undertaken by the Basques and the Normans (Musset 1964; Aguilar 1986; van den Hurk 2020).

The Norse certainly had the necessary boats available to perform both drive-whaling and spear-whaling. Drive-whaling was undertaken in small manoeuvrable boats. Indeed, small clinker-built boats have been unearthed from a 9th-century Norse context in Gokstad, Norway, and a larger 11m longboat (the Skuldelev 6 vessel) from an early 11th-century context in Roskilde, Denmark. These would have been suitable for drive-hunting (Szabo 2008: 108–9).

Small boats appear to have been used for spear (or harpoon) whaling as well. Traditional whale hunters, from the Americas to Asia, apply basic strategies of harpoon hunting using a single small boat or a group of small boats to approach the whale and harpoon the animals. To ensure a kill, particularly sensitive areas of the whale are targeted, as the thick blubber present in most locations might be too thick to penetrate with a harpoon. The small boats used by the Norse were likely suitable for harpoon-whaling as well (Szabo 2008: 110–11).

The Norse also brought complex laws with them to northern Scotland, including those dealing with whaling. The *Gulaþing* (Norway's oldest legal code, dating to the mid-11th century AD, which travelled with Norse settlers to the Orkney Islands) declared that if a whaler was able to take a whale at open sea it was his property. However, if the wounded whale beached, the whale had to be divided between the whaler and owner of the land upon which the whale beached (Laist 2017: 89). Furthermore, a man of a higher rank was allowed to claim a stranded whale under 18 ells in length (1 Viking ell is approximately 46cm, and 18 ells 828cm), while any other man could only claim one that was half as long. Moreover, if whale products were taken from the foreshore to the land after butchering, and were transported over someone else's land, a portion had to be given to the landowner as well. If no witnesses were present, the whale's backbone, fin and head had to be left in place to testify that the whale was below the maximum size allowed to be exploited (Szabo 2005, 2008).

While historical sources provide a wealth of information regarding past whaling practices, much still remains unclear regarding early cetacean exploitation practices. Zooarchaeology offers the possibility to fill a gap in our knowledge of early cetacean exploitation in Scotland. However, the zooarchaeological discipline faces its own problems. Since whales are large, it is very likely that whalers left their osteological remains at the foreshore, where they are often inaccessible to archaeologists. This practice leads to an under-representation of cetacean bones at archaeological sites and has resulted in cetaceans being called archaeologically 'invisible' (Smith & Kinahan 1984).

Cetacean bone was probably only transported inland if value was placed on the bones

themselves, for example for the creation of artefacts or tools (eg combs, pegs, weaving tablets, mattocks, etc) or for oil extraction. Mulville (2002) concluded that whale bone was a valuable resource in Scotland from the Neolithic onwards and was sought after for its architectural and artefactual utility. These utilitarian modifications, however, make species identification through morphological analysis very difficult as the bones are highly altered or fragmented. Additional limitations on our understanding of past cetacean exploitation are imposed by the existence of very few comprehensive osteological cetacean reference collections, the near-complete lack of cetacean osteological reference manuals, and the often limited budget available for the analysis of cetacean material (not allowing for aDNA analysis).

The recently developed Zooarchaeology by Mass Spectrometry (ZooMS) method has allowed for taxonomic identification through minimally destructive sampling, and has truly revolutionised zooarchaeological analysis (Buckley et al 2014). While it is not as precise as aDNA analysis, it can regularly identify specimens to the family, genus or species level. As part of this study, a zooarchaeological assessment combined with ZooMS was undertaken in order to answer the question of which species were exploited. This assessment included a review of previously published zooarchaeological data from a variety of archaeological sites (6000 BC – AD 1600). Based on this, a selection of zooarchaeological cetacean specimens were sampled for ZooMS analysis. Wherever possible, morphological analysis was also conducted to optimise the ZooMS identifications.

The results of this assessment were subsequently integrated into a larger body of data, including historical, ethnographic and modern stranding data, in order to assess whether active whaling (either of the two whaling forms previously described) was undertaken or whether opportunistic scavenging was the main source of procurement. If particularly large numbers of long-finned pilot whales, but also other dolphin species, were encountered, it could be argued that drive-hunting was undertaken; whereas large numbers of the North Atlantic right whale, in particular, and to a lesser extent the humpback whale and grey whale, might suggest that spear-whaling was undertaken. A large variety of species being identified might suggest that opportunistic exploitation was the main source of procurement. However, in all cases, conclusions should be drawn with caution, as strandings have likely contributed to a large extent to the zooarchaeological cetacean findings made in Scotland.

MATERIAL AND METHODS

Firstly, an assessment of archaeological sites in Scotland with cetacean remains was conducted. A considerable number of Scottish archaeological publications were systematically assessed looking for archaeological sites dating from the Mesolithic to the post-medieval period with cetacean remains. This assessment was built upon a similar review conducted by Mulville (2002), with new discoveries being added. All data regarding the NISP (Number of Identified Specimens) for cetaceans were collected and incorporated into a database. While a high number of archaeological reports were assessed and a substantial amount of sites with cetacean remains have been identified, it is very likely that many more sites with cetacean remains exist in Scotland, making the created dataset non-exhaustive.

One of the main issues when considering prehistoric Scotland is that there is no single agreed periodisation. Several dates, for example, have been provided to characterise the ‘Scottish Iron Age’. Many of the whale bone specimens have been assigned to certain periods (for example ‘Iron Age’ or ‘Norse’) without any specific dates being mentioned, making the creation of a temporal overview of cetacean exploitation for Scotland problematic. Therefore, the following periodisation displayed in Table 1 was considered as part of this study.

All identified sites have been temporally plotted by assessing the number of identified cetacean specimens and dividing those by the length of the date range of that site to give an estimate

TABLE 1
Periodisation of Scotland

Period	*Dates*
Mesolithic	10,000 – 4000 BC
Neolithic	4000 – 2000 BC
Bronze Age	2000 – 800 BC
Iron Age	800 BC – AD 800
Viking/Norse period	AD 800 – 1300
Medieval/Middle Ages	AD 400 – 1500
Post-medieval	AD 1500 – recent

of frequency density across that range. This provided an estimated frequency distribution in a similar manner to that performed by Orton et al (2014) in their analysis of cod (*Gadus morhua*) remains from London. Twenty-five-year intervals for the period of 6000 BC – AD 1600 were used to produce an overall distribution. In order to compensate for sites with extremely large amounts of cetacean remains, a cut-off of five was instigated for each 25-year interval per site. Unfortunately, for many of the sites, the number of identified cetacean species was not recorded and it was just the presence of whale bone at the site that was noted. As a result, the NISP for these sites was placed at just one specimen, although for many it is possibly more.

Secondly, based on the zooarchaeological assessment, 35 cetacean specimens from five sites in northern Scotland were selected for ZooMS. These 35 samples derive from the National Museums of Scotland (NMS), Edinburgh, and the McDonald Institute for Archaeological Research, Cambridge. From the NMS, samples from the Brough of Birsay (Orkney Islands), Jarlshof (Shetland Islands) and Freswick Links (Caithness) were taken, while from the McDonald Institute samples from Quoygrew and Deerness (both Orkney Islands) were collected. These sites were chosen due to their locations in the Shetland Islands, Orkney Islands and Caithness, where large numbers of cetacean remains have been recovered. Large numbers of cetacean remains were found at each of these sites, and all specimens were accessible for minimal destructive samples (as is required for ZooMS). Samples were selected to cover the Iron Age to the post-medieval period, and to cover cetacean remains of different size ranges.

The zooarchaeological material of the five sites considered has been previously studied and most of the specimens have been published already. A large variety of unworked and worked whale bones have been recovered from the sites. A short description of the sites and the specimens selected is provided here.

