Land and Sea: Understanding Diet and Economies through time in the North Atlantic Islands

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Summary

This thesis explores changes in dietary and economic behaviour through time in the North Atlantic Islands of Scotland, from the Mesolithic-Neolithic transition through to the Norse period. Traditional zooarchaeological techniques are used alongside human and faunal stable isotope analysis to explore past diet of humans and animals. The challenges of integrating these two different datasets and methodologies for enhancing interpretations of these lines of evidence are explored.

A suite of faunal isotopic values though time were generated to characterise animal diets, past husbandry strategies, to provide a baseline to interpret human values, and to understand temporal and geographical variations in isotopic values. Faunal isotopic values indicate that shore front resources were used by past populations, and highlight temporal and geographical differences in management practices and foddering strategies.

Results demonstrated that marine species were not a major aspect of diet in the Neolithic, supporting Schulting and Richards (2002a). In the Bronze Age there is an increase in the quantity of fish bones present within the faunal assemblages in the Western Isles, however they were not being consumed in sufficient quantities to affect the human bone collagen isotopic values. During the Iron Age there is a further increase in the quantity of fish bones present in assemblages in the Western Isles, and evidence of fish consumption in human and pigs. In contrast evidence of marine food consumption in Iron Age Orkney is minimal, indicating divergent dietary and economic practices in place between these regions. During the Norse period fish bones account for high proportions of the zooarchaeological assemblages in both Orkney and the Western Isles, with different species being exploited. Finally comparisons are drawn with island and inland sites in Britain and Europe, exploring how far these dietary and economic practices observed are influenced by localised environmental conditions, and wider social factors.

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Chapter 1: Introduction

The North Atlantic Islands have a long history of occupation, with evidence of settlement in the region from around 6,000 cal. BC onwards (Mithen 2000), leaving behind a rich archaeological record. Archaeological explorations in the islands have been pursued since the late 1800s, and today an extensive archive of zooarchaeological and human remains exists that can inform on past subsistence strategies in the islands. The ecotonal environments occupied by the islands allow access to a diverse resource base including marine species such as fish, birds, sea mammals, and shellfish in addition to domestic and wild terrestrial species. Despite being surrounded by the sea, the use of marine resources by past populations in the North Atlantic Islands has been hotly debated. Recent concerns relating to fishing and fish stock levels in the North Atlantic has increased archaeological interest in understanding the relationship that past societies had with the sea (Bailey *et al.* 2008), and the exploitation of marine and non-marine species.

Traditional models of human subsistence across of the Mesolithic-Neolithic transition in the United Kingdom and Europe suggest that with the onset of farming in the Neolithic there is a shift away from utilising marine resources (e.g. Schulting and Richards 2002a; Tauber 1981), leading Schulting and Richards to the conclusion that the North Atlantic Island populations were "turning their backs on the sea to face the land' (2002a, 155). Previous models suggested that there was a level of fluidity in the dietary behaviour of the Neolithic people of the West Coast of Scotland with populations switching back and forth between using different resources and/or economic strategies (Armit and Finlayson 1996). The next evidence for marine resource use in the islands is marked by the arrival of Scandinavian settlers in the Norse Period, with the 'Fish Event Horizon' (Barrett and Richards 2004). Currently little is known about marine resource use in the interim periods.

The Neolithic marine food avoidance model is based primarily on isotopic evidence and does not fully take into account the zooarchaeological record, with faunal assemblages from the Neolithic and beyond containing evidence of fish, shellfish and sea mammal remains (Milner *et al.* 2004). The presence of marine resources in the zooarchaeological record, compared with the lack of marine signature in the longer term human bone collagen record indicates that there is a discrepancy between these two lines of evidence that needs to be fully explored. Several possible explanations are that marine resources may have been only occasionally used such as in times of famine, as a seasonal resource or as livestock fodder (Schulting *et al.* 2004), all of which would explain the presence of marine species in the zooarchaeological record, without a marine signature being observed in the human bone collagen record.

Extensive research has been conducted into the human stable isotope evidence in the North Atlantic Islands (e.g. Schulting and Richards 2002a, Barrett and Richards 2004; Richards *et al.* 2006; Schulting and Richards 2009; Schulting 2010). To date only limited baselines of local fauna exist despite the importance of faunal stable isotopic evidence for valid interpretation of human values and to learn more about the diet and foddering of animals, past land management strategies and environmental changes.

This thesis integrates traditional zooarchaeological analysis with detailed stable isotope analysis of human and animal remains from across the North Atlantic Islands to explore changes in dietary and economic behaviour through time. This investigation is an holistic study integrating new and pre-existing human and faunal isotopic data, with more traditional zooarchaeological evidence, to understand the relationship between these datasets and to characterise the changing interaction between coastal communities and marine resources through time across the North Atlantic Islands. Comparisons between the constituent groups of the North Atlantic Islands (Orkney, Shetland and the Western Isles) are drawn to understand differences between the island groups. This provides an understanding of cultural variations in dietary behaviour, and resource management, providing an insight into similarities and differences in the subsistence strategies employed across these archaeologically distinct islands.

Using a combination of analytical techniques provides a more thorough understanding of dietary behaviour on several different scales. Isotopic analysis is a direct indicator of diet and represents longer term trends in dietary behaviour (e.g. Ambrose and Norr 1993; Chisholm *et al*. 1982; Lovell 1986). Zooarchaeological remains on the other hand are indirect dietary indicators, and represent a variety of different scales depending on the deposit being analysed, and can therefore be beneficial in understanding long or short term/occasional utilisation of different food sources. This thesis explores the relationship between these datasets, and the challenges and constraints of integrating and interpreting these two methodologies in order to understanding the relative importance of different food sources.

This research is part of a larger NERC funded project ('Changing Patterns of Marine Product Exploitation in Human Pre-History via Biomarker Proxies in Archaeological Pottery' NERC grant Ref.: NE/F021054/1) investigating pottery lipid residues, and is predominantly focussed on the Neolithic through to the Norse Period. The Norse period marks the end point of this investigation as it marks the reappearance of marine foods on a large scale, with fishing on an almost commercial scale, referred to as the 'Fish Event Horizon' (Barrett *et al.* 2004a, 2417). These periods provide the temporal range covered by this thesis.

Following this thesis outline, Chapter 2 provides a short introduction to the North Atlantic Islands, and the environmental niches they occupy followed by a brief history of excavation in the islands, demonstrating the wide variety of research agendas influencing the archaeological record that exists today. This introduces the chronology of the evidence concerned and defines the terminology used throughout this thesis. A summary of zooarchaeological research in the islands is presented in chapter 3 including discussions of analytical techniques previously employed. Past approaches towards quantifying zooarchaeological material and the challenges of combining archaeological datasets iare discussed in chapter 4, followed by an outline of the methodology utilised for the zooarchaeological analysis in this study.

Chapter 5 introduces the principles of stable isotopes $\delta^{13}C$ and $\delta^{15}N$ in dietary investigation, and their use in exploring marine food consumption in the North Atlantic Islands, with particular reference to the Mesolithic-Neolithic transition. The methodological approach towards isotopic sample selection, collagen extraction and analytical processes are discussed in chapter 6, followed by an introduction to interpreting isotopic data in Northern Europe.

The baselines and palaeoenvironmental models comparing $\delta^{13}C$ and $\delta^{15}N$ for each time period and in each island group are presented in chapter 7. Faunal dietary behaviour is explored and discussed in terms of the implications for animal management and foddering strategies. Also potential marine dietary inputs to aid with the interpretation and discussion of human behaviour in the islands and across the island groups are considered. Typical faunal values for each time period are outlined and compared to human isotopic values in chapter 8.

The results of the traditional zooarchaeological analysis are presented in chapter 9, highlighting the key trends identified, and critiquing the methodologies employed. Chapter 10 explores some of the key challenges associated with the utilisation and integration of isotopic evidence and zooarchaeological evidence, providing a discussion of the opportunities and constraints of utilising isotopic data in conjunction with more traditional zooarchaeological techniques, suggesting potential solutions to these challenges.

Chapter 11 draws together all of the isotopic and zooarchaeological evidence to outline the trends in dietary behaviour through time in each island group. The potential explanations for the observed patterns in dietary behaviour and marine resource use are discussed. Broader comparisons between North Atlantic Island marine exploitation patterns, economic strategies, and animal management practices and those observed in mainland and insular environments within Europe and Britain are discussed in Chapter 12.

This thesis concludes by summarising the key observations explored. Areas for potential future research are introduced that may further our knowledge and understanding of trends in the dietary and economic behaviour of past North Atlantic Island populations.

Chapter 2: Introduction to the North Atlantic Island Environments, Sites, and Potential for Dietary Evidence

In this study the term 'North Atlantic Islands' is used as a blanket term to describe the islands situated off the coast of mainland Scotland, encompassing the Northern Isles of Shetland and Orkney, and the Western Isles, also referred to as the Outer Hebrides (Figure 1). The North Atlantic Islands have been affected by combinations of sea level changes and coastal erosion, resulting in the exposure and the destruction of various archaeological sites (Hansom 2005; Ashton 1993). These processes have resulted in great opportunity for excavation and exploration of Scottish Island archaeology.

This chapter provides a brief introduction to the geological and environmental characteristics of Orkney, Shetland and the Outer Hebrides, before introducing a brief history of archaeological exploration in the islands. The chronology of archaeology in the islands, and the characteristic archaeological traits of each period are presented, before introducing some of the key sites utilised in this thesis for zooarchaeological analysis and stable isotope analysis

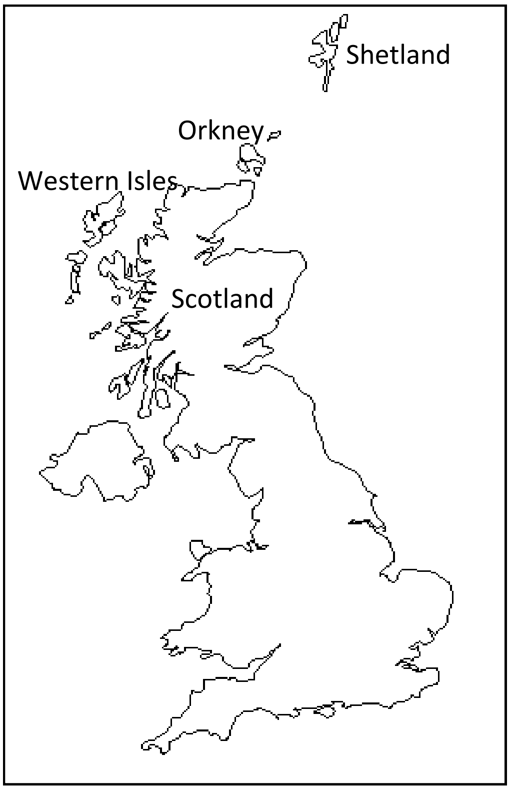


Figure 1: Map showing Britain and the North Atlantic Islands
(Map base: WWW1)

This thesis is centred predominantly on the Outer Hebrides, Shetland and Orkney. The Inner Hebrides have not been a major focus of this investigation due to the poor quality of bone preservation in the islands caused by limited shell sands, and lack of major archaeological works in this island group. This research only briefly refers to the Inner Hebrides of Scotland, particularly in relation to Mesolithic, as the Oronsay middens represent the largest body of evidence for the Mesolithic in the North Atlantic Islands.

The North Atlantic Island Environments

The economic strategies employed by North Atlantic Island populations both in the past and in the present are heavily dependent on the localised environments, influenced by factors such as weather conditions and geographical constraints. These can heavily influence the crops that can be grown, and the animal management strategies that can be employed. These environments offer a wide range of wild and domestic resources. Having an appreciation of the environmental histories experienced by past populations is crucial in understanding the subsistence strategies selected by these coastal communities.

There are commonalities in the environments of the North Atlantic Islands in terms of topography, weather, climate and tree cover. Glaciation has played a major role in the formation of the geological environments observed in the North Atlantic Islands today (Reed 1989). Machair, a light shell sand formed from a combination of crushed shell fragments and glacial activity, covers large swathes of the Outer Hebrides and Orkney. Machair stretches across the 120 km stretch of the West Coast of the Outer Hebrides, forming landscapes of dunes, sand plains and sand hills (Mate 1992; Ritchie 1979; Ritchie and Whittington 1994, 40). Today the coastal areas of Mainland Orkney are typified by grass sward with limited areas of overlying machair deposits (Donaldson *et al.* 1981). Peat is a common feature in the islands dating back to around 8,300BP (Ritchie 1985), and is commonly used in the islands today as a valuable source of fuel in the absence of wood supplies from trees. The machair environments therefore provide calcareous environments in the islands, with peat providing richer, more humic conditions.

Trees are scarce in all of the Scottish Islands today. Tree cover in Orkney is suggested to be stunted by the high salt content of the prevailing winds (Ballin Smith 1994, 2), a factor contributing to the lack of general vegetation across the North Atlantic Islands. Similarly foliage in the Western Isles is limited to small numbers of shrubs and small trees (Parker Pearson *et al.* 2004), and few trees exist in Shetland today (Bennett *et al.* 1992). Archaeologically tree cover was more prolific in the Neolithic period, but a decline in woodland in the Western Isles is observed during the 5th millennium cal. BC, and by around 2,500 cal. BC the islands are virtually treeless, resulting from factors relating to climate change and human activity (Lomax 1997, 242), leaving behind the conditions that we observe today.

Whilst there are similarities between these island groups, there is environmental variability in terms of local geology, soil type, and pH, influencing the plant and animal resources available to the populations living on the islands. In relation to the archaeology these environmental differences impact on the preservation of archaeological bone remains within sites. Differences in soil types between the islands have the potential to alter the isotopic values of plants between the island groups, subsequently influencing any consumers of these products. The differences in environmental conditions also may have implications for the palaeoenvironmental δ^{13}C and δ^{15}N values observed in archaeological animal and human specimens, emphasising the need to consider each island group individually, in addition to drawing broader comparisons.

Orkney

Orkney is an archipelago of roughly 70 islands, of which 20 are currently inhabited (Haswell-Smith 2004; Wickham-Jones 2007). The geology of Orkney is mainly Middle Old Red Sandstone, with igneous outcrops, and occasional sequences of metamorphosed rock (Wainright 1962, 5). The soil pH of Orkney is generally between 5.4-5.7 (Berry 1985), conducive to relatively good bone survival (Gordon and Buikstra 1981). Gently rolling hills account for the main topography of the islands, with the larger hills being present in West Mainland, Rousay and Westray (Reed 1989).

Agricultural land accounts for approximately half of the current day land surface (Bailey 1971). The other key ecological zones in Orkney are mainly machair, fens, and valleys with herbaceous plants being strongly represented (Bullard and Goode, 1975). Palynological evidence from soil profiles sampled from Mainland Orkney (e.g. Bunting 1994; Keatinge and Dickson 1979; Moar 1969) suggest that there were very low quantities of trees and shrubs throughout prehistory, and wooded areas of Orkney would have been limited in scope.

Shetland

Shetland is an archipelago of over 100 islands, 16 of which are currently inhabited, situated roughly 27 miles north of Orkney (Sharples 1998). The complex geology of Shetland is reflected by a series of metamorphic rocks, creating steep sided valleys in central and east Mainland (the largest island); coupled with more expansive, open topography in the western region of Mainland (Mykura 1976). Bands of limestone also exist in the islands, producing areas of more fertile soil (Wainwright 1962, 5), in addition to swathes of Old Red Sandstone

(Mykura 1976). Soil is highly variable in Shetland, reflecting the diverse geological history of the islands, with pH neutral soils on the valley floors, combined with acidic peaty soils predominating on the valley sides (Dry and Roberts 1982). Acidic soils are detrimental to bone preservation, resulting in faunal remains being under represented and poorly preserved at some of the Shetland sites (e.g. Scord of Brouster). Peat deposits cover much of Shetland, with plant species such as heather, sedges, and grasses providing rough grazing for sheep (Hulme 1980).

The Western Isles

The Western Isles, or the Outer Hebrides as they are also known, are an archipelago of approximately 50 islands, 15 of which are currently inhabited. The principal islands include Lewis, Harris, North Uist, South Uist, Benbecula, Barra and Berneray. Geology is less varied than observed in Shetland, Lewis and Harris being predominantly composed of Lewisian Gneiss, with areas of sandstone in North Eastern Lewis (Parker Pearson and Smith 2012, 1). The landscape of the Outer Hebrides ranges from undulating valley systems in Lewis and Harris, to mixed machair and mountain environments in the Southern Islands (Parker Pearson and Smith 2012, 1).

The low pH of the machair acts to neutralise the acidic qualities of the Hebridean soil (Henley 2005, 325), providing more favourable conditions for the preservation of archaeological bone specimens, but it is not optimal for successful crop cultivation. Machair soils are generally deficient in nitrogen, phosphate, potash, copper and manganese, and have low capacity to hold water (Smith 2012, 379). The fragile machair is heavily susceptible to wind erosion, reducing its suitability for agricultural purposes (Smith 2012, 379). The vegetation represented in the Outer Hebrides is said to be typical of insular environments (Boyd and Boyd 1990). There is a relatively low range of species represented in the Outer Hebrides, which is potentially a product of low habitat diversity resulting from unfavourable soil conditions and the effects of humans on the environment (Parker Pearson and Smith 2012, 1).

A Brief History of Archaeological Excavation and Exploration in the Islands

The North Atlantic Islands have a long history of occupation, dating back to the Mesolithic, and have been a popular focus of archaeological excavation, resulting in a vast wealth of archaeological information pertaining to this region. As with most geographical regions, biases exist in the choice of archaeological sites excavated in the North Atlantic basin resulting from different approaches to answering archaeological questions, and personal research interests (Bailey *et al.* 2008), directly affecting the archaeological information available.

Orkney

Orkney has a rich archaeological heritage. One of the earliest recorded archaeological explorations was undertaken in 1868 by William Watt, the Laird of Skaill, at the site of Skara Brae, who cleared out four houses, and removed a wealth of artefacts (Clarke and Maguire 1989). Other early recorded explorations include excavations undertaken at the site of Earl's Bu, which recovered a Viking comb, and revealed a structure consistent with a drinking hall described in the Orkneyinga saga (Johnston 1903).

More formal excavations in Orkney were undertaken from the late 1920s, under the instruction of the Ministry of Works (now known as the 'Department for the Environment, Food and Rural Affairs'), who were responsible for undertaking archaeological research at a range of sites across the North Atlantic Islands during this period. The site of Skara Brae was explored by the archaeologist V. Gordon Childe during 1928-1930 erroneously interpreting the site as being a 'Pictish Village' (Childe 1931), before further research revealed the site to be Neolithic in origin (Childe 1950). Similarly the first excavations at Knap of Howar resulted from initial explorations by William Trail, the landowner revealing evidence of a house at the site (Traill and Kirkness 1937).

Rescue work and land development underpin several of the larger excavations in Orkney such as the more recent excavations at Skara Brae conducted by Clarke (1976) following the exposure of stone work as a result of storm activity. Similarly the excavations at Howe between 1978 and 1982 were undertaken in advance of developing the land for agricultural use (Hedges *et al.* 1979).

More recent large scale research excavations have been undertaken in Orkney, providing a wealth of archaeological evidence relating to prehistoric activity in the islands. The large research excavations during the 1980s at the multi-period sites of Tofts Ness and Pool have provided valuable chronological spans at sites to be achieved and are invaluable in determining the extent of continuity and change in dietary behaviour within a localised geographical area (Dockrill 2007; Dockrill and Bond 2009). Currently research excavations are being undertaken in Orkney, such as the Neolithic settlements of Ness of Brodgar (Nick Card, Orkney College) and Links of Noltland (Historic Scotland) which when published will provide a valuable insight into the Neolithic people living in Orkney. New archaeological data are being generated continually, which have the ability to change perceptions of archaeology in the islands.

Shetland

Some of the earliest known excavations in Shetland were also Ministry of Works projects, such as the initial excavations exploring the Bronze Age phases at Jarlshof, carried out in 1937 (Childe 1938). During the 1950s substantial excavations in Shetland were undertaken through the Ministry of Works such as the excavations at Clickhimin Broch undertaken between 1953 and 1957 (Hamilton 1954; 1968), in addition to exploration of the Iron Age and Norse phases at the site of Jarlshof (Hamilton 1956).

Expansion and development in Shetland have been the impetus for further investigations in the 70s and 80s, such as the large scale excavations to facilitate the construction of Sumburgh Airport in 1967-74 (Downes and Lamb 2000), and the excavations at Kebister in 1985 in advance of the construction of an oil rig supply base (Owen and Lowe 1999). Other rescue investigations in Shetland include the projects exploring the Iron Age settlement and Medieval cemetery at Scalloway (Sharples 1998).

Research excavations started to become a focus of archaeological research in Shetland during the 1970s and 80s, such as undertaken at the Norse settlement at Biggins, Papa Stour by Crawford during the late 1970s (Crawford and Smith 1999), and the explorations at the Neolithic settlement of Scord of Brouster between 1977-79 (Whittle *et al.* 1986). Recently research projects have been undertaken by teams at Bradford University exploring Mesolithic occupation at West Voe (Melton and Nicholson 2004), and excavations of the settlements at Old Scatness and Jarlshof exploring Iron Age and Norse occupation in the island group (Dockrill *et al.* 2010) to create tourist attractions in the area. A range of archaeological sites have been explored in Shetland. Unfortunately poor bone preservation due to soil acidity has resulted in few zooarchaeological assemblages having been analysed and published.

Outer Hebrides

The rich and diverse archaeological heritage of the Outer Hebrides has been the focus of archaeologists over the past 30 or so years. This has resulted in intensive archaeological investigations in the islands in the form of both large multi-site research projects, and smaller scale excavations of individual sites.

The earliest excavations in the islands were undertaken by Erskine Beveridge between 1897 and 1920, resulting in the excavation of 19 sites in North Uist being undertaken, with additional survey and place name studies. These investigations were swiftly followed by further excavations focusing on later prehistory conducted by Sir Lindsay Scott (Sharples 2012, 8). Excavations undertaken prior to the creation of a rocket range by the Ministry of Works in the late 1950s revealed a wealth of archaeological sites (Sharples 2012, 10). Excavations at the Iron Age settlements at A'Cheardach Mhor (Young and Richardson 1960) and A' Cheardach Bheag (Fairhurst 1971) extended our knowledge and understanding of Iron Age archaeology in the North Atlantic Islands.

Excavations at the multi period site at the Udal were conducted by Ian Crawford between 1963 and 1995. The Udal provided a broad chronological spread of archaeological material from the Neolithic period through to the Post-Medieval period. To date few publications relating to the excavations at the Udal exist (e.g. Crawford 1986; Crawford and Switsur 1977), and much of the archaeological evidence remains unanalysed. Plans are currently underway to undertake extensive post excavation work on the Udal excavation archive (Ballin Smith pers. comm.).

The Neolithic to Iron Age site of Northton, excavated between 1965 and 1966 provided a valuable insight into the first farming communities of the Outer Hebrides, an area currently under-represented in the archaeological record (Simpson *et al.* 2006), providing a vast zooarchaeological dataset for inclusion in this project (Finlay 1984).

Over the past 30 years the SEARCH (Sheffield Environmental and Archaeological Research Campaign in the Hebrides) and derivative projects enabled survey and excavation of a wide range of archaeological sites in the Outer Hebrides including sites on Mingulay, Barra and Pabbay (Branigan and Foster 2000), Late Iron Age and Norse Bornais (Sharples 2005; 2012; forthcoming) Iron Age Dun Vulan (Parker Pearson and Sharples 1999), Cille Donnain (Parker Pearson *et al*. 2012), and Bronze Age Cladh Hallan (Parker Pearson forthcoming). The SEARCH research has provided a wealth of valuable archaeological data spanning through time, centred on the island of South Uist.

The wealth of archaeological research in the Outer Hebrides has resulted in a wide chronological spread of archaeological sites having been excavated, producing a large quantity of data available for analysis. The quality of the data collected is highly variable, and the bulk of zooarchaeological information for the Western Isles comes from the more recent excavations where sampling strategies and analytical procedures were designed to enhance the quality of the archaeological data.

Summary: Excavations in the North Atlantic Islands

Archaeological investigations in the North Atlantic Islands have been conducted over a long chronological period. There have been a range of different motivations behind these investigations being conducted including commercial development, rescue work, and research excavations. The temporal and geographical spread of sites investigated is heavily influenced by factors such as personal research interests of the site directors conducting the excavation, visibility of the archaeological record, funding availability, and accessibility of sites. These differences in the focus of excavation projects has resulted In differential representation of temporal periods between the islands, in addition to disparities in the archaeological evidence available for these sites.

North Atlantic Island Archaeology and Potential for Dietary Evidence

The following section takes a chronological approach towards outlining the archaeology of the islands, identifying sites suitable for palaeodietary reconstruction and baseline isotopic modelling. A list of sites, and their locations within Orkney (Figure 4 and Table 1), Shetland (Figure 5 and Table 2) and the Outer Hebrides (Figure 6 and Table 3), is provided at the end of this chapter.

Mesolithic (c.10, 000 cal. BC- 4,500 cal. BC)

Mesolithic occupation in the islands, as in mainland Britain, is notoriously difficult to locate, with few sites having been identified due to the fragile nature of hunter-gatherer camps (Mithen 2000; 2001; Wickham-Jones and Firth 2000). The mobile nature of Mesolithic hunter-gatherer fisher communities has resulted in low archaeological visibility of these populations (Armit 1999). Locating the Mesolithic in the Northern and Western Isles is further reduced by a range of factors further obscuring the scant archaeological evidence such as coastal erosion and the formation of peat (Warren 2005, 11), in addition to human impact from thousands of years of occupation such as cultivation of land and drainage (Armit 1999, 24). A major feature contributing to the lack of visibility of the Mesolithic in the islands is isostatic sea level change, resulting in the submergence of coastal Mesolithic sites in the islands (Phillips 2004; Saville and Wickham Jones 2012). Palynological evidence has demonstrated a Mesolithic presence in the Outer Hebrides, Orkney and Shetland (Edwards 1996; 2000; Edwards and Mithen 1995), but Mesolithic sites are rare. The Mesolithic therefore plays a rather elusive role in North Atlantic Island history.

Archaeological evidence for the Mesolithic period in Orkney is extremely limited, although some artefactual evidence of these hunter gatherer populations has been recovered (Saville 2000; Wickham-Jones and Firth 2000). Projects such as the Aberdeen University ‘The Rising Tide: Submerged Landscape’ project, exploring submerged Mesolithic evidence in Orkney (Bates *et al.* 2010), are working to improve current knowledge of Mesolithic Orkney.

The Mesolithic in Shetland is restricted to the site of West Voe in Sumburgh, where shell middens dating to the Late Mesolithic/Early Neolithic were identified (Melton and Nicholson 2004). This is the only tangible evidence of Mesolithic in the Shetland. Unfortunately zooarchaeological reports from West Voe were not available for study in this thesis.

As for Orkney and Shetland, archaeological evidence for Mesolithic activity in the Outer Hebrides is limited. Recent excavations at Teampuil Bágh, Northton, on the Isle of Harris have revealed evidence of Mesolithic deposits (Blake *et al*. 2011a; Bishop *et al*. 2010). Similarly investigations at Tràigh na Beirigh on Lewis also demonstrated evidence of a Mesolithic shell midden containing a wealth of environmental evidence (Blake *et al*. 2011b), but these sites form an as yet unpublished research project into the Hebridean Mesolithic.

Unlike Orkney and the Western Isles where many Mesolithic sites are submerged due to isostatic sea level change, there is a greater archaeological visibility of Mesolithic activity in the Inner Hebrides. The Oronsay middens, of Caisteal nan Gillean II, Cnoc Sligeach, Cnoc Coig and Priory Midden, located in the Inner Hebrides represent the largest body of evidence for Mesolithic occupation in the islands (Mellars 1987), and are part of a larger landscape of Mesolithic sites across the island group (Mithen 2000; 2001). Human remains from these sites were studied isotopically, and were a major component in the famous Mesolithic-Neolithic marine food consumption debate (Richards and Mellars 1998; Schulting and Richards 2002a). The Oronsay middens have a combined zooarchaeological assemblage size of around 800 identifiable bone fragments (Grigson and Mellars 1987). Unfortunately poor bone preservation limits the zooarchaeological information available, within the Mesolithic Inner Hebrides. Mesolithic evidence at present is generally scarce, aside from intermittent shell midden accumulations, which are not necessarily representative of Mesolithic dietary behaviour.

Neolithic (c. 4500 cal. BC-2500 cal. BC)

Evidence for the Neolithic occupation in the islands is more accessible than the Mesolithic evidence, partially due to the more permanent nature of the settlements occupied by these populations. The Neolithic period in the North Atlantic Islands is characterised by several distinct archaeological features including settlements (e.g. Skara Brae; Ness of Brodgar, Knap of Howar), chambered tombs (e.g. Maeshowe; Quanterness, Bharpa Langais), and monuments (e.g. Ring of Brodgar, Callanish).

Orkney contains a wealth of Neolithic archaeology, as demonstrated by the World Heritage site status awarded to the 'Heart of Neolithic Orkney'. Excavations at the settlement site of Skara Brae (Figure 2) in the 1970s produced a large collection of zooarchaeological remains available for stable isotope analysis. Unfortunately the mammalian data from the site have not been published and are not publically available, preventing this information from being included in further dietary investigations, but fish, shellfish and bird bone information were all available as part of the MARES database (Cerón Carassco *et al.* 2006). The settlement at the Links of Noltland during 1980s provided a wealth of faunal remains from this period (Armour Chelu 1992), and current excavations at the site yield extensive assemblages for future dietary and economic analysis. Similarly assemblages at Knap of Howar (Noddle 1983), and Pierowall Quarry (McCormick 1984) yielded zooarchaeological data for dietary reconstruction. Excavations of the Neolithic settlement at the Ness of Brodgar are currently being undertaken, and a small sample of bones from this site were available for isotopic analysis, but the faunal remains from this site are yet to be fully recorded, therefore preventing them from being included in this study.

Figure 2: Neolithic Settlement of Skara Brae, Orkney

Neolithic tombs are fairly common in Orkney, and collections of skeletal remains from Quanterness (Schulting *et al.* 2010), and Holm of Papa Westray (Schulting and Richards 2009) have been the subject of δ^{13}C and δ^{15}N isotopic analysis. Faunal assemblages in the tombs are highly varied in terms of the deposits that they represent, with many assemblages having accumulated as a result of non-human processes; for example otter spraint was highly prevalent in the tomb at Holm of Papa Westray (Harland and Parks 2009). Faunal remains found in tombs are not necessarily representative of dietary behaviour of the populations interred within the tombs, as bone accumulations could relate to more recent events.

There is little evidence from the Neolithic economies in the Shetland archives due to poor bone preservation; for example the entire zooarchaeological assemblage from the Scord of Brouster consisted of only 112 highly fragmented animal bones, of which only 18 were identifiable to species level (Noddle 1986). On further examination the preservation of the Scord of Brouster faunal remains was not conducive to collagen survival, and these bones were not suitable for stable isotope analysis. One human arm bone was recorded in the Scord of Brouster assemblage (Noddle 1986), but the rarity of the specimen and the fragile nature of the bone as a result of poor preservation meant that the destructive sampling of this specimen for isotopic analysis was not appropriate.

Neolithic sites in the Western Isles are less commonly represented. The multi period site of Northton contained faunal remains dating back to the Neolithic (Simpson *et al.* 2006; Finlay 1984), and provides the most coherent faunal dataset for the Western Isles. The Neolithic sites of Eilean Domhnuill (Armit 1986) contained low quantities of Neolithic faunal remains, but preservation of the bones was poor, and the remains are highly fragmented. Excavations at Loch a’ Choire provided evidence revealed an additional Neolithic settlement on South Uist, but no faunal remains were present at this site (Henley 2012). The same is true for the Neolithic settlement of Eilean an Tighe (Scott 1951), with pottery and lithic fragments dominating the archaeological record at the site. Neolithic dietary evidence for the Outer Hebrides is generally limited in scope in comparison to the wealth of evidence available from Orkney.

Beaker Period (c. 2500 cal. BC-1700 cal. BC)

North Atlantic Beaker period sites to date have only been identified in the Outer Hebrides, and are characterised by the presence of pottery vessels, with elaborately decorated surface designs such as zigzags and banded patterns (Parker Pearson *et al.* 2004, 45). Beaker period houses and settlements are rare, and many of those found in the Outer Hebrides were excavated during a time when rigorous landscape surveys were undertaken, raising their visibility in the archaeological record (Parker Pearson *et al*. 2004, 48). Many of the Hebridean Beaker period settlements are generally situated on the machair, in locations that continue to be used as village locations over the following two millennia (Parker Pearson *et al.* 2004, 49). Beaker period phases of occupation were identified at several different sites. The site of Northton held the largest Beaker period assemblage with around 800 bone fragments present (Finlay 1984; Simpson *et al.* 2006). The zooarchaeological specimens from Northton were well preserved, and therefore provided good isotopic sampling opportunities. Beaker Period zooarchaeological data were also available from Udal North, Rosinish and Sligenach in the

Uists, but the assemblages are limited in size. There is little existing dietary evidence for the Beaker period, however the limited assemblages available provide only a glimpse into dietary practices at that time.

Bronze Age (c. 1700 cal. BC-600 cal. BC)

The nature of the Bronze Age of the North Atlantic differs between the island groups. Structures excavated in the Orkney and the Western Isles take the form of stone built circular houses (e.g. Tofts Ness and Cladh Hallan), whereas Late Bronze Age settlements in Shetland, such as at Jarlshof, are cellular in design (Sharples 2012, 16). The differences between the structures suggest that there are differences between the lifestyles of the populations living in these islands, which could potentially be manifested in variations in dietary behaviour.

Bronze Age dietary evidence from Orkney is represented by three different sites. The multi period settlement of Tofts Ness held the largest corpus of Bronze Age zooarchaeological data, containing over 3,000 animal bone fragments. Smaller scale assemblages at Point of Buckquoy (Noddle 1996-1997), Skaill (Deerness; Noddle 1997), and Bay of Moaness (Buckland *et al.* 1997) also contribute to the Bronze Age zooarchaeological dataset, providing a greater insight into dietary behaviour during this period.

Whilst there are Bronze Age phases represented at Jarlshof in Shetland (Hamilton 1956), the zooarchaeological assemblages from this site have not been published, therefore dietary evidence for Bronze Age Shetland was not available.

The Bronze Age in the Western Isles is predominantly represented by the site of Cladh Hallan in South Uist. The site of Cladh Hallan was extensively excavated and sampled as part of the SEARCH project, producing around 20,000 animal bone fragments (Mulville and Powell forthcoming a). The preliminary zooarchaeological analysis from the evaluations at Udal North (Serjeantson n.d.) provided a zooarchaeological assemblage of around 700 fragments. The other major collection of Late Bronze Age faunal remains from the Outer Hebrides is represented by approximately 2000 fragments from the excavations at Baleshare (Halstead 2003). In terms of human skeletal remains analysed for isotopic analysis 6 bones from the two composite individuals from Cladh Hallan were sampled for isotopic analysis (Parker Pearson 2005). A small number of Bronze Age animals from the site of Cladh Hallan have also been sampled (Craig *et al. 2005*) as part of a wider project investigating the role of milk in the islands.

Iron Age (c.600 cal. BC-900 cal. AD)

The Iron Age in the North Atlantic is characterised by monumental stone houses with distinctive architectural features (Sharples 2003). Wheelhouses and brochs (elaborate roundhouses) are scattered across the North Atlantic landscape, resulting in the Iron Age being well represented in the archaeological record in Orkney, Shetland and the Western Isles. The Scottish Iron Age is divided into three periods of Early (c. 600-200 cal. BC) Middle (200BC-400 cal. AD) and Late (c.400AD-900 cal. AD) based on differences in architectural design, and pottery style, combined with dating of archaeological structures (Sharples 2012, 16-18). A thorough discussion of characteristic features of the Early, Middle and Late Iron Age in each island group is given by Sharples (2012, 16-20). Brochs begin to emerge in the first millennium cal. BC, and as they are contemporary with less complex wheelhouses and round houses, they are said to be hierarchical structures (e.g. Parker Pearson *et al.* 2008), although this hypothesis is contested (Armit 2005). Brochs are present in Orkney (e.g. Broch of Gurness), Shetland (e.g. Mousa, Figure 3) and the Outer Hebrides (e.g. Dun Vulan), alongside wheel houses and Atlantic round houses. The hierarchical societies presented by Iron Age architectural evidence in the North Atlantic Islands present interesting questions in terms of diet and status, and whether this is possible to identify within the faunal assemblages and stable isotope evidence.