JARLSHOF

Jarlshof is located on Mainland, Shetland and is one of the best-known archaeological sites in Scotland. Excavations commenced in 1925 and have been led by Dr A O Curle, Professor V G Childe, Miss B Laidler, Dr J S Richardson and Dr J R C Hamilton. The site has been dated from 2500 BC to the 17th century AD. Though excavations have been undertaken for several years, with zooarchaeological remains unearthed under the guidance of various excavation directors, no clear overview of cetacean remains exists; a vast number are mentioned, however, in Hamilton (1956). Seventeen specimens were selected for ZooMS analysis, including 12 unworked specimens (five vertebrae, one cranial fragment, one atlas, one phalanx, one rib, and three unidentifiable specimens) and five worked specimens (one piece of an atlas, two vertebral epiphyses with a hole drilled in the centre, one hollowed out vertebral vessel, and one piece of bone with a square

hole in the centre). Most of these specimens derived from Iron Age and Norse contexts.

BROUGH OF BIRSAY

The Brough of Birsay is located on an uninhabited tidal island off the north-west coast of the Mainland of Orkney. Remains of Pictish and Norse settlements have been unearthed on the island. At least 12 artefacts and tools made of whale bone have been found at the site of the Brough, including two large pins, a large vice or clamp with a flat base and a curved top decorated with four rows of dot-in-circles, a notched peg, a line stretcher, another large whale bone implement, a gaming board, a hook, two rectangular tablets, a fragment of shaped whale bone, and a rib fragment (Curle 1982). As part of this study the fragment of shaped whale bone, the notched peg and a tablet were selected for ZooMS analysis. The first of these derived from the Upper Norse horizon (AD 950–1200) and the other two from the Middle Norse horizon (AD 850–1000).

FRESWICK LINKS

Freswick Links, located in Caithness, is a multi-period site with remains dating from the Bronze Age to the 13th century AD. Excavations at the site have been undertaken since *c* 1900, including by A O Curle and V G Childe. Research by Batey (1987) has identified that the bulk of archaeological material is of a Late Norse dating. Several artefacts and tools were identified as whale bone, including two whorls, seven snecks, two gaming pieces and four other unidentified pieces. Three of the snecks were selected for further analysis and all dated to the Late Norse period.

QUOYGREW

Quoygrew, located on the island of Westray in Orkney, is a late Viking Age and medieval rural settlement. Excavations were undertaken between 1999 and 2006, as part of the Viking Age Transition project. The zooarchaeological analysis was published in Barrett (2012). As part of the zooarchaeological study 27 cetacean specimens were identified, dating between AD 900 and 2000. From these, ten specimens were selected for ZooMS analysis, covering a variety of contexts.

BROUGH OF DEERNESS

The Brough of Deerness, located in the east of Orkney's Mainland, is a Viking Age settlement on top of a small sea stack. The McDonald Institute for Archaeological Research, University of Cambridge, in collaboration with Orkney College and the Friends of St Ninian's, have undertaken excavations at Deerness at the site. Several Viking Age houses have been investigated and several Pictish layers dating to the 6th to 9th century AD have also been unearthed (Barrett & Slater 2009). Two whale bone specimens deriving from strata dating to the 10th to 12th century AD were selected for further analysis.

Of the selected specimens, samples of approximately 30mg were taken from each bone and processed at the BioArCh laboratory at the University of York, UK. Collagen extraction, purification, mass spectrometry and peptide mass fingerprinting identifications followed the method outlined in Rodrigues et al (2018). Briefly, the bone was demineralised in 0.6M hydrochloric acid, and the resulting collagen gelatinised through incubation in 100µl of 50mM ammonium bicarbonate at 65°C for 1 hour. The collagen was digested through incubation with 0.4µg of trypsin overnight at 37°C and purified using a 100µl C18 resin ZipTip® pipette tip (EMD Millipore). Each sample was spotted in triplicate with a matrix of α-cyano-4-hydroxycinnamic acid on a 384 spot MALDI target plate, with calibration standards and run on a Bruker ultraflex III MALDI TOF/TOF mass spectrometer. Averaged spectra were created from the replicates for each specimen using mMass software (Strohalm et al 2008), and then compared to published m/z markers for mammals, as presented in Buckley et al (2009), Kirby et al (2013), Buckley et al (2014), Welker et al (2016) and Hufthammer et al (2018).

Thirdly, as ZooMS is not able to differentiate between several species, the samples that allowed for morphological comparison were

compared with photos taken of cetacean specimens from the Natural History Museum, part of the Smithsonian Institution, USA, in order to narrow down species identification. Since many of the specimens were fragmented, this was only possible for three specimens.

Fourthly, modern stranding data provided by the Scottish Marine Animal Stranding Scheme (2016) was compared to the zooarchaeological data to determine whether there was any variation. Modern strandings are often caused by anthropogenic factors, such as ship strikes or the ingestion of plastic (Jefferson et al 2008), making them not wholly comparable to situations in the past. However, certain trends might still be useful to assess differences, such as the presence of a species in an area during a particular period. Several species, including pilot whales, false killer whales and sperm whales, are known to mass-strand occasionally (Rodrigues et al 2018, and relatively large numbers of specimens belonging to those species might be acquired through the opportunistic exploitation of such events.

Finally, the species identifications of the 35 specimens were compared with other studies in north-western Europe that performed ZooMS on cetacean specimens in order to assess whether regional or temporal variation in species exploitation could be identified. The studies used for comparison focused on Scotland as well (Buckley et al 2014; ArchaeologyOrkney 2020 (the latter representing some preliminary results of the study conducted by Dr Vicki Szabo and Dr Brenna McLeod Frasier)), and also Iceland (Buckley et al 2014), the Netherlands and Flanders (van den Hurk et al 2020), London (van den Hurk et al 2021), and Spain and Morocco (Rodrigues et al 2018).

RESULTS

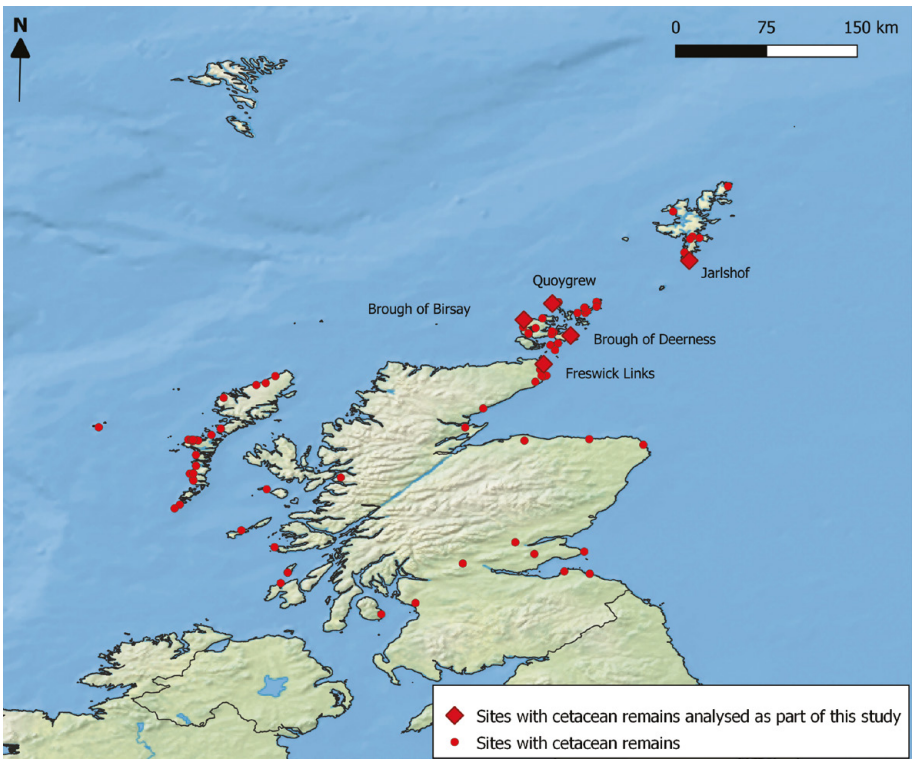
TEMPORAL OVERVIEW OF CETACEAN REMAINS FROM SCOTLAND

A total of 94 sites (Illus 2; Supplementary Table 1) with cetacean specimens were assessed with at least 1,422 cetacean specimens spread across these sites. The vast majority of these specimens are still unidentified and are simply identified as 'unknown cetacean' (at least 1,041 specimens; 73.2% of total). Just 138 (9.7% of total) specimens (including those identified as part of this study) have been given a taxonomic identification using morphological, ZooMS or aDNA analysis.

The estimated frequency density graph (Illus 3) clearly indicates that cetaceans were only occasionally exploited during the Mesolithic-Bronze Age periods, though this can be explained by a lower human population density (Bradley 2007). In later time periods, the estimated frequency data shows a clear increase from the onset of the Iron Age (around 800 BC) up until AD 1000, with only a short decrease in numbers for the 9th century, though this is most likely a result of an edge effect of the periodisation used by various archaeologists. From the 11th century onwards, the estimated frequency data indicates a sudden drop in cetacean remains that continued until the mid-14th century, suggesting whale bone fell out of favour as a raw material resource or cetacean exploitation may have halted.

A large number of the identified cetacean specimens show signs of working or have been identified as artefacts, indicating that whale bone was a common raw material used for the creation of a variety of tools and artefacts such as chopping blocks, perforated vertebral epiphyseal discs, pegs, snecks, mallets, vertebral cups/vessels, plaques, combs and scutching knives (Mulville 2002). Working marks have been observed on at least 331 specimens (23.28% of total) from at least 73 sites (77.66% of total), though these numbers are probably higher, as for many publications little information is provided regarding the unearthed whale bone remains.

Sign of butchery were visible on whale remains from at least four sites (4.26%), indicating that cetacean meat was also occasionally consumed. However, based on this data it remains unclear to what extent active whaling was undertaken and which species were potentially targeted.



Illus 2 Map of sites in Scotland with cetacean remains. (© Youri van den Hurk)

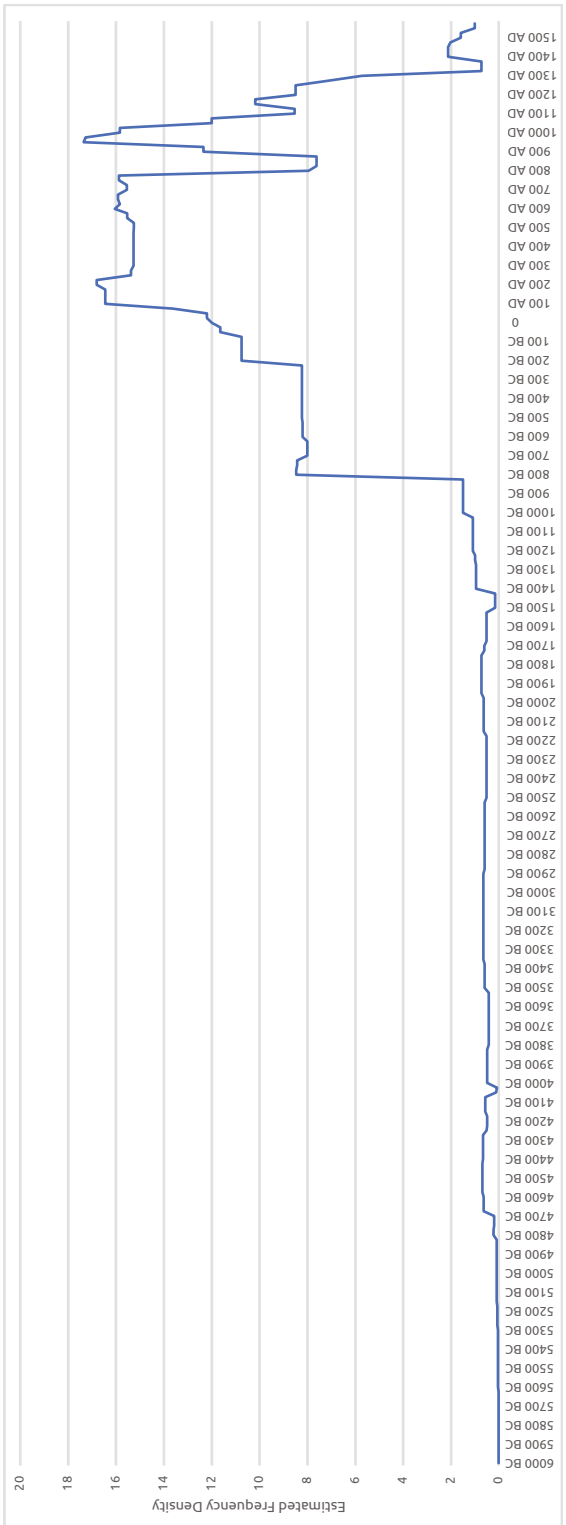
ZooMS

ZooMS was conducted on 35 cetacean specimens (10 from Quoygrew, 2 from Deerness, 17 from Jarlshof, 3 from Freswick Links and 3 from Brough of Birsay). These specimens included a variety of tools and artefacts (including several snecks, pegs, perforated vertebral epiphyseal discs, a chopping block, a plaque and a hollowed out vertebral cup), and also unworked remains (Illus 4). The results (Table 2, Supplementary Tables 2 and 3) of the ZooMS analysis indicate that a wide variety of species were exploited in northern Scotland.

ZooMS analysis revealed that nine specimens belonged to either long-finned pilot whale (*Globicephala melas*), false killer whale (*Pseudorca crassidens*) or Risso's dolphin (*Grampus griseus*). ZooMS is not able to discriminate between these three species, but further analysis based on morphological data may reveal to which of these three species the nine specimens belong.

Another nine remains were identified to represent the bowhead whale (*Balaenidae mysticetus*) or the North Atlantic right whale (*Eubalaena glacialis*). While bowhead whale cannot be ruled out, it is normally restricted to more northern waters, making it likely that these specimens represent North Atlantic right whale. The North Atlantic right whale is currently rarely seen in Scottish waters and can now only be found in the north-western part of the Atlantic. Numbers of this species are dropping rapidly, with ship strikes and entanglements in nets its major threats (Jefferson et al 2008). The archaeological data suggests that this species was once commonly found in Scottish waters, but centuries of whaling activities have rendered it virtually extinct.

Furthermore, the sperm whale (*Physeter macrocephalus*) and the humpback whale (*Megaptera novaeangliae*) were also frequently



ILLUS 3 Estimated frequency data of cetacean remains deriving from Scottish sites

Table 2
ZooMS identification per site for this case study

Family	*Species*	*Quoygrew*	*Deerness*	*Jarlshof*	*Freswick Links*	*Brough of Birsay*	*Total*
Mysticeti	Humpback whale			2	1	1	**4**
	Minke whale		1				**1**
	Grey whale			1			**1**
	Balaenidae sp	5	1	2		1	**9**
Odontoceti	Sperm whale	2		2	2	1	**7**
	Bottlenose/Sowerby's beaked whale	1		1			**2**
	Pilot whale/false killer whale/Risso's dolphin	2		7			**9**
	Bottlenose/striped/common/ white-beaked dolphin			2			**2**
Total		**10**	**2**	**17**	**3**	**3**	**35**

identified. These two species are still occasionally sighted in Scottish waters. Interestingly, just one common minke whale (*Balaenoptera acutorostra*) was identified. This species is now by far the most common large cetacean species in Scottish waters, making the identification of just one specimen of this species intriguing (Jefferson et al 2008).

Moreover, the finding of a grey whale specimen was unexpected (Illus 5). This species is now completely extirpated from the North Atlantic and is only present in the North Pacific. Findings from the southern part of the North Sea are abundant (van den Hurk et al 2020), but this finding from one of the most northern parts of the North Sea suggests that the species was once widely spread in the coastal waters of north-western Europe.

Morphological analysis

Most of the specimens were worked, damaged or weathered, limiting morphological comparison. Morphological comparison with cetacean specimens held at the Smithsonian Institution allowed for optimisation of only three ZooMS identifications (Illus 6).

- Specimen 18, an atlas, identified through ZooMS to be either pilot whale/false killer whale/Risso's dolphin, was identified as a long-finned pilot whale (Illus 7). This identification was based on the specimen being too large to represent the Risso's dolphin, and the transverse process too elongated to represent the false killer whale, while it showed clear similarities with the long-finned pilot whale.
- Specimen 21, a lumbar or caudal vertebral body, identified through ZooMS to be pilot whale/false killer whale/Risso's dolphin, was identified as Risso's dolphin based on morphological comparison with specimens at the Smithsonian.
- Specimen 24, a vertebral epiphysis with a perforation and a diameter of 95.89mm, identified through ZooMS to be pilot whale/false killer whale/Risso's dolphin, was identified as either a long-finned pilot whale or false killer whale, based on the size of the specimen being considerably larger than any adult Risso's dolphin specimen present in the Smithsonian Institution. Unfortunately, no distinction between long-finned pilot whale and false killer whale could be made for this specimen.