Burial practices in the North Atlantic Iron Age, as observed in mainland Britain, are less formal than the inhumation burials observed in Neolithic, and fragmentary human remains are frequently identified in domestic refuse deposits (Armit and Ginn 1997; Shapland and Armit 2012). Human remains from Iron Age North Atlantic contexts have been identified as cultural objects, for instance, such as perforated cranial fragments and femoral heads (Shapland and Armit 2012). Fragmentary remains buried in domestic contexts could reflect possible ancestor veneration, or could simply be a normal funerary practice within the local population, or alternatively these individuals were outsiders and body parts were utilised as trophies (Armit and Gin 1997), all of which may impact on observed dietary behaviour of these individuals.

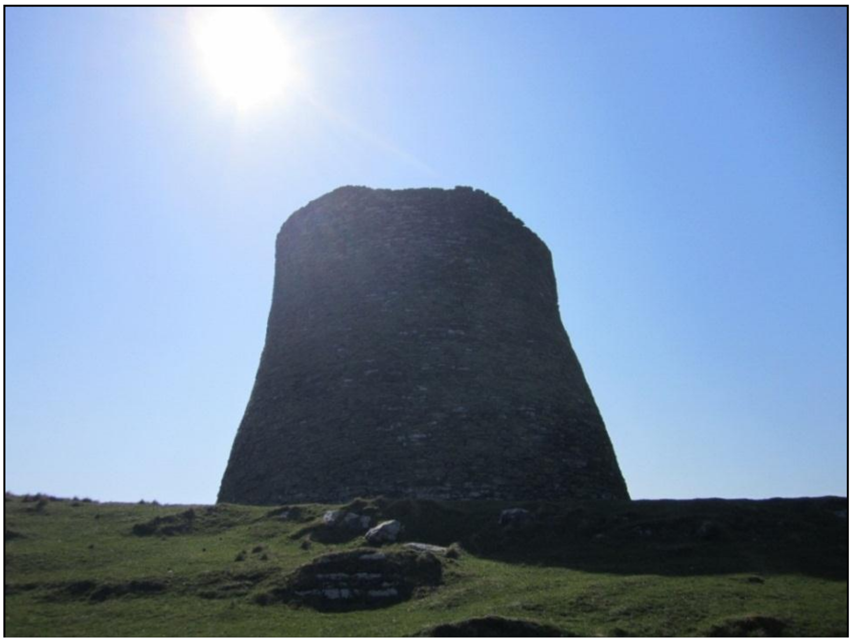


Figure 3: The Iron Age Broch at Mousa, Shetland

Radiocarbon dating of the Iron Age has enabled some good site chronologies to be achieved, but the dating at many archaeological sites is not sufficient to enable a greater temporal resolution within the assemblages. Many sites therefore had to be assigned to the umbrella term 'Iron Age' when this information was not known. Generally Iron Age sites are well represented in each of the North Atlantic Islands.

There are numerous Iron Age sites represented in Orkney. The Iron Age in Orkney is also well represented. The multi period sites of Tofts Ness (Nicholson and Davies 2007) and Pool (Bond 2007) provide a wealth of data for the Iron Age, with well-preserved bone archives available for isotopic sampling. Zooarchaeological data from multi period sites can provide a useful insight into the changing economy through time within a localised area. The site of Howe generated a vast quantity of data spanning through the Early, Middle and Late Iron Age, providing a thorough chronology of dietary evidence. Isotopic values of Iron Age humans were available from Lingro and Icegarth (Shapland and Armit 2012; pers. comm.). The recently excavated site of Knowe o' Skea presented good isotopic sampling opportunities, although published zooarchaeological data for this site do not currently exist.

In Shetland excavations at Old Scatness undertaken by Bradford University from 1995 onwards provided an insight into Iron Age economies. The first volume has been published, providing zooarchaeological data from the Iron Age and Norse Period for use in dietary reconstruction (Cussans and Bond 2010). The other major Iron Age site with zooarchaeological evidence available from Shetland is the site of Scalloway excavated by Niall Sharples in 1989-1990 (Sharples 1998). The Scalloway faunal remains were well preserved, making them available for isotopic analysis. A small bone assemblage from St Ninian's also provided sampling opportunities, but the data were not formally published. One Iron Age individual from Jarlshof in Shetland was radiocarbon dated by Shapland and Armit (2012). Two Late Iron Age individuals from Scalloway had previously been radiocarbon dated, but these individuals did not yield usable carbon and nitrogen values. Further Iron Age human remains from Shetland were not available for analysis.

In the Outer Hebrides the SEARCH campaign is responsible for the excavation and recovery of a wealth of Iron Age material. The site of Bornais presents a large dataset pertaining to the Late Iron Age occupation at the site (Mulville and Powell 2012). Numerous wheelhouses in the Outer Hebrides have been excavated, such as Sollas (Campbell 1991), A'Cheardach Mhor (Clarke 1960), Cnip (McCormick 2006), and A'Cheardach Bheag (Fairhurst 1971), although there is great variation in the quantity and quality of the zooarchaeological remains recovered from these sites. The broch of Dun Vulan was subject to large scale excavations during the 1990s and therefore has produced a wealth of zooarchaeological data relating to Iron Age faunal management (Mulville 1999). Dating of the human skeletons at Dun Vulan has provided δ^{13}C and δ^{15}N values from several Middle Iron Age individuals (Marshall pers. comm.) which until this point have not been used for dietary reconstruction. Radiocarbon dating of Iron Age skeletons by Armit and Shapland (2012) provided a wealth of associated carbon and nitrogen values from humans at Cnip and Sloc Sabhaid in the Outer Hebrides. Late Iron Age individuals from Northton had also previously been analysed providing a greater insight into dietary behaviour (Jay pers. comm.).

The terms ‘Picts’ and ‘Pictish’ have been avoided due to their strong cultural association with eastern Scotland, which is not comparable with the artefactual evidence existing in the Western Isles (Armit 1996, 162). Sites which referred to ‘Pictish’ are therefore listed as ‘Late Iron Age’.

Norse Period (c.800 cal. AD-1200 cal. AD)

The Norse period is signified by the arrival of the Scandinavian invading parties that settled in the North Atlantic islands in the latter part of the 8th Century AD bringing with them, amongst other things, market economies, and centralised authorities (Barrett *et al.* 2000b). The arrival of this seafaring population therefore represents a dramatic change in behaviour at the time. There is a wealth of archaeological data relating to the Norse period, and preservation of zooarchaeological remains is generally good. The large cemeteries at Newark Bay and Westness in Orkney have been dated and intensively studied for stable isotope analysis (Barrett and Richards 2004, Richards *et al.* 2006), but dietary faunal evidence for these sites are not present for either isotopic analysis or dietary reconstruction. There is extensive zooarchaeological evidence for Norse occupation in Orkney. Large scale excavations at sites such as Quoygrew have given rise to extensive analysis of archaeological fish bones, mammalian remains and shellfish evidence (Colley 1983; Harland 2006). The site of Earl's Bu provided a wealth of Norse animal bone analysed as part of an interim report by Mainland (1995), with good collagen preservation available for isotopic analysis. Skaill, in Deerness, also provides good zooarchaeological evidence for dietary behaviour in Norse Orkney (Noddle 1997).

The Norse period in Shetland has been a focus of attention, but few formally published zooarchaeological reports exist, presumably partially due to acid conditions. Zooarchaeological remains from the site of Jarlshof are present in the National Museum of Scotland archives, but the faunal remains were never included in the published report of the 1950s (Hamilton 1953). The site of Old Scatness provided dietary and economic evidence from Norse Shetland (Cussans and Bond 2010). As observed for most of the temporal periods in the North Atlantic Islands there are few published zooarchaeological reports present for the Norse Period in Shetland.

In the Western Isles the Norse Period site of Bornais represents a large, coherent body of zooarchaeological remains, and provided a wealth of data and bone sample remains for analysis in this project (Mulville and Powell 2012; forthcoming a). Small scale isotopic research of faunal remains from Bornais has been conducted (Mulville *et al.* 2009), but there is great scope for more detailed analysis of a range of fauna to allow better characterisation of faunal dietary behaviour and animal management practices. The site of Cille Pheadair (Mulville and Powell forthcoming c) also generated a wealth of zooarchaeological data for reconstructing Norse dietary behaviour. The bone preservation at Cille Pheadair was exceptional, ensuring good collagen survival for isotopic analysis.

The term 'Viking' has been avoided in preference of the term 'Norse'. The archaeological sites mentioned throughout this study are referred to by the names used in their related publications, meaning that a combination of Anglicised and Gaelic words are used throughout this thesis.

Summary

The North Atlantic Islands have a long history of occupation, and a wealth of archaeological sites exist. There is variability as to the visibility of different periods in the North Atlantic islands; for example extensive dietary evidence is available from many Neolithic sites in Orkney. However there are few settlement sites and faunal assemblages existing for the Outer

Hebrides. Likewise no Beaker period settlements have been noted in Orkney, whereas several sites have been identified in the Outer Hebrides. Bronze Age evidence is generally represented by a couple of sites in each island group, but when we reach the Iron Age and Norse periods there is extensive evidence for settlement in the islands. The scope of archaeological investigation within each island group is varied, and comparability of assemblages between the islands was frequently limited.

In addition to variations in the types of archaeological evidence for each of the North Atlantic Islands there are also variations in how the zooarchaeological remains have been recorded for each of these sites. The following chapter presents a brief historiography of zooarchaeological evidence in the North Atlantic Islands, considering trends in analysis, the quality of the zooarchaeological evidence available to date, and past approaches to palaeodietary analysis in the North Atlantic Islands to date.

Key sites utilised in this study

Orkney

Figure 4 is a map of Orkney showing some of the key sites (Table 1).

Figure 4: Map of Orkney showing key sites commonly referred to in this study
(Base map WW2)

Site	Island	Site type	Phase	Grid ref.	Key references
Skara Brae	Mainland	Settlement	Neolithic	HY 2312 1874	Childe (1950); Clarke (1976)
Links of Noltland	Westray	Settlement	Neolithic	HY 428 493	Armour-Chelu (1992)
Pierowall Quarry	Westray	Cairn	Neolithic	HY 4389 4905	Sharples (1984)
Skaill	Mainland	Settlement	Neolithic	HY 2295 1874	Noddle (1997)
Tofts Ness	Sanday	Settlement	Neolithic	HY 760 470	Dockrill *et al*. (2007)
Pool	Sanday	Settlement	Neolithic	HY 6194 3785	Bond (2007)
Howe	Mainland	Settlement	Neolithic	HY 2759 1092	Ballin Smith (2004)
Holm of Papa Westray	Papa Westray	Cairn	Neolithic	HY 5091 5183	Schulting and Richards (2009)
Tofts Ness	Sanday	Settlement	Bronze Age	HY 760 470	Dockrill *et al*. (2007)
Howe	Mainland	Settlement	Iron Age	HY 2759 1092	Ballin Smith 2004
Mine Howe	Mainland	Settlement	Iron Age	HY 5105 0603	Mainland and Ewens (2003); Mainland *et al*. (2004).
Buckquoy	Mainland	Settlement	Iron Age	HY 2428 2839	Noddle (1976-77)
Skaill	Mainland	Settlement	Iron Age	HY 2295 1874	Noddle (1997)
Tofts Ness	Sanday	Settlement	Iron Age	HY 760 470	Dockrill *et al.* (2007)
Pool	Sanday	Settlement	Iron Age	HY 6194 3785	(Hunter *et al*. 2007; Bond 2007)
Pierowall Quarry	Westray	Settlement	Iron Age	HY 4389 4905	Sharples (1984)
Mine Howe	Mainland	Settlement	Iron Age	HY 5105 0603	Mainland *et al*. 2003; Mainland and Ewens 2003.
Buckquoy	Mainland	Settlement	Norse	HY 2428 2839	Noddle (1976-77)
Quoygrew	Westray	Settlement	Norse	HY 4433 5065	Colley 1983; Harland (2006)
Skaill	Mainland	Settlement	Norse	HY 2295 1874	Noddle (1997)
Earl's Bu	Mainland	Settlement	Norse	HY 3346 0442	Mainland (1995)
Newark Bay	South Ronaldsay	Cemetery	Norse	HY 2759 1092	Richards *et al*. (2006)
Westness	Rousay	Cemetery	Norse	HY 3759 2932	Barrett and Richards (2004)

Table 1: Phases of Key sites in Orkney commonly referred to in this study

Shetland

Figure 5 is a map of Shetland showing some of the key sites utilised in this study (Table 2).

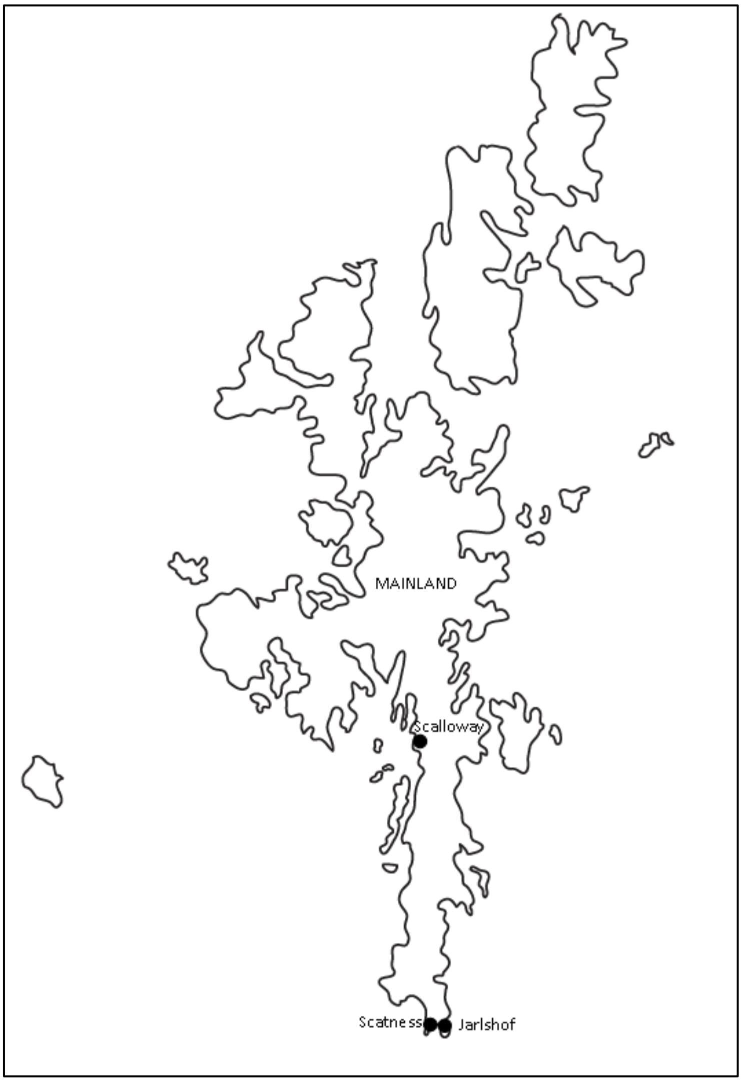


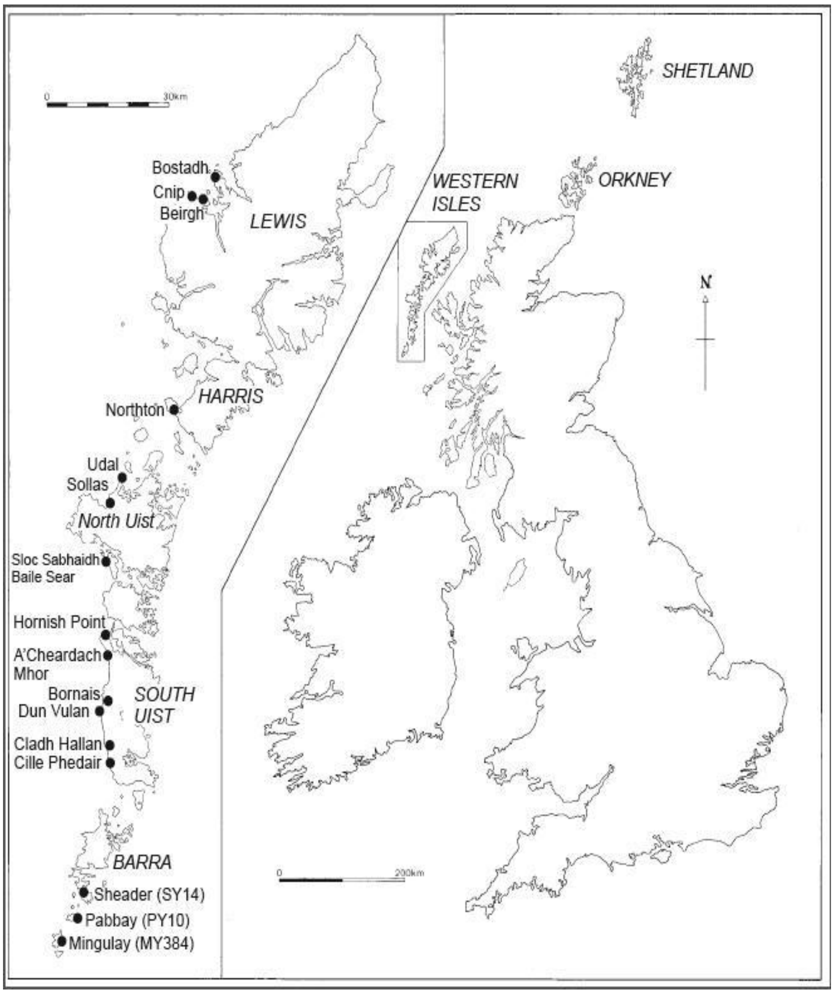
Figure 5: Map of Shetland showing key sites commonly referred to in this study
(Map bases WWW2)

Site	Island	Site type	Phase	Grid ref.	Key references
Scalloway	Mainland	Settlement	Iron Age	HU 406 399	(Sharples 1999)
Scatness	Mainland	Settlement	Iron Age	HU 3899 1060	Dockrill *et al.* (2010)
Jarlshof	Mainland	Settlement	Iron Age	HU 39819 09551	Hamilton (1953)
Scatness	Mainland	Settlement	Norse	HU 3899 1060	Dockrill *et al.* 2010
Jarlshof	Mainland	Settlement	Norse	HU 39819 09551	Hamilton (1953)

Table 2: Phases of Key sites in Shetland commonly referred to in this study

Western Isles

Figure 6 is a map of the Britain, focussing on the Western Isles showing some of the key sites utilised in this study (Figure 6).



(Image courtesy of Ian Dennis, Cardiff University)

Figure 6: Map of the Western Isles showing key sites commonly referred to in this study

Site	**Island**	**Site Type**	**Period**	**Grid Ref.**	**Key publication(s)**
Caisteal Nan Gillean	Oronsay	Midden	Mesolithic	NR 3582 8797	Mellars (1987); Richards and Mellars (2002)
Cnoc Coig	Oronsay	Midden	Mesolithic	NR 3606 8833	Mellars (1987); Richards and Mellars (2002)
Crarae	Oronsay	Midden	Mesolithic	NR 9874 9736	Mellars (1987); Richards and Mellars (2002)
Carding Mill Bay	Oronsay	Midden	Mesolithic	NM 847 294	Mellars (1987); Richards and Mellars (2002)
Eilean Domhnuill	North Uist	Settlement	Neolithic	NF 7469 7533	Armit (1986)
Northton	Harris	Settlement	Neolithic	NF 9753 9123	Finlay (1984)
Udal North	North Uist	Settlement	Neolithic	NF 8242 7843	Serjeantson n.d.
Northton	Harris	Settlement	Beaker	NF 9753 9123	Finlay (1984)
Sligenach	South Uist	Settlement	Bronze Age	NF 7250 2889	Sharples (2012a)
Cladh Hallan	South Uist	settlement	Bronze Age	NF 73138 21977	Parker Pearson *et al.* (forthcoming)
Udal North	North Uist	Settlement	Bronze Age	NF 8242 7843	Serjeantson n.d.
A'Cheardach Bheag	South Uist	Settlement	Iron Age	NF 7577 4038	Fairhurst (1971)
A'Cheardach Mhor	South Uist	Settlement	Iron Age	NF 7570 4129	Clarke (1960)
Udal North	North Uist	Settlement	Iron Age	NF 8242 7843	Serjeantson n.d.
Sligenach	South Uist	Settlement	Iron Age	NF 7250 2889	Sharples (2012a)
Dun Vulan	South Uist	Settlement	Iron Age	NF 71407 29815	Parker Pearson and Sharples (1999)
Bornish	South Uist	Settlement	Iron Age	NF 729 302	(Sharples 2005; Sharples 2012; Sharples forthcoming)
Northton	Harris	Settlement	Iron Age	NF 9753 9123	Finlay (1984)
Sloc Sabhaidh	Baleshare	Settlement	Iron Age	NF 7823 6085	Armit and Shapland (2012)
Cnip	Lewis	Settlement	Iron Age	NB 0980 3659	Armit (2006)
Bornish	Sout Uist	Settlement	Norse	NF 729 302	(Sharples 2005; Sharples 2012; Sharples forthcoming)
Cille Pheadair	South Uist	Settlement	Norse	NF 7292 1979	Parker Pearson *et al.* forthcoming
Bostadh	South Uist	Settlement	Norse	NB 1373 4010	Thoms (2007)

Table 3: Phases of Key sites in the Western Isles sites commonly referred to in this study

Chapter 3: Background to Zooarchaeological Research in the Scottish North Atlantic Islands

Zooarchaeological research in the North Atlantic Islands has a long history, dating back as far as the 1930s, and has resulted in the generation of numerous zooarchaeological reports. Approaches towards studying these remains changed through time, and there is extensive variation in the quality and quantity of the data included in existing zooarchaeological reports. Interpretations of the zooarchaeological data differ between excavation reports, and the relationship of individual sites to the wider palaeoeconomic strategies of the region is frequently neglected during analysis. To date there have been no attempts to cross compare different resource types from sites in the North Atlantic. Understanding differences in the collection, analysis and dissemination of zooarchaeological data is crucial in identifying challenges and constraints of the current North Atlantic Island dataset.

The following paragraphs take a chronological approach towards exploring key trends in zooarchaeological research through time in the North Atlantic Islands to explore the origins of modern zooarchaeological analysis in the region today. The successes and limitations of past approaches will be considered, to explore the current state of zooarchaeological research in the islands.

Early Zoological Approaches

The purpose of zooarchaeological research is to understand human interactions with animals (Reitz and Wing 2008, 1). Today modern zooarchaeological standards aim to maximise the recorded information about an assemblage. This results in a degree of standardisation between methodologies recording information on species, skeletal element, butchery, fusion/ageing data, sexing information, taphonomy, fragmentation, and pathologies (e.g. Davis 1987; O'Connor 2000; Reitz and Wing 2008), answering questions related to animal management, human diet, and trade, among others. In the past different standards and conventions in zooarchaeological studies have been applied.

Some of the earliest reports of zooarchaeological material from excavations are written by Margery Platt, a zoologist based at the Natural History department of the Royal Scottish Museum, investigating faunal remains from sites such as Midhowe (1934), Eday (1937b) and Blackhammer (1937a). The zoological nature of the recording focussed more on species presence, with less emphasis on the archaeological interpretations behind these assemblages. Platt (1934, 1937a, 1937b) provides discussion of the skeletal elements encountered, but there is no numerical quantification of the remains. These accounts are highly generalised, with little detail on the zooarchaeological remains present, and no discussion of ageing or sexing of the animals. Bird, fish and mammal bones are acknowledged in these reports, but they are not discussed in great detail, and little consideration is given to the relationship between these different food sources, and the role they each played in past diets. The raw zooarchaeological data are not included in the early Platt (1934, 1937a, 1937b) reports, and in many cases the bone archives were not curated, preventing reanalysis by modern zooarchaeological techniques. The lack of any form of bone quantification prevents these assemblages from being integrated into wider zooarchaeological studies of the region.

The Rise of Zooarchaeology

A new wave of studies relating to North Atlantic Island palaeoeconomy began in the late 1970s and early 1980s with a move away from zoological techniques towards modern zooarchaeological practice.

Typical reports of this era include Dun Mhor Vaul, Dun Ardtrek, Dun Cul Bhuirg (Noddle 1978-80), Knap of Howar (Noddle 1983), Isbister (Barker 1983) and Buckquoy (Noddle 1976). These reports contain a much higher level of detail in comparison to the 1930s reports. For the first time NISP and MNI values are recorded, providing basic quantification of the numbers of bones from each species present. These reports include more detailed analysis of the faunal assemblage taking into account body part representation, butchery patterns, measurements and ageing information such as fusion and toothwear. The reports of this generation draw comparisons between similar sites in the region, for example the brochs of Dun Mhor Vaul, Dun Ardtrek, and Dun Cul Bhuirg are compared in the same publication (Noddle 1978-80), but generally the zooarchaeological studies of this era record sites individually, with few broader comparisons of wider regional economies.

Specialist study of specific fractions of the assemblages are initiated at this time. Specialist reports enable a greater level of detail in the recording of different zooarchaeological fractions, but this approach can prevent an holistic interpretation of economic activity, as each aspect of the assemblage is considered independently, rather than as part of a much wider economy. For example at the site of Buckquoy the bird bones were studied by Bramwell (1976), as were the Isbister bird bones (Bramwell 1983), with the Isbister marine fauna studied by Colley (1983).

Work conducted in the 1980s such as studies by McCormick such as at Pierowall Quarry (1984) and Iona Guest House (1981), employ similar traditional recording techniques to the 70s reports, but there is much more of an emphasis on trying to interpret the data in terms of how it relates to the wider economy. McCormick (1984; 1981) draws comparisons to nearby North Atlantic Island sites to explore common features between the assemblages. Such zooarchaeological reports include MNI calculation, in addition to the frequency of different skeletal parts, ageing information, and measurement. Marine mammals and bird bones are considered, however they are not fully integrated into the rest of the report, and their place in the overall economy is not discussed.

Finlay (1984) demonstrates one of the earliest attempts to draw together palaeoeconomic data from several different island assemblages, collating information from 13 sites in the Outer Hebrides from the Neolithic through to the Iron Age. The study focused on the mammal remains, whilst also considering to a lesser extent the bird remains, fish bones, marine mammals and shellfish. The approach taken by Finlay (1984) provided a useful summary of palaeoeconomy in the Western Isles, however it was confined to a limited geographical area preventing comparisons between the different island groups. However Finlay's (1984) approach did not relate the different zooarchaeological resources to each other to determine relative importance of each of these resources.

Some of the studies in the late 80s such as Grigson and Mellars (1987) work on the Mesolithic site of Cnoc Coig takes the approach of examining each different species individually. In terms of the data provided in the report, the elements, age, and measurements of each animal group are discussed. At Cnoc Coig there is an emphasis on the interpretation of the faunal remains, and the implications that the patterns have on wider subsistence and procurement strategies, such as possible uses of red deer and explanations for variations in their size (Grigson and Mellars 1987). Terrestrial and marine mammals are analysed, however bird and fish remains are not included in the study. There is limited comparison between the Cnoc Coig and the smaller assemblages at Priory Midden, Caisteal non Gillean II, and Cnoc Silgeach, to investigate common themes in the data (Grigson and Mellars 1987). This consideration of other sites on Oronsay alongside Cnoc Coig begins to draw out regional trends in the zooarchaeological data, although in this case the extent of comparison was limited. The study demonstrates progression towards interpretive analysis of assemblages, reflecting on wider site comparisons.

An Increase in Zooarchaeological Detail

More recent bone reports based on the North Atlantic Islands (e.g. Mulville 2000; 2005; Bond 2007; McCormick 2006; Nicholson and Davies 2007) record the zooarchaeological remains including detailed data on species MNI, NISPS, toothwear, fusion, butchery and taponomy. The increase in the level of detail of the reports in this era has achieved a greater level of understanding about the sites. The reports from the 2000s generally consider many different lines of zooarchaeological evidence, looking at characteristics such as toothwear, fusion, butchery and element representation. These recent reports often include sections of work on fish, birds and marine shells, in addition to traditional mammal reports. There is a greater level of integration of the different datasets, in these types of report, although there is scope to consider the wider economy more thoroughly. The Dun Vulan report (Mulville 1999) includes a wide range of data, discussed in terms of the individual phases the bones represent, and the wider economic implications of the assemblages as a whole. The individual phase by phase analysis provided by these studies enhances the level of detail achieved in these reports, and allows potential for the integration of raw data with other zooarchaeological reports. Additionally detailed sampling protocols employed in recent excavations such as Bornais (Sharples forthcoming; 2012; 2005) and Cladh Hallan (Parker Pearson *et al.* forthcoming) provide greater scope for detailed zooarchaeological analysis.

Marine resources have been more central to economic investigations over the past 10 years. Archaeological fish bones in the Western Isles were analysed as part of a PhD by Cerón-Carrasco (2005) undertaking archaeoicthyological analysis to determine the role of fishing in the lives of communities in the Outer Hebrides, including later Iron Age and Norse phases at Bostadh beach. Corresponding mammalian data had been conducted for these sites (Thoms 2003), but no work to relate the fish bone evidence with the terrestrial fauna has been undertaken. Norse palaeodietary behaviour in Orkney was explored in PhD research by Colley (1983a) and Harland (2006), analysing in detail fish bones and terrestrial mammals from the Norse sites of Quoygrew and Earl's Bu. Harland's research (2006) provided detailed spatial and temporal analyses of fish bone evidence, but, as with many studies investigating marine economies the importance of fish as a resource in relation to the wider mammalian assemblage was not included as part of this analysis. Further work on the shellfish assemblages from Quoygrew were undertaken by Milner *et al.* (2007) to investigate the importance of shellfish at the site, a theme frequently excluded from zooarchaeological analysis in the North Atlantic Islands. Work by Barrett *et al.* (1999) considered wider patterns in fish exploitation across Northern Scotland in the Iron Age and Norse period. The detailed studies of zooarchaeological fractions such as fish bone remains and shellfish has resulted in thorough datasets. However there is little understanding of how these datasets relate to the wider economic strategies both within sites, and within larger geographical locations, especially when determining the relationship between fish, mammals, shellfish, and sea mammal assemblages.

Recently studies completed as part of the SEARCH and affiliate projects are analysed to a very high level of detail, for example the published work from Bornais Mound 1 (Mulville and Powell 2012) and Mound 3 (Mulville 2005). Importantly zooarchaeological analysis at sites such as Bornais (Mulville and Powell 2012; forthcoming a), Cladh Hallan (Mulville and Powell forthcoming b), and Cille Pheadair (Mulville and Powell c) were all recorded using the same methodology by the same faunal analysts, enabling a high degree of comparability between the zooarchaeological datasets at these sites. Each zooarchaeological fraction was recorded by different specialists e.g. fish (Ingrem 2012; forthcoming) and birds (Best and Cartledge forthcoming; Best and Powell forthcoming). As these sites were all excavated, sampled for environmental remains, and analysed in similar ways, there is a greater degree of comparability between these sites than experienced with other North Atlantic sites, which potentially provides the ability to reconcile these different datasets more easily.

The approach of comparing the palaeoeconomy of several different sites has become increasingly utilised over time. Dockrill and Bond (2009) compared the faunal data at Old Scatness, Jarlshof, and Tofts Ness, to summarise the key trends in the palaeoeconomy of the Northern Isles. The study considered the anthropogenic soils and the faunal data to try and recreate a clearer picture of past economic practices. The approach taken by Dockrill and Bond (2009) involved comparing mammal remains, birds, fish, and molluscs found at each of the sites, to piece together a more complete view of the past economy. Dockrill and Bond (2009) provide a useful summary of changes in economic strategies through time in the Northern Isles. Drawing comparisons between the North Atlantic Island sites can enable a clearer idea of past subsistence practices to be understood.

Exploring the Role of Individual Resources

Several recent studies have taken the approach of studying single resource types to explore the importance of these through time. Work by Fairnell and Barrett (2007) has explored the role of fur bearing species in the Scottish Islands on a temporal basis to determine the utilisation and perceptions of these animals in prehistoric populations. A similar approach was taken by Mulville (2010), to identify existing red deer bones in assemblages through time in each of the island groups to track the introduction and extinction of red deer through time in the islands. The use of marine mammals in the islands through prehistory has also been the subject of discussion (Mulville 2002). Fish exploitation has been a focus in specific periods in the islands (e.g. Barrett *et al.* 2001; Harland 2007; Colley 1983a), but to date not even simple NISP comparisons of fish species through time in the islands have been attempted.

The use of Online Publications

Several zooarchaeological reports were published as online accounts of the economic evidence. The analytical work from the sites Baleshare and Hornish Point by Lee (1987) via *Scottish Internet Archaeology*, and research by Drew (2005) investigating faunal evidence from the Inner Hebridean faunal assemblages from the site of High Pastures cave are available through the project websites.

The online publications are not limited by word counts or page restrictions, and can provide access to extensive raw datasets. The Archaeology Data Service (ADS) hosts a range of online publications, including raw datasets available for download, such as data from the Mesolithic explorations at Sand (Hardy and Wickham Jones 2007). In some situations pure data are published online for public use; for example the 'Marine Resource Exploitation in Scotland' (MARES) database (Cerón-Carrasco *et al.* 2006) provides NISP counts of a range of fish, shellfish, bird, and marine mammal evidence from a range of published, and unpublished 'grey literature'. For some sites we have bird and fish evidence from sites where the mammalian evidence is not available; for example the MARES database contains fish and bird NISPS from Clarke's excavations at Skara Brae in the 1970s, yet the mammalian bone report remains unpublished.

Towards an Integrative Zooarchaeology

Increasingly there has been more of a focus on comparing changes in resource type use through time, integrating different lines of economic evidence. Wide scale accounts of faunal change across Scotland exist (e.g. McCormick and Buckland 1997; Edwards and Ralston 2003), and provide an overview of Scottish zooarchaeology. These accounts are highly generalised, coming from a more environmental perspective, and are not specific to the North Atlantic Islands.

Broader palaeoeconomic studies specific to the North Atlantic have been produced in recent years. Smith and Mulville (2004) summarised floral and faunal changes from the early prehistoric through to Norse periods on the Uists, Benbecula and Barra, providing a wider insight into economic strategies in the region. The paper takes a chronological approach towards investigating changes in land use, secondary product use, and changing relationships with the sea. A range of zooarchaeological and palaeobotanical data is used to investigate these economic trends, providing a more interpretive view of North Atlantic Island economy. By comparing several different sites of various time periods Smith and Mulville (2004) are able to consider changes in food procurement and consumption over time, using zooarchaeological and palaeobotanical datasets. Developing the analytical strategy used by Smith and Mulville (2004) to incorporate a wider geographical area will be a useful way of understanding more about the wider palaeoeconomy. It is important for each fraction of the palaeodietary evidence to be studied by specialists in the field, but it is also crucial for the data to be re-integrated and considered as a whole when investigating past diet.

Analysis of resource utilisation across different ecotones has been utilised in the Western Isles to provide an understanding of landscape use by past human populations. Site reports for several Hebridean assemblages such as Bornais (Sharples 2005; 2012; forthcoming) and Dun Vulan (Parker Pearson and Sharples 1999) provide valuable case studies for the integration of datasets relating to different ecotones considering resources available from the sea, the shore, and the machair. These studies demonstrate an integrated approach, drawing together archaeological data from specialist reports to summarising resource exploitation in different environmental regions, and exploring the archaeological implications of these findings. Such accounts present a valuable model for future inter-resource comparisons within North Atlantic Islands.

Bailey *et al.* (2008) produced an interesting alternative to the traditional zooarchaeological report, in the form of a broad summary of changes in marine resource use through time in the North Sea Basin. This study is concerned with identifying past relationships with sea based resources, for instance by looking at direct indicators such as changes in size of shellfish and fish, then comparing this to indirect methods such as isotope studies of human bone. This synthesis of information is useful for giving a broad idea of patterns in subsistence, but it lacks the detailed data of the formal zooarchaeological site reports. This demonstrates how a compromise between detailed bone analysis for individual sites and broader investigations considering wider paleaoeconomic patterns can be successfully applied to enhance understanding of past dietary trends.