Illus 4 Selection of cetacean specimens analysed using ZooMS as part of this study. 1. No. 24 Jarlshof HSA4127 perforated vertebral epiphyseal disc identified to be long-finned pilot whale or false killer whale through ZooMS and morphological analysis; 2. No. 25 Jarlshof HSA4125 perforated vertebral epiphyseal disc identified to be long-finned pilot whale/false killer whale/Risso's dolphin through ZooMS analysis; 3. No. 33 Brough of Birsay HB278 peg identified to be humpback whale through ZooMS analysis; 4. No. 30 Freswick Links IL546 sneck identified to be sperm whale through ZooMS analysis; 5. No. 28 Freswick Links IL545 sneck identified to be sperm whale through ZooMS analysis; 6. No. 29 Freswick Links IL544 sneck identified to be humpback whale through ZooMS analysis; 7. No. 6 Deerness mandible fragment used as chopping block with numerous chop- and cutmarks identified to be common minke whale through ZooMS analysis; 8. No. 32 Brough of Birsay plaque identified to be sperm whale through ZooMS analysis. (© Youri van den Hurk)

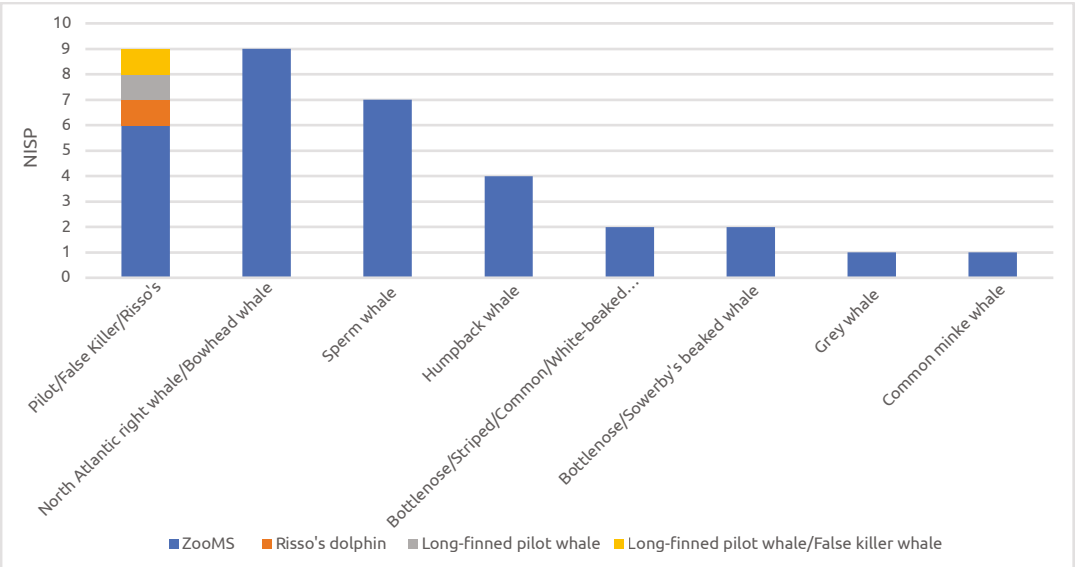
ILLUS 5 Specimen No. 26 Jarlshof HSA 3210 hollowed out thoracic vertebral cup dating to the Iron Age identified to be grey whale through ZooMS analysis. Cut- and chopmarks are present all over the bone, as well as fresh breaks. Orange glue used to glue a small part to the bone again. Both the cranial and caudal side are fused, indicating the specimen was likely an adult individual. Upper left: dorsal side. Bottom left: ventral side. Right: caudal side. (© Youri van den Hurk)

The identifications through the combination of ZooMS and morphological analysis on a temporal scale do not clearly indicate a preference for one species during a particular time period, though some species are more frequently identified than others (Illus 8).

COMPARISON WITH MODERN STRANDING DATA

Stranding data by the Scottish Marine Animal Stranding Scheme (2016) was compared with the zooarchaeological data. Strandings are now often the result of anthropogenic factors such as ship strikes, entanglements in nets or the ingestion of plastic. Furthermore, not all species are prone to strandings. Some of the pelagic species, such as the beaked whales, only strand very rarely (Jefferson et al 2008). Therefore, stranding data should be treated with caution when compared with zooarchaeological data. The stranding data for the years of 2009–10 and 2012–16 were analysed.

The harbour porpoise (*Phocoena phocoena*) is by far the best-represented species in the stranding data, and the most common cetacean species in north-western Europe. Surprisingly, few harbour porpoise remains have been identified from archaeological contexts, which may



ILLUS 6 Number of Identified Specimens (NISP) of the 35 zooarchaeological samples identified using ZooMS. The non-blue specimens were identified through ZooMS as long-finned pilot whale/false killer whale/Risso's dolphin, but subsequent morphological comparison was able to narrow down species identification

reflect harbour porpoise remains being too small for bone-working.

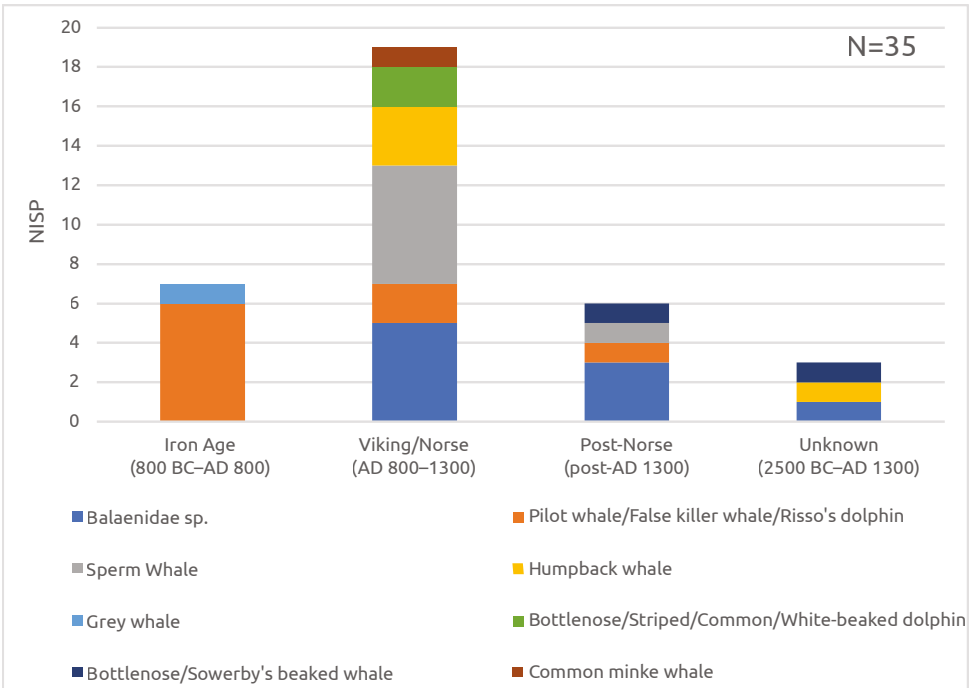
The long-finned pilot whale is the second most common species in the stranding data, followed by several other dolphin species. The high number of long-finned pilot whale remains identified as part of the zooarchaeological assessment might indicate that this stranding frequency was similar in the past. The species is indeed known to mass-strand on occasion, suggesting that the zooarchaeological specimens might derive from stranding events rather than active whaling ventures. Additionally, the osteological remains of long-finned pilot whales are large enough for bone-working and as such might be better represented in the archaeological record than some of the smaller dolphin species (eg common dolphin (*Delphinus delphis*), white-beaked dolphin (*Lagenorhynchus albirostris*), Risso's dolphin (*Grampus griseus*), striped dolphin (*Stenella coeruleoalba*) and Atlantic white-sided dolphin (*Lagenorhynchus acutus*)), which are also strongly represented in the stranding data but not in the zooarchaeological record.