Discussion

In order to fully understand palaeoeconomic strategies it is necessary to consider all available zooarchaeological evidence. The approaches by Sharples (2005; 2012; forthcoming), Parker Pearson and Sharples (1999) and Parker Pearson *et al.* (forthcoming) provide a valuable model for understanding resource use on an intra-site basis that would be beneficial to apply to future site studies. Research to combine this information between sites would be beneficial in enhancing broader regional trends in different resource use.

Characterisation of different resource uses has not really been applied to assemblages in Southern Britain, where reports typically provide discussions of the zooarchaeological remains in isolation from the wider resource bases, and without full integration with the archaeological evidence. Few sites in Southern Britain have covered such a wide scope of environmental analysis, and regional or local reviews of zooarchaeological resources are not commonly undertaken. The difference in style of zooarchaeological studies between North Atlantic inter resource uses analysis and mainland British sites is interesting. It is possible that the exceptional preservation experience in the North Atlantic Islands lends itself particularly well to enabling inter-resource comparisons to be drawn, whereas in mainland Britain there is less consistency in the types of remains present, with projects having a different research focus. The islands are also unusual in that they represent a constant finite resource zones, allowing greater degrees of inter-resource comparisons to be achieved than is possible in areas where environments are less diverse. The wealth of sites excavated using similar excavation, sampling and analytical strategies (e.g. SEARCH projects) provides an extensive dataset for inter-resource comparison, and therefore this region is particularly well suited to enhancing understanding of different resource types. The North Atlantic Islands therefore provide a unique opportunity to begin considering temporal and regional trends in dietary behaviour.

Summary

The North Atlantic Islands have a long history of zooarchaeological analysis aimed at investigating palaeodietary behaviour. As demonstrated there is a marked difference in the approaches towards the analysis of faunal material through time. The level of detail recorded in each site study varies extensively. Generally more recent studies (e.g. Mulville 2012; 2005; Bond 2007 etc.), provide a greater level of detail than some of the older reports (e.g. Platt 1934), including information on bone measurements, fusion, dental toothwear and detailed analysis of fragmentation. The increased level of recording of present in the later sites provides a wealth of data that can be added to a central database to understand paleaoeconomic themes through time. There is no real standardisation between zooarchaeologists as to how assemblages are recorded, which can make the integration of data from different sites challenging. Unpublished material can also prove to be a barrier to integrating datasets; for example the highly important Neolithic settlement site of Skara Brae produced a wealth of mammal bone information, but the data were not available for inclusion in this study.

More recently more integrated approaches have been attempted to compare palaeoeconomic strategies employed within the island groups. Specifically the relationship between marine and terrestrial resources has very much played a minor role when investigating past dietary behaviour. The highly varied nature of the recording and sampling strategies utilised at each of the sites means that combining the data and quantifying the faunal remains in a meaningful way are complex.

There is a strong need to integrate all of this zooarchaeological data to understand how subsistence practices and resource diversification changed through time. Although there have been some attempts to summarise palaeoeconomical data within specific island groups, there has been so far no work undertaken to draw together data from mammals, birds, fish and shellfish, in each of the island groups to compare patterns of subsistence through time. By making comparisons between the different island groups it will be possible to understand recurring themes in diet in the Northern and Western Isles.

The following chapter will discuss some of the challenges of quantifying zooarchaeological remains in terms of integrating data from a range of different sites, and then relating mammal bone evidence to fish, shellfish, bird and marine mammal data, before outlining the methodology used in this research.

Chapter 4: Quantifying North Atlantic Zooarchaeological remains

This chapter examines inter-site comparisons of zooarchaeological assemblages on a regional scale, and the impact of differences in excavation, sampling and recording strategies. Past approaches towards inter-site and intra-site comparisons are outlined demonstrating the strengths and limitations of combining data from multiple sites. The challenges of comparing fish, shellfish, birds, terrestrial mammals, and sea mammals are discussed in addition to critiquing past attempts to reconcile these very different datasets. This discussion is guided by the use of examples demonstrating the applications of these principles to the North Atlantic Island assemblages.

The second half of this chapter introduces the methodology used in this study to understand the use of marine species through time, addressing both data collection strategies and analytical techniques practiced.

Inter-Site Comparisons

Meaningfully quantifying each fraction of a zooarchaeological assemblage is complex. Successful methods of quantifying zooarchaeological remains have been a focus of discussion by various zooarchaeologists including Reitz and Wing (2008); Davis (1987); O'Connor (2000); and Lyman (2009) among others. However these studies do not provide a sufficient solution to the challenges of cross-resource comparisons between zooarchaeological assemblages.

The lack of comparability between sites and assemblages can be attributed to three broad categories: preservation, excavation methods/sampling strategies, and analytical procedures. The impact of each of these factors and their influence on the zooarchaeological record will be discussed with reference to examples from the North Atlantic Islands.

Preservation

Differences in preservation of zooarchaeological remains, particularly between each fraction of the faunal assemblage (i.e. fish bones, shellfish, sea mammals and terrestrial mammals) can be a concern when amalgamating bodies of data for wider regional comparisons. Acidic soils cause greater degradation of bone remains than alkaline soils (Gordon and Buikstra 1981); therefore there is a direct link between soil pH and bone preservation. Depth of burial, temperature, and rainfall in a given region can affect the rate of microbial decay within an assemblage (Nicholson 1996a), potentially causing comparability issues between zooarchaeological assemblages from different locations.

There are three main impacts of differential preservation. First, poor bone preservation conditions can affect specimen identification as a result of higher levels of fragmentation (Davis 1987, 29), affecting the NISP values generated for each species type, and inhibiting the ability to identify scraps of bone. Second, poor preservation can cause differential preservation of skeletal elements; for example acidity experiments conducted by Lubinski (1996) demonstrated that when exposed to acidic conditions fish head bones degrade more than vertebrae. Finally variable preservation between different sites with localised environmental conditions can prevent comparable datasets from being achieved in terms of size and species representation (Davis 1987, 27; O'Connor 2000, 24), causing challenges when interpreting the importance of marine taxa in each time period and between geographical locations.

As discussed in Chapter 2, the diverse geology between the islands directly impacts on the topography and soil types within the islands, creating a range of preservation conditions within the North Atlantic Islands. For example in Shetland soil type differs locally, with the valley floors having pH neutral soils, and the valley sides being predominantly characterised by acidic soils (Dry and Roberts 1982), causing differential preservation within the island group. In comparison the shell sands of the machair on the western coast of the Outer Hebrides are more alkaline (Henley 2005, 325) which is favourable for the preservation of bone remains (Gordon and Buikstra 1981), providing a wealth of faunal assemblages available for study. We can therefore expect to see differences in the preservation of zooarchaeological assemblages between these two regions, and inter-regional comparisons may be challenging.

Excavation Methods and Sampling Strategies

Archaeological decisions made during the excavation processes inherently influence zooarchaeological assemblages, such as which areas of the site are excavated, sampling policies, and sieving strategies employed (Davis 1987, 22). Sampling strategies have a huge impact on the diversity of assemblages recorded (O'Connor 2000), thus providing potential biases between assemblages.

A crucial factor influencing archaeological assemblages is the location of excavation trenches. Typically archaeological excavations only cover roughly 10% of the total site, biasing the zooarchaeological assemblages recovered (O'Connor 2000, 28). The placement of trenches determines the type of zooarchaeological assemblages recovered, for example refuse middens may be located outside the main settlement area to minimise odour, and may therefore may not be identified and investigated during the excavation of settlements. The challenges of inter-site comparisons can be mitigated by the involvement of osteoarchaeologists when designing excavation and sampling strategies (David 1987, 28), but this is not always practiced.

Sampling policies at archaeological sites directly affect the zooarchaeological assemblages collected from excavation, especially the recovery of smaller versus larger bones (Payne 1972). For example research has shown the proportion of identifiable fragments of bone retained by a 4mm sieve was dramatically higher than recorded from 10mm sieves of the same deposits (Clason and Prummel 1977, 173). Similarly when considering shell remains sieving using smaller screen sizes also increases the number of species represented (Clason and Prummel 1977, 173), and therefore there is frequently a large quantity of 'missing shells' that simply fall through sieves or get crushed during sample processing (Mason *et al.* 1998, 306). Differential sieving can also affect the representation of smaller fish species; for example at the site of Bornais Mound 3 the <10mm fraction of the fish bone assemblage contained 1643 herring bones, compared to 1 herring bone found in the >10mm fraction (Ingrem 2005, 146). Comparing data from sites with detailed sieving strategies with sites where hand collection only was employed is therefore problematic. Unfortunately the sieving strategies used at a site are not always clearly identified in excavation reports (e.g. Noddle 1974). Awareness of potential biases between assemblages that have been sieved to different levels is crucial when attempting to piece together an accurate understanding of marine resource use and wider economic and dietary trends through time in the North Atlantic Islands.

Potential strategies used to collect zooarchaeological data, and depth of zooarchaeological analysis depends on the scientific research questions asked of an assemblage (Clason and Prummel 1977, 171). There is a high degree of variability in sampling strategies in the North Atlantic Islands due to the diverse nature of the archaeological projects undertaken, and the research questions being asked.

Recording and Analysis

The final factor presenting a challenge when drawing inter-site comparisons is analytical biases. This can be a result of differences in the level of detail recoded by zooarchaeological analysts, methodologies used to record data, interpretations of datasets, and the level skill of the person recording the assemblage. These factors can directly impact on the zooarchaeological information recorded about different assemblages making inter-assemblage comparisons more challenging.

An example of the impact of recording using different methodologies is exhibited in the recording of ageing information about assemblages. Ageing information from herds can provide insights into animal management strategies and secondary product production, such as milk and wool (e.g. Davis 1987; O'Connor 2000; Reitz and Wing 2000). Integrating ageing information from a multitude of different datasets is exceptionally challenging when different recording systems have been utilised, as different age ranges are represented by different methodologies. The resulting effect is that smaller age ranges have to be combined into larger ones (e.g. data for 3-6 months would have to be combined into 3-9 months), causing a great loss of detail, and potentially affecting the interpretation of the mortality profiles. In the North Atlantic Islands toothwear in various different reports has been recorded in accordance with Grant (1982), Payne (1973), Halstead (2002), Legge (1972), and Silver (1969), demonstrating the high degree of variability of recording in the islands, and the limitations of attempting to integrate data achieved using these differing recording strategies.

A further aspect to consider is the availability of zooarchaeological data, as there can be discrepancies between the information that is recorded about a zooarchaeological assemblage and the data that is formally published (Davis 1987, 22). Raw tables in publications are ideal for enabling data from a range of different sources to be amalgamated into one coherent body. Unfortunately due to limited amounts of space available in publications, raw data are frequently not included in published reports.

Some zooarchaeological reports do not explicitly outline the methodologies utilised for recording or generating calculations, which can cause challenges when drawing comparisons between datasets. Sometimes zooarchaeological reports remain unpublished, with the raw data remaining inaccessible to other researchers; for example the mammalian zooarchaeological report from the 1970's excavations at Skara Brae has not been published, whereas the fish remains from the same site are made publically available as part of the 'Marine Resource Exploitation in Scotland' (MARES) database. Some North Atlantic faunal reports do not include any quantitative data, such as the assemblages from Eday (Platt 1937a), Blackhammer (Platt 1937a) and Midhowe (Platt 1934), all discussed qualitatively.

Ideally for inter-site comparisons of wider geographical regions, each site would have been excavated using a common research framework, using the same sieving and sampling, and all bone material would be recorded using the same methodologies to allow datasets to be reliably compared.

Past approaches to Quantification: Regional reviews

Despite the challenges of cross-comparing zooarchaeological data outlined in the previous paragraphs several zooarchaeological studies have successfully integrated data from a range of different sites (e.g. Hambleton 2008; Serjeantson 2011; Conolly *et al.* 2010). These past approaches towards quantification demonstrate how larger regional comparisons can be utilised to understand broad temporal patterns in subsistence, and provide valuable comparative models for this research.

Hambleton (2008) reviewed 152 faunal assemblages from the Mid Bronze Age-Late Iron Age in Southern Britain focussed on comparing percentage NISPs of each species type. The Hambleton (2008) review enables broad comparisons between species, depicting the introduction and decline of different species using species representation. Sexing and ageing data included, however, is very broad, and generalising age and sex categories in sites prevents detailed modelling of the economy. Hambleton (2008) incorporated a relatively low level of detail in the analysis, counting species presence and absence, and noting the assemblages dominated by juvenile bones. The challenges encountered in Hambleton’s (2008) synthesis are similar to those experienced in this project such as extensive variation between excavation and recording strategies, and differences in the level of detail recorded. This approach enabled basic patterns to emerge in each time period and region.

Serjeantson (2011) undertook a similar approach to Hambleton, looking at dietary trends based on Neolithic and Early Bronze Age assemblages in Southern Britain. Serjeantson (2011) compared NISP values across the sites, in addition to providing broad age profiles, whilst working within the confines of amalgamating large quantities of data from different datasets. This approach allowed broad trends in dietary behaviour to emerge, enhancing our understanding of economic strategies across a wide region. These reviews demonstrate how broad scale analysis can be conducted using general species comparisons, and provide potential for application to the North Atlantic region.

Recent work by Conolly *et al.* (2010) comparing zooarchaeological data from SW Asia and SE Europe provides a useful example of the successful synthesis of data across wide regions. The focus of the study was to track domestication across the region, therefore a key aim was to understand the relationship between wild and domestic species (Conolly *et al.* 2010). Conolly *et al.* (2010, 540) predominantly used site NISP comparisons in their calculations, and only noted broad ranges of ageing, sexing, domestication and biometrics. The study predominantly compared percentage NISPs of each species type temporally across each region and demonstrated that the uptake of domestic species happened at different rates across each of the study regions (Conolly *et al.* 2010). The study emphasised the need for a consistent and systematic approach towards integrating data (Conolly *et al.* 2010, 539), which unfortunately results in a reduction in the level of detail that can be retained. Conolly *et al.* (2010) used broad analytical techniques, to address the research questions asked by the study, demonstrating realistic expectations of the dataset, and by using exploratory statistics it is possible to get a clearer understanding of these complex datasets.

The Conolly *et al*. (2010), Serjeantson (2011) and Hambleton (2008) reviews all provide useful examples of approaches to integrate large datasets however they are predominantly focussed on understanding terrestrial mammal assemblages. They do not address the specific challenges associated with integrating mammals, with sea mammals, fish, and shellfish. There is therefore a need to consider alternative methodologies of cross-comparing resources to explore populations that have a greater reliance on the sea.

Past approaches to Quantification: Comparing Zooarchaeological Fractions

The North Atlantic Island populations in this study are farming populations, but they have parallels with Arctic hunter-gatherer-fisher populations, for whom shellfish, fish and marine mammals all play a central role in diet. Studies of the hunter-gatherer populations of the Northwest Territory in Canada (Betts and Friesen 2004; Betts and Friessen 2006) demonstrated that marine foods accounted for 100% of the diet, and used relative abundance indices based on NISPs to determine the importance of marine resources between different sites (Betts and Friesen 2004; 2006), but all of these studies were comparing sites that had been excavated by the authors using controlled and consistent strategies, and therefore provide a high level of comparability between the assemblages.

Inter-resource comparisons have been conducted in the North Atlantic region, but are limited mainly to chronological comparisons within single sites such as those reported by Church *et al.* (2005), Lawson *et al.* (2005) and Barlow *et al*. (1997). A common feature of these cross-resource comparisons are composite bar charts to analyse the relative percentages NISPs of each resource type, a technique useful for comparing assemblages of different sizes. Even with the favourable conditions of the datasets, the quantity of meat represented by fish, shellfish, sea mammals and terrestrial mammals is not calculated, and there is no assessment of how important these resources were to the site inhabitants. These investigations have the luxury of consistent sampling and analytical strategies, which enables a greater scope for more detailed resource comparisons to be drawn.

As discussed in chapter 3 there have been several studies drawing zooarchaeological comparisons between sites in the North Atlantic Islands such as Finlay (1984), Mulville and Smith (2004), Thoms (2004) and Mulville (1999), however, these comparisons are limited geographically and temporally, and to date there have been no studies providing chronological comparisons in diet from the Neolithic period to the Norse period in both the Northern and Western Isles.

Reconciling data from sites with very varied excavation strategies, preservation conditions and analytical variations in a meaningful way is exceptionally challenging, and no coherent method of overcoming these challenges has been utilised in past multi-regional studies.

Intra-Site Comparisons

Factors Influencing the Zooarchaeological Record

Drawing comparisons between mammalian remains, fish, shellfish, marine mammals, and birds can also be highly complex due to cultural processes, and biological differences between species affecting the zooarchaeological record.

Human factors play a vital role in shaping the assemblages of archaeological material excavated on site. Trading in animals may result in the presence of certain species in an archaeological site, and likewise material may have been traded out, resulting in the absence of animals or parts of animals (O'Connor 2000, 262). The 'Schlepp Effect' can bias site assemblages due to the differential transportation of skeletal elements (Perkinson and Daly 1968). For example whale meat is often butchered and taken back to settlements without any bone being removed (Mulville 2005b, 161; Smith and Kineham 1984), and therefore whale bones will not necessarily make it back to the archaeological sites. The presence of species at a site is not necessarily a result of consuming products; for example ethnographic evidence from St. Kilda demonstrated that birds were utilised for clothing, medicines, and footwear, and fuels (Maclean 1977). Assessing the role of these resources from the quantity of bones represented by these resources is a challenge using zooarchaeological evidence alone. Many calculations used to determine the percentage of carcasses used, and the quantity of meat represented by these animals, fail to take into account other potential uses of carcasses as a resource, such as a raw material for the creation of artefacts, as an architectural resource, or as a source of fuel (e.g. Monks 2005; Mulville *et al.* 2002; Savelle 1997).

Biological differences between species make estimating the importance of different resources difficult to assess, as different species groups provide variable quantities of meat per individual (Lyman 1979; Smith 2011; Stewart and Stahl 1997; White 1953). There is a vast difference in meat available between cod, sheep, cattle, and whale (Smith 2011), and therefore understanding the value of these species to past populations can be complex. Equally there is variability in the calorific content and nutritional value of each of these resources (Stewart and Stahl 1977), information that is complex to access using bone counts.

NISP

The technique most commonly used in zooarchaeology to quantify remains is the 'number of identified specimens' (NISP), and is a simple count of bones, or fragments of bones present for each taxon (Lyman 2008, 27), and is consistently recorded between analysts.

NISP has limitations, discussed at length by zooarchaeologists (e.g. Chaplin 1971; Grayson 1973; 1979; 1984; Lyman 2008; O'Connor 2000; 2003), citing concerns such as anatomical differences between species, differential bone survival, and variable fragmentation patterns between sites and within sites. A key drawback of NISP analysis is that it over-inflates the number of bones present, due to fragmentation and taphonomic processes (Lyman 2008).

MNI

'Minimum Number of individuals' (MNI) is also commonly used by zooarchaeologists. MNI provides a quantification of the number of animals represented in assemblages of animal bones. MNI addresses some of the concerns of NISP as it takes into account anatomical differences between species (Lyman 2008), but MNI only provides an estimate of the number of animals present on a site, not an absolute count (O'Connor 2000, 60). The constraints of using MNI to quantify faunal remains include: over-inflating the importance of rarely exploited taxa, the lack of consistency in how MNI is calculated between analysts, and gross under-representation of the number of individuals present within assemblages (e.g. Chaplin 1971; Grayson 1973; 1979; 1984; Lyman 2008; O'Connor 2000; 2003). Lyman (2008, 40) noted that there are 16 different definitions of MNI utilised by various zooarchaeologists, which demonstrates the high degree of variability in how this attribute can be calculated by different specialists, making inter-site comparisons problematic.

NISP and MNI are not consistent between mammals and fish. For example as previously discussed, preservation, sampling, and analytical differences can all create biases between these datasets, and therefore drawing comparisons between species groups to assess their relative importance is a constant challenge to archaeologists.

In the North Atlantic Island faunal assemblages NISP is the most commonly recorded piece of zooarchaeological data across published assemblages, and as it is a simple count of species recorded, can be influenced by methodological differences in how the value is calculated, which is one of the concerns of using MNI (Lyman 2008, 40). NISP therefore can be beneficial in allowing simple inter-site comparisons of the relative importance of different species.

Meat Weight Analysis

The advantage of using meat weight is that it accounts for differences in the quantity of meat provided by different species (White 1953, 397). The weight of meat represented by an archaeological assemblage can be used to assess the relative contributions of different species to diet. Meat weight values are dependent on several assumptions; firstly that the presence of bones on the site means that these animals were being consumed, secondly that the bones were not utilised for cultural purposes, and finally that the faunal remains found on the site are representative of the typical diet consumed. White (1953) pioneered the technique of converting animal bone counts into meaningful assessments of the actual dietary contribution of different species. This enables a greater understanding of the relative importance of each resource set in terms of the dietary contributions made by each of these resource types.

There are two main methods utilised to calculate meat weights. The traditional method devised by White (1953) involves using MNI to calculate the quantity of meat represented by a zooarchaeological assemblage. A problem with this method is that it is based on MNI, and is therefore subjected to the same limitations as MNI, and is likely to under-represent the quantity of meat estimated (Casteel 1978; Lyman 2008).

The second technique, known as the 'weigemethod', calculates meat weights from the dry weight of bone (Casteel 1978). The 'weigemethod' technique assumes a linear relationship between bone weight and meat weight, which is not necessarily correct (Lyman 1979, 538). Bone weights can be affected by mineralization, leaching, weathering, and preservation (Uerpmann 1973, 311), which can affect the total quantities of meat calculated. Characterising the relationship between dry bone weights and the quantity of meat they represented is very complex, and there are concerns as to the effectiveness of this technique. As none of the North Atlantic Island assemblages contain information on the bone weights of each species, it is not therefore possible to determine the meat weights based on the 'weigemethod'.

Neither of these techniques take into account factors such as sex, age and health and of the animals involved, all of which can impact on the meat weight achieved (Lyman 1979, 538). A further critique is that there is little standardisation in how meat weights are calculated, for example weights calculated by White (1953), based primarily on domestic species are somewhat heavier than the values of wild species as calculated by Stewart and Stahl (1977).

Casteel (1978, 72) criticises the level of accuracy of the constants used in meat weight calculations, causing limitations for the use of these values.

Techniques such as meat weight calculations do not account for differences in carcass utilisation. The intensity of carcass utilisation by past populations differs depending on the needs and requirements of past populations (Stewart and Stahl 1977, 269). Carcass utilisation is therefore not consistent or predictable between archaeological assemblages. Lyman (1979, 539) states that the presence of one or two bones from a carcass does not mean that the whole body was utilised. This concern can be addressed by calculating the meat weights for each individual bone, using MNE (Minimum Number of Element) counts (Casteel 1978). For many of the North Atlantic Island assemblages MNE counts have not been generated, preventing this technique from being utilised. The use of carcasses for products other than meat also needs to be considered. Bone marrow has been identified as a valuable product available exploited from carcasses (Binford 1978), providing a valuable source of fat (Speth and Spielman 1983). Meat weight values for marrow have been calculated for various different species (e.g. Binford 1978; Blumenschine and Madrigal 1993; Outram and Rowley-Conwy 1998), and can be applied to zooarchaeological deposits to determine the importance of this resource. Ideally this method of calculation should reflect any zooarchaeological evidence for carcass utilisation; for example if there is no evidence of marrow cracking (e.g. Outram 2001), then it would be inaccurate to include bone marrow in meat weight calculations.

Differences in animal size can also impact on the quantity of meat available for consumption. Jackson (1989, 607) advocates weighing and measuring each skeletal element to calculate the amount of meat that can adhere to the bones, ideally measuring several different specimens from each stratigraphic unit to ensure accuracy in results. This technique would enable a greater level of meat weight accuracy to be achieved, but it is a highly time-consuming methodology for a relatively low return. Considering differences in the size of individuals is especially pertinent when wishing to investigate the quantity of meat represented by fish bones. There is a high level of size variability within fish species; for example cod size can range between 18cm at the end of their first year of their life, to become up to 2 meters long in later life (Wheeler 1969), and therefore the quantity of food that they represent is highly dependent on the size of fish in question. To assess the real importance of marine species Colten (1995; 2002) utilised meat weights and calculated multipliers to enable inter-species comparisons of the quantity of meat provided by each different resource type, which can be calculated using MNI and NISP values. This provides a generalised understanding of dietary behaviour, and enables access information about the importance of each fraction of the zooarchaeological assemblage, providing an understanding of the proportions of each resource type.

Meat weight values are particularly useful when assessing the contribution of shellfish to diet. Shellfish are highly fragmentary and meat weights for shellfish rely on weighing shell remains to determine the quantity of meat they represent. This can be problematic as some molluscs are heavy in relation to the amount of meat they provide, whereas some shells have lighter shells compared to the amount of meat they represent (Mason *et al*. 1998, 306). Calculating meat weight values using MNI, or using the average weight of shells, provide a more accurate value that takes into account the number of individuals represented in an assemblage (Mason *et al.* 1999). Meat weight values can be further enhanced improved by using taxon-specific values to apply to each identifiable species of shell (Classsen 2000). Unfortunately MNI based calculations mean that not all of the shell assemblages are included in the analysis; only fragments with hinges or apexes can be used, which negates a large proportion of shell assemblages. In many zooarchaeological reports from the North Atlantic Islands shellfish MNI was not calculated at all, presenting a great challenge to assessing the importance of shellfish species.

Meat weights are designed to be estimates rather than exact figures (Lyman 1979, 538) providing a greater insight into past consumption patterns and relative species importance than can be achieved from simply counting the bones. There are few North Atlantic assemblages that are suited to generating accurate meat weight values, and therefore this technique cannot be applied to all datasets.

Abundance Indices

Abundance indices can be used to define the relationship between different food sources belonging to different size fractions Abundance indices have been used to assess the importance of larger bodied creatures (high ranked prey items) to smaller creatures (low ranked prey items) (Betts and Friesen 2004; 2006; Brougton 1994a; 1994b). Accurately calculating abundance indices requires a sampling strategy that ensures that mammals and sea mammals are collected using a representative and comparable methodology such as sieving all deposits on site to 6mm (Betts and Friesen 2004; 2006). This rigorous sampling strategy was not applicable to many of the North Atlantic Island sites, making the abundance indices more challenging to utilise, but the technique provides a valuable insight into the relative importance of larger bodied prey resources within faunal assemblages, and therefore would be beneficial to utilise.

Summary: Quantification Methodologies

There are a wide range of different approaches towards quantifying zooarchaeological resources, and assessing their relative importance in terms of dietary contribution. Due to the nature of recording strategies previously used in the North Atlantic Islands techniques that can accurately be applied to understand the importance of different resources are limited. The methodologies employed in this research aim to work within the parameters of the North Atlantic Island dataset to provide comparisons between the different resource types utilised in each period. Integrating data from a range of different sites limits the level of detail in analysis that can be undertaken, but it is still possible to achieve an understanding of the relative importance of marine foods through time in the North Atlantic Islands.

Methodology

Due to the highly diverse nature of the North Atlantic zooarchaeological assemblages a two tiered approach towards comparing the datasets was utilised. First a broad scale of analysis of NISP values of each species after Hambleton (2008), Serjeantson (2011) and Conolly *et al.* (2011) is used to enable comparisons of numerous different sites across the whole of the North Atlantic Islands. The second approach is to use zooarchaeological data from a range of comparable sites in South Uist, to generate meat weight values to assess how useful the technique is for assessing the relative contribution of the different resources to diet.

Broad Scale Analysis

The aims of the broad scale analysis are to maximise the zooarchaeological evidence by incorporating all existing datasets available for each island group to explore the changing importance of marine resources through time. Zooarchaeological evidence from the Northern Isles and the Western Isles are compared to explore whether different economic strategies were being practiced between the island groups. The NISP counts for each site, and bibliographic references for these data are included in Appendix 6 and Appendix 7.

Broad Scale Analysis: Compiling the Dataset

The dataset includes all published data on the islands, in addition to several datasets awaiting publication (e.g. Best and Cartledge forthcoming; Best and Powell; Ingrem forthcoming; Mulville and Powell forthcoming a, b, c). This comprised 5 occupation phases of sites from Shetland, 23 occupation phases in Orkney, and 31 occupation phases in the Outer Hebrides. Unidentifiable bone fragments such as mammal size classes, fish species families, and unidentifiable bird bone fragments were excluded to reduce inaccuracies resulting from identification biases.

To maintain temporal integrity sites were input into the database using the chronological period assigned in the published report. In this way they could be combined into larger period groups (e.g. Iron Age), or kept as smaller temporal units (e.g. Early, Middle and Late Iron Age) when conducting further analysis. When contexts or phases were described as topsoil, or heavily disturbed, they were not included in the database. This prevented temporal inaccuracies resulting from residual bone rather than *in situ* assemblages. Contextual and interpretative information for each assemblage was consulted to ensure that discrete primary deposits from specific time periods were analysed.

Several sites were excluded from this study, for example the mammal and fish bone evidence from the chambered cairn at Holm of Papa Westray (Harman 2009; Harland and Parks 2009), as dating and phasing information was not clear for the tomb, and could have potentially caused false temporal patterns to emerge. Similarly any contexts interpreted as otter spraint were not included in the database as they would not necessarily be indicative of human exploitation patterns, and could confuse the interpretation of the zooarchaeological data. Sites published containing qualitative data could not be included in this study, as they lacked the information necessary to be incorporated into the quantitative methodologies used in this study (e.g. Midhowe (Platt 1934), Eday (Platt 1937a) and Blackhammer (Platt 1937b)).

Within the database a separate record was made for each phase of occupation of the site; for example the site of Tofts Ness in Orkney had a different entry for the Neolithic, Bronze Age and Iron Age phases of the site as identified by (Nicholson and Davis 2007), resulting in multiple entries for the same site within the database. In total 122 different phases from North Atlantic Island sites were included in the main site database.

Fish and shell that were both hand-collected and sieved were included to the database. For comparability using only hand-collected fish remains would have been beneficial, but this would have resulted in loss of information on some fishing economies. For several sites sieved material was not recorded separately to hand-collected material and so combining these two totals was necessary. Also different species are represented within sieved and hand-collected assemblages; for example Norse deposits from Bornais M2a contained 3111 herring bones that were only present in the <10mm sieved deposits (Ingrem forthcoming), highlighting the need to utilise sieved and hand-collected fish bone data.

Grey literature provided supplementary data unavailable from formally published sources e.g. from 'An Archaeological Database of Marine Resource Exploitation in Scotland' (MARES) (Cerón-Carrasco *et al*. 2006). The MARES database enabled access to previously unpublished data. Fish bone data from the more recent excavations would otherwise have been inaccessible. The sites that included MARES data were: Scalloway, Skara Brae, Knap of Howar, Pierowall Quarry, Berigh, Bostadh, Cnip and Galston. Similarly several datasets were available from interim reports such as Mine Howe (Mainland *et al.* 2003; Mainland and Ewens 2004) and Earl's Bu (Mainland 1995).

In some scenarios red deer antler and bones fragments were recorded in separate fields (e.g. Point of Buckquoy: Rackham 1989; A' Cheardach Mhor: Finlay 1986; Udal North: Serjeantson N.D.). These were recorded separately in the database, but the totals were combined when analysing the data, to ensure consistency in values as not every site explicitly stated whether red deer totals included antler fragments or bone fragments.

Statistical Exploration of the Data

The data was explored using correspondence analysis (CA). CA is a form of multivariate analysis, frequently used as a measure of abundance in ecological datasets (Gauch 1982). CA is a descriptive technique, enabling comparisons between the assemblage compositions of each site to be drawn, grouping together sites with similar characteristics (Shennan 1997, 318). CA calculates the importance of different variables within the data, and plots each assemblage in accordance with how each site 'corresponds' to each other (Shennan 1997, 320). This technique was used to compare plant species NISP values within different sites to trace the spread of agriculture across SW Asia and Europe (Colledge *et al.* 2006), demonstrating the applications of the technique for broad regional comparisons. Correspondence analysis comparing NISPs of terrestrial, sea mammal, fish and shellfish resources for each site will be used for initial exploratory analysis of the sites to enable initial comparisons of archaeological sites to be identified. By generating correspondence plots comparing NISPS of terrestrial mammals, marine mammals, fish, shellfish and bird bone it is possible to provide an initial exploration of the data to identify possible similarities and differences between archaeological sites.

The CA was performed using Canoco 4.45, a specialist programme for analysing environmental data. Only sites with greater than 50 mammal bone fragments are included in the statistical analysis to prevent the results being affected by non-representative samples; for example Bagh Ban on Barra had a total NISP of 10 (Mulville 2000) and was excluded from the analysis.

Assemblage Proportions of each Zooarchaeological Fraction

To explore the relative proportions of each different resource type utilised, NISP values of each resource type present (i.e. fish, mammal, sea mammal, shellfish) were compared graphically. NISP values of fish, shellfish, mammal and sea mammal remains were totalled for each period and island group in question to provide average values, reducing the impact of factors such as preservation, sampling and analytical biases that cause difficulties during inter-site comparisons. By calculating percentage proportions it is possible to achieve an understanding of the relative importance of each type of resource irrespective of assemblage size.

The mammalian data utilised in the analysis focused on the major food species. Dog, cat, pine marten, badger and small mammal NISPs have been excluded from all calculations as they can potentially skew the values observed by inflating the importance of terrestrial food sources. Due to problems with the absence of shellfish in many assemblages, NISP proportions were generated both including and excluding the shellfish data.

Understanding the Importance of Marine Mammals

To assess the importance of sea mammal resources, abundance indices based on NISP were generated to compare the number of sea mammal fragments to the number of bones from all non-sea mammal species, and to provide an understanding of their importance in relation to the wider faunal spectrum. The abundance of sea mammal fragments was then compared to the total number of fish bones to determine the relationship between the aquatic resources utilised.

Analysis of the species of sea mammals represented by NISP is then conducted to achieve an understanding of the different types of sea mammal being used by archaeological populations of the islands.

The calculation used to calculate abundance indices is:

$$\frac{\Sigma NISP\ Sea\ mammal\ (or\ high\ ranked\ prey)}{\Sigma NISP\ sea\ mammal + \Sigma NISP\ other\ species\ (or\ low\ ranked\ prey)}$$

Fish Species Analysis

To assess fishing strategies practiced in the islands it was necessary to compare the fish species represented in these island groups. Fish bone evidence was available for 42 occupation phases of sites in the Northern and the Western Isles, permitting information on broad trends in fish species exploitation to be accessed. Quantifying fish bone remains in a meaningful way is challenging, considering the range of human and environmentally influenced factors affecting the assemblage composition, for example differences in sampling strategies. The fish bone investigation focuses on providing an overview of trends in the species exploited, rather than numerical comparisons, which are not possible given the range of different sampling and analytical strategies practiced between assemblages. Understanding temporal trends in fish species exploitation can provide insights into trade, possible seasonal exploitation, and environmental factors influencing procurement strategies, enhancing understanding of the changing relationship between human populations and fish resources.

Shellfish Species Analysis

Shellfish NISP information was available from 21 sites in the North Atlantic Islands. Non edible species of marine shell were not included in the analysis of this study, as they do not provide an understanding of past dietary behaviour. Matthew Law (Cardiff University) is studying marine and land molluscs for his PhD thesis, and will discuss the potential of this resource further.

To determine the types of shellfish species being utilised in the islands, cumulative shellfish NISP values for each period were used. NISP counts can provide an understanding of the relative importance of different shellfish species, but it is acknowledged that these values are heavily biased by excavation and collection strategies, and may not necessarily be representative of foods consumed by humans. MNI was rarely calculated for shellfish in the North Atlantic Island assemblages, and the exact number of shellfish present on sites is not possible to achieve with the current dataset. Whilst shellfish evidence enabled broad temporal patterns in shellfish species consumption in the North Atlantic Islands, accurate quantification of this resource was not possible to achieve.