When considering only the baleen whales and the sperm whale strandings (Illus 9) and comparing those to the zooarchaeological data, some interesting trends show up. The grey whale and the North Atlantic right whale are now extirpated from Scottish waters and therefore it is not surprising that these are not represented by strandings data. Especially high numbers of common minke whales strand along the Scottish coastlines, while this zooarchaeological study has only identified one specimen. Sperm whales, and to a lesser extent humpback whales and fin whales, strand frequently as well. The first two species are represented in the zooarchaeological data, but the fin whale is missing. Fin whale has been identified, however, in other sites in north-western Europe, as will be discussed below. Only one sei whale stranding happened for the periods considered and the species has not been identified as part of this study.

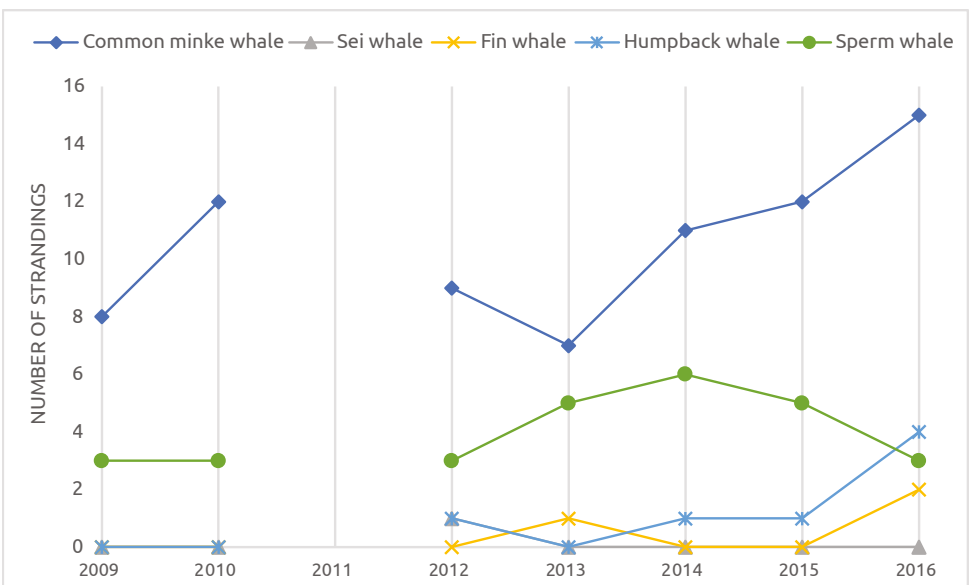
GEOGRAPHIC COMPARISON

Several similar studies using ZooMS have been undertaken in other north-western European

ILLUS 7 Specimen No. 18 from Jarlshof dating to the Norse period, in comparison to the atlas of long-finned pilot whale specimen 504625, false killer whale specimen 593725, and Risso's dolphin specimen 550437, all from the Smithsonian Institution. The arrows for specimen No. 18 and the long-finned pilot whale specimen indicate the position and elongated shape of the transverse processes which clearly indicate the specimen to be long-finned pilot whale. (© Youri van den Hurk)



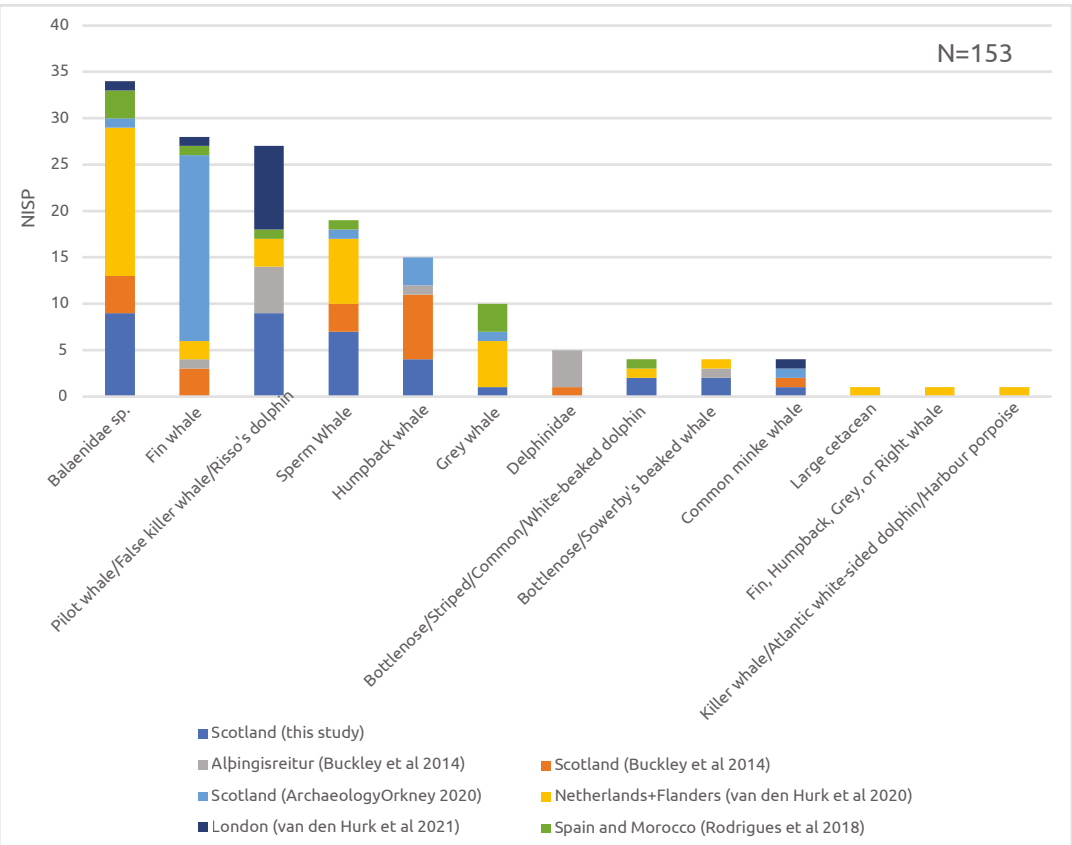
ILLUS 8 ZooMS identifications per period



ILLUS 9 Strandings of large whales in Scotland. Based on Scottish Marine Animal Stranding Scheme (2016) data. No data was available for 2011 and post-2016

regions. These studies have focused on Scotland (Buckley et al 2014; ArchaeologyOrkney 2020; both studies integrated aDNA analysis as well), and also Iceland (also by Buckley et al 2014), Netherlands and Flanders (van den Hurk et al 2020), London (van den Hurk et al 2021) and Spain and Morocco (Rodrigues et al 2018; also used aDNA analysis). Considering solely the ZooMS identifications, these studies reveal that different species were exploited within the various regions (Illus 10). However, this may reflect differing selection of specimens for analysis between studies. ZooMS cannot effectively differentiate between several of the Delphinidae species and some of the above studies might have opted out of selecting small specimens likely to represent Delphinidae remains. As a result, these studies are not conclusive, but some general trends in species representation might still be noted.

From these studies it appears that especially high numbers of Balaenidae sp were identified throughout the various studies. Most of these are most likely North Atlantic right whale (four specimens were confirmed to be North Atlantic right whales based on aDNA analysis (ArchaeologyOrkney 2020, Rodrigues et al 2018)). Furthermore, high numbers of fin whale (though 19 specimens belong to just one individual from The Cairns in Orkney (ArchaeologyOrkney 2020)), sperm whale, humpback whale and Globicephalinae sp were identified. Osteometric and morphological identification on some of the specimens from London confirmed the identification as long-finned pilot whale (van den Hurk et al 2021).



Illus 10 ZooMS identification on cetacean specimens from seven case studies

Nevertheless, there is some variation between the geographic regions. Humpback whales have only been identified for Scotland and Iceland, while sperm whales have been identified for five of the seven case studies. Additionally, Globicephalinae sp remains have only been identified for this Scottish case study and not for the other two, while they were also frequently identified in the other case studies.