Meat Weight Analysis in South Uist

This section of the analysis aims to determine the relative quantities of food represented by each resource type, and to act as a model to assess and quantify marine resource use, in relation to other resources, through time. The island of South Uist was selected as a case study region to attempt meat weight analysis, to provide an indication of the relative importance of each resource type in terms of total dietary contribution.

The South Uist sites excavated have large bodies of consistently collected and recorded zooarchaeological data making them ideal for detailed dietary analysis. There will be variations in the assemblages as a result of taphonomic processes, but by using sites subjected to similar excavation and analytical strategies it is possible to more accurately calculate meat weights represented by the bones present on site.

The South Uist sites and the periods that they represent used in the meat weight analysis are shown in Table 4.

Site	**Periods Analysed**	**Reference**
Cladh Hallan	**Early Bronze Age** **Late Bronze Age**	**Parker Pearson *et al.* (forthcoming).**
Dun Vulan	**Middle Iron Age**	**Parker Pearson and Sharples (1999).**
Cille Pheadair	**Norse**	**Parker Pearson *et al.* (forthcoming)**

Table 4: Case study site information

The sites of Cladh Hallan and Cille Pheadair were excavated as part of the 'Sheffield Environmental and Archaeology Research Campaign Hebrides' (SEARCH), and using a research framework with very similar methodologies and sampling strategies. Dun Vulan was excavated in the 1990s (Parker Pearson and Sharples 1999), and subjected to similar sieving and sampling strategies as the sites of Cladh Hallan and Cille Pheadair. The isotopic evidence from Middle Iron Age Dun Vulan revealed some interesting dietary trends, and therefore this site was selected for more detailed analysis to aid with the interpretation of these results.

Faunal remains from all three sites were analysed by Jacqui Mulville and Adrienne Powell (Mulville and Powell forthcoming a, b), ensuring consistency in the analysis achieved. These sites have been analysed in great detail for their relevant publications (Mulville and Powell forthcoming a, b), and their main use in this thesis will be to provide a reliable dataset from which to begin constructing meat weight analysis.

Fish bone analysis was undertaken by Claire Ingrem, who kindly provided data from Cladh Hallan (forthcoming a) and Cille Pheadair (forthcoming b). Where the total fish bone assemblages and samples had not been analysed 'Projected NISP' and 'Projected MNI' values were calculated by multiplying the sample analysed by the total volume of the sample (Ingrem pers. comm.). Fish MNIs are estimated based on the proportions of the samples analysed, to provide projected MNI values (Ingrem pers. comm.), and are therefore estimates based on the proportion of the assemblage already analysed.

The case studies are limited by the shellfish data, as small samples of shellfish had been analysed for species identification, however in many case the proportions of the samples analysed were not listed, preventing greater levels of quantification from being achieved (e.g. Sharples 2012). Ideally 'projected NISP' values relating samples analysed to the total volume of the assemblage, as calculated for the fish remains, would be beneficial.

Calculating Meat Weights

MNI was only calculated for the major fish species present in the assemblage, and so the meat weight values do not represent the entirety of the fish bone evidence available from these sites. Fish sizes within species are highly variable and as fish length was not calculated alongside the MNI values it was not possible to calculate the meat weight based on varying sizes of individuals. The fish meat weight values achieved are therefore are only estimates. The challenges of using MNIs are discussed earlier on in this chapter, and these challenges will also impact on the meat weight values generated using MNIs. Therefore the meat weights produced are likely to under represent the quantity of meat represented by each food type. Shellfish could not be included in this analysis as MNI values were not available from these resources.

MNI was not possible to calculate for sea mammals due to the homogenous nature of sea mammal bone. NISP was used to calculate meat weights instead, and only sea mammal fragments that were attributed as being either 'seal' or 'whale' were included in the analysis. Generic sea mammal class fragments were excluded from calculations. Whilst this was not ideal, it provided the best solution to the challenge given the available data. It is expected therefore that the values generated for sea mammals are likely to provide more of an over-estimation of the importance of sea mammals in the zooarchaeological assemblages.

Values for usable meat weight of carcasses were taken from several different sources to enable the most appropriate proxies for the North Atlantic Island species to be used. The meat weights utilised are shown in Table 5.

Species	Meat Weight (KG)	Reference
Gadid	3.94	Barrett 1993
Seal	*150.00*	Smith 2011
Whale	*829.60*	Smith 2011
Cattle	226.80	Lyman 1979
Sheep/Goat	18.14	Lyman 1979
Pig	77.79	Lyman 1979
Red Deer	45.36	White 1953

Table 5: Dressed Meat Weight values

Sheep, cattle and pig values (Lyman 1979, 542) are based on the original work by White (1953). White's meat weight values for Virginia deer were used as a proxy for red deer (1953, 397) as they represent similar sizes of animals. Values from White (1953) and Lyman (1979) were converted into kilograms to enable cross-comparisons between species. Smith (2011) provided meat weights for the sea mammals, with leopard seals used as proxy for the North Atlantic seals, and pilot whales were used to represent the whale specimens found at the sites, as many of the sea mammal bones in the North Atlantic were not attributed to species. The use of proxies does not provide the most accurate values of meat weight, but they provide the best available estimates to date. The meat weight analysis also works on the assumption that everything on site was consumed, which is incorrect as bones can be utilised for a range of cultural purposes.

As saithe fish weight values were not available, cod (which are also from the gadid family) values were substituted from Barrett (1993, 12), as a useful proxy. The weight for an 80cm long cod were utilised as an average fish size, in the absence of more detailed fish size information.

Bird MNI values were kindly provided by Julia Best (Best 2013; Best and Powell forthcoming; Best and Cartledge forthcoming). Values for each bird species were available from Smith (2011) and where the exact bird species was not available, values from birds within the same family were utilised as a proxy instead. Table 6 shows the dressed carcass weights for the most commonly encountered species from the North Atlantic Islands.

Species	**Meat Weight KG (Smith 2011)**
Gannet	1.61
Cormorant	1.11
Greylag goose	3.50
Great black backed gull	0.60
Herring/Lesser black backed Gull	0.60
Whooper swan	3.50
Great auk	0.77
Shag	1.11
Curlew	0.28
Puffin	0.77
Guillemot	0.77
Fulmar	0.11

Table 6: Dressed Meat Weight values for the most commonly consumed birds in the North Atlantic Islands

The meat weight values generated have to be viewed with caution as they do not take into account the relative sizes of the individual specimens. This is especially pertinent when considering fish, as there can be extensive size variations within a species depending on the age of the individuals involved; for example cod can range from 5cm-100cm in size (Cerón-Carrasco 1999, 276). Meat weight values for different sizes of fish are still being developed, and whilst Barrett (1993) provided meat weights for different fish sizes of cod, values for other fish species of varying sizes are not yet available.

Summary

The highly diverse and varied nature of archaeological deposits, and the analytical decisions made during analysis, mean that drawing accurate comparisons between different sites and geographical locations is complex. Successful methodologies used previously to compare zooarchaeological remains across regions are broad in scope based primarily on NISP counts (e.g. Hambleton 2008; Serjeantson 2011; Conolly *et al.* 2011). NISP comparisons are used in this thesis to explore broad temporal trends in the proportions of wild, domestic, and marine species across the islands. Case study sites from South Uist are used to generate meat weight values to provide a more in-depth understanding of the relative contribution of each resource type in diet. The results of the zooarchaeological analysis are then compared to the stable isotope analysis to allow diet to be assessed on a range of different scales. These methodologies are applied to the dataset, and their value critiqued in chapter 9. The following chapter outlines the background to isotopic research, and its applications in the North Atlantic Islands.

Chapter 5: Background to Dietary Stable Isotopes in Archaeology and Current Isotopic Research in N. Atlantic Islands.

Stable isotope analysis is a popular technique used in archaeology to enhance understanding of human and animal dietary behaviour, and has become increasingly applied to the North Atlantic as a method of exploring palaeodietary trends. This chapter outlines the theory of stable isotope analysis and the debate surrounding its use. Past applications of stable isotope analysis in the North Atlantic Islands are explored, before outlining the strengths and limitations of the current dataset to identify potential for further analysis. The chapter concludes by outlining the aims of the isotopic research undertaken in this project.

A History of Stable Isotope Analysis

Stable isotope analysis has commonly been used in archaeology since the mid-1980s when research demonstrated the validity of the technique for reconstructing palaeodietary behaviour, providing valuable insights into past dietary behaviour and economic strategies (Schoeninger *et al.* 1983; DeNiro 1985; Schoeninger and DeNiro 1984; Chisholm *et al.* 1982). Archaeological applications of stable isotope analysis of human remains have been used in a variety of different geographical regions and time periods ranging from Jomon period hunter-gatherers in Japan (Kusaka 2010), Middle Archaic humans in Florida (Quinn *et al.* 2008), English Anglo-Saxon populations (Mays and Beavan 2012) to Australian hunter-gatherer groups (Pate 1995; 1997). Stable isotope analysis has also been used to explore the past diet of animals, for example studies comparing the diet of aurochs and cattle in Neolithic Scandinavia (Noe-Nygaard *et al.* 2005), and investigations of saltmarsh grazing in the Severn Estuary (Britton *et al.* 2008). The applications of stable isotope analysis are multi-faceted, and the technique is a vital tool in investigating direct dietary behaviour in archaeological human and animal populations.

Stable Isotope Theory

Stable isotope analysis is essentially based on the principle that the foods consumed by an individual are reflected in the isotopic composition of bodily tissues (‘you are what you eat’) (Chisholm *et al.* 1982; Schoeninger and DeNiro 1984). These elements are used by biological tissues as part of the growth and regeneration process, entering the body through consumption of dietary protein, and accumulate in the body of organisms over time. The isotope ratios between the elements carbon (^{13}C:^{12}C) and nitrogen (^{15}N:^{14}N) are used by archaeologists to understand past diet. Amino acids are the 'building blocks' of collagen, and the composition of amino acids varies little between species, ensuring that stable isotope studies show only inter-species dietary variation, and not differences in the chemical makeup of the collagen (Schoeninger and DeNiro 1984). Dietary protein accounts for approximately 22% of the amino acids in bone collagen (Dürrwächter *et al.* 2006). Due to differences in the uptake of $\delta^{13}C$ and $\delta^{15}N$ and fluctuations in metabolic process the isotope ratios are constantly changing throughout an organism's life.

Collagen is present in a range of bodily tissues including teeth, nails, hair and bone, with each tissue experiencing different turnover and fractionation rates (O'Connell *et al.* 2001; O'Connell and Hedges 2002; Tieszen *et al.* 1983). In archaeology bone is the most commonly preserved tissue found on archaeological sites, and is therefore the target for bulk collagen dietary analysis. Bone collagen is relatively stable through time, preserving the elements found within it reliably (Chisholm *et al.* 1982).The renewal rate of human bone collagen is approximately 10-15 years (Chisholm *et al*. 1982; Lovell 1986), although it has been suggested that stable isotope values can represent dietary intake over a 5-20 year time span depending on collagen renewal rates within individuals (Ambrose and Norr 1993). Stable isotope analysis therefore provides an insight into longer term average dietary trends of individuals. Experiments have demonstrated that foods containing higher quantities of protein have a greater impact on the carbon and nitrogen values than low protein foods (e.g. Ambrose and Norr 1993; Hedges and Reynard; Howland *et al.* 2003; Tieszen and Fagre 1993). These values therefore predominantly reflect animal protein consumption (e.g. meat and/or milk), protein-rich cereals and nuts can influence the isotopic values observed if consumed in sufficient quantities (Hedges 2003).

Carbon ($\delta^{13}C$: $\delta^{12}C$)

The isotopes carbon 12 and carbon 13 have different atomic masses, with ^{13}C having an additional neutron. Both of these isotopes of carbon exist in the atmosphere, with ^{12}C being more abundant, accounting for 98.89 % of atmospheric carbon (Bowen 1988, 452; Hoefs 1997, 38). These isotopes are stable, meaning that they are not subject to radioactive decay, and therefore are present in consistent proportions in the atmosphere. Plants absorb atmospheric CO_2 during photosynthesis, and there is differing uptake of ^{12}C and ^{13}C depending on the metabolism of the individual plants and environmental conditions (O'Leary 1981, 553; 1988, 328; Troughton 1972, 421), resulting in differing accumulations of ^{13}C between plant species. Plants are then consumed by humans and animals, and the different carbon isotopes are then passed up through the food chain.

The different masses of ^{12}C and ^{13}C are measured using mass spectrometry to determine the ratios of these two values. The ratio of these values measured in a sample is then compared to a standard to generate a δ value, which is expressed in percentage parts per million (‰).

The expression used to calculate the δ value of ^{13}C is:

$$\delta^{13}\mathrm{C} = \left[\frac{(^{13}\mathrm{C}/^{12}\mathrm{C})\mathrm{sample}}{(^{13}\mathrm{C}/^{12}\mathrm{C})\ \mathrm{standard}} - 1\right] \times 1000$$

The ratios between can be used to determine a number of things about past diet. Firstly $\delta^{13}C$ and $\delta^{12}C$ are valuable for understanding marine food consumption, as oceans have a prevalence of dissolved bio-carbonate that contains greater quantities of ^{13}C, and therefore marine species utilising this carbon have enriched $\delta^{13}C$ values (Ambrose 1993, 93-94; Schoeninger and DeNiro 1984, 637). Marine species and consumers of marine species can therefore be identified by the enriched $\delta^{13}C$ values that they display. A further application of carbon isotope ratios is to determine the trophic level that an organism is feeding at. The $\delta^{13}C$ values increase by a small amount (approx. 1-1.5 ‰) with trophic stage, in accordance with the rise in $\delta^{15}N$ (Dürrwächter *et al.* 2006), resulting in organisms higher up the food chain having enriched $\delta^{15}N$ and $\delta^{13}C$ values. Finally, the third major application of carbon stable isotope analysis is to determine C_3 and C_4 plant consumption. C_3 plants (e.g. wheat, barley, potatoes) metabolise using the 'Calvin System', whereas C_4 plants (e.g. millet, maize, sugar cane) adapted to arid environments metabolise using the 'Hatch–Slack System'. The differences between the metabolic pathways of these two plants results in C_4 plants retaining higher levels of ^{13}C than C_3 plants (Bender 1968; O'Leary 1981; Troughton *et al.* 1974; 775), and and therefore any consumers of the C_4 rich plants would also have enriched $\delta^{13}C$ values. Diets including C_3 and C_4 plants combined can produce a similar $\delta^{13}C$ signature to a marine diet (Chisholm *et al.* 1982). Fortunately C4 pathway plants are not common in prehistoric European contexts; Millet (*Panicum miliaceum*), a C4 plant has been identified in some regions of mainland Europe in the Neolithic and later periods (Renfrew 1973, 99), and isotopic research at the Late Iron Age site of La Tène, in Switzerland demonstrated that some individuals consumed millet (Le Huray and Schutkowski 2005), but these instances are rare. To date no C_4 plants have been identified in prehistoric British contexts (Van Klinken *et al.* 2000), and therefore will not impact on the isotopic values observed in the North Atlantic Islands.

Nitrogen ($\delta^{15}N$: $\delta^{14}N$)

As with the carbon the two isotopes of nitrogen (^{14}N and ^{15}N) have different atomic masses, with ^{15}N having one additional neutron. In the atmosphere ^{14}N is the most common isotope accounting for 99.64% of the atmospheric nitrogen, with ^{15}N accounting for only 0.36% (Bowen 1988: 425; Hoefs 1997, 44). Atmospheric nitrogen (N_2) is fixed in the soil as a result of nitrification in plants, aided by N_2 fixing bacteria on the roots of plants known as rhizobia (Lodwig *et al.* 2003; Postgate 1998, 59). Nitrogen isotope ratios are influenced by factors such as soil properties, microbial activity, rainfall, vegetation and agricultural practices (Granhall 1981). The ^{15}N values observed are closely linked to soil properties, which change as a result of differences in the environment (Ambrose 1991, 296). More enriched ^{15}N values are linked to highly saline environments and also to arid environments (Ambrose 1991, 295; Heaton 1987; van Groenigen and van Kessel 2002), more depleted ^{15}N values are typically found in more moist, forested areas (Heaton 1987). The input of nitrogen into the ecosystem in processes such as manuring (Bogaard *et al.* 2007; Senbayram *et al.* 2008) can increase the $\delta^{15}N$ values observed in consumers. The ratios of $\delta^{15}N$ to $\delta^{14}N$ demonstrate the trophic level that the organism feeds at with enriched $\delta^{15}N$ values indicative of organisms feeding higher up the food chain. Enriched $\delta^{15}N$ values are also observed in marine ecosystems, and consumers of marine products, as the food chains are more elongated than observed in terrestrial ecosystems, resulting in a greater accumulation of $\delta^{15}N$ (Pollard and Heron 2008, 347).

As for calculating $\delta^{13}C$ values, the ratios of ^{15}N to ^{14}N are measured using mass spectrometry and compared to a standard to generate a δ value, which is expressed in parts per million (‰). The expression used to calculate δ values of ^{15}N is:

$$\delta^{15}\mathrm{N} = \left[\frac{(^{15}\mathrm{N}/^{14}\mathrm{N})\mathrm{sample}}{(^{15}\mathrm{N}/^{14}\mathrm{N})\ \mathrm{standard}} - 1\right] \times 1000$$

Interpreting $\delta^{13}C$ and $\delta^{15}N$ values

Existing research has provided evidence of typical isotopic values for Holocene Europe, shown in Table 7 (Bocherens *et al.* 1991; Murray and Schoeninger 1988; Schulting and Richards 2002a).

Stable Isotope	Value (‰)	Interpretation
$\delta^{13}C$	-20 /-21	Terrestrial signature
$\delta^{13}C$	-12	Marine signature
$\delta^{15}N$	3	Plant
$\delta^{15}N$	6	Herbivore
$\delta^{15}N$	10	Carnivore
$\delta^{15}N$	12	Consumer of marine products

Table 7: Typical $\delta^{13}C$ and $\delta^{15}N$ values for Holocene Europe
(Richards and Schulting 2002a, 154)

In Holocene Europe $\delta^{13}C$ value of around -20—21‰ is typical of terrestrial subsistence, with values of -12‰ being indicative of an intense marine dietary input (Chisholm *et al.* 1982, Schoeninger *et al.* 1983, Barrett *et al.* 2000). A $\delta^{15}N$ a value of 3‰ would represent a typical plant, with herbivores having a value of around 6‰, and approximately 9-10‰ for carnivores, with higher values being indicative of a marine diet (Bocherens *et al.* 1991; Murray and Schoeninger 1988; Schoeninger *et al.* 1983). A greater discussion of common interpretations of isotopic values in Holocene Europe is included in Chapter 6.

Factors affecting the Individual Isotopic Record

The isotopic record is highly variable, with a wide range of physiological factors that can influence bone collagen isotopic values observed within individuals, linked to environmental, biological, and cultural considerations (Hare *et al.* 1991; Van Klinken *et al.* 2000).

Plant specimens can have a degree of natural variation in carbon of up to 3% as a result of genetic differences between plant metabolic processes, which in turn influences the $\delta^{13}C$ expected in herbivores consuming these plants (Tieszen 1991, 244).

Within human and animal specimens the age of the individual being studied can affect the isotope reading observed, as diet can be highly age-specific. Juvenile individuals consuming their mother's milk have inflated nitrogen values as they are higher up the food chain due to consumption of protein produced by an omnivore (Richards *et al.* 2006). There have been several studies conducted that demonstrate the effect of weaning on bone collagen $\delta^{15}N$ values, from studying known age individuals (Schurr 1997; 1998). Weaning signatures have also been identified in archaeological skeletons (Richards *et al.* 2006) Typical $\delta^{15}N$ values for juvenile individuals could be as high as 15-17‰, compared to 10-12‰ typical of consumers of terrestrial protein (Schurr 1997; 1998; Richards *et al.* 2006). How long the weaning signature stays in the bulk collagen isotope signature is not currently known. In this study by sampling only fully mature individuals elevated $\delta^{15}N$ values as a result of weaning are avoided.

Manuring of crops can impact on the isotopic readings of humans and animals. Animal manure used as a fertilizer on plants raises the $\delta^{15}N$ values in plants and the animals feeding on them (e.g. Bogaard *et al*. 2007; Senbayram *et al.* 2008; Simpson *et al.* 1999; Wagner 1991; Yoneyama 1996). Long term experiments exploring the effects of manuring on crops demonstrated that $\delta^{15}N$ levels were enriched as a result of the process (Bogaard *et al.* 2007; Senbayram *et al.* 2008). When manure is added to plants the enriched $\delta^{15}N$ observed in animal dung causes the loss of the lighter ^{14}N in the form of ammonia gas, leaving the soil high in ^{15}N to be absorbed by plants (Kendall 1998; Heaton 1986). Thus whilst traditionally values with elevated $\delta^{15}N$ readings (e.g. 8-11‰), are interpreted as evidence of a high meat diet, these inflated $\delta^{15}N$ values can also be evidence of consumers eating plants that have been fertilized with manure (Bogaard *et al.* 2007; Senbayram *et al.* 2008).

Baselines and Palaeoenvironmental modelling

It is also highly important to set up baselines for each study to counteract possible temporal and geographical fluctuations in isotope readings (Schulting and Richards 2002a). The isotopic signatures of animals are crucial in aiding with the interpretation of human values (Hedges and Reynard 2007; Mulville *et al.* 2009; Koshiba *et al.* 2007; Redfern *et al.* 2010; Richards *et al.* 2006). Faunal isotopes can be used to act as a baseline from which to interpret human values and to model palaeoenvironmental differences in background $\delta^{13}C$ and $\delta^{15}N$ readings. Microenvironments have distinctive isotopic baselines, sometimes referred to as ‘isozones’ (Stevens *et al.* 2010; 2013). The characterisation of these ‘isozones’ is important in understanding dietary behaviour, and land management strategies of past human and animal populations.

Differences in isotopic values observed between species, especially herbivores, exist due to factors such as dietary behaviour, access to resources and inter-species variations in metabolic processes (e.g. Fizet *et al.* 1995; Katzenberg and Weber 1999; Miller *et al* 2010). Coltrain *et al.* (2004) observed that $\delta^{15}N$ values of Caribou from Greenland were approximately 3‰ higher than atmospheric nitrogen values, as a result of Caribou diet being heavily reliant on nitrogen-rich lichen. Makarewicz and Tuross (2006) determined that there were differences in the $\delta^{13}C$ and $\delta^{15}N$ values of wild and domestic caprines, as a result of foddering versus browsing. Regional variations in isotope results between species are likely to be a result of access to different food sources (Katzenberg and Weber 1999). Sampling of all the major food species for each region being studied is essential in understanding the typical readings for each species to characterise typical values expected for each geographical region and temporal period in question.

Due to differences in climate small-scale variations in diet nitrogen values observed can differ between geographical regions. One of the key factors influencing δ^{15}N values observed is differences in climate between locations (Heaton 1986). Nitrogen differences can occur on a small scale as a result of variations in nitrogen cycling due to topographical differences and variations in soil inputs (Ugan and Coltrain 2011). Water availability influences δ^{15}N, and studies have demonstrated that African ruminants have enriched δ^{15}N values as a result of stress from lack of water (Van Klinken *et al.* 2000). Whilst there have been developments in understanding the factors influencing δ^{15}N in the bone collagen record there is still much to be understood (Britton *et al.* 2006).

A major factor that affects carbon stable isotope values is climatic and environmental variations in isotope readings. Carbon shifts are diverse in nature, and are highly variable in size (Van Kinken *et al.* 2000), making them difficult to predict. For example Bocherens and Drucker (2003) found that in the space of only 40 years in the Bialowieze primeval forest that the δ^{13}C values had increased from 7.5‰ to 8.5‰. Analysis of past tree remains in Europe has identified several different climate shifts dating back thousands of years (e.g. Aucour *et al.* 1993; Leavitt and Danzer 1992). An important shift in carbon at the Pleistocene-Holocene boundary of about 1-3‰ has also been identified (Van de Water *et al*. 1994; Becker *et al.* 1991). Geographical differences in δ^{13}C values have also been observed between Northern and Southern Europe, with northern European specimens having δ^{13}C values that are on average 1-2‰ lower than Southern European specimens (Schulting 2011, 19).

Palaeoenvironmental isotopic modelling is being increasingly used as a tool to understand background isotope values and in recent years there have been several successful studies from a variety of different ecosystems to understand background isotope levels (Phillips and Gregg 2003). Establishing an accurate baseline of isotopic results is crucial in being able to understand the relationships between different food sources. Archaeologically baselines on a large scale have been less commonly used, but recently environmental modelling using isotopes has been successfully applied to archaeological situations to enhance interpretations of human values (Phillips and Gregg 2003). Stable isotope values can be subjected to fluctuations as a result of a wide variety of natural and human processes, which highlights the need to understand the wide variety of different factors affecting stable isotope readings.

Compound Specific Stable Isotope Analysis

Compound specific stable isotope analysis of single amino acids has been identified as a technique that can be used to provide a more detailed understanding of past diet. Bone collagen is composed of a range of amino acids, all of which have slightly different $\delta^{13}C$ and $\delta^{15}N$ values (O'Connell and Hedges 2001, 422). Bulk collagen samples are an averaged result of all of these amino acids (Styring *et al*. 2010). In recent years bulk collagen isotope analysis has been criticised as little is known about the individual amino acids that make up collagen, and how these isotope values fluctuate in response to diet (Fogel and Tuross 2003; Choy *et al.* 2010; Styring *et al.* 2010). Therefore, different dietary behaviours could potentially result in the same average values being generated in the bulk collagen (Corr *et al*. 2005). Corr *et al.* (2005) identified the potential of distinguishing between the similar signals produced by C_4 plant diets and marine intensive diets by looking at individual amino acids. The benefits of using compound specific analysis of single amino acids removes the averaging effect produced using bulk collagen analysis, therefore giving a more accurate reading. There have been attempts to understand how single amino acids are affected by dietary behaviour. For example Fogel and Tuross (2003) attempted to identify the relative contributions of animal and plant protein to the isotopic signature produced within individual amino acids. To date the technique is still in its infancy relative to bulk collagen analysis. Current understanding of the behaviour of each amino acid in response to dietary consumption is still not fully understood, reducing the applicability of this technique (Styring *et al.* 2010). A criticism of the technique however is that it is very costly in comparison to bulk collagen analysis, and does not necessarily enhance understanding of food consumption patterns.

To ensure comparability with the wealth of pre-existing stable isotope values from across the North Atlantic Islands such as (e.g. Barrett and Richards 2004; Richards *et al.* 2006; Richards and Mellars 1998; Schulting and Richards 2002a; 2009; 2010), all isotopic values generated in this research were achieved using bulk collagen analysis. Re-analysis of human skeletal remains would result in additional destruction of the archaeological record, and would not necessarily have enhanced understanding of past dietary behaviour.

The use of Stable Isotopes in the North Atlantic Islands

Stable isotope studies have been an important part of North Atlantic Island dietary research over the past decade. These studies are often limited to specific sites, or time periods such as Newark Bay (Richards *et al.* 2006) and Westness (Barrett and Richards 2004). Understanding human diet using isotopes has been the most common application of the technique (e.g. Hedges and Reynard 2007; Schulting and Richards 2002a etc.), with a lesser emphasis on the isotopic analysis of faunal remains which can be used to help interpret human isotope values, understand alternative uses of marine foods and model palaeoenvironmental isotope levels. There has been no research to holistically examine changes in isotope and faunal evidence through time in the island groups.

The Mesolithic-Neolithic Transition

A major area of stable isotope research in the North Atlantic Islands has been the Mesolithic-Neolithic transition. Richards and Mellars (1998) discovered strong marine signatures from 6 human specimens from the Mesolithic Oronsay middens. Schulting and Richards (2002a) built on this study, completing human isotope analysis of coastal Neolithic specimens from Carding Mill Bay and Crarae on the West coast of Scotland, and demonstrated that the Neolithic specimens had terrestrial isotopic signatures, whereas the Mesolithic individuals had strong marine signatures. Researchers investigating British Neolithic diet concluded that “Marine foods, for whatever reason, seem to have been comprehensively abandoned from the beginning of the Neolithic in Britain” (Richards *et al.* 2003, 366). There has been extensive debate as to the validity of these conclusions. For example Milner *et al.* (2004) argue that there are sampling biases, as the skeletons analysed may not be representative for those time periods, that the sample sizes are small, and there was little integration of the zooarchaeological remains. Richards and Schulting (2004) responded to this, arguing that the point of isotopic analysis is to obtain a broad understanding of diet over a period of time rather than subtle nuances in dietary behaviour, and the results are therefore valid.

The stable isotope evidence of Neolithic marine food avoidance is compelling, but these results are not consistent with the zooarchaeological record, which continues to include fish, shellfish and sea mammal remains (Milner *et al.* 2004). As levels of marine species in the Neolithic archaeological record are small, Richards and Schulting (2004) argue that these are the remains of an occasional meal, rather than making a major contribution to diet. There are several other possible explanations as to why human bones do not have a marine signature, but the zooarchaeological assemblages still contain marine products. Marine products may have been eaten as a famine food in times of hardship, as a seasonal resource, or they may even have been used as animal fodder (Schulting *et al.* 2004). Whilst Mesolithic and Neolithic humans have been a research focus, to date few contemporary fauna have been analysed despite their importance in establishing a baseline, and in understanding past animal diets and management practices (e.g. Hedges and Reynard 2007; Mulville *et al.* 2009; Richards *et al.* 2006).

The 'Fish Event Horizon'

A secondary focus of attention in isotopic research in the North Atlantic Islands has centred on the Norse period. Stable isotope analysis of human remains and traditional zooarchaeological techniques have provided evidence to suggest that the Norse period marks a resurgence in marine resource use, in what has been termed the 'Fish Event Horizon' (Barrett and Richards 2004; Richards *et al.* 2006; Barrett *et al.* 2004a, Barrett *et al.* 2004b). The 'Fish Event Horizon' is represented by a large increase in the use of cod and herring in faunal assemblages around AD 1000, which has been consistently identified throughout the UK (Barrett *et al.* 2004a; Barrett *et al.* 2004b). Expansion of the fishing industry on a larger scale for trade has been identified as a major factor contributing to the dramatic increase in fishing during this period (Barrett *et al.* 2004b, 628). The zooarchaeological evidence has been supported by isotopic studies of Norse cemeteries confirming the consumption of fish within these populations (Richards *et al.* 2006; Schulting and Richards 2004).

Isotopic studies investigating the 'Fish Event Horizon' have predominantly focussed on the Northern Isles, where a collection of skeletons from Newark Bay, Orkney, dating from the Iron Age to the Late Medieval period were sampled by Richards *et al.* (2006) to investigate past dietary behaviour. Similarly 32 Norse individuals from the cemetery site of Westness were analysed for dietary isotopic analysis (Barrett and Richards 2004). Skeletons from a range of different ages were selected and male and female skeletons were studied from both Newark Bay and Westness, allowing insights into resource use between different sectors of the population (Richards *et al.* 2006). A criticism of the study is that only one each of the major food species was sampled from the fauna found on site, preventing a valid baseline from being established from which to interpret data. This study, like many focussed on using stable isotopes also neglects to consider the faunal evidence from the site that can further enhance understanding of marine resource use. This site was a cemetery, and therefore little zooarchaeological evidence was available for analysis, but comparisons to faunal assemblages from contemporary settlement sites in Orkney would have enhanced the arguments introduced by Richards *et al.* (2006).

In addition to the larger-scale period focuses, analyses of individual burials from various different sites have been conducted, often as part of a wider suite of techniques, designed to extract as much information about each individual as possible. Examples include Cladh Hallan human remains which were sampled for carbon and nitrogen readings, in addition to radiocarbon dating, strontium analysis, and oxygen isotope analysis and ADNA (Parker-Pearson *et al.* 2005; 2008; Hanna *et al.* 2012).

The Mesolithic-Neolithic transition and the 'Fish Event Horizon' both mark very different patterns of marine food consumption, and the temptation is to assume that communities stopped eating marine foods in the Neolithic, a trend which remained until the larger scale trading of fish occurred in the Norse period. In terms of isotope studies, and indeed faunal investigations, more detailed analysis of the periods in between these two very distinctive events is needed to understand more nuanced patterns in dietary behaviour between these two periods. It is clear that more research into marine food consumption both through time in the North Atlantic Island is necessary, by reviewing existing datasets and generating new results. Further investigation of human and animal isotopic signatures aids with exploring possible explanations behind these changes in dietary behaviour between these two periods.

Fauna Isotopic analysis and Palaeoenvironmental Modelling in the North Atlantic Islands

Faunal isotope studies have been undertaken in British archaeology to provide an insight into past foddering strategies, land management and environmental conditions (Stevens *et al.* 2010; 2013; Millard *et al.* 2011; Hamilton *et al.* 2009; Drucker *et al.* 2008). In the North Atlantic Islands there have been limited studies investigating faunal isotopes alongside human isotopic analysis (e.g. Richards *et al.* 2006; Schulting and Richards 2002a; Barrett *et al.* 2001). The sample sizes of these studies in general have been very restricted to occasional specimens, and the range of species analysed was limited. Mulville *et al.* (2009) and Madgwick *et al.* (2012) started to redress the balance, and initiated the creation of a detailed faunal baseline for the Western Isles. These studies can be further enhanced by increasing the sample sizes for these periods, and by providing greater diversity in the species analysed. Further work on sites from comparative periods will also enhance the baseline work already initiated. It is only by extensively sampling species from each time period within each island group that it is possible to get an accurate view of typical $\delta^{13}C$ and $\delta^{15}N$ values for each time period.

Faunal isotope studies can identify other possible alternative uses of marine resources, such as animal foddering. In the North Atlantic Islands the use of marine foods for fodder has been explored using archaeological and modern sheep from Orkney. Ethnography has demonstrated that sheep on North Ronaldsay today rely heavily on seaweed as a dietary component, feeding on brown kelp washed ashore in storms (Balasse *et al.* 2005; 2009). Following these observations isotope studies of ancient sheep on Orkney were undertaken to understand more about seaweed foddering. Results demonstrated that out of 3 teeth from the Neolithic site of Point of Cott, and 3 teeth from Iron Age Mine Howe, one specimen from each site demonstrated marine isotope signatures (Balasse *et al.* 2009; 2006). In three specimens from Earl's Bu the isotopes suggested that there was no evidence of seaweed consumption (Balasse *et al.* 2009). Analysis of Neolithic Sheep at Holm of Papa Westray provided evidence of seaweed consumption in these individuals (Balasse *et al.* 2006). By expanding on the Orkney studies, to look at a wider range of animals, and time periods, and by analysing specimens from the Western Isles it will be possible to obtain a greater understanding of past diversification in terms of how marine foods were utilised.

An area of isotopic research currently lacking currently in the North Atlantic Islands is the analysis of birds as a potential resource. The role of seabirds in North Atlantic Island communities is highly variable, and several of the smaller island communities of the North Atlantic such as St Kilda (Maclean 1977) and the Shiant Isles (Best and Mulville 2012) relied heavily on sea birds as a resource. Some small-scale investigations of seabird isotope readings in the North Atlantic have been conducted, such as work by Stapp (2002) to understand predation of seabirds by rats on ships in the Shiant Isles. Other more general isotopic analysis of seabirds has previously focussed on fractionation within bird tissues (e.g. Hobson and Clark 1992a; Hobson and Clark 1992b) and an understanding of dietary behaviour of birds in a wider ecological context (Hobson 1987; Hobson *et al.* 1994). Little archaeological isotopic investigation of seabird isotopes has been conducted to determine their environmental niches, and their potential impact on the human stable isotope values observed. There is great scope for sampling of archaeological sea bird specimens in North Atlantic Island populations.

The major isotope studies so in the far North Atlantic Islands have demonstrated the applications of $\delta^{13}C$ and $\delta^{15}N$ analysis to explore past human and animal diets. There is a need to expand on these pre-existing studies to investigate greater numbers of sites with a high resolution of detail in order to be able to consider broad temporal and spatial patterning in the different North Atlantic island groups.

Aims of the Human and Animal Isotopic Analysis in this study

Isotopic analysis of specimens from the Neolithic through to the Norse period was undertaken to identify any temporal patterns in the data. The isotope data was then compared to the zooarchaeological information from sites in the Western and the Northern Isles through time. This information is combined with the results from the lipid residue analysis of the pottery from these sites in order to achieve a holistic view of the relationship between coastal communities and marine resources.

Objectives

There were several key objectives in this study to enhance understanding of past human and animal dietary behaviour and to determine the role of marine resources in past human and animal populations.

1. *Collate existing human and animal data generated to date.*

By collecting all of the isotope data produced so far it was possible to identify which time periods required more attention. This enabled targeted sampling to fill in the gaps in the species and locations analysed to ensure a diverse spread of specimens with different dietary preferences. New data generated can be added to the existing dataset to generate a larger sample for analysis. Collating existing data prevents further destruction of a finite archaeological resource.

2. *Characterise typical isotopic values of fauna for each temporal period and geographical region.*

By targeting the most commonly consumed domestic and terrestrial species from each period in both island groups it was possible to characterise the local baselines of typically observed isotopic values across time. This provided an in-depth understanding of human isotopic values, in addition to enabling faunal diets to be characterised. Statistical comparisons of faunal $\delta^{13}C$ and $\delta^{15}N$ values enable any potential geographical differences in the background isotopic levels between which may be key in accurately interpreting the human isotopic values.

3. *Understand past foddering practices and how they affect the faunal stable isotope values.*

Differences in stable isotope values can be used to investigate the general dietary behaviour of different animals to enable characterisation of past farming strategies from variations in the stable isotope values, and the implications that this has for the humans consuming these animals. Understanding past foddering practices is necessary in being able to determine the importance of marine resources as animal fodder, and to identify potential manuring.

4. *Comparison of human and animal isotopic values with the zooarchaeological evidence.*

By comparing the results of the isotopic analysis with existing zooarchaeological data it was possible to understand dietary behaviour on a range of different scales. Isotopic data provide information on long-term dietary trends, with the zooarchaeological evidence providing more detailed information on potential infrequent or occasional consumption of marine foods. This integrated approach will enable a more enhanced understanding of marine resource use in the islands to be achieved.

5. *Explore the utilisation of dogs as a proxy for human diet.*

Dogs have been suggested as a proxy for human diet (Clutton-Brock and Noe-Nygaard, 1990; Fischer 2007; Schulting and Richards 2002b). By comparing isotopic values achieved for dog specimens with the isotopic values observed in humans it is possible to determine how closely the diet of dogs reflects that observed in humans. The results of the cross comparison are discussed in chapter 8.

This research aimed to increase the isotopic dataset for the North Atlantic Islands, to enable a thorough understanding of changes in dietary behaviour through time in each of the different island groups to be achieved. The isotopic evidence is then compared to the different faunal datasets to correlate these two lines of evidence in order to understand the changing relationship between coastal communities and the sea. The following chapter outlines the methodology utilised when sampling and preparing collagen samples for $\delta^{13}C$ and $\delta^{15}N$ values.

Chapter 6: Stable Isotope Analysis Methodology

This chapter discusses the sampling strategy for the $\delta^{13}C$ and $\delta^{15}N$ stable isotope analysis employed in this study, before outlining the methodology used to extract bulk collagen samples from bone collagen, and the techniques utilised to analyse this data.

Sampling Strategy

The sampling strategy was designed to complement the existing human and animal bulk collagen isotopic datasets available for the North Atlantic Islands. Human and faunal isotopic data previously generated were collated from published and unpublished sources and current gaps in the dataset identified. Only sites and species that had not previously been sampled were targeted to fill in gaps in the current dataset, and to prevent destruction of the archaeological record when samples already exist. To ensure comparability between the various aspects of the wider research project samples of human isotopic values, pottery lipid residue analysis evidence, and zooarchaeological assemblages were selected from single sites.

Stable isotope values are also produced as part of the radiocarbon dating process. Modern radiocarbon techniques can provide accurate carbon and nitrogen values that can be utilised in palaeodietary analysis (Ascough pers. comm.). Radiocarbon dating of human remains from at Dun Vulan (Marshall pers. comm.), and several Iron Age coastal and island sites in the North Atlantic (Shapland and Armit 2012) has produced $\delta^{13}C$ and $\delta^{15}N$ values that had previously not been used for reconstructing past diets. Critiques have suggested that stable isotope values acquired from radiocarbon dating can sometimes be less precise than values acquired from collagen-specific analysis (Schulting 2002, 163). Modern radiocarbon procedures typically extract additional collagen separately from the samples for radiocarbon dating, to achieve viable and accurate carbon and nitrogen results alongside radiocarbon dates (Ascough pers. comm.; Jay 2005, 201). Research comparing isotopic values achieved through radiocarbon dating with those from $\delta^{13}C$ and $\delta^{15}N$ specific analysis demonstrated there was no difference between the values achieved using these two different methodologies (Jay 2005, 201). Older $\delta^{13}C$ values achieved from radiocarbon dating (often contributing only $\delta^{13}C$ values) have not been included in this study as there are questions as to the reliability of reconstructing diet from the older radiocarbon results.

A set of 74 cattle bones had been subject to $\delta^{13}C$ and $\delta^{15}N$ analysis by David Clarke and Pete Marshall (pers. comm.) as part of a wider radiocarbon data project at Skara Brae and were incorporated into the project. Isotopic values of human remains achieved using radiocarbon dating techniques were available from the sites of Dun Vulan, Bornais, and Cille Pheadair

(Marshall pers. comm.), and Icegarth, Cnip, Sloc Sabhaidh and Lingro (Armit and Shapland pers. comm.). Only two new human bone samples were analysed from the site of Broch of Gurness. The decision was made not to sample a Neolithic skeleton from the Scord of Brouster as identified in the zooarchaeological data (Noddle 1986), as the specimen was poorly preserved, and sampling for $\delta^{13}C$ and $\delta^{15}N$ analysis would have caused destruction of the bone, without necessarily yielding results. Radiocarbon dating this specimen would be beneficial for future analysis.

Many of the North Atlantic human bone assemblages have previously been analysed as part of large-scale projects investigating dietary behaviour. The largest pre-existing isotopic datasets are from the Norse to Medieval period cemeteries of Westness (Barrett and Richards 2004) and Newark Bay (Richards *et al.* 2006). Only individuals that had been securely dated within these datasets were utilised to prevent false patterning in the data. Smaller-scale studies such as the suite of techniques applied to the Bronze Age Cladh Hallan mummies also provided $\delta^{13}C$ and $\delta^{15}N$ values that could be utilised for dietary reconstructions (Parker Pearson *et al.* 2005), in addition to burials from the Neolithic tombs of Quanterness (Schulting *et al.* 2010) and Holm of Papa Westray (Schulting and Richards 2009).

Several datasets could not be included in this study, such as the compound specific values of amino acids generated from the site of Isbister (Dunn 2011), as these values would not be comparable with data achieved using bulk collagen analysis. Bulk collagen isotopic data from several unpublished PhD theses were not available, such as the study by Dawn Gooney investigating dietary behaviour at Iron Age Knowe O'Skea, and recent work by David Laurence at the Neolithic tomb of Isbister. When published these datasets will be invaluable in enhancing our understanding of dietary behaviour in the North Atlantic.

Mammalian specimens formed a central focus of this research. Zooarchaeological evidence demonstrated that these were the most commonly consumed resources (chapter 9) and therefore have the biggest impact on the human isotopic values observed. The study aimed to analyse samples from 7 individuals of each of the major terrestrial food species (cattle, sheep, pig, and red deer) from each site to enable average values to be generated. The range of terrestrial species present facilitates comparisons between the potentially closely managed (cattle) and less intensively farmed herbivorous stock (sheep) as well as the omnivorous pig. These were thought to provide good information on various aspects of animal husbandry. Additionally as wild herbivores red deer were important as they represent populations not managed by humans, and therefore provide values for the natural environment unaltered by anthropogenic processes.

Dog bones were also sampled as whilst they were not strictly eaten, they are recognised as a useful proxy for human diet, as they are frequently fed from the human table, and have been suggested as a potential proxy for past human diet (Clutton-Brock and Noe-Nygaard 1990; Fischer 2007; Schulting and Richards 2002b, 238). The validity of utilising dogs as a proxy for human diet is explored further in chapter 6.

When present seals, fish and bird bones were sampled to provide a comparative marine signature. The availability of fish bones in assemblages is heavily reliant on good sieving and sampling strategies, as discussed in chapter 4. A further complexity with fish remains is that the bones of some fish species utilised in the North Atlantic islands are very small, for example herring, as utilised at Bornais (Ingrem 2005; 2012). Extracting sufficient collagen for isotope analysis from individual herring specimens was not possible, and this species was therefore excluded from this analysis. Therefore the identification and sampling of fish were particularly challenging.

Finally any human bones available that had not previously been subjected to $\delta^{13}C$ and $\delta^{15}N$ analysis were also sampled. Due to the varied nature of archaeological assemblages, the full complement of samples for all species was not always possible to achieve for each time period. For example red deer die out through time in Orkney (Mulville 2010), and therefore are not available to sample in the later phases.

Table 8 lists the sampled sites from the Northern and Western Isles.

Site	Island group	Period	Cattle	Sheep	Pig	Red Deer	Dog	Bird	Fish	Seal	Human
Oronsay Middens	Inner Hebrides	Mesolithic				10					
Eilean Domhnuill	Outer Hebrides	Neolithic	2	3							
Northton	Outer Hebrides	Neolithic	7	8		7		6		2	
Skara Brae	Orkney	Neolithic		7	7	7	2				
Tofts Ness	Orkney	Neolithic	2	7	3	1					
Links of Noltland	Orkney	Neolithic	10	10	4	5			3		
Ness of Brodgar	Orkney	Neolithic	10								
Northton	Outer Hebrides	Beaker	6	9	1	7		6		1	
Cladh Hallan	Outer Hebrides	Bronze Age	6	7	3	8		12			
Sligenach	Outer Hebrides	Bronze Age	2	4	1	2					
Tofts Ness	Orkney	Bronze Age	5	4	2	1					
Baleshare	Outer Hebrides	Iron Age	5	7	5	1	1			1	
Bornais	Outer Hebrides	Iron Age	5	3	2	6					
Dun Vulan	Outer Hebrides	Iron Age	7	7	8	1					
Northton	Outer Hebrides	Iron Age	4	4		5		1		2	
Sligenach	Outer Hebrides	Iron Age	1	5	1						
Broch of Gurness	Orkney	Iron Age									1
Knowe o'Skea	Orkney	Iron Age	5	5	3	1	2		3		
Mine Howe	Orkney	Iron Age	7	8	6	12		1			
Pool	Orkney	Iron Age	5	6	7	2			1		
The Cairns	Orkney	Iron Age	6	3	2						
Tofts Ness	Orkney	Iron Age	4	5							
St Ninian's Isle	Orkney	Iron Age	1	2	1						
Howe	Orkney	Iron Age	2	1	1						
Scalloway	Shetland	Iron Age	8	8	7				10		
Bornais	Outer Hebrides	Norse	9	9	10	15	1	8			
Cille Pheadair	Outer Hebrides	Norse	5	7	8	6		15		2	
Bostadh	Outer Hebrides	Norse	2	1		1					
Earl's Bu	Orkney	Norse	14	15	13	1	2				
Broch of Gurness	Orkney	Norse									1
Jarlshof	Shetland	Norse	7	7			2			2	

Table 8: Samples Achieved from the North Atlantic Island Sites

Selection of Bone Specimens

Careful selection of elements was undertaken due to differences in the amount of collagen yielded by skeletal elements. Cortical bone yields the highest levels of collagen, making long bones such as the femur, tibia, and radius ideal for isotopic analysis and where possible these bones were sampled. Ribs are the bone of preference utilised in many human stable isotope studies (e.g. Jay 2005; Mays and Beavan 2012; Oelze *et al.* 2011; Richards *et al.* 2003, 74; Yesner *et al.* 2003). They give high collagen yields, and have a shorter bone turnover rate (Snyder *et al.* 1975, 75) and as numerous elements within individuals their sacrifice destroys less information and integrity of the skeleton. Unfortunately animal rib bones, aside from in burials, are not sufficiently diagnostic to make them clearly identifiable to species. There can be small differences in the isotopic composition of bones (Balasse *et al.* 1999; O'Connell and Hedges 2002). Ideally the same element would be selected for analysis each time, but the effects of taphonomic and cultural processes (e.g. body part selection) on the assemblages make this impractical to achieve. Only bones that could be positively identified to a specific species were sampled to ensure accuracy in the interpretation of faunal diets. Additionally other factors affected sample selection (e.g. availability of phasing information, accessing archives) with the result that there was a need to be flexible in the bones extracted for analysis. Bones with interesting taphonomic markings, such as gnawing or butchery marks, were avoided to prevent destruction of evidence that may be useful for other studies.

To prevent individuals from potentially being analysed multiple times the same diagnostic zone, of the same skeletal elements from the same side of the body, were sampled where possible. This was achieved by identifying the most common skeletal element within the zooarchaeological reports of the assemblage, and then selecting the most common side. Due to the variability of zooarchaeological datasets this was not always possible to achieve. Where repeating elements were not available additional methods were employed to ensure that different individuals were sampled, such as comparisons of the morphology of elements, and sampling bones from different archaeological contexts.

Fully mature individuals were targeted to avoid weaning signatures that can cause inflated $\delta^{15}N$ values (Schurr 1997; 1998; Richards *et al*. 2006). Bones were assessed for maturity based on epiphyseal fusion and surface texture, although this was not always possible.

To ensure archive integrity and to track destructive sampling each extracted sample was replaced by a label providing information on the material removed and the project details. Curators of the assemblages were provided with a full record of all the specimens that had been sampled for analysis.

All bones were fully recorded using the ‘Cardiff Osteoarchaeological Research Group’ methodology prior to analysis to prevent any potential loss of information as result of destructive sampling. All specimens were given a sample number that can be utilised to trace the progress of the sample. A lab book was kept to maintain a record of the preparation stage of each specimen.

Preparation of Collagen for Isotopic analysis

Collagen was prepared for analysis using the Longin (1971) method, a technique forming the basis of collagen extraction techniques utilised commonly today (e.g. Jay and Richards 2006; Madgwick *et al.* 2012a; 2012b; Schulting and Richards 2002a; 2002b; Stevens *et al.* 2013). The Longin (1971) method is based on the concept of dissolving the mineral content of the bone, heating the specimen in a process of gelatinisation and filtering to remove any impurities, before freeze drying and weighing of the samples for analysis using isotope ratio mass spectrometry. The methodology utilised in this study is virtually identical to that utilised by Mulville *et al.* (2009) and Madgwick (2012b) analysing North Atlantic Island fauna, allowing greater comparability with these existing datasets.

The protocol used to extract and analyse collagen for $\delta^{13}C$ and $\delta^{15}N$ stable isotope analysis was as follows:

1. Specimen Extraction and Cleaning

Approximately 1cm^2 (1g) of bone was removed from the specimen using a diamond edged circular drilling wheel, where possible avoiding any epiphyses that could potentially be useful in further zooarchaeological analysis. The surfaces of the samples were cleaned using aluminium oxide particles in a mechanical air abrasion unit to remove any potential surface contaminants. When cleaned, samples were placed straight into test tubes before being covered to prevent contamination.

2. Demineralisation

To dissolve the mineral component of the bone the samples were covered with an excess of 0.5 molar hydrochloric acid. Previous studies have utilised sodium hydroxide (e.g. Richards 1998, Liden *et al.* 1983, Chisolm *et al.* 1983), but these acids often require additional washing process following demineralisation. As this can result in lower levels of collagen yield this technique was not utilised in this methodology. The samples were then re-covered and placed in the fridge to prevent bacteria formation as this could potentially impact on the $\delta^{13}C$ and $\delta^{15}N$ values achieved. The samples were kept in the acid and stirred every other day, using clean pipettes to avoid contamination, to speed up the demineralisation process. The HCL was changed on a weekly basis to maintain the demineralisation process. Demineralisation normally took between 1-4 weeks and samples were deemed to be fully demineralised when they had a homogenously malleable texture.

3. *Washing and Gelatinisation*

Once fully demineralised the samples were removed from the HCL and rinsed in deionised water, then left to soak in fresh deionised water for 24 hours to remove any remaining acid residues. After this time the samples were drained, and topped up with a pH3 solution made by diluting HCL and deionised water. Samples were placed in a preheated 75^{o}C hotblock for 48 hours to undergo the process of gelatinisation.

After 48 hours the samples were removed from the hot block and allowed to cool. The samples were then filtered using biological filters to ensure that only pure collagen was left behind in the test tubes. The ultrafiltration process was not used as studies experimenting with the collagen extraction process have demonstrated this can result in lower collagen yields (Jørkov *et al.* 2007). The test tubes were then sealed with parafilm to keep out contaminants and were placed into a freezer at -20°C.

4. *Freeze Drying*

Once frozen the samples were placed in a freeze drier at -40°C for approximately 72 hours, until all liquid had been removed, leaving behind the pure collagen. The freeze drying process occasionally resulted in crispy brown deposits. In this case samples were refreshed with approximately 2ml of distilled water and reheated in the hot block for approximately an hour to encourage the dissolving process. They were then re-frozen and re-freeze dried. If these samples failed a second time they were discarded. This was an infrequent occurrence.

5. *Weighing*

To avoid contamination all equipment was washed using deionised water and dried on clean tissue paper prior to the weighing process. Between 0.700mg and 1.000mg of each specimen was weighed out into tin capsules for combustion and mass spectrometry. These values were selected as they are within the sample size range for accurate calibration with the standards utilised at the analytical facilities used in this project.

6. *Isotope Ratio Mass Spectrometry*

A grant in kind was kindly awarded by the NERC 'Life Sciences Mass Spectrometry Facility' in East Kilbride to analyse the samples (Grant Ref. EK158-03/10). The weighed collagen specimens were combusted using an ECS 4010 elemental analyser (Costech, Milan, Italy), before being analysed in a Delta V Plus isotope ratio mass spectrometer (Thermo Scientific, Bremen, Germany), and were calibrated to international and in house standards (Alanine, Glycine, Gelatine, Tryptophan) to ensure accuracy in the results. Samples JJ01-JJ97 (Appendix 1) were analysed at the Dorothy Garrod Laboratory for Isotopic Analysis at the Cambridge McDonald Institute for Archaeological Research. A control test was undertaken cross-comparing results of specimens analysed at the Cambridge Dorothy Garrod laboratory and the NERC LSMSF facility and showed that the inter-lab difference was negligible (Table 9).

Sample No.	**Species**	**Cambridge $\delta^{13}C$**	**NERC LSMSF $\delta^{13}C$**	**Inter-Lab difference $\delta^{13}C$**	**Cambridge $\delta^{15}N$**	**NERC LSMSF $\delta^{15}N$**	**Inter-Lab difference $\delta^{15}N$**
JJ18	Sheep	-21.121	-21.049	**-0.072**	6.079	6.065	**0.014**
JJ53	Dog	-12.495	-12.327	**-0.168**	15.095	15.559	**0.464**
JJ64	Sheep	-20.499	-20.480	**-0.019**	6.462	6.166	**0.296**
BOM2A 03	Red Deer	-21.331	-21.210	**-0.121**	5.647	5.490	**0.157**
BOM2A 05	Red Deer	-21.650	-21.570	**-0.080**	6.169	6.000	**0.169**
BOM2A 07	Red Deer	-21.621	-21.550	**-0.071**	6.040	6.130	**0.090**

Table 9: Inter -Lab reliability comparisons: Cambridge and NERC

Assessing Collagen Quality

The C:N ratio for each specimen was calculated to determine the extent of post depositional alteration of collagen carbon and nitrogen. There is some variation in C:N ratio value interpretation. DeNiro (1985, 807) suggests that prehistoric specimens within the C:N range of 2.9-3.6 C:N are typical of *in vivo* collagen, with values outside of this indicative of contaminated collagen. Ambrose (1993, 75) suggests a value above 3.4 would demonstrate contamination and (Van Klinken 1999, 691) advocates 3.1-3.5 as being the best range to work within. Bearing in mind these recommendations any specimens with values outside of the C:N ratio ranges 2.9-3.5 were excluded from this study to prevent any potentially contaminated samples from skewing the isotopic results achieved.

Data Analysis

Graphical Depictions

Scatter plots were generated plotting both $\delta^{13}C$ and $\delta^{15}N$ values. On occasion box plots were utilised to demonstrate the spread of the data. In some cases the mean value is depicted, with error bars depicting the standard deviations around the mean.

Statistical Analysis

The $\delta^{13}C$ and $\delta^{15}N$ data generated do not follow a normal distribution, and the small sample sizes analysed demonstrated that non-parametric tests were the most appropriate form of statistical analysis to use. The non-parametric test, Mann Whitney U, similar to a student's T-test, is suitable for data that do not follow a normal distribution, and when the dataset is small (Madrigal 1998, 144). It was therefore selected to determine the difference in means of $\delta^{13}C$ and $\delta^{15}N$ when two datasets were being compared, for example to compare average cattle and sheep values within a site, or to compare average cattle values between two different sites. A *p*-value of 0.05 or below was taken to be indicative of a statistically significant result, with *p*-values of 0.01 or below being indicative of a strong statistical difference. The results of all statistical tests are shown in Appendix 2, 3 and 4 (statistically significant results are highlighted in bold).

Interpreting stable Isotope results

Interpretation of $\delta^{13}C$ values

In characterising dietary changes there are two key factors impacting on carbon values: salinity, and marine protein consumption. Salinity can affect the $\delta^{13}C$ values observed in plants as a result of changes in stomatal opening and exchange with atmospheric carbon (Guy *et al.* 1986a; 1986b; van Groenigen and van Kessel 2002). Thus consumers of coastal plant resources will show different values to those foddering on plants from non-coastal locations. Values observed in previous North Atlantic Island studies suggest that enrichment of $\delta^{13}C$ to around -20‰ or greater is considered to be indicative of the consumption of plants grown in saline environments such as seaweed (e.g. Barrett and Richards 2004; Magwick *et al.* 2012b; Mulville *et al.* 2009; Schulting and Richards 2002a; 2009; Richards *et al.* 2006). Further enrichment of isotopic values up to and beyond -18‰ is considered to be indicative of humans or animals having diets including a greater level of marine protein intake, which will typically coincide with enrichment of $\delta^{15}N$ values.

Interpretation of δ^{15}N values

The δ^{15}N values observed between individuals differ depending on the quantity of protein consumed between individuals, and like δ^{13}C values, can be affected by salinity. Typically weaning mammalian individuals would be expected to have δ^{15}N values ranging between 9-12‰ depending on whether the species is predominantly herbivorous or omnivorous. Values above 12‰ have previously been interpreted as being indicative of marine protein consumption (Schulting and Richards 2002a, 154), which is also linked to enriched δ^{13}C values. Salinity can also result in enriched δ^{15}N values observed (Britton *et al.* 2008), and in general the North Atlantic Island nitrogen and carbon values are slightly enriched relative to isotopic values from mainland British sites (e.g. Jay 2005; Jay and Richards 2006; Müldner and Richards 2007).

The δ^{15}N values are enriched due to external environmental factors, such as manuring fertilisation, and penning (Bogaard *et al.* 200; Simpson *et al.* 1999; Wagner 1991; Yoneyama 1996). Given that typical δ^{15}N values of herbivores lie between 6-8‰ (Schulting and Richards 2002a), any herbivorous animals demonstrating values above 8‰ can be interpreted as having been foddered on plants that have been manured, or as being subject to penning.

Figure 7 shows generic interpretations of typical isotopic values for Northwest Europe based on previous isotopic studies (Bocherens *et al.* 1991; Jay 2005; 2006; Madgwick *et al*. 2012a; 2012b; Mulville *et al*. 2009; Murrary and Schoeninger 1988; Schoeninger *et al*. 1983; Schulting and Richards 2002a; 2002b). These values act as a guideline for the interpretation of isotopic values discussed in this research. As observed there can be some overlap between the isotopic values observed for herbivores and omnivores, and between omnivores and carnivores (Figure 7). The overlaps observed depend on factors such as manuring and penning, weaning and quantities of protein consumed by omnivores. Interpretation of isotopic values therefore needs to take into account human influences on the isotopic record, in addition to environmental factors.

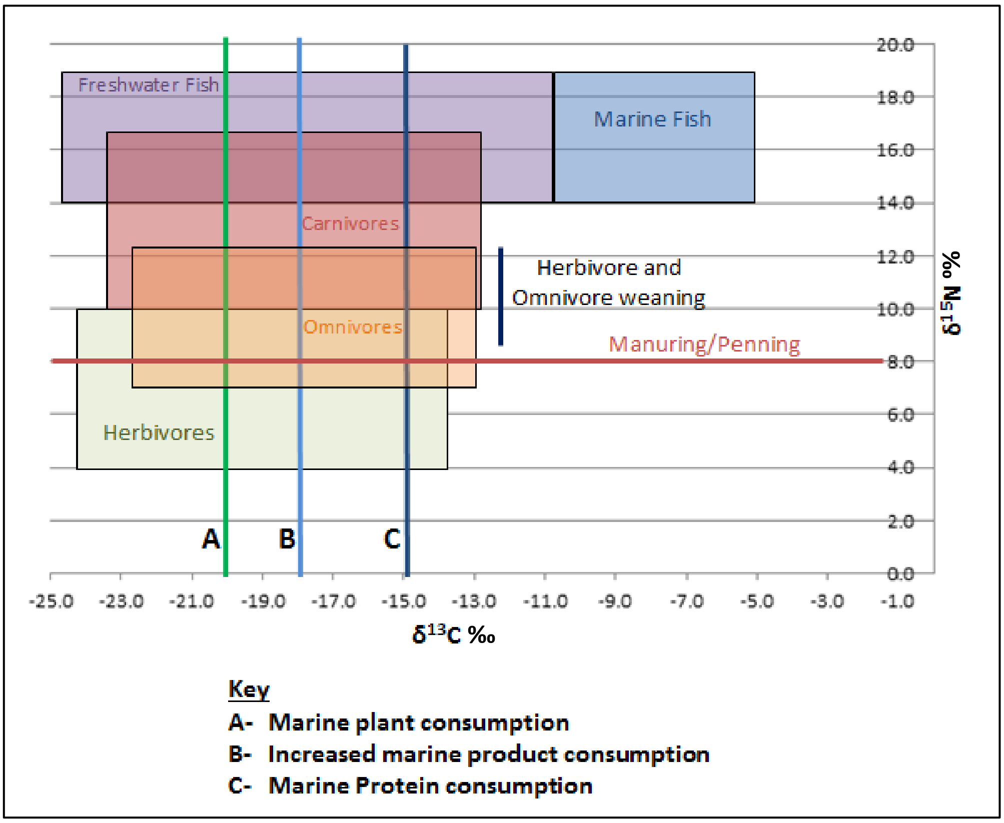


Figure 7: Generic typical isotopic values and interpretations of isotopic values for NW Europe

These guidelines provide typical interpretations of the isotopic data achieved from the North Atlantic Islands based on previous research. The main factors influencing differences in the isotopic values observed will relate to the intensity and duration of food consumption between individuals that will impact on the isotopic values observed. The interpretations suggested above however provide valuable guidelines as to the interpretation of the isotopic data expected from this assemblage.

The following chapter applies these interpretations to the faunal isotopic values achieved using this study in order to model past animal diets, management practices and to explore environmental differences in δ^{13}C and δ^{15}N values between the island groups.

Chapter 7: Results and Discussion: The Faunal Baseline and Palaeoenvironmental Modelling

In total 622 faunal specimens from across the Atlantic Islands were analysed for $\delta^{13}C$ and $\delta^{15}N$ stable isotope analysis during the course of this research. These results were combined with pre-existing stable isotope data from published reports, articles, and personal communication, resulting in values from 1025 different specimens available for inclusion in this study. A full list of faunal isotopic values utilised in this study, in addition to the C:N ratios, is included in Appendix 1.

This chapter presents the faunal stable isotope data for each period in the Northern and Western Isles. A chronological approach towards introducing the faunal baselines for the island groups is taken, focussing on inter-species dietary differences. Geographical differences in isotopic values between the regions are then explored, before drawing temporal comparisons in the dietary behaviour of individual species to determine foddering and animal management strategies in the islands. A proportion of these results have been discussed by the author in Jones *et al.* (2012), and these findings have been elaborated on as part of this thesis. Statistical techniques (Mann U Whitney tests) were used to compare average values to determine differences in the $\delta^{13}C$ and $\delta^{15}N$ values between species, geographical regions and temporal periods. The Mann U Whitney test results are included in Appendix 2 (baseline comparisons between species), Appendix 3 (geographical comparisons) and Appendix 4 (temporal comparisons of faunal diet).

The faunal isotopic data discussed in this chapter are discussed in relation to the interpretive guidelines as demonstrated in Figure 7.

Interpretations of Faunal Stable Isotope Data

There are two main forms of outliers identified in the faunal analysis: herbivorous specimens with enriched nitrogen values, and herbivorous specimens with enriched carbon values. Several of the specimens with enriched nitrogen values did not have sufficient ageing evidence and therefore are potentially juveniles with weaning signatures. Other individuals were sampled for radiocarbon dating techniques, and the ageing information is absent. Articulating skeletal elements are commonly utilised in radiocarbon dating to represent primary deposits, and therefore it is highly probable that these samples represented articulating unfused epiphyses and shafts and therefore represent younger individuals influenced by weaning.

The specimens with carbon values enriched beyond 20‰ by greater degrees of salinity (van Groenigen and van Kessel 2002; Guy *et al*. 1986a; 1986b) can be interpreted as having consumed plants growing in saline environments (e.g. seaweed).

Other explanations for outliers could be that individuals are not local to the islands, for example through trading cuts of meat, although there is currently no zooarchaeological evidence to support trade in domestic species. The red deer populations have more potential to represent non-local diets, for example animals introduced to the islands in the Neolithic could have non-local isotopic signatures (Mulville 2010).

Temporal characterisation of Isotopic Values

Mesolithic

The Inner Hebridean sites of Caisteal Nan Gillean II, Priory Midden, Cnoc Sligeach and Risga were sampled from specimens available at Cambridge University. Unfortunately the main assemblage from the Oronsay midden sites is not possible to locate at present, and only a limited number of red deer specimens were available for analysis. No Mesolithic specimens were available from Orkney or the Outer Hebrides for comparison.

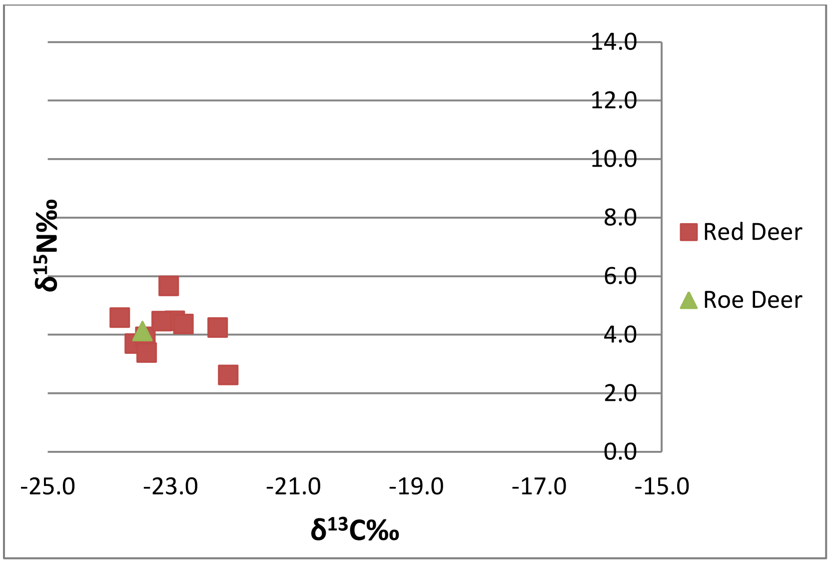


Figure 8: Mesolithic terrestrial faunal baseline: Inner Hebrides

The Mesolithic red deer stable isotope values are consistent with the consumption of an herbivorous terrestrial diet (Figure 8). There is little variation in δ^{13}C values observed with standard deviation of average values accounting for only 0.5‰ (Table 10), indicating homogeneity in the dietary behaviour of these individuals. There is also little difference in the δ^{15}N values observed between individuals, with a standard deviation of only 0.8‰. These values are consistent with the isotopic values achieved from analysis of modern Scottish red deer populations from the Isle of Rum (Stevens *et al.* 2006). The roe deer specimen δ^{13}C and δ^{15}N also plots in the same area of the graph as the red deer samples, indicating that these species had similar diets, as observed in modern comparative ecological studies of the two species living in Scottish habitats (Latham 2000; Latham *et al*. 1999).

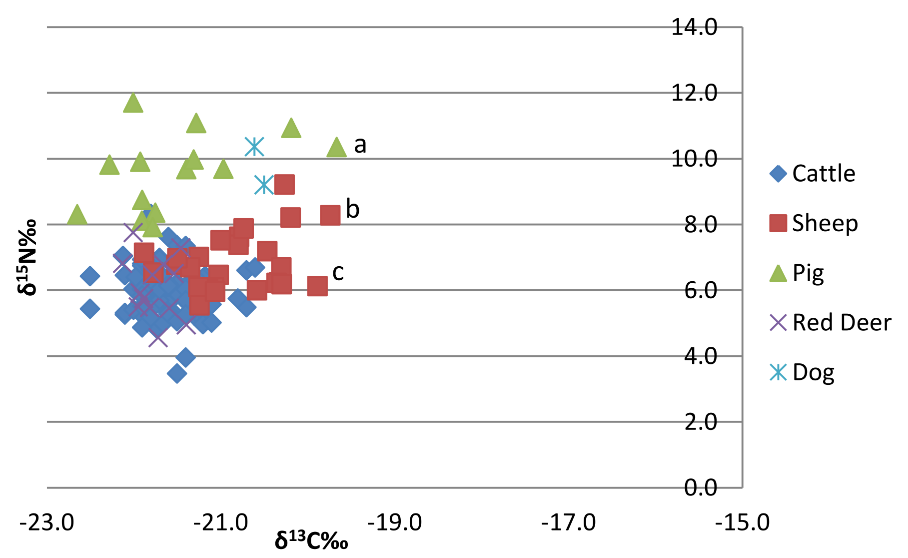
Species	n=	Mean δ^{13}C ‰	Std. δ^{13}C ‰	Mean δ^{15}N ‰	Std. δ^{15}N ‰
Red Deer	10	-23.0	0.6	4.1	0.8
Roe Deer	1	-23.5	n/a	4.1	n/a

Table 10: Mesolithic faunal isotopic averages and standard deviations: Inner Hebrides

The following section discusses inter-species comparisons in the Neolithic dietary behaviour of animals sampled in each island group. There were no Neolithic bone samples available for Shetland, and therefore discussion is focussed on datasets from Orkney and the Western Isles.

Neolithic Orkney

The samples from Neolithic Orkney derived from the sites of Skara Brae, Links of Noltland, Tofts Ness, and Ness of Brodgar.



(Skara Brae cattle data from Marshall Pers. Comm)

Figure 9: Neolithic terrestrial faunal baseline: Orkney

*Note different scale to Mesolithic period; all subsequent graphs use current scale

The Neolithic fauna analysed from Orkney have stable isotope values indicative of consumption of a terrestrial diet (Figure 9). A strong statistically significant difference was also identified between cattle and sheep δ^{15}N values, with average sheep values approximately 0.3‰ more enriched than the cattle, but this difference in the average values is potentially small enough to be a result of lab reproducibility. The range of δ^{13}C values identified for the pigs (-22.6‰ to -19.7‰) is much broader than observed for any of the other species. Pigs are enriched in δ^{15}N by 2-4‰ in relation to the herbivorous specimen, which was a strong statistical significance. These isotopic values are typical of an omnivorous diet being consumed, with a protein element consisting of meat and/or milk products, a characteristic frequently observed in faunal isotopic studies involving pig specimens (e.g. Hamilton 2010; Madgwick *et al.* 2012a). One pig (a) had an enriched δ^{13}C value consistent with the occasional consumption of marine plants. Two sheep specimens (b and c) also had enriched δ^{13}C values, suggesting that they were also marine plant consumers.