Grey whale specimens have been identified in four of the seven case studies. This species is no longer present in the North Atlantic, but their remains originate from various contexts and periods, suggesting that the species might once have been abundant. However, the grey whale, like the North Atlantic right whale and the humpback whale, is a coastal species which potentially might lead to an over-representation in comparison to other more pelagic species such as the rorquals and the beaked whales.

Stranding records from San Diego County, California, USA, from 1851 to 2008, indicate that 80 grey whale strandings occurred, of which 77 were dead strandings and three were live strandings (Danil et al 2010). These numbers are significantly higher than for any of the other large whale species in the region, indeed suggesting that strandings for the species are more common than for other large species. Similar trends have been observed by Pyenson (2010) as part of an assessment of cetacean stranding records in the eastern North Pacific. Industrial whaling endeavours have severely depleted numbers of large whale species in the region during the 19th and 20th centuries, potentially altering stranding trends significantly as well, limiting the conclusions that can be drawn from this data concerning stranding susceptibility per species. Both Danil et al (2010) and Pyenson (2010) noted that strandings peaked during migration periods along its migration route, suggesting this might have been the same for the Atlantic population of the grey whale.

The low number of common minke whales from the other studies is also quite interesting. This species is now the most common baleen whale in north-western Europe (Roman & Palumbi 2003), but only three specimens have been identified as part of the seven case studies. The low number of Delphinidae specimens (excluding the larger Globicephalinae) can likely be ascribed to them less frequently being used for the creation of artefacts or tools, giving them less visibility in the archaeological record. Additionally, the fact that ZooMS struggles to differentiate between the various species may result in them not being incorporated into ZooMS studies.

DISCUSSION

ACTIVE WHALING VERSUS OPPORTUNISTIC SCAVENGING

Based on historical and ethnographic sources, it has been argued that two distinct forms of whaling might have been practised in Scotland. The drive-hunting, like the *Grind*, would have targeted the smaller species such as the Globicephalinae species (especially the long-finned pilot whale), while the spear-whaling form described by al-ʿUdhri would have targeted the Balaenidae species (most probably the North Atlantic right whale, but potentially the grey whale and humpback whale as well). The ZooMS results of this study indicated high numbers of these species were present at archaeological contexts, hinting that both forms were undertaken.

Very few cetacean specimens derive from pre-Iron Age contexts all over Scotland. This suggests that before the Iron Age, only stranded cetaceans were opportunistically exploited. During the Iron Age the number of cetacean remains increased drastically, especially in the Orkney and Shetland Islands. Seven specimens from Iron Age Jarlshof were analysed, of which one specimen was identified as grey whale. This specimen might have been acquired through spear hunting, but since this is the only specimen for this species little can be said regarding the possibility that spear-whaling was already undertaken during the Iron Age period. The other six specimens were identified as Globicephalinae, potentially suggesting that drive-hunting was carried out at Jarlshof during the Iron Age period.

Besides the six Globicephalinae specimens from the Iron Age, another Globicephalinae specimen from a Norse context, two common bottlenose/striped/common/white-beaked dolphin specimens also from Norse contexts, and one northern bottlenose/Sowerby's beaked whale specimen from a Bronze Age-Norse context, have been identified at the site of Jarlshof. All these species are currently targeted by drive-hunting activities in the Faroe Islands (Fielding 2018: 92), which could have been undertaken in Jarlshof as well. The site is located at the very southern tip of Mainland Shetland and oversees a large shallow bay that could be used for driving pods into. Several other bays are also situated near the site and could have been used for drive-hunting activities.

Besides these species, Balaenidae, sperm whale, humpback whale and common minke whale specimens from Norse contexts have also been identified. The zooarchaeological Balaenidae specimens all originate from Norse or post-Norse contexts and have been identified at four of the five sites analysed as part of this study (Freswick Links being the exception). The historical documentation regarding spear-whaling seems to suggest that the Balaenidae were targeted through this whaling technique; therefore the presence of Balaenidae at these sites is consistent with the historical documentation, suggesting it was undertaken from the Norse period onwards. Additionally, the three humpback whale specimens from the Norse contexts from Jarlshof, Freswick Links and Brough of Birsay could also have been acquired through spear-whaling.

While a portion of the zooarchaeological specimens analysed here might indeed have been acquired through either of the two forms of active whaling previously discussed, another possibility is that they derive from stranded individuals that were opportunistically exploited. The sperm whale is known to be aggressive when attacked and the common minke whale is a fast swimming species, and for these reasons these two species were most likely not actively hunted. Specimens of these species primarily derive from Norse contexts as well, potentially suggesting that the Norse relied on a combination of active hunting as well as opportunistic exploitation of stranded individuals. Furthermore, the North Atlantic right whale is known to have been abundant in European waters, and as it is a coastal species that tends to float post-mortem, strandings are more likely to occur for this species than other species (Laist 2017). This might suggest that the specimens identified actually derive from stranded individuals that were opportunistically exploited. Moreover, members of the Globicephalinae subfamily are indeed known to mass-strand (Jefferson et al 2008), and the high number of specimens from this group might be explained by past mass-stranding events.

The zooarchaeological study undertaken at The Cairns (ArchaeologyOrkney 2020) indicated that a large number of fin whale specimens were identified there, while Buckley et al (2014) also identified three fin whale specimens. Interestingly, no fin whale specimens were identified as part of this study, while high numbers of Balaenidae and sperm whale specimens were found, both of which are only represented at The Cairns by just one specimen (ArchaeologyOrkney 2020). Buckley et al (2014) identified four Balaenidae and three sperm whale specimens. This lack of a clear preference for just one species suggests that opportunistic scavenging was undertaken, though this might have varied between regions. Indeed, a huge amount of resources can be extracted from just one carcass, and some communities in the north of Scotland might have relied heavily on these occurrences.

It will remain impossible to distinguish between specimens obtained through active whaling and specimens obtained through opportunistic scavenging. Losey & Yang (2007) came across a humpback whale phalanx with a bone point made of elk (*Cervus elaphus*) bone embedded in it at the site of Par-tee in Northern Oregon. This piece clearly demonstrates that whaling was undertaken in the region, but it is also a very rare find. For other cases it will remain hard to conclusively prove that active whaling was undertaken; however, the combination of zooarchaeological, ethnographic and historical sources certainly

suggests that active whaling was undertaken in Scotland at least during the Norse period.

Mulville (2002) suggested that a greater range of species and proportion of whale bone found at Norse sites indicated a rise in cetacean utilisation, and the data seems to confirm that this was indeed the case. However, following the 11th century, whale bone numbers gradually decreased until the mid-14th century AD, following which far fewer cetacean bone specimens are encountered. It is during this period (11th–14th century AD) that many European cultures performed active whaling, including the Basques, Normans and Flemish (Musset 1964; De Smet 1981; Aguilar 1986; van den Hurk 2020). They likely targeted the North Atlantic right whale on its annual migration route past the west coast of Europe. The decrease in numbers of cetacean bone found in Scotland from the 11th century onwards might be the direct result of whaling activities undertaken elsewhere, causing North Atlantic right whale numbers to plummet along the entire European coastline. This could have led to a cessation of whaling potentially undertaken by the Norse present in Scotland at the time. Another alternative is that fewer North Atlantic right whales stranded on the Scottish coastline as a direct result of a general decline of the population in European waters, making whale bone a less common resource in Scotland.

Indeed, a large number of whale bone specimens analysed using ZooMS as part of this study were identified as North Atlantic right whale/bowhead whale. Specimens derive from contexts post-dating the 14th century as well, indicating that they were likely still present in Scottish waters, but probably numbering fewer than several centuries before.

This period also saw a rise in marine fishing activities in the region and many other parts of Europe as part of the Fish Event Horizon (Barrett et al 2011). Fewer whale bones deriving from the region might attest to a change in reliance on fish over cetaceans. Moreover, the Black Death arrived in the Orkney and Shetland Islands in AD 1350, which reduced the population significantly (Crawford 2013). By extension this led to fewer cetaceans being exploited (either actively hunted or opportunistically scavenged), and to fewer cetacean bones ending up in archaeological contexts.

ARTEFACT AND TOOL PRODUCTION

Just as for many other cetacean remains, the specimens analysed as part of this study were used for the creation of tools or artefacts. Mulville (2002) noted that whale bone was used from the Neolithic onwards for the creation of tools and artefacts, though the high number of remains from the Iron Age and Norse period suggest that whale bone was especially frequently used during those two periods. In particular, bones deriving from large species were used for the creation of artefacts and tools as they provided more raw material. One of the large vertebrae studied herein (identified as a grey whale) was hollowed out in a similar way as a fin whale vertebra from The Cairns (ArchaeologyOrkney 2020). More examples like this are known and were probably used as storage containers or for grinding practices (Mulville 2002). Whale bone appears to have been a sought after raw material until the 11th century AD.

Recent aDNA research on cetacean bone material from the broch of The Cairns, revealed that out of 33 specimens analysed, 20 were identified as fin whale (ArchaeologyOrkney 2020). Furthermore, mitochondrial haplotype analysis indicated that 19 probably belonged to just one individual fin whale. From this, it is clear that a single whale carcass was optimally used during the site's occupation.

This is an intriguing discovery and might suggest that similar situations are the case for other sites. The dozens of cetacean specimens deriving from various Scottish sites might only represent a handful of individuals. Most of the specimens analysed as part of this study were selected from different layers and periods, suggesting they derive from different individuals. However, cetacean bones left at the foreshore by a stranding might be picked up at a later date, potentially even decades or centuries later, to then be used for the creation of artefacts or tools. Thus the remains of a single individual may be found across

several archaeological layers. Furthermore, if cetacean bone was a valued commodity, it may have been traded to other areas or curated for long periods of time. In this way, bone from one individual might end up in other regions. These possibilities can only be confirmed by extensive aDNA analysis and for now remain unclear.

Whale bones from a variety of sites also displayed signs of burning, which might be the result of whale bone being used as a fuel source (Mulville 2002). High quantities of burned whale bone are also known for the site of Gröf, Iceland (Hambrecht & Gibbons 2018) and clearly indicate that its use as a fuel source was widespread.

SPECIES PRESENCE

Besides evidence of cetacean exploitation, the ZooMS data also provides the opportunity to assess which species were present in Scottish waters in prehistoric times. While it is possible that some of the bones were transported to Scotland and actually derive from cetaceans exploited elsewhere, they are still likely to originate from nearby European regions, making it likely that the species observed were present in Scottish waters as well. While the sample size is small, providing limited opportunities to make observations, the data appears to suggest that the Balaenidae (more likely represented by the North Atlantic right whale than the bowhead whale) were still present in early modern Scotland.

Furthermore, the data indicates that the grey whale was present in Scottish waters during the Iron Age, and probably for centuries after. Several specimens from the Netherlands recently proved that the grey whale was present in European waters until at least AD 1200 (van den Hurk et al 2020). As a coastal species, grey whales were potentially within the reach of active whalers; however, it remains unclear whether the grey whale was extirpated from the North Atlantic as a direct result of whaling practices (Rodrigues et al 2018).

The low number of common minke whales showing up in the zooarchaeological record for Scotland is surprising. It is now the most abundant baleen whale species present in Scottish waters, as well as the species that most commonly strands (Scottish Marine Animal Stranding Scheme 2016). Genetic diversity of North Atlantic populations of humpback, fin and common minke whales revealed that historical population sizes were around 240,000, 360,000 and 265,000 individuals, respectively, while current populations number 10,000, 56,000 and 149,000, respectively (Roman & Palumbi 2003). The larger modern population of minke whales could explain the relatively high numbers of modern strandings; however, the historical population numbers do not explain the low numbers of common minke whales identified in the archaeological record. Even though historical population numbers of the fin whale exceed that of the common minke, the humpback whale does not, and yet the archaeological data for humpback significantly exceeds that of the common minke whale. However, the genetic data of the historical population sizes are long-term population numbers and do not necessarily reflect those that occurred right before the onset of industrial whaling endeavours (Roman & Palumbi 2003).

Multiple factors could contribute to the low number of common minke whales recovered from archaeological contexts. A possibility is a preference for the larger bones of the fin and humpback whales for bone-working, but the bones of the common minke whale are also relatively large and would suffice for the creation of artefacts and tools. Another explanation might be found in species selection by whalers. The humpback whale displays a more coastal lifestyle and moves at a slower speed, making it an easier target for whalers. The fin whale, on the other hand, is larger and, in comparison to the common minke whale, would have entailed a more difficult hunt. Fin whale was not identified in this study, but it has been found by other studies focusing on Scotland (Buckley et al 2014; ArchaeologyOrkney 2020).

At this time, it remains unclear why there are low numbers of common minke whales in the archaeological record. More ZooMS analyses might reveal higher numbers of common minke whale remains than have been found so far, and indeed the sample size of this study and the other

studies concerned with Scotland is limited, but aDNA analysis of those specimens is necessary in order to fully assess population shifts through the centuries.

Furthermore, the very low number of small dolphin species identified in the archaeological data stands in contrast to the modern stranding data. This difference might be the result of the smaller bones of dolphins being unsuitable for bone-working and thus not ending up in the archaeological record while the bones of larger whale species, brought to settlements for bone-working, end up over-represented (Mulville 2002). This perhaps suggests that bone-working was the primary reason for exploiting cetaceans, and consumption of cetacean meat was of secondary importance. It is additionally possible that smaller cetaceans were exploited for food, but their bones were not transported to the settlement with the blubber and meat, again leading to their invisibility in the archaeological record. A more extensive analysis of cetacean specimens deriving from multiple contexts might reveal a clearer overview of species exploitation during particular periods, and species presence in Scottish water throughout the centuries.

CONCLUSION

Since Mulville (2002) published her research on whaling in prehistoric and historic Scotland, little attention has been given to the zooarchaeology of cetaceans in Scotland. The groundbreaking new method of ZooMS has offered the possibility to reconstruct early whaling endeavours as never before. As part of this study, ZooMS revealed a diverse range of species being exploited in Bronze Age to post-medieval Scotland. While proving active whaling occurred based solely on zooarchaeological evidence is almost impossible, the zooarchaeological evidence for Scotland, in combination with historical and ethnographic sources, is consistent with the two distinct historically documented forms of Norse whaling.

These two forms include spear-whaling (which probably targeted the North Atlantic right whale) and drive-hunting (which targeted the long-finned pilot whale and other Delphinidae). The large number of Globicephalinae specimens from Jarlshof dating from the Iron Age to the Norse period, as well as the presence of several shallow bays in the area surrounding the site, suggest that drive-hunting was practised at the site. The large number of Balaenidae and humpback whale specimens from several sites, primarily dating to the Norse period, add to the possibility that spear-whaling was undertaken during the Norse period in parts of northern Scotland.

However, even based on these zooarchaeological sources, the suggestion that active whaling was undertaken will remain a hypothesis that might never be fully proven. Whaling might only have been undertaken occasionally or opportunistically. The high number of large whale species present in the zooarchaeological assemblages suggest that opportunistic scavenging was undertaken, and may have been the main source of obtaining cetaceans, as most of the species were probably not within the reach of early whalers. Cetaceans, especially larger species, appear to be primarily utilised for bone-working, though the meat is likely to have been consumed as well.

Moreover, cetacean populations in prehistoric Scotland were probably quite different to present-day populations. Grey whales and North Atlantic right whales once occurred in Scottish waters, but the former have been extirpated from the North Atlantic and the latter might soon follow this fate. The archaeological scarcity of common minke whale specimens is interesting, though more research is needed in order to assess how these low numbers could be explained.

This study has revealed the wealth of information that can be extracted from the identification of zooarchaeological cetacean species in combination with the analysis of historical and ethnographic sources. Further species identification analyses performed on a larger number of archaeological specimens might reveal clear evidence for (or against) active whaling endeavours. Furthermore, the incorporation of aDNA analysis will be needed in order to provide greater detail regarding the poorly understood early whaling practices and the population dynamics of the various species. This could potentially reveal

the impact of early whaling activities on various cetacean populations, most predominantly the North Atlantic right whale and the grey whale.