The standard deviation of δ^{13}C values for red deer is small, with the range lying between -22.1‰ and -21.5‰, indicating consistency in the diet of the red deer observed (Figure 11). The sheep are enriched in δ^{13}C relative to red deer and cattle the other species by about 1-2‰. The difference in average carbon values between sheep and the other two herbivore species (cattle and red deer) was observed to be statistically significant. The δ^{13}C differences are potentially being influenced by the two individuals with isotopic signatures indicative of marine plant consumption, which are raising the average δ^{13}C values observed.

Species	n=	Mean δ^{13}C ‰	Std. δ ^{13}C ‰	Mean δ^{15}N ‰	Std. δ^{15}N ‰
Cattle	**94**	-21.6	0.3	6.0	0.8
Sheep	**26**	-20.8	0.6	6.8	0.9
Pig	**13**	-21.5	0.8	9.6	1.2
Red Deer	**13**	-21.8	0.2	6.1	0.9

Table 11: Neolithic faunal isotopic averages and standard deviations: Orkney

Neolithic Western Isles

The number of available Neolithic faunal specimens in the Western Isles was limited, with only two sites having animal bones preserved: Northton (Finlay 1984; Finlay 2006) and Eilean Domhnuil (Armit 1986). No pig remains from either of these sites were available for analysis.

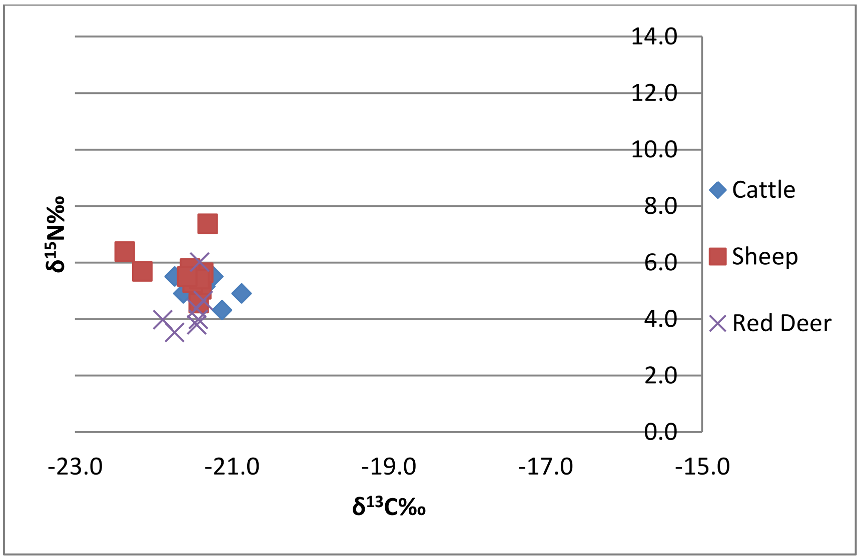


Figure 10: Neolithic terrestrial faunal baseline: Western Isles

The Neolithic Western Isles cattle, sheep and red deer specimens all have isotope signatures typical of consumption of a herbivorous terrestrial diet (Figure 10). A statistically significant difference in the δ^{15}N values was identified between the cattle and sheep, with sheep having values enriched by approximately 0.6‰. There were also statistically significant differences identified between the δ^{15}N values of red deer and sheep, with sheep enriched by 1.3‰. The δ^{15}N difference between red deer and the domestic sheep and cattle is potentially indicative of farming practices. Nitrogen can accumulate in ecosystems where manuring is being practiced (Bogaard *et al.* 2007; Senbayram *et al.* 2008), and therefore animals being grazed on land that has been manured will have enriched δ^{15}N signatures, relative to animals foddering on land that has not been subjected to fertilisation processes.

There may also be natural differences in the localised environments where these animals are foddered that cause this discrepancy between the species. For example, if cattle were foddered on the lowland machair type environments, they would be expected to have δ^{15}N values that are relatively depleted, as nitrogen and other nutrients are leached quickly from these soils (Smith 2012).

There were no statistically significant differences observed between the average δ^{13}C‰ values of cattle, red deer or sheep. Two of the sheep are depleted in δ^{13}C relative to the other sheep specimens analysed. These two individuals were from the site of Eilean Domhnuil, whereas all but one of the other specimens were from the site of Northton. Therefore these individuals may have been foddered on different food sources, suggesting inter-site differences in animal management strategies.

Species	n=	Mean $\delta^{13}C$ ‰	Std. $\delta^{13}C$ ‰	Mean $\delta^{15}N$ ‰	Std. $\delta^{15}N$ ‰
Cattle	9	-21.3	0.1	5.1	0.2
Sheep	11	-21.6	0.1	5.7	0.2
Red Deer	7	-21.5	0.1	4.3	0.3

Table 12: Neolithic faunal isotopic averages and standard deviations: Western Isles

Beaker Period Western Isles

No Beaker period zooarchaeological remains were available from Orkney or Shetland. The Western Isles specimens derived from the sites of Northton and Sligenach (Mulville *et al.* 2009).

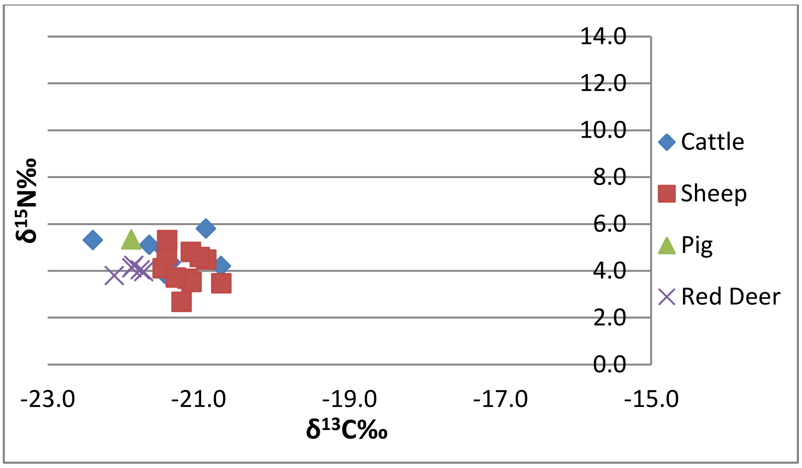


Figure 11: Beaker period terrestrial faunal baseline: Western Isles

The Beaker period sheep, cattle, pig and red deer from the Western Isles all have typical terrestrial isotopic signatures (Figure 11). There was no statistically significant difference between the average $\delta^{13}C$ values or $\delta^{15}N$ values of the sheep and cattle, indicating that they were consuming a similar diet, possibly foddering nearby to each other. Statistically significant differences in the $\delta^{13}C$ were observed between cattle and red deer, and sheep and red deer, with the domestic species having enriched $\delta^{13}C$ values in comparison to the red deer (Table 13). This difference may be a result of these species feeding in different locations in the island. For example cattle and sheep may be kept closer to the settlement, where they can be tended to regularly, and a watch kept over them for their safety, whereas wild red deer would be able to roam over a greater area, with access to different sources of fodder.

A statistically significant difference in $\delta^{15}N$ values was observed between cattle and red deer, with average cattle values being 0.7‰ enriched compared to red deer. This is potentially a reflection of dung accumulation resulting from continual pasturing of the same area, or could be related to intentional manuring of crops (Bogaard *et al.* 2007; Senbayram *et al.* 2008), which were subsequently being fed to domesticates.

	n=	**Mean δ^{13}C**	**Std. δ^{13}C**	**Mean δ^{15}N**	**Std. δ^{15}N**
Cattle	**9**	-21.5	0.5	4.7	0.6
Sheep	**11**	-21.2	0.2	4.1	0.8
Pig	**1**	-21.9	n/a	5.3	n/a
Red Deer	**6**	-21.9	0.2	4.2	0.4

Table 13: Beaker period faunal isotopic averages and standard deviations: Western Isles

Bronze Age Orkney

Due to destructive sampling constraints in place at Tankerness House museum in Orkney only a small number of samples from the settlement site of Tofts Ness could be collected.

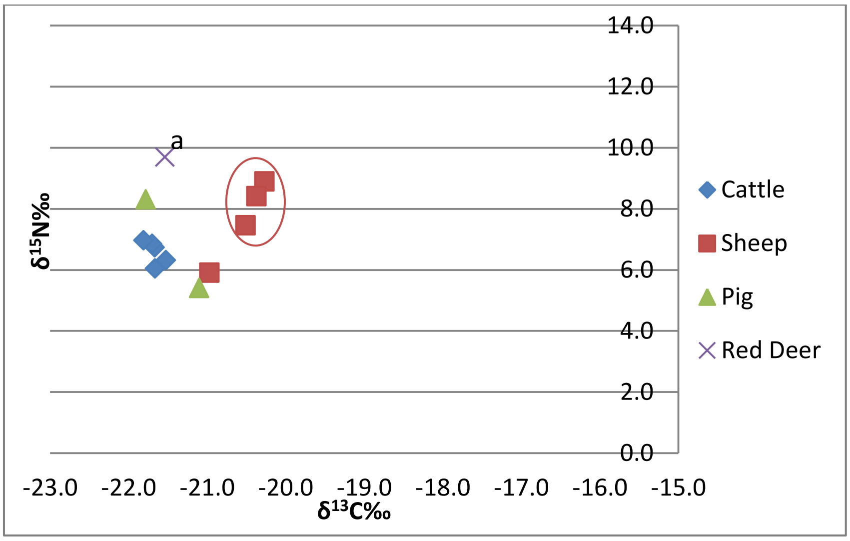


Figure 12: Bronze Age terrestrial faunal baseline: Orkney

All Bronze Age Orkney individuals sampled have typical terrestrial signatures (Figure 12, Table 14). Three of the sheep specimens (circled in red) had enriched δ^{13}C values, indicative of a diet containing marine plant products. This is supported by the enriched δ^{15}N values observed in the sheep, a phenomenon also observed in saltmarsh grazing (Britton *et al.* 2008).

The two pig specimens sampled demonstrated a large difference in δ^{15}N values. One individual has a δ^{15}N value of 5.4‰ (TN28), indicative of an herbivorous diet, with the other individual having a value of 8.3‰ (TN27), suggesting a higher level of protein consumption. These two pig specimens were feeding on different diets, potentially resulting from these animals being foddered on a household level (Madgwick *et al.* 2012). The red deer specimen (labelled (a) in

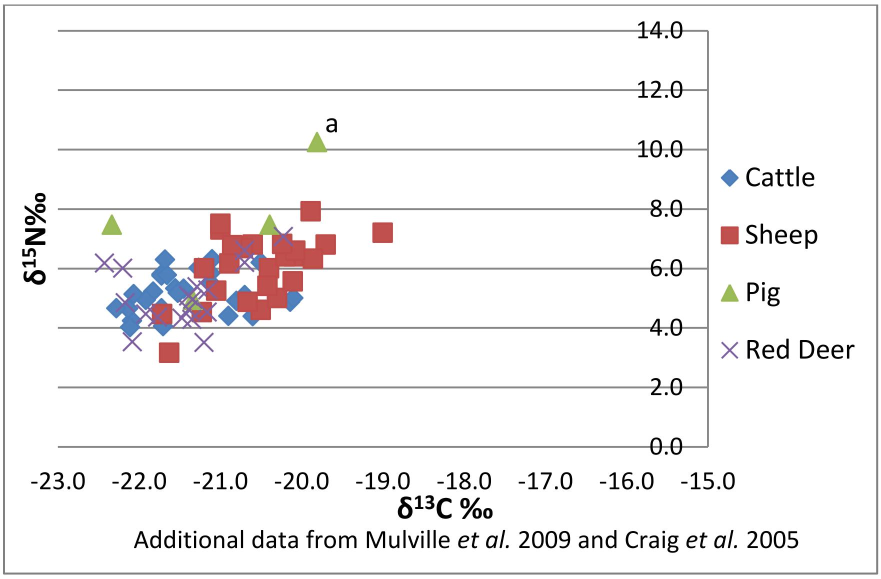
Figure 12) has an enriched δ^{15}N value of 9.7‰ (TN24). This was a metacarpal shaft fragment of unknown age and is potentially exhibiting a weaning signature.

Species	n=	Mean δ^{13}C ‰	Std. δ^{13}C ‰	Mean δ^{15}N ‰	Std. δ^{15}N ‰
Cattle	5	-21.7	0.1	6.6	0.4
Sheep	4	-20.5	0.3	7.7	1.3
Pig	2	-21.4	0.5	6.9	2.1
Red Deer	1	-21.5	n/a	9.7	n/a

Table 14: Bronze Age faunal isotopic averages and standard deviations: Orkney

Bronze Age Western Isles

The stable isotope samples from the Western Isles are primarily from the site of Cladh Hallan, with additional specimens from Sligenach. This builds on the pre-existing isotopic research at the sites conducted by Craig *et al.* (2005) and Mulville *et al.* (2009).



Additional data from Mulville *et al.* 2009 and Craig *et al.* 2005

Figure 13: Bronze Age terrestrial faunal baseline: Western Isles

The Western Isles Bronze Age cattle, sheep, red deer values are all typical of a land-based herbivorous diet (Figure 13, Table 15). There is a high degree of variability within the δ^{13}C of the cattle and sheep specimens analysed.

Species	**n=**	**Mean δ^{13}C ‰**	**Std. δ ^{13}C ‰**	**Mean δ^{15}N ‰**	**Std. δ^{15}N ‰**
Cattle	**27**	-21.4	0.6	5.165	0.7
Sheep	**25**	-20.5	0.6	6.020	1.2
Pig	**4**	-21.0	1.1	7.526	2.2
Red Deer	**18**	-21.4	0.6	5.064	1.0
Dog	**5**	-19.5	0.7	9.272	1.3

Table 15: Bronze Age faunal isotopic averages and standard deviations: Western Isles

The average δ^{13}C values of cattle are depleted in relation to the sheep specimens analysed (Table 16). A strong statistically significant difference between average cattle and sheep δ^{13}C values was observed, with average sheep values 0.8‰ enriched relative to the cattle specimens analysed, suggesting differences in the pasturing location of these animals. A statistically significant difference in δ^{15}N values between sheep and cattle was also identified, with average sheep values being enriched by an average of 0.9‰. The combination of these isotopic signatures suggests that the sheep were consuming plants growing in saline environments, as identified in the three sheep specimens from Bronze Age Orkney.

The Bronze Age pigs from the Western Isles have varied dietary behaviour. The diverse ranges in δ^{15}N and δ^{13}C‰ values are all consistent with highly variable dietary behaviour. One pig (a, in Figure 13) with a δ^{15}N value of 10.2‰ was an unfused humerus. This fuses at the age of 1 year (Silver 1969), and the individual is potentially exhibiting a weaning signature. The other three individuals sampled all have δ^{15}N values reflective of diverse omnivorous diets, with differing levels of protein consumption.

Iron Age Orkney

The sheep from Iron Age Orkney have a greater range in δ^{15}N and δ^{13}C values (difference between highest and lowest values of 4‰ and 3% respectively), indicating diversity in the foddering practices at an intra-species level (Figure 14, Table 16). One sheep (a) has an enriched δ^{13}C value, indicative of a seaweed dietary component. Red deer and cattle exhibit a similar range of δ^{15}N and δ^{13}C values and demonstrate consistency in diets observed between these species.

The pig specimens show diversity in δ^{15}N and δ^{13}C values observed, with a small cluster of individuals having a predominantly herbivorous diet, and another group having omnivorous diets. This is potentially due to household ownership of pigs, with owners feeding their pigs on waste food, causing a greater diversity in the isotopic values observed between individuals.

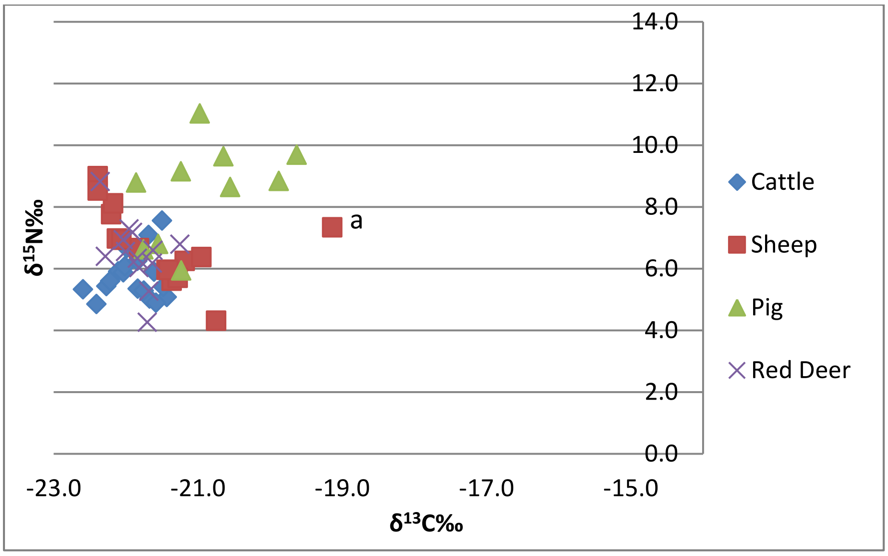


Figure 14: Iron Age terrestrial faunal baseline: Orkney

Species	n=	Mean δ^{13}C	Std. δ^{13}C	Mean δ^{15}N	Std. δ^{15}N
Cattle	41	-219	0.1	5.8	0.2
Sheep	38	-21.5	0.2	6.8	0.3
Pig	24	-20.3	0.7	9.2	0.9
Red Deer	35	-21.8	0.1	6.5	0.3

Table 16: Iron Age faunal isotopic averages and standard deviations: Orkney

Iron Age Shetland

All specimens from Shetland derived from the Middle Iron Age phases at Scalloway (Figure 15). The sheep and cattle have similar average values of δ^{13}C and δ^{15}N values (Table 17) and no statistically significant difference between the diets of these species was identified in the Mann Whitney U test. The Scalloway pigs displayed δ^{15}N values indicative of consuming a predominantly herbivorous diet.

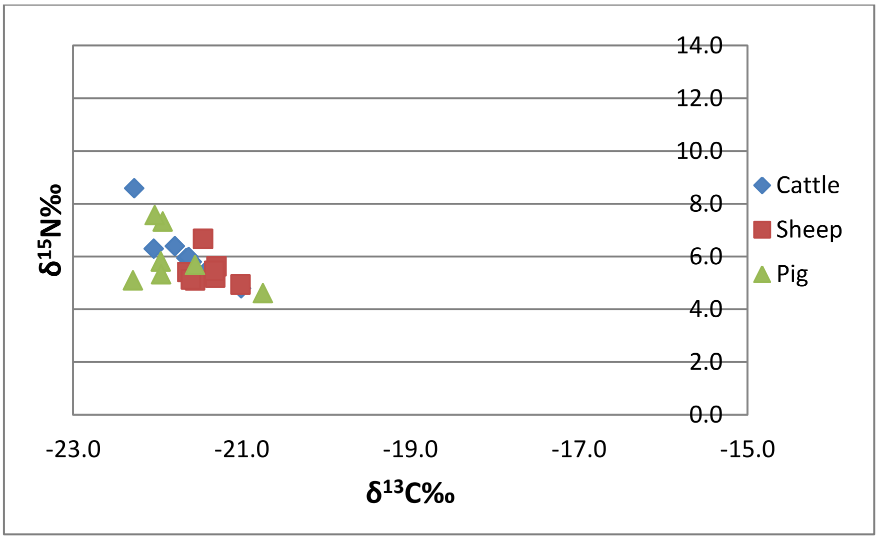


Figure 15: Middle Iron Age terrestrial faunal baseline: Shetland

Species	n=	Mean δ^{13}C	Std. δ^{13}C	Mean δ^{15}N	Std. δ^{15}N
Cattle	8	-21.7	0.4	6.2	1.1
Sheep	8	-21.4	0.2	5.4	0.5
Pig	7	-21.8	0.5	5.9	1.1

Table 17: Iron Age faunal isotopic averages and standard deviations: Shetland

Iron Age Western Isles

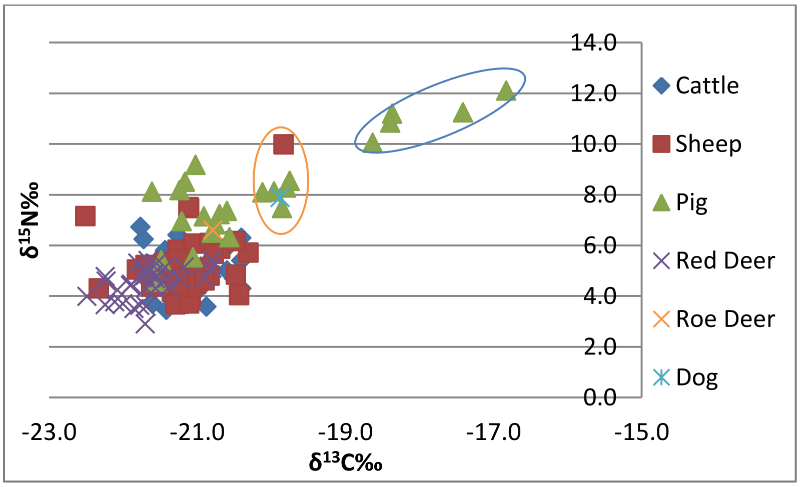


Figure 16: Iron Age terrestrial faunal baseline: Western Isles

Species	n=	Mean δ^{13}C	Std. δ^{13}C	Mean δ^{15}N	Std. δ^{15}N
Cattle	19	-21.1	0.1	4.9	0.1
Sheep	15	-21.2	0.1	5.2	0.2
Pig	11	-20.2	0.3	8.1	0.4
Red Deer	13	-21.6	0.1	4.5	0.1

Table 18: Iron Age faunal isotopic averages and standard deviations: Western Isles

Iron Age specimens from the Western Isles were obtained from the sites of Dun Vulan, Bornais, Sligenach, Baleshare and Northton (Figure 16). The cattle, sheep and red deer all have low standard deviations in the mean values (Table 18). This period provides the first evidence for faunal consumption of marine proteins, with several pig specimens (circled in green) having enriched δ^{15}N and δ^{13}C values associated with the consumption of fish or shellfish products. These were all from the Middle Iron Age deposits at Dun Vulan, and will be discussed in detail later in the section relating to pig dietary behaviour. The pigs with non-marine signatures have slightly enriched δ^{15}N values, indicative of protein consumption as part of an omnivorous diet. A further group of individuals (circled in orange), including a sheep, 4 pigs, and one dog, have carbon signatures below -2-‰, indicative of a minor marine dietary component, and could be indicative of seaweed consumption, or even infrequent consumption of marine products.

Norse Orkney

The Norse specimens analysed from Orkney were from the site of Earl's Bu. The cattle and sheep from Norse Orkney have very similar δ^{13}C and δ^{15}N values, and low standard deviations, indicating consistency in foddering strategies employed between the two species (Figure 17 and Table 19). Two cattle and one pig (circled in green) have enriched δ ^{13}C values indicative of feeding in an area of higher salinity such as the shore front, potentially with a seaweed dietary component. The pig specimens have enriched δ^{15}N relative to the herbivorous fauna indicative of protein consumption within all of these specimens, with a low standard deviation in δ^{13}C values observed. This suggests that these individuals had access to very similar diets.

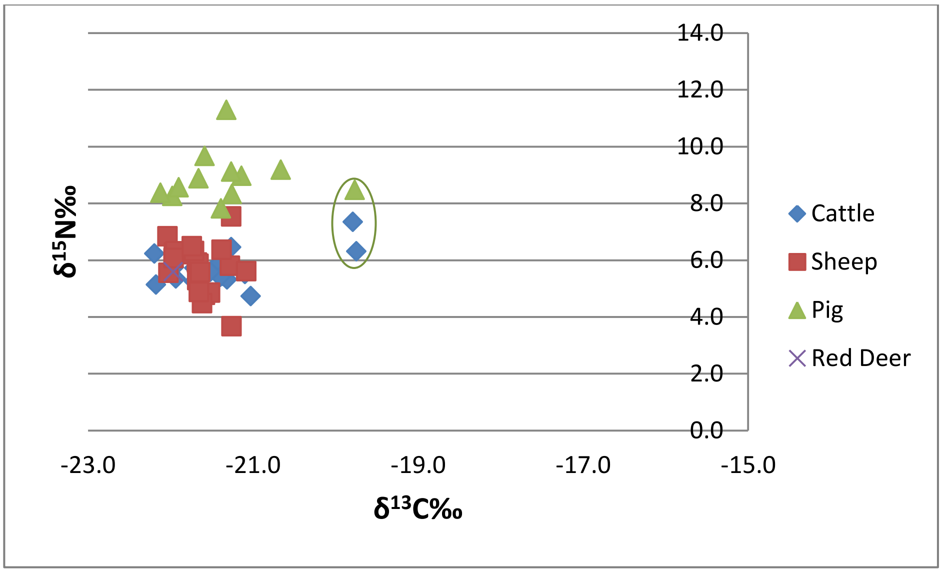


Figure 17: Norse terrestrial faunal baseline: Orkney

Species	n=	Mean δ^{13}C	Std. δ^{13}C	Mean δ^{15}N	Std. δ^{15}N
Cattle	14	-21.7	0.1	5.7	0.1
Sheep	15	-21.7	0.1	5.9	0.2
Pig	12	-21.3	0.2	8.9	0.3
Red Deer	4	-22	0.1	5.6	0.2

Table 19: Norse faunal isotopic averages and standard deviations: Orkney

Norse Shetland

The Norse faunal specimens available from Shetland were all from the site of Jarlshof. Unfortunately no other species were available for further analysis. All of the sheep specimens and five of the cattle specimens analysed clustered together and had similar average δ^{13}C and δ^{15}N values observed (Figure 18, Table 20). This indicates that these individuals had comparable diets, which is consistent with the sheep and cattle diets in Orkney. Two cattle (circled in green) have enriched δ^{13}C values relative to the other specimens indicative of diets including saline plants such as seaweed. This is discussed further in the cattle dietary trends section. These are all from the same site, and potentially reflect differing foddering strategies within the population.

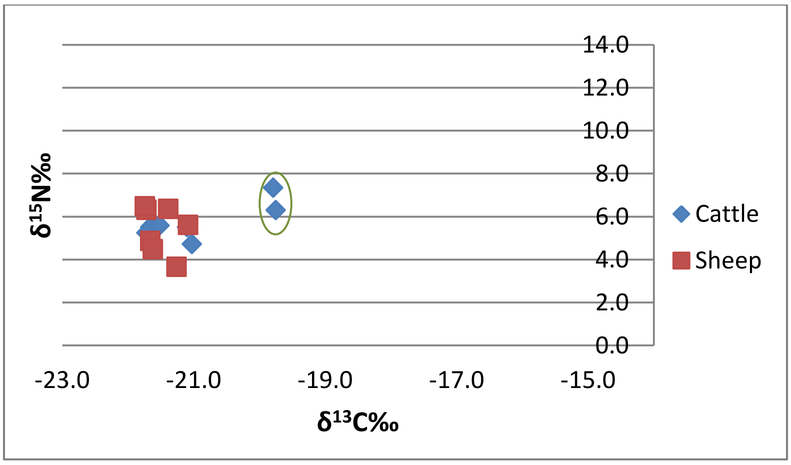


Figure 18: Norse terrestrial faunal baseline: Shetland

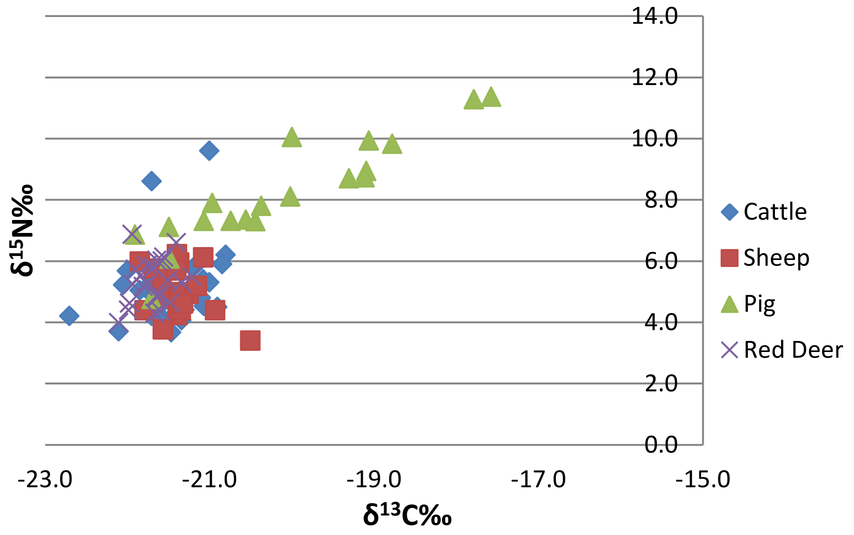
Species	n=	Mean δ^{13}C	Std. δ^{13}C	Mean δ^{15}N	Std. δ^{15}N
Cattle	**7**	-20.9	0.8	5.7	0.8
Sheep	**7**	-21.5	0.3	5.4	1.1

Table 20: Norse faunal isotopic averages and standard deviations: Shetland

Norse Western Isles

The Norse specimens from the Western Isles are from the sites of Bornais, Cille Pheadair, and Bostadh. One of the most striking aspects of the Norse faunal baseline is the cluster of pig specimens with isotopic signatures consistent with consumption of marine foods (Table 21), similar to the Hebridean pig specimens analysed from the Iron Age. The herbivorous specimens analysed all have isotopic values consistent with the consumption of a terrestrial herbivorous diet.

The cattle demonstrate inter-species variation in the δ^{13}C, covering a range of 3‰ between the highest and lowest values observed. This suggests that different animal management practices were being employed within the island group. This could relate to the utilisation of different pasturing locations, or foddering strategies. The sheep specimens are more homogenous, indicating that there was more consistency in the animal management strategies employed.



(additional data from Madgwick 2012a; Mulville *et al.* 2009)

Figure 19: Norse terrestrial faunal baseline: Western Isles

Species	n=	Mean $\delta^{13}C$	Std. $\delta^{13}C$	Mean $\delta^{15}N$	Std. $\delta^{15}N$
Cattle	23	-21.5	0.07	5.1	0.22
Sheep	20	-21.4	0.07	5.0	0.18
Pig	19	-20.1	0.29	8.3	0.39
Red Deer	24	-21.7	0.05	5.3	0.15

Table 21: Norse Faunal isotopic averages and standard deviations: Western Isles

Geographical Characterisation of Stable Isotopic Values

To understand geographical differences in isotopic values, red deer values are compared across the island groups. Red deer can be utilised as a proxy for the 'natural' environmental herbivorous signature as they are a wild species and therefore are less influenced by anthropogenic processes. Red deer are occasionally influenced by anthropogenic activity, for example they can be semi-managed by humans, channelling their movement possibly to keep them away from crops (Mulville 2010; Mulville and Powell 2012), but we would still expect this activity to produce 'natural' baseline isotopic signatures. The dietary behaviour of domestic fauna is more likely to be controlled and influenced by human management strategies, such as foddering and pasturing choices and therefore may not reflect the natural environment as efficiently as wild species (Stevens *et al.* 2006, 13). Domestic species were also cross-compared between the island groups to determine whether any geographical variations were being observed in these species. The Mann Whitney U test was utilised to determine statistically significant differences between any one species average values between the two different island groups. The results of the Mann Whitney U tests exploring geographical variations are displayed in Appendix 3.

Differences in $\delta^{15}N$ values between the Western Isles and Orkney

Statistically significant differences in $\delta^{15}N$ values of red deer, cattle, and sheep were observed between the specimens analysed in Orkney and the Western Isles during the Neolithic (Figure 20), Bronze Age (Figure 21) and Iron Age (Figure 22). On average the Orkney values are approximately 1‰ enriched in $\delta^{15}N$ compared to the specimens from the Western Isles. The difference in $\delta^{15}N$ values between the two locations is consistently observed for the wild red deer specimens analysed (and all domestic species) indicating that there are geographical differences in $\delta^{15}N$ between Orkney and the Outer Hebrides. This could be due to two possible factors: differences in vegetation between the islands, and differences in the soil type.

Plant such as legumes have higher levels of protein than leafy plants (Southgate 2000a, 336), and a greater presence of more protein rich plant species in Orkney could impact on the faunal isotopic values observed, creating a difference in average values of species between the islands. These plants would need to be relatively widespread across the island in order to affect both the wild and domestic species. Archaeobotanical work in the islands is predominantly focussed on plants found in domestic contexts (e.g. Colledge and Smith 2012); further environmental work coring in the wider landscapes of the islands would be beneficial in determining palaeobotanical landscapes further.

Another possibility is that there are differences in the soil composition in the islands. Nitrogen values are closely linked to soil properties in the geographical location in question (Ambrose 1991, 296). The fragile machair environments of the Outer Hebrides are less able to retain nutrients, and have been suggested as being deficient in nitrogen, potash, phosphate and manganese (Smith 2012), implying that the variation is directly related to environmental differences between the two islands. The differences in $\delta^{15}N$ content observed between the island groups may be due to differences in soil quality and nutrient retention.

Norse red deer were not available to provide a wild isotopic signature as the species had died out on the island by this point (Fairnell and Barrett 2007; Mulville 2010). However evidence from the domestic species suggests that during the Norse period the environment in Orkney were no longer enriched in $\delta^{15}N$ relative to the Western Isles (Figure 23). That is, no statistically significant differences in the domestic species were observed between the Northern and Western Isles. The greater degree of homogeneity in $\delta^{15}N$ values between the two island groups during the Norse period is intriguing and may relate to cultural practices. The Norse settlers in the North Atlantic Island group may have been fertilising the land to enhance crop growing ability, adding nitrogen-rich products such as manure to the land. This would have filtered through into the local plants and animals, creating greater homogeneity between the two island groups.

The possibility of manuring is supported by additional lines of evidence, for example Mulville and Powell (2012, 252) suggest that cattle were potentially being moved onto the machair during the winter months to manure the land for crop growth. Archaeobotanical evidence from Bornais M1 demonstrated an increase in the number of plant species observed between the Late Iron Age and the Norse period, with expansion of cultivation on the machair, requiring additional fertilisation of the land (Sharples 2012, 251). This supports the hypothesis that manuring was being practiced in the Outer Hebrides, and could explain the homogenisation in isotopic values observed between the islands.

The difference in $\delta^{15}N$ between the two island groups during the Neolithic, Bronze Age and Iron Age has implications for the interpretation of human stable isotope values between these island groups. Humans from Orkney would have $\delta^{15}N$ values that would appear elevated in comparison to contemporary counterparts from the Western Isles even if they were consuming identical diets. The faunal isotopes provide a good understanding of potential factors influencing the human isotopic record.

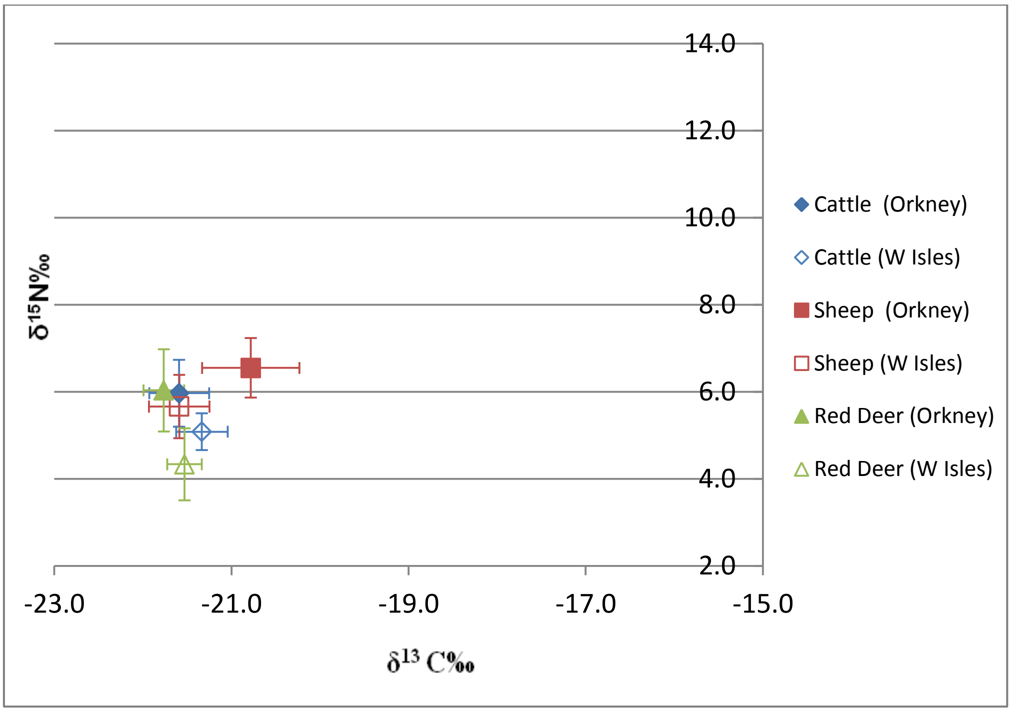


Figure 20: Geographical comparisons of average isotopic values for Neolithic specimens in Orkney and the Western Isles

*error bars show one standard deviation from the mean.

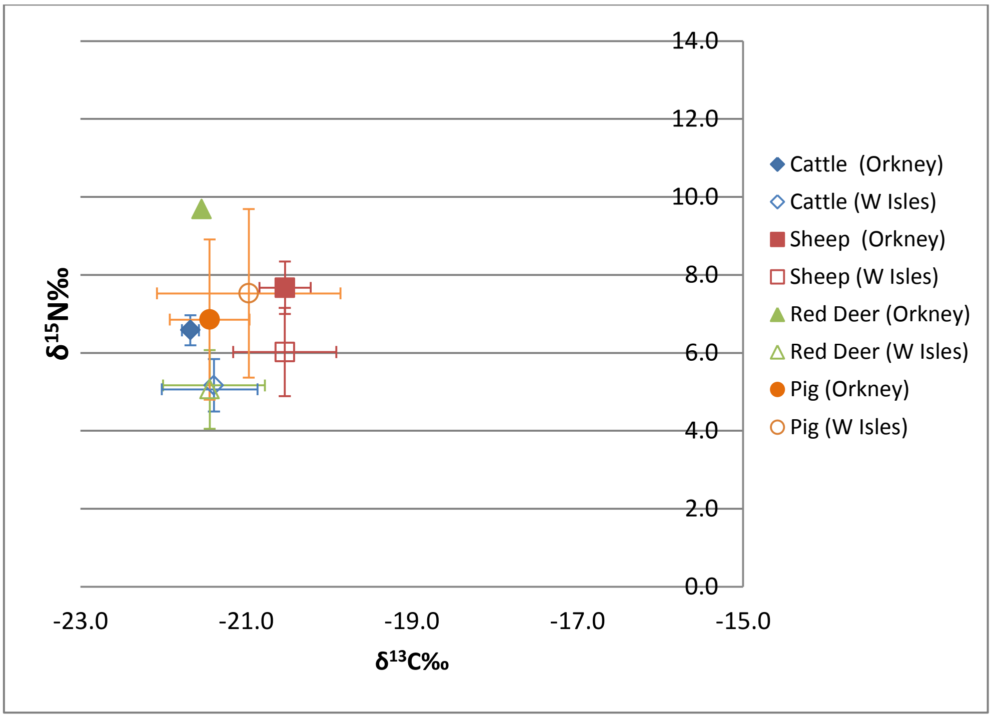


Figure 21: Geographical comparisons of average isotopic values for Bronze Age specimens in Orkney and the Western Isles

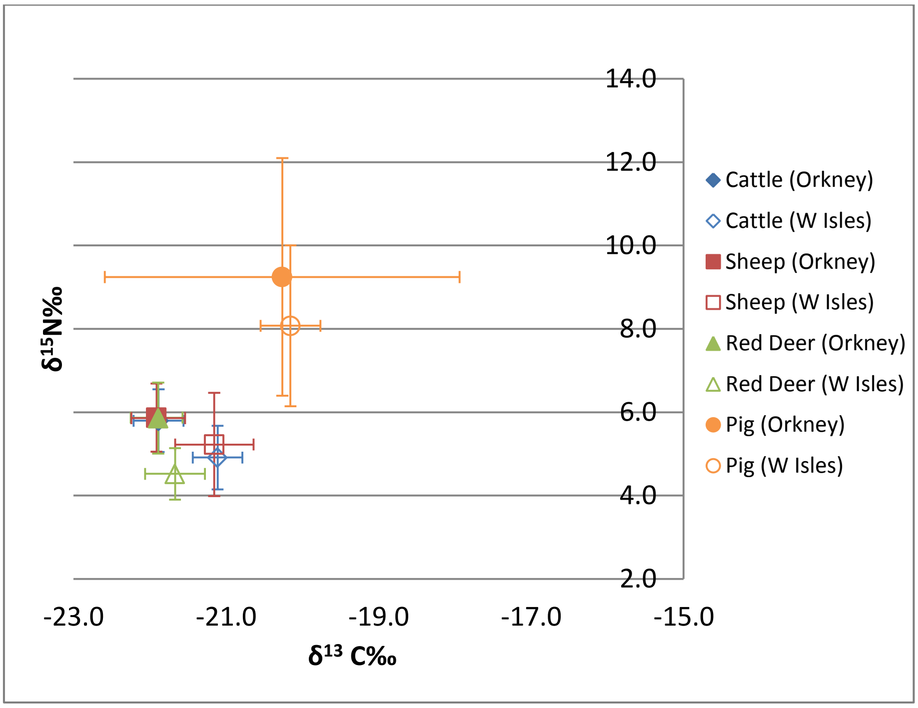


Figure 22: Geographical comparisons of average isotopic values for Iron Age specimens in Orkney and the Western Isles

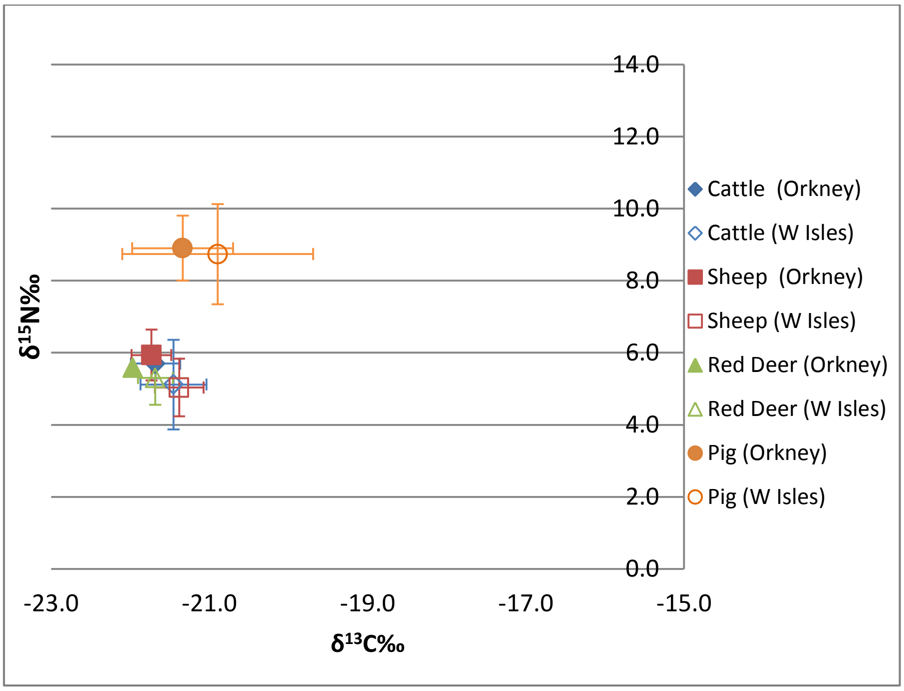


Figure 23: Geographical comparisons of average isotopic values for Norse specimens in Orkney and the Western Isles

Geographical δ^{13}C Value differences between the Western Isles and Orkney

Differences in δ^{13}C values between the islands were not consistently observed in the wild red deer specimens or the domestic species analysed. The differences that are observed can therefore be interpreted as localised differences in feeding strategies between the regions rather than wider-scale environmental differences observed between the islands. The results of the Mann Whitney U test comparing the two geographical regions are included in appendix 4. There were statistically significant differences between δ^{13}C of individual species observed during certain time periods.

A strong statistically significant difference was observed between the sheep δ^{13}C values in Orkney and the Western Isles during the Neolithic period (Table 22). Average sheep δ^{13}C values from Orkney were enriched by 0.8‰ in comparison to their Western Isles counterparts. This was not observed in any other species. This difference in the δ^{13}C values between the two sites is likely to be due to the sheep being kept under slightly different conditions, and is potentially a reflection of differences in foddering strategies. The three Orkney specimens may have been foddering close to the shore front, grazing on seaweed, which would explain the values observed. Studies of apatite δ^{13}C and δ^{18}O of teeth in Neolithic sheep from Orkney have demonstrated that some individuals were foddered on seaweed (Balasse *et al.* 2006; 2009), indicating that shore-side pastures were being utilised for as sheep grazing in Orkney. The differences in isotopic values between sheep in both island groups therefore could be explained by Orkney sheep being foddered on coastal pastures on a regular basis, causing enriched δ^{13}C values in the bone collagen. The Western Isles specimens were predominantly from the site of Northton, which is also by the shore front, suggesting that the sheep at the site were being grazed in an alternative location. There appears to be a difference in the use of pasturing locations between islands.

No statistically significant different differences in faunal Bronze Age δ^{13}C values between Orkney and the Western Isles were visible for either cattle or sheep, suggesting that there was a degree of similarity in diet between the two island groups in this period (Table 23). Unfortunately sample sizes for red deer and pigs were limited and therefore could not be used for statistical comparisons. The Iron Age specimens displayed a statistically significant difference between the average δ^{13}C values of Iron Age cattle and sheep in Orkney and the Western Isles. The Orkney values were depleted by approximately 0.8‰ and 0.7‰ respectively (Table 24) and as discussed previously this is potentially linked to consumption of seaweed plants.

During the Norse period cattle, sheep and pig all displayed statistically significant differences in $\delta^{13}C$ between the island groups. The average cattle and sheep were only different by 0.2‰ and 0.3‰ respectively (Table 25), representing a minor average dietary difference between these island groups. The difference in average pig $\delta^{13}C$ values is 0.4‰. The Norse pig isotopic values are highly varied as some individuals were consuming marine foods, and comparing the mean values statistically is not necessarily appropriate.

Neolithic	**n=**	**Mean δ^{13}C‰**	**Std.δ^{13}C ‰**
Cattle (Orkney)	94	-21.6	0.3
Cattle (W Isles)	9	-21.3	0.3
Sheep (Orkney)	26	-20.8	0.5
Sheep (W Isles)	11	-21.6	0.3
Pig (Orkney)	13	-21.5	0.8
Pig (W Isles)	0	n/a	n/a
Red Deer (Orkney)	13	-21.8	0.2
Red Deer (W Isles)	7	-21.5	0.2

Table 22: Mean Neolithic δ^{13}C values for animals in the Western Isles and Orkney

Bronze Age	**n=**	**Mean δ^{13}C‰**	**Std. δ13C ‰**
Cattle (Orkney)	5	-21.7	0.1
Cattle (W Isles)	27	-21.4	0.6
Sheep (Orkney)	4	-20.5	0.3
Sheep (W Isles)	25	-20.5	0.6
Pig (Orkney)	2	-21.4	0.5
Pig (W Isles)	4	-21.0	1.1
Red Deer (Orkney)	1	-21.5	n/a
Red Deer(W Isles)	18	-21.4	0.6

Table 23: Mean Bronze Age δ^{13}C values for animals in the Western Isles and Orkney

Iron Age	**n=**	**Mean δ^{13}C‰**	**Std. δ^{13}C ‰**
Cattle (Orkney)	19	-21.9	0.3
Cattle (W Isles)	40	-21.1	0.4
Sheep (Orkney)	15	-21.9	0.3
Sheep (W Isles)	38	-21.2	0.5
Pig (Orkney)	11	-20.3	2.3
Pig (W Isles)	24	-20.2	1.3
Red Deer (Orkney)	13	-21.2	0.4
Red Deer (W Isles)	34	-21.7	0.4

Table 24: Mean Iron Age δ^{13}C values in the Western Isles and Orkney

Norse	**n=**	**Meanδ^{13}C ‰**	**Std. δ^{13}C ‰**
Cattle (Orkney)	14	-21.7	0.3
Cattle (W Isles)	31	-21.5	0.4
Sheep (Orkney)	15	-21.7	0.3
Sheep (W Isles)	20	-21.4	0.3
Red Deer (Orkney)	1	-22.0	n/a
Red Deer (W Isles)	24	-21.7	0.2
Pig (Orkney)	12	-21.3	0.6
Pig (W Isles)	19	-20.9	1.2

Table 25: Mean Norse δ^{13}C values in the Western Isles and Orkney

Exploring Past animal diets, management and foddering strategies

A major focus of this form of analysis was to characterise past animal management strategies by the communities occupying these liminal island environments, and to identify instances of potential marine foddering. The $\delta^{13}C$ and $\delta^{15}N$ values of each species through time within each island group were compared to understand changing dietary practices, starting with the wild and then domestic species. The isotopic values of less utilised resources including seal, fish and birds, are then explored.

Red Deer in Orkney

As mentioned earlier, as wild species, red deer are more representative of the local environment. Red deer have a wider degree of selectivity in terms of the foods that they choose to eat (Latham *et al*. 1999; Latham 2000). The diet of modern Scottish red deer populations is relatively consistent with grasses being a major food source in the summer and winter months, with a greater breadth of diet being observed over the winter period (Latham *et al.* 1999: Latham 2000).

It was not possible to compare red deer from all island groups due to their scarcity in the zooarchaeological record in Shetland, and when present they are often traded antler and associated cranial fragments (Mulville 2005).

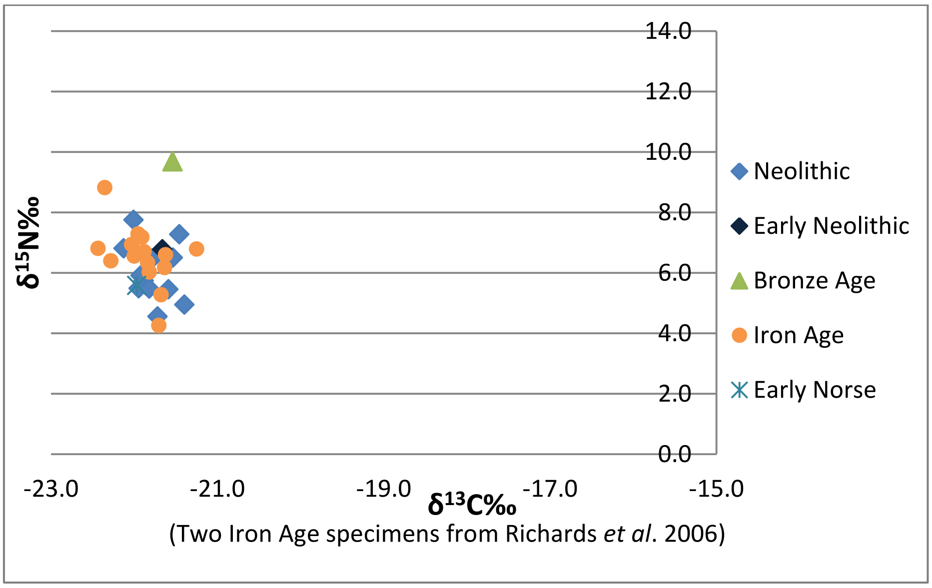


Figure 24: Temporal trends in red deer isotopic values: Orkney

The range of $\delta^{13}C$ observed across time in the red deer from Orkney are between -22.4‰ to -21.2‰ (Figure 24, Figure 25) suggesting a similarity in the red deer dietary behaviour.

The $\delta^{15}N$ values of the red deer (Figure 26) show a smaller range of values. The greatest variation is observed within the Neolithic specimens, although they are all still within the normal range of values expected for inter-individual comparisons (O'Connell *et al.* 2001).

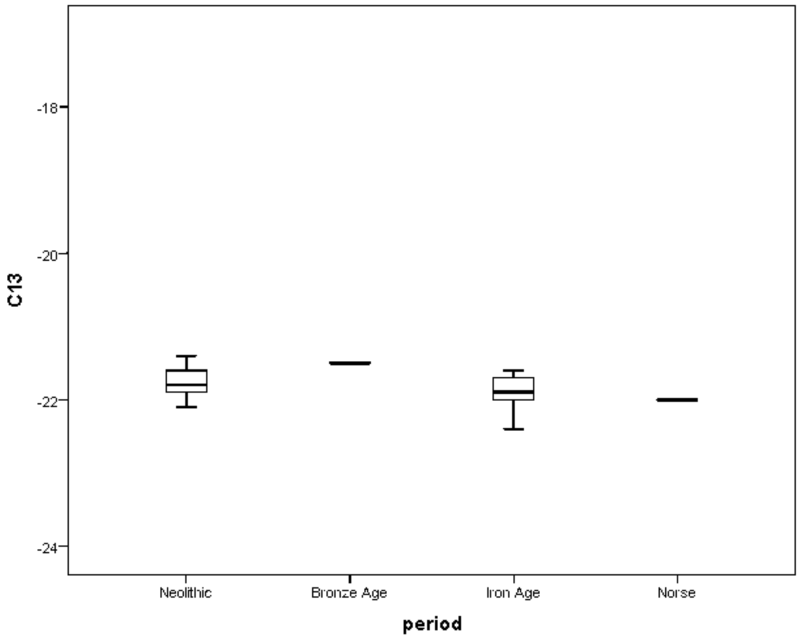


Figure 25: Boxplot showing red deer $\delta^{13}C$ values through time: Orkney

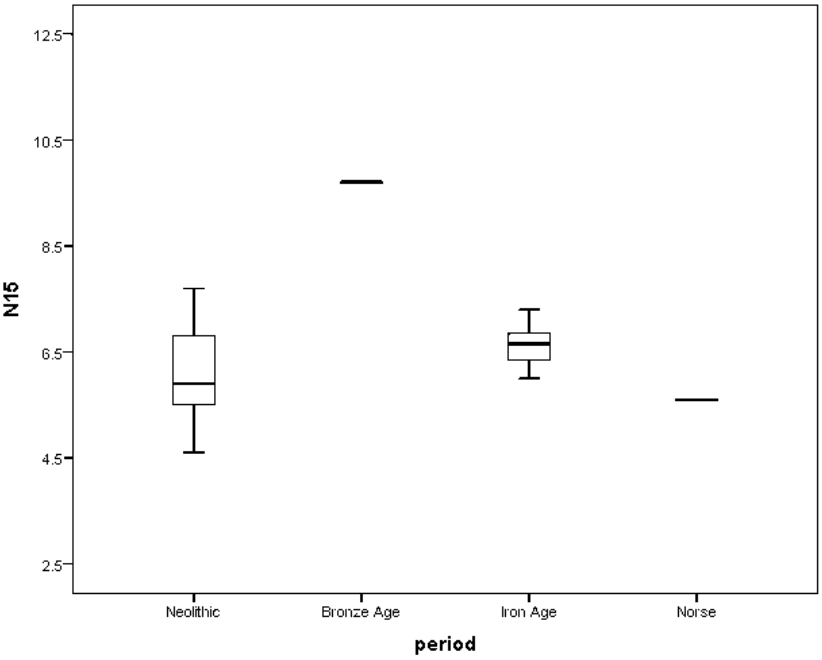
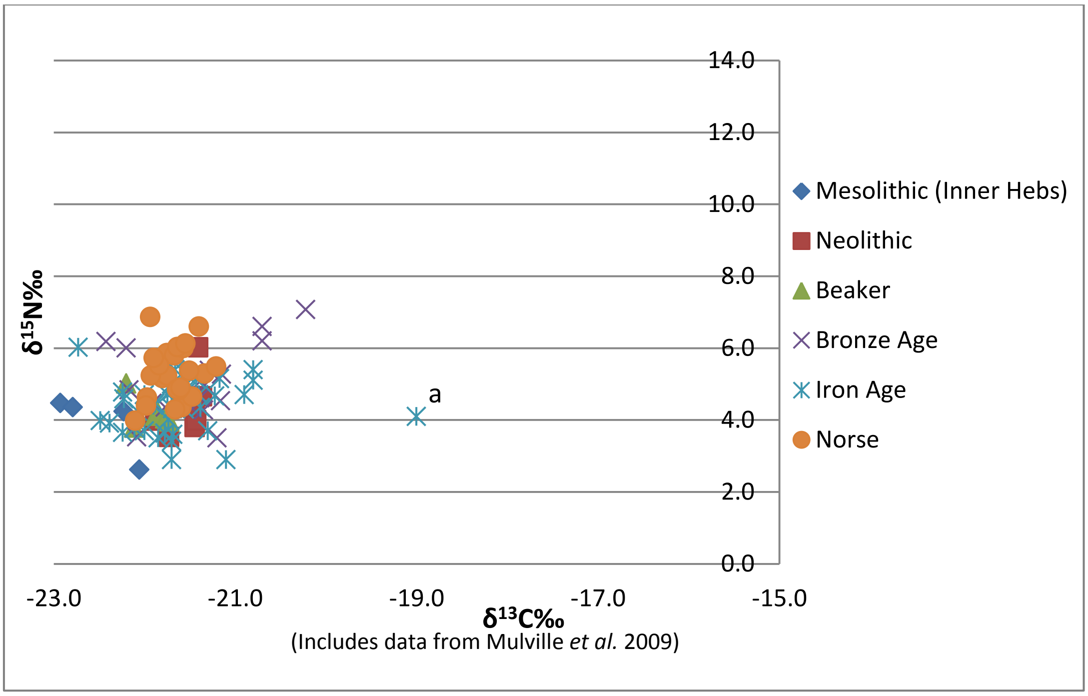


Figure 26: Boxplot showing red deer $\delta^{15}N$ values through time in Orkney



(Includes data from Mulville *et al.* 2009)

Figure 27: Temporal trends in red deer isotopic values: Western Isles

The isotopic values for Mesolithic specimens from the Inner Hebrides are generally more depleted in δ^{13}C relative to the Outer Hebridean individuals analysed (Figure 27), potentially relating to differing soil types or environments between the two island groups with variations in δ^{13}C values. These comparable depleted δ^{13}C values are also observed within the modern red deer population on the Scottish Island of Rum (Stevens *et al.* 2005), suggesting that differences in the environments may explain the depletion in the Mesolithic specimens from Oronsay. There is debate as to whether the Mesolithic red deer in the Inner Hebrides were local to Oronsay (Mithen and Finlayson 1991), and these individuals may not necessarily be reflective of the isotopic environments of the Inner Hebrides.

Individual (a) from late Iron Age Bornais was analysed in a previous study and was identified as having consumed seaweed (Mulville *et al.* 2009), demonstrating that individuals would roam onto the shore front to graze.

The red deer values are interesting for both island groups in that they have a low range of values particularly in the δ^{13}C values over time (Figure 28). This small range in δ^{13}C probably reflects the high selectivity in the dietary choices of deer identified in ecological studies (Latham *et al.* 1999; Latham 2000) and corroborated by the similarities in average δ^{15}N values observed over time (Figure 29).

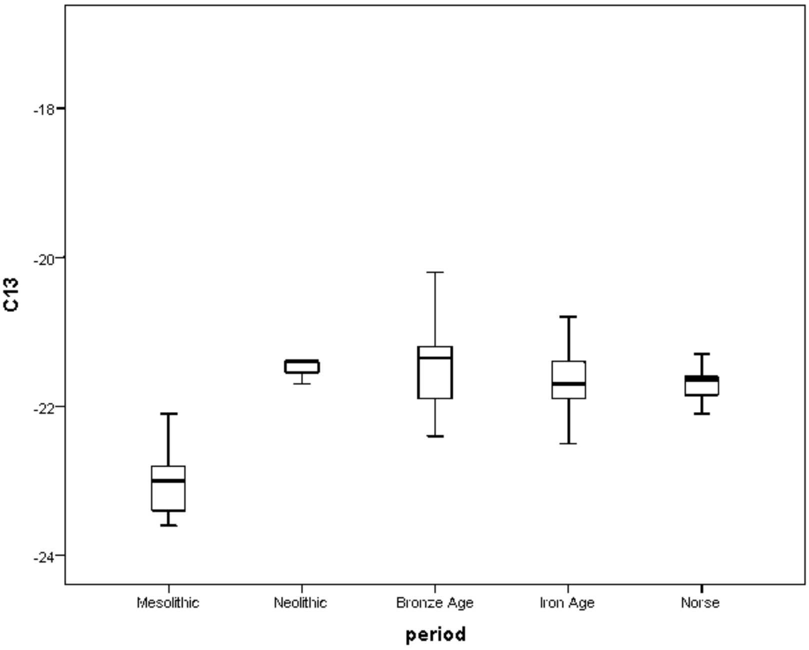


Figure 28: Boxplot showing red deer δ^{13}C values through time: Western Isles

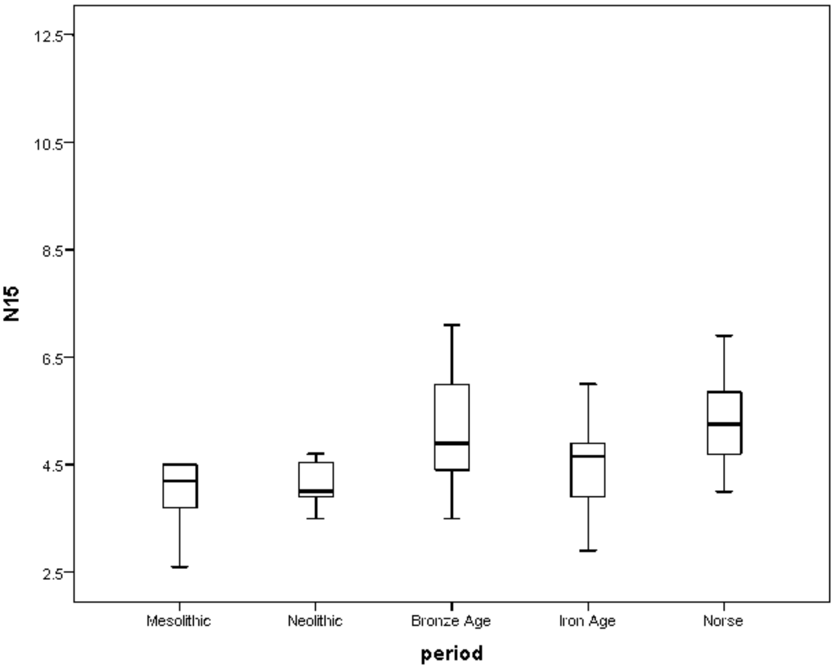


Figure 29: Boxplot showing red deer δ^{15}N values through time: Western Isles

Cattle in Orkney

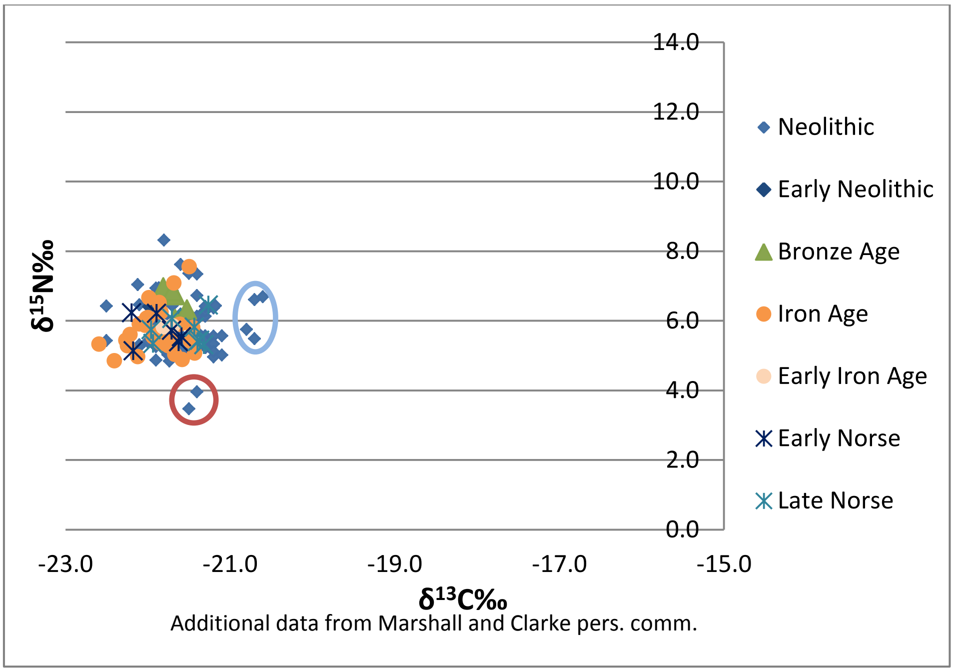


Figure 30: Temporal trends in cattle isotopic values: Orkney

Within the Orcadian specimens two Neolithic cattle (circled in red) were observed to have depleted δ^{15}N in relation to the other specimens (Figure 30). These values derived from the radiocarbon dating work by Clarke and Marshall (pers. comm.); further information about these specimens is not available. Within the Skara Brae specimens a small cluster of Neolithic individuals had enriched δ^{13}C values (circled in blue). It is possible that they were being foddered on marine plant materials, indicating that these individuals were being treated differently to others and it may be that these individuals were being kept closer to the settlement, and were being fed products from the nearby shorefront, which could explain the diversity in δ^{13}C values observed. Such a strategy was suggested at the Late Iron Age site of Bornais in the Outer Hebrides where herd management strategies included keeping the bulk of the herd away from the settlements, and retaining some individuals within the settlement to provide a source of fresh milk (Mulville and Powell 2012, 233).

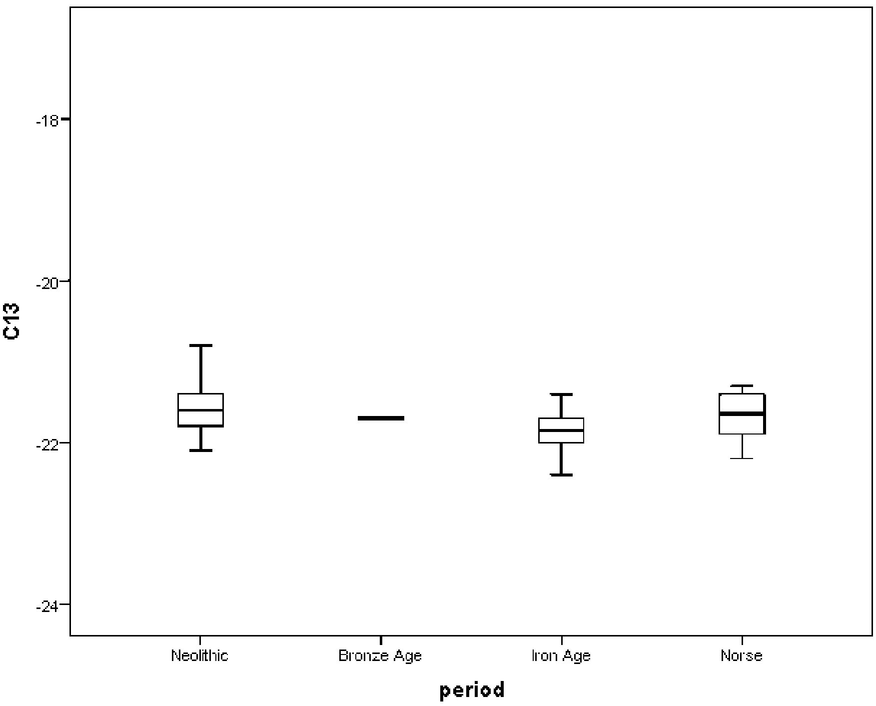


Figure 31: Boxplot showing cattle δ^{13}C values through time: Orkney

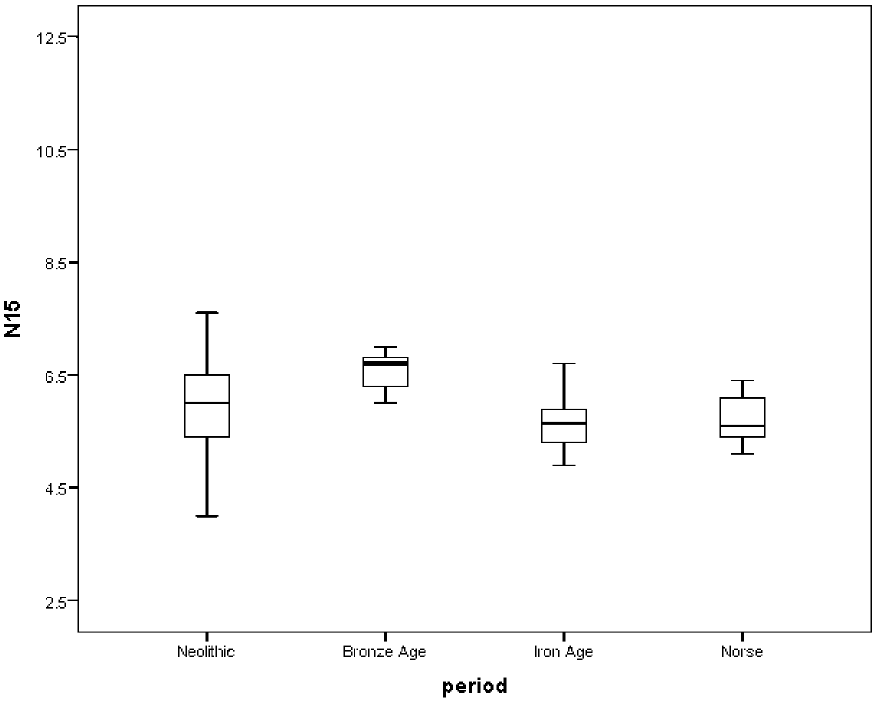


Figure 32: Boxplot showing cattle δ^{15}N values through time: Orkney

The Orkney cattle values all have similar average δ^{13}C and δ^{15}N values over time (Figure 31 and Figure 32), indicating that in general the diet of these animals does not alter temporally, and no statistically significant differences in the values were observed (Appendix 4).

During the Neolithic period and Bronze Age in Orkney there is a greater range in the δ^{13}C and δ^{15}N values observed for the specimens. This is potentially a product of sample size, as the Neolithic cattle assemblage comprised 94 individuals whereas the other assemblages are based on fewer individuals. As these samples were generated from radiocarbon dating (Marshall and Clarke pers. comm.), some juvenile animals may have been included in the dataset, which needs to be taken into account when interpreting the data.

Cattle in Shetland

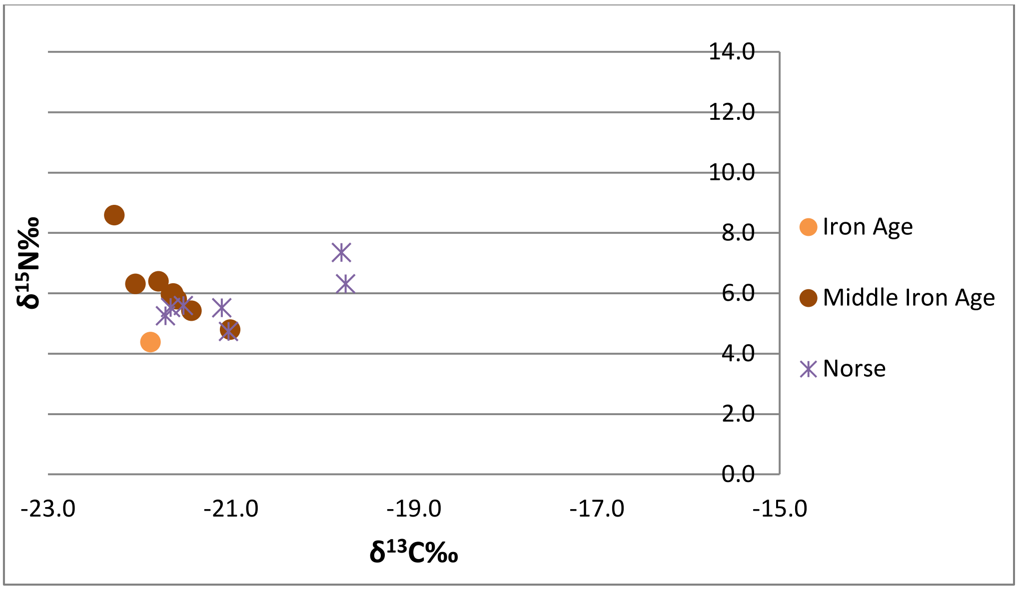


Figure 33: Temporal trends in cattle isotopic values: Shetland

Two of the Norse cattle have enriched δ^{13}C values (JA09, JA10) similar to those observed at Skara Brae, indicative of seaweed consumption (Figure 33). They derived from the settlement of Jarshof, situated on the shorefront, and seaweed would be readily available as a resource to feed any individuals kept nearby. As hypothesised for Skara Brae these individuals could represent milking cattle kept near the settlement as a ready source of protein.