Supplementary Tables 1, 2, and 3 are available online at https://doi.org/10.9750/PSAS.150.1324

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REFERENCES

Aguilar, A 1986 'A review of old Basque whaling and its effect on the right whales of the North Atlantic', *Report: International Whaling Commission* (special issue) 10: 191–9.

ArchaeologyOrkney 2020 'Whale bone genetics and the extraordinary closure of Cairns broch'. https://archaeologyorkney.com/2020/03/14/whale-bone-genetics-and-the-extraordinary-closure-of-a-broch/.Accessed 19 November 2020.

Barrett, J H 2012 *Being an Island: Production and Identity at Quoygrew, Orkney, AD 900–1600*. Cambridge: McDonald Institute.

Barrett, J H & Slater, A 2009 'New excavations at the Brough of Deerness: Power and religion in Viking Age Scotland', *Journal of the North Atlantic* 2: 81–94.

Barrett, J H, Orton, D, Johnstone, C, Harland, J, Van Neer, W, Ervynck, A et al 2011 'Interpreting the expansion of sea fishing in medieval Europe using stable isotope analysis of archaeological cod bones', *Journal of Archaeological Science* 38(7): 1516–1524.

Batey, C E 1987 *Freswick Links, Caithness: A Re-appraisal of the Late Norse Site in its Context*. Oxford: British Archaeological Reports, British Series 179.

Bradley, R 2007 *The Prehistory of Britain and Ireland*. Cambridge: Cambridge University Press.

Buckley, M, Collins, M, Thomas-Oates, J & Wilson, J C 2009 'Species identification by analysis of bone collagen using matrix-assisted laser desorption/ionisation time-of-flight mass spectrometry', *Rapid Communications in Mass Spectrometry* 23: 3843–54.

Buckley, M, Fraser, S, Herman, J, Melton, N D, Mulville J & Pálsdóttir, A H 2014 'Species identification of archaeological marine mammals using collage fingerprinting', *Journal of Archaeological Science* 41: 631–41.

Clark, G 1947 'Whales as an economic factor in prehistoric Europe', *Antiquity* 21: 84–104.

Crawford, B E 2013 *The Northern Earldoms: Orkney and Caithness from AD 870 to 1470*. Edinburgh: Birlinn.

Curle, C L 1982 *Pictish and Norse finds from the Brough of Birsay 1934–1974*. Society of Antiquaries of Scotland Monograph Series No. 1. Edinburgh: Society of Antiquaries of Scotland.

Danil, K, Chivers, S J, Henshaw, M D, Thieleking, J L, Daniels, R & St Leger, J A 2010 'Cetacean strandings in San Diego County, California, USA: 1851–2008', *Journal of Cetacean Research and Management* 11(2): 163–84.

De Smet, W M A 1981 'Evidence of whaling in the North Sea and English Channel during the Middle Ages', *Advisory Committee on Marine Resources Research Working Party on Marine Mammals, General Papers and Large Cetaceans, Mammals of the Seas* 3: 301–9.

Fielding, R 2018 *The Wake of the Whale: Hunter Societies in the Caribbean and North Atlantic*. Cambridge, MA: Harvard University Press.

Fitzhugh, W 2000 'Puffins, ringed pins, and runestones: the Viking passage to America', *in* Fitzhugh, W & Ward, E (eds) *Vikings: The North Atlantic Saga*, 11–25. Washington DC: Smithsonian Institution Press.

Hambrecht, G & Gibbons, K S 2018 'Whale bone as fuel at an Iceland farm in Early Modern Iceland', *Arctic Anthropology* 55(1): 63–72.

Hamilton, J R C 1956 *Excavations at Jarlshof, Shetland*. Edinburgh: Her Majesty's Stationery Office.

Hufthammer, A K, Arntsen, L, Kitchener, A C & Buckley, M 2018 'Grey whale (*Eschrichtius robustus*) in Norwegian waters 2000 years ago', *Palaeogeography, Palaeoclimatology, Palaeoecology* 495: 42–7.

Hurk, Y van den 2020 *On the Hunt for Medieval Whales: Zooarchaeological, Historical, and Social Perspectives on Cetacean Exploitation in Medieval Northern and Western Europe*. Oxford: British Archaeological Reports, International Series 2998.

Hurk, Y van den, Spindler, L, McGrath, K & Speller, C 2020 'Medieval whalers in the Netherlands and Flanders: zooarchaeological analysis of medieval cetacean remains', *Environmental Archaeology: The Journal of Human Palaeoecology*: 1–15.

Hurk, Y van den, Rielly, K & Buckley, M 2021 'Cetacean exploitation in Roman and medieval London: reconstructing whaling activities by applying zooarchaeological, historical, and biomolecular analysis', *Journal of Archaeological Science: Reports*, 36. *https://doi.org/10.1016/j.jasrep.2021.102795*.

Jefferson, T A, Webber, M A & Pitman, R L 2008 *Marine Mammals of the World: A Comprehensive Guide to their Identification*. London: Academic Press.

Kirby, D P, Buckley, M, Promise, E, Trauger, S A & Holdcraft, T R 2013 'Identification of collagen-based materials in cultural heritage', *Analyst* 138(7): 4849–58.

Laist, D W 2017 *North Atlantic Right Whales: From Hunted Leviathan to Conservation Icon*. Baltimore, MD: Johns Hopkins University Press.

Lindquist, O 1995 'Whaling by peasant fishermen in Norway, Orkney, Shetland, the Faroe Islands, Iceland and Norse Greenland: medieval and early modern whaling methods and inshore legal régimes', *in* Basber, B L, Ringstad, J E & Wexelsen, E (eds) *Whaling and History Perspectives on the Evolution of the Industry*, 17–54. Sandefjord: Kommmandor Chr. Christenses.

Losey, R J & Yang, D Y 2007 'Opportunistic whale hunting on the southern northwest coast: ancient DNA, artefact, and ethnographic evidence', *American Antiquity* 72(4): 657–76.

Mulville, J 2002 'The role of cetacea in prehistoric and historic Atlantic Scotland', *International Journal of Osteoarchaeology* 12: 34–48.

Musset, L 1964 'Quelques notes sur les baleiniers Normands, du Xe au XIIIe siècles', *Revue d'histoire économique et sociale* 42(2): 147–61.

Orton, D C, Morris, J, Locker, A & Barrett, J H 2014 'Fish for the city: meta-analysis of archaeological cod remains and the growth of London's northern trade', *Antiquity* 88: 516–30.

Pyenson, N D 2010 'Carcasses on the coastline: measuring the ecological fidelity of the cetacean stranding record in the eastern North Pacific Ocean', *Paleobiology* 36(3): 453–80.

Rodrigues, A S L, Charpentier, A, Bernal-Casasola, D, Gardeisen, A, Nores, C, Millán, J A P, McGrath, K & Speller, C F 2018 'Forgotten Mediterranean calving grounds of grey and North Atlantic right whales: evidence from Roman archaeological records', *Proceedings of the Royal Society B*. https://doi.org/10.1098/rspb.2018.0961

Roman, J & Palumbi, S R 2003 'Whales before whaling in the North Atlantic', *Science* 301(5632): 508–10.

Scottish Marine Animal Stranding Scheme 2016 *SMASS Annual Report*. https://www.strandings.org/smass/publications/. Accessed 17 March 2020.

Smith, A B & Kinahan, J 1984 'The invisible whale', *World Archaeology* 16: 89–97.

Strohalm, M, Hassman, M, Kosata, B & Kodícek, M 2008 'mMass data miner: an open source alternative for mass spectrometric data analysis', *Rapid Communications in Mass Spectrometry* 22(6): 905–8.

Szabo, V E 2005 ' "Bad to the bone"? The Unnatural History of Monstrous Medieval Whales', *The Heroic Age: A Journal of Early Medieval Northwestern Europe* 8: 1–30.

Szabo, V E 2008 *Monstrous Fishes and the Mead-Dark Sea: Whaling in the Medieval North Atlantic*. Leiden: Brill.

Welker, F, Hajdinjak, M, Talamo, S, Jaouen, K, Danneman, M, David, F et al 2016 'Palaeoproteomic evidence identifies archaic hominins associated with the Châtelperronian at the Grotte du Renne', *Proceedings of the National Academy of Sciences* 113(40): 1162–7.

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