One of the Shetland Middle Iron Age cattle (SC12) was enriched in δ^{15}N relative to the other specimens. This specimen was a fused distal humerus, then 10 months of age (Silver 1969), which would be late for a weaning signature to still be evident. This individual is therefore indicative of consuming a diet enriched in δ^{15}N, such as foddering in areas that have a build-up of animal dung.

Cattle in the Western Isles

Figure 34 shows the individual cattle isotopic values generated for the Western Isles. The majority of data is very similar, but two of the Norse cattle have enriched δ^{15}N relative to the other specimens analysed. These individuals were from the Norse phases of Bornais M1 and were achieved through radiocarbon dating techniques, and could potentially represent young un-weaned individuals (Sharples 2005).

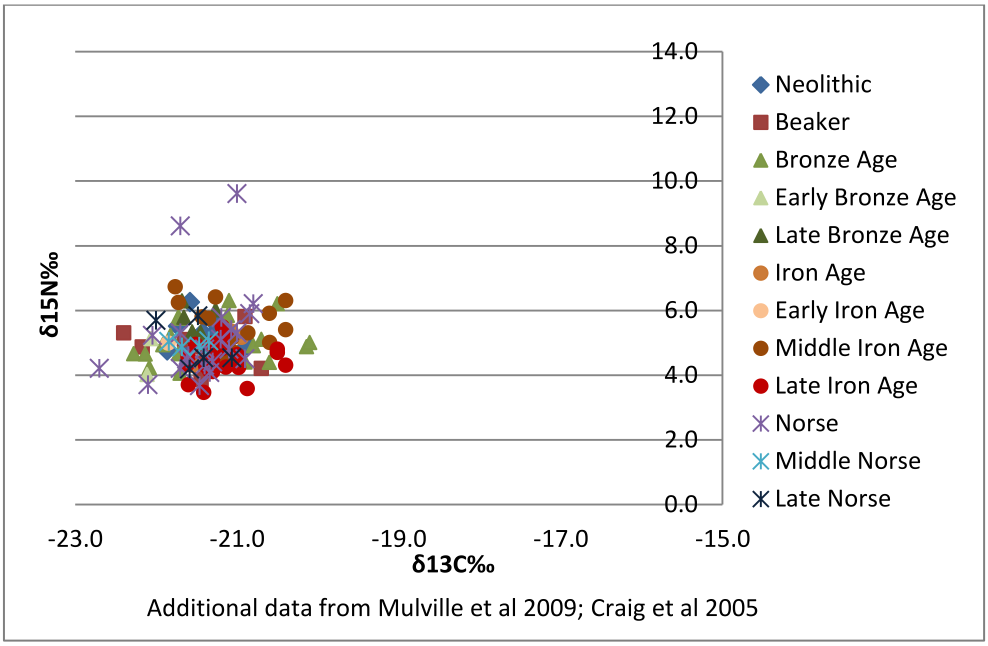


Figure 34: Temporal trends in cattle isotopic values: Western Isles

Bronze Age Western Isles cattle have a much broader range in δ^{13}C values than observed in any of the other periods (Figure 35). This suggests that there is a greater degree in variation in the foddering strategies employed, and could indicate that cattle are being pastured in different areas of the landscape.

There is also great variation in the δ^{13}C values observed in the Bronze Age sheep from the Western Isles (Figure 41). Almost all of the faunal specimens from the Bronze Age were from the site of Cladh Hallan, suggesting that the inhabitants of the site were making greater use of the variety of surrounding environments than in the preceding and proceeding periods.

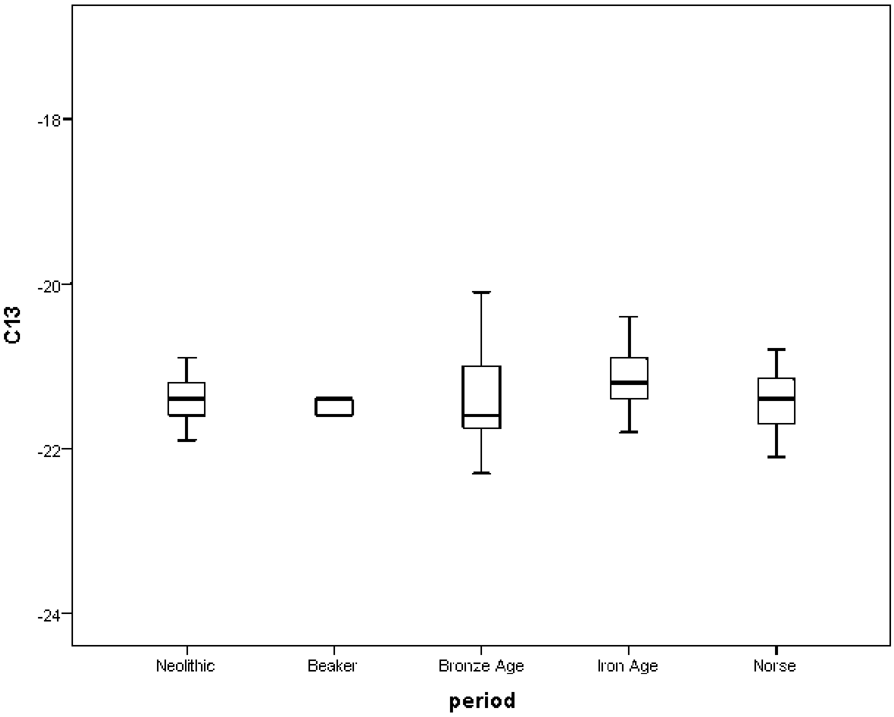


Figure 35: Boxplot showing cattle δ^{13}C values through time: Western Isles

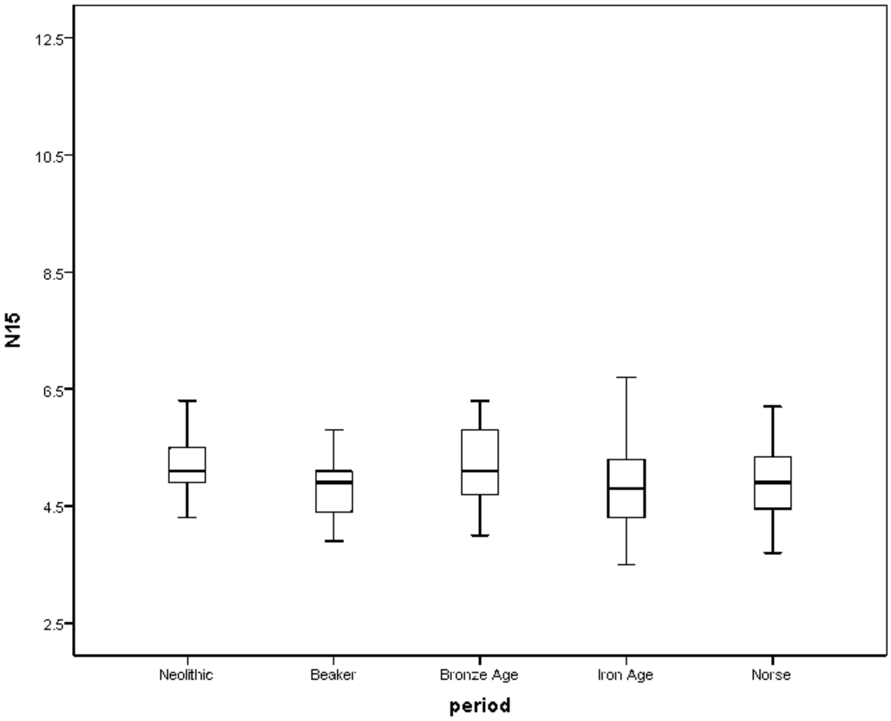


Figure 36: Boxplot showing cattle δ^{15}N values through time: Western Isles

Sheep in Orkney

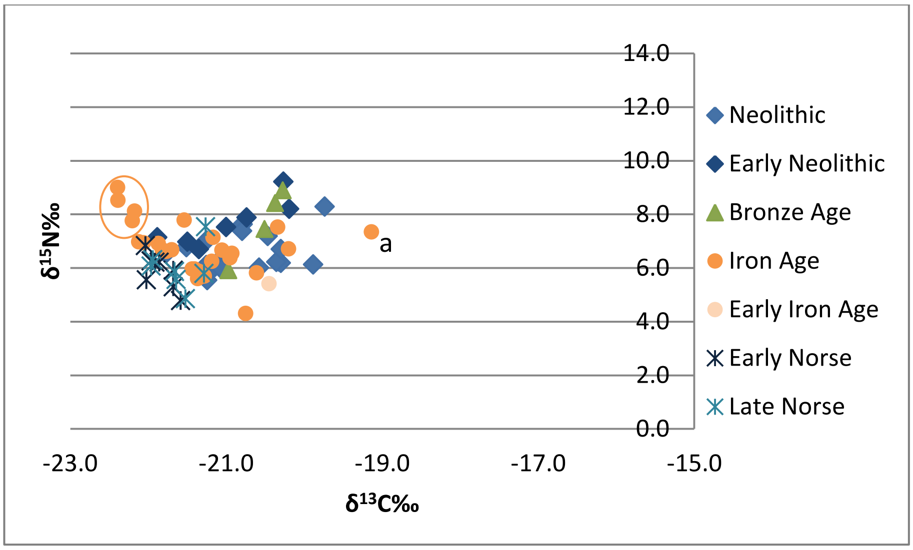


Figure 37: Temporal trends in sheep isotopic values: Orkney

The isotopic values of sheep through time in Orkney can be seen in Figure 37. One Iron Age individual (a) has a $\delta^{13}C$ value outside of the range of values associated with a typical terrestrial herbivorous diet in Orkney. Individual 'a' can potentially be interpreted as having consumed some marine products such as seaweed, as identified in previous studies of sheep in Orkney (Balasse *et al.* 2006; 2009; Mainland 2000).

Four Iron Age individuals (circled in orange) have depleted $\delta^{13}C$ values. This is potentially indicative of foddering in a different location to the other individuals, perhaps in pastures further from the coast, causing the depletion of the carbon values.

The sheep isotopic values show a greater range in $\delta^{13}C$ in the Neolithic and Iron Age specimens (Figure 38), indicating that foddering strategies were more diverse during these periods. The small sample size for the Bronze Age specimens is potentially responsible for the small range in $\delta^{13}C$ values. The Norse sheep have a small range. Norse Sheep on Orkney were all from the Early and Late Norse deposits at Earl's Bu. The small range in values observed is indicative of consistency in the animal management practices employed at the site through time.

There is a larger degree of variation in the range of $\delta^{15}N$ values observed in the sheep from Orkney (Figure 39). As discussed previously this could be a result of manuring, or penning as a husbandry practice (Bogaard *et al.* 2007; Senbayram *et al.* 2008). In the fragile North Atlantic ecosystems there would be a need to pen animals during periods of crop growth to protect the valuable crops (Mulville and Powell 2012, 233). Penning could explain the individuals at the higher end of the nitrogen scale.

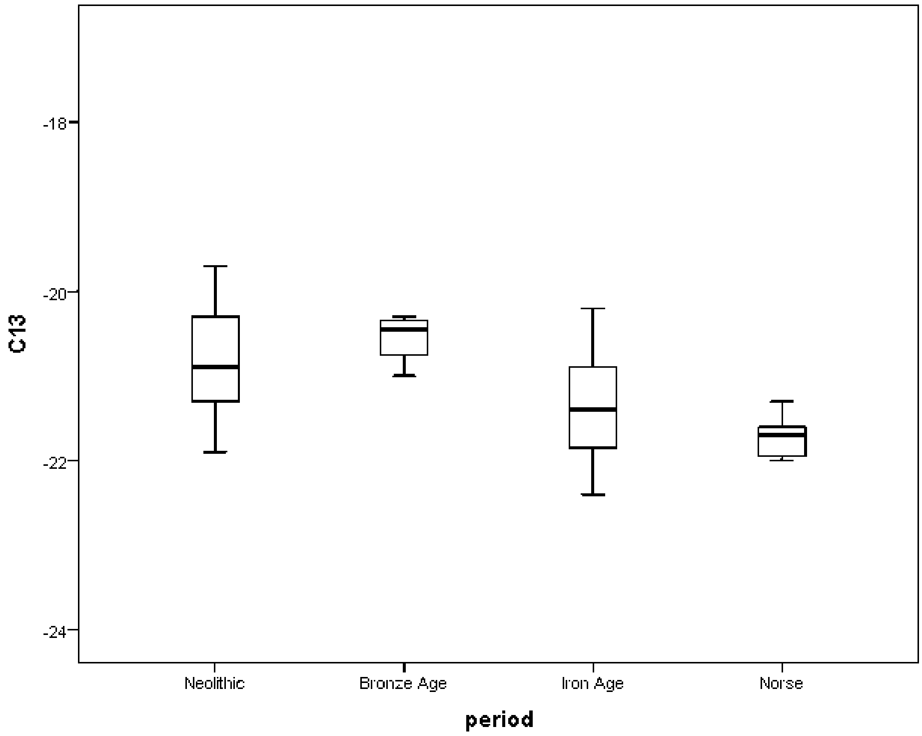


Figure 38: Boxplot showing sheep δ^{13}C values through time: Orkney

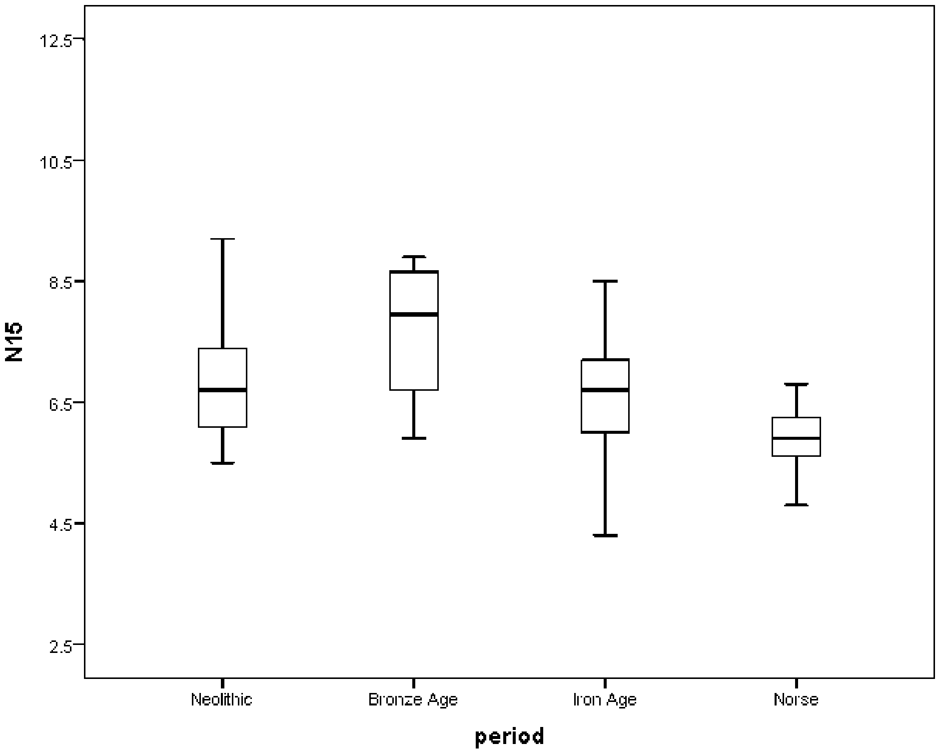


Figure 39: Boxplot showing sheep δ^{15}N values through time: Orkney

Sheep in Shetland

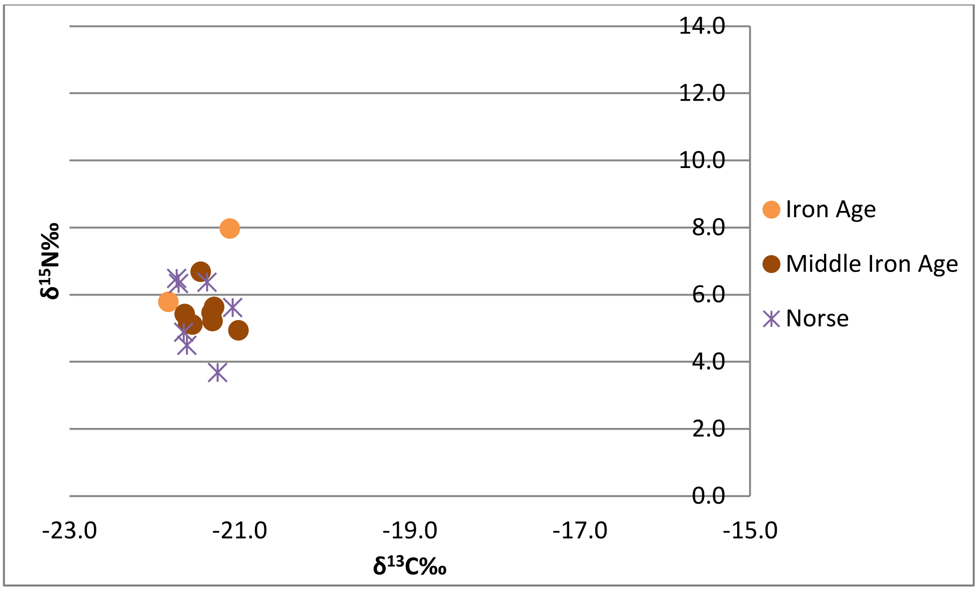
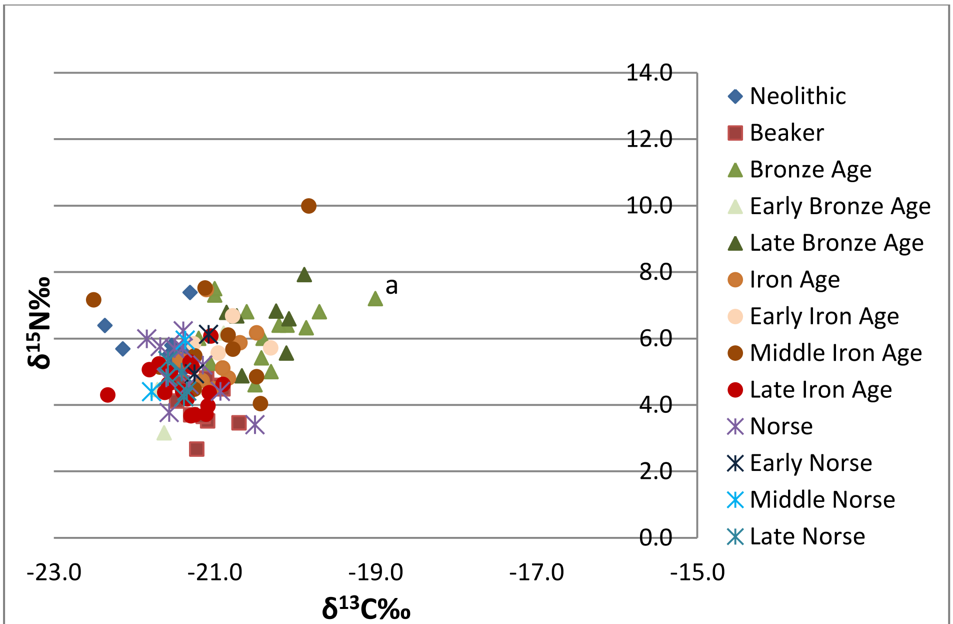


Figure 40: Temporal trends in sheep isotopic values: Shetland

The few Shetland specimens have isotopically similar $\delta^{13}C$ and $\delta^{15}N$ values. This indicates consistency in the dietary behaviour observed between these individuals (Figure 40). This limited sample indicates that sheep management practices in Shetland were similar between the Iron Age and Norse periods.

Sheep in the Western Isles



(Additional data from Mulville et al. 2009)

Figure 41: Temporal trends in sheep isotopic values: Western Isles

Figure 41 shows the sheep isotopic values for the Western Isles. One Bronze Age individual (a) has an enriched δ^{13}C value, similar to the individual identified in Figure 37 from Orkney, and is potentially indicative of seaweed foddering, with a further 3 specimens with values enriched past -20‰, which may also have consumed some marine plants, also observed in one middle Iron Age individual. This suggests that the shore was an important pasturing location for some of the past populations of Orkney.

There is a greater range of variation in the δ^{13}C values observed in the Bronze Age sheep specimens (Figure 42), which as previously noted is indicative of a diverse use of the local environments for animal husbandry.

The ranges of sheep δ^{15}N and δ^{13}C observed in the Neolithic period are small (Figure 42 and Figure 43), indicative of similarities in the foddering strategies applied during this period. Much broader ranges in δ^{15}N are observed in the Beaker period, Bronze Age, Iron Age and Norse period, suggesting that there are greater differences in the management practices as noted previously. Penning processes could explain this difference, with the accumulation of dung causing enrichment of δ^{15}N within some species. Other individuals kept in larger pastures would potentially have depleted δ^{15}N values. These two processes would explain the diversity in δ^{15}N observed between individuals.

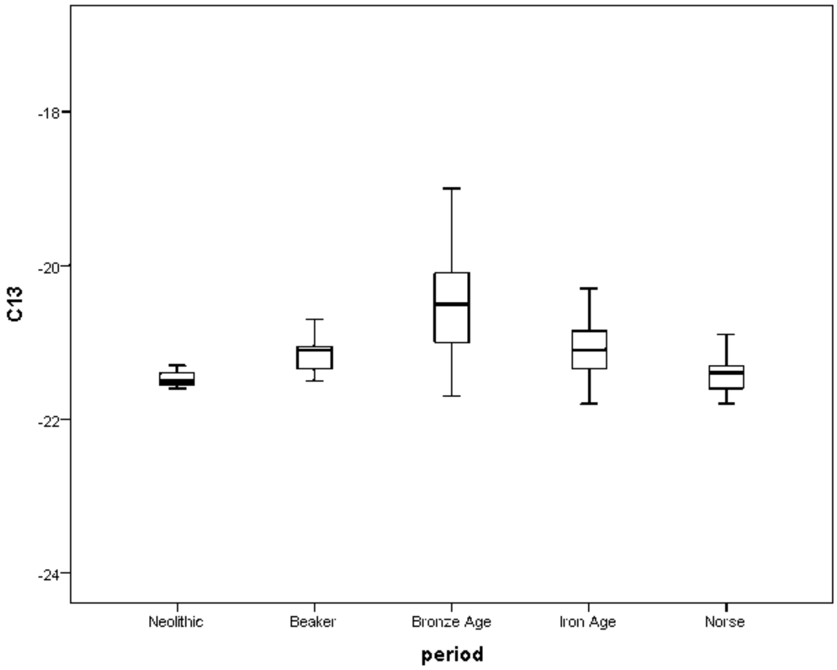


Figure 42: Boxplot showing sheep δ^{13}C values through time: Western Isles

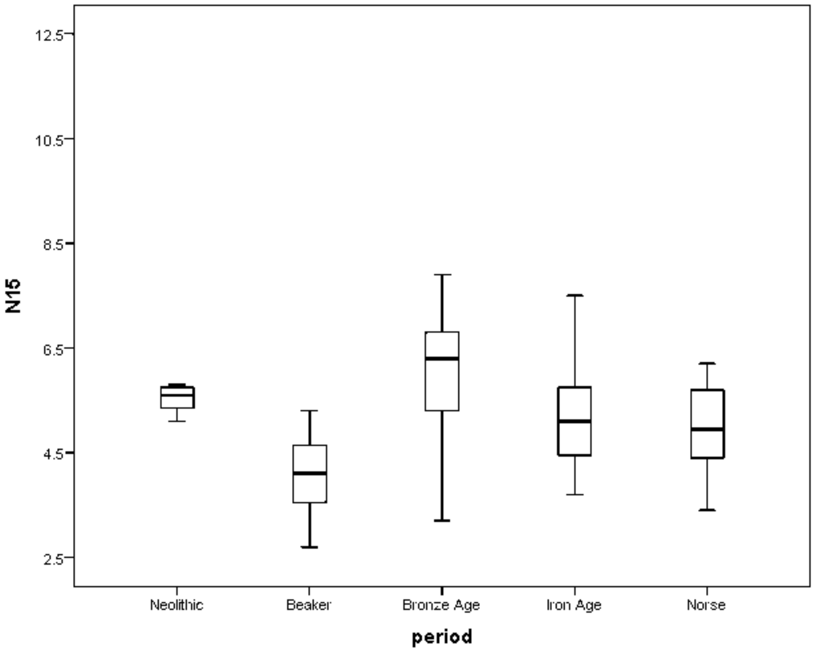


Figure 43: Boxplot showing sheep δ^{15}N values through time in: Western Isles

Pigs in Orkney

Pigs are omnivorous and are highly adaptable in terms of diet, and can generally be fed on whatever foods are available locally (Grigson 1982; Schley and Roper 2003). Therefore a high level of variation in the pig isotopic values is expected. Interpretations from previous isotopic studies have suggested that pigs are frequently foddered on waste foods in a piecemeal approach, potentially on a household level (Madgwick *et al.* 2012a). Rearing pigs either requires large amounts of unmanaged space as pannage, or careful penning of animals to prevent destruction of agricultural produce (Grigson 1982; Ward and Mainland 1999).

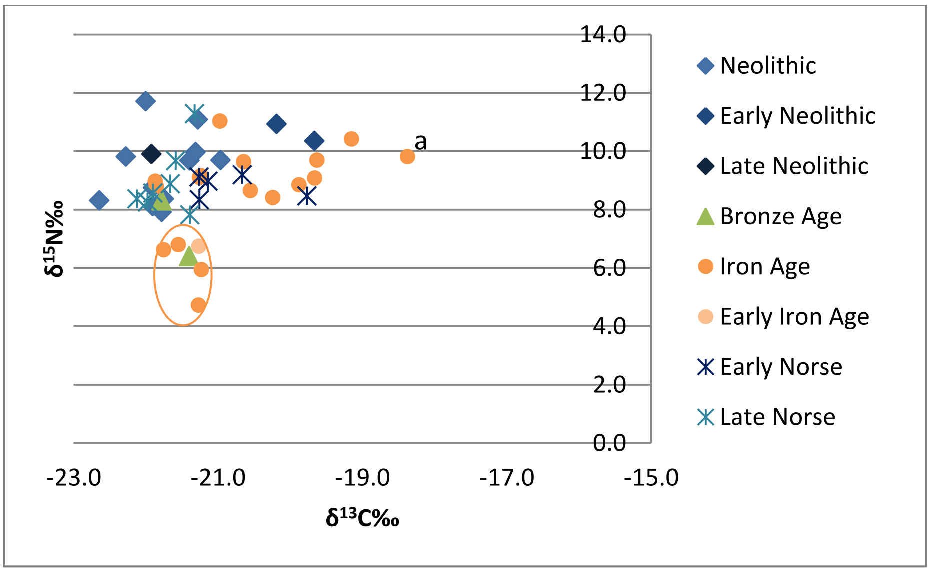


Figure 44: Temporal trends in pig isotopic values: Orkney

Hamilton *et al.* (2010) suggest that in the Neolithic period pigs have been observed as having enriched δ^{13}C resulting from the canopy effect. The data from Orkney are not consistent with the findings of Hamilton *et al.* (2010), with δ^{13}C values of the Neolithic pigs being on average more depleted than their Iron Age counterparts. The scarcity of trees identified in Neolithic Orkney (e.g. Bunting 1994; Keatinge and Dickson 1979; Moar 1969) would not have provided a suitable environment for pannage, which explains why the North Atlantic Island pigs do not follow the trends of those observed by Hamilton *et al.* (2010) in mainland Britain.

The majority of pigs analysed had isotopic signatures consistent with lots of protein consumption, indicative of an omnivorous diet (Figure 44). A cluster of five Iron Age individuals and one Bronze Age individual (circled in orange) have depleted δ^{15}N consistent with a more herbivorous diet This is not unusual for pigs, and studies of wild boar dietary behaviour have demonstrated that plants are often the most commonly consumed food source (Schley and Roper 2003).

One Iron Age Orcadian individual (a) has an enriched δ^{13}C value indicative of occasional foddering on marine foods. The signature is not as strong as that observed for the Western Isles pig specimens (Figure 48), indicating that marine resources were a minor part of the diet of this individual.

A spread in δ^{13}C and δ^{15}N values for pigs was observed in the Iron Age, with the smallest ranges observed in the Norse period (Figure 45 and Figure 46). During the Iron Age and Norse period there are greater numbers of pigs present in the zooarchaeological assemblages (Figure 69, Chapter 9) indicating that they were a more important resource in comparison to the preceding periods. The average values for each period are similar suggesting that their overall diet was consistent, but the change in the range of values between the Iron Age and Norse period suggests that there was a greater level of homogeneity in pig foddering strategies during the Norse period. If pig rearing was being undertaken on a household level with pigs being fed refuse, this could be indicative of a greater similarity between the diets of humans during the Norse period.

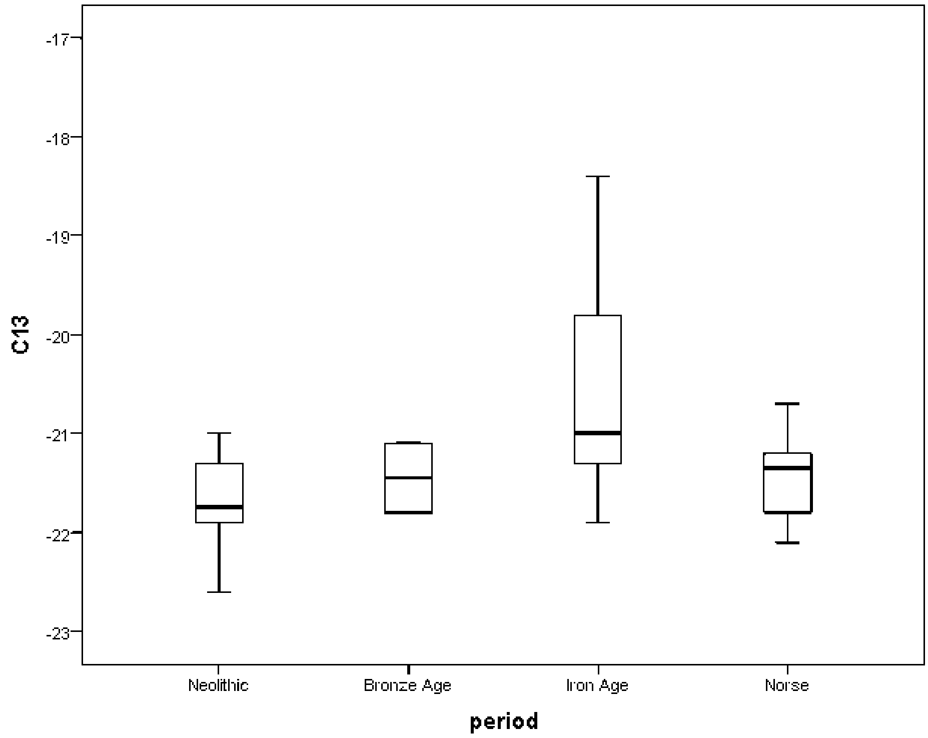


Figure 45: Boxplot showing pig δ^{13}C values through time: Orkney

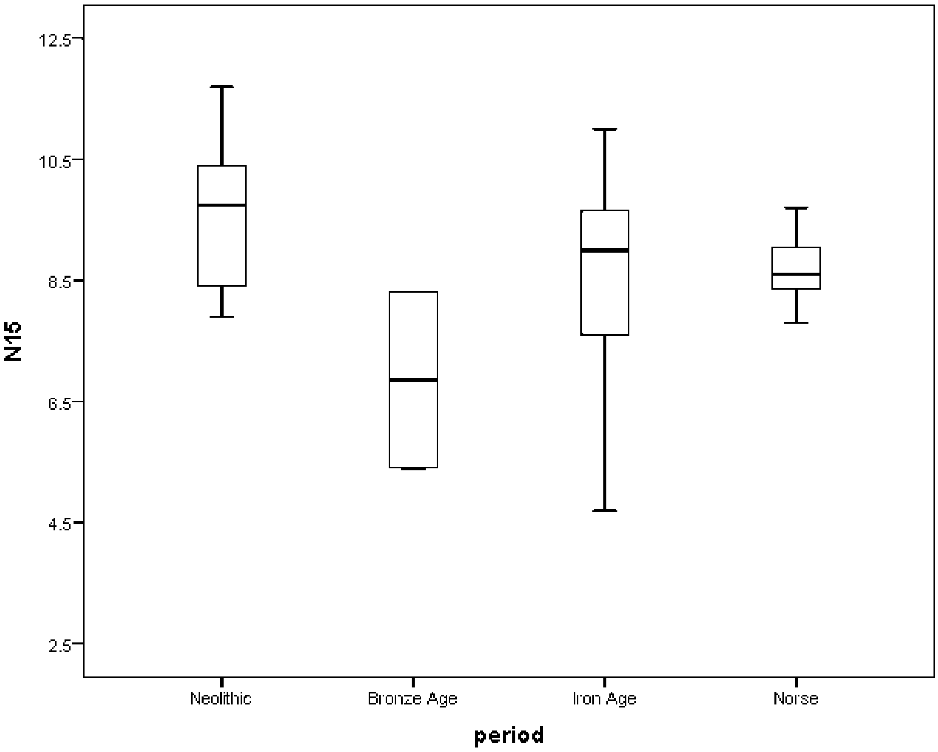


Figure 46: Boxplot showing pig δ^{15}N values through time: Orkney

Pigs in Shetland

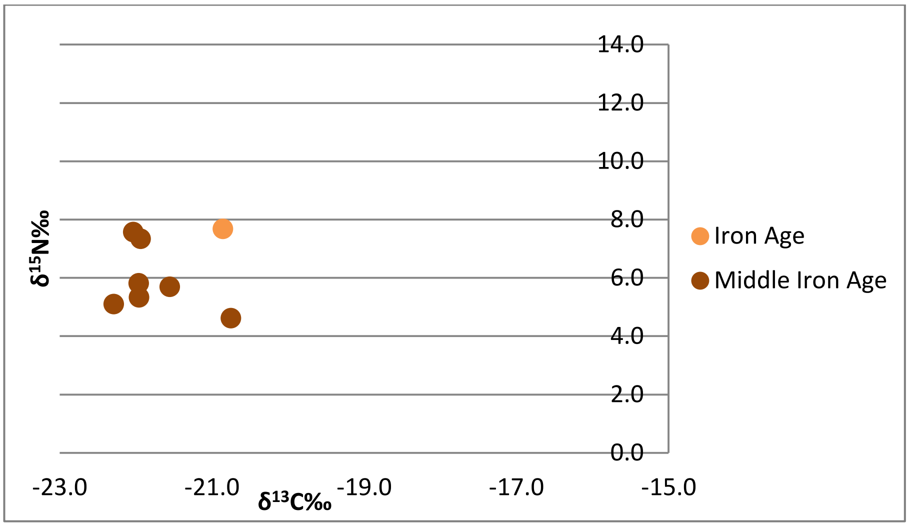


Figure 47: Temporal trends in pig isotopic values: Shetland

The Iron Age pig specimens derived from the site of St. Ninian's, with the Middle Iron Age pig specimens coming from the site of Scalloway. All of these pigs fall well within the terrestrial herbivorous dietary range, indicating that their diets did not include much, if any, protein. Several pigs from Orkney also had isotopic values consistent with a predominantly herbivorous diet (Figure 44). Three of the individuals have δ^{15}N values enriched by approximately 2‰ relative to the other specimens analysed, indicative of higher levels of protein consumption, but this is still well within the typical range of pig nitrogen levels observed in previous studies. (Hamilton *et al.* 2009; Madgwick *et al.* 2012a)

Pigs in the Western Isles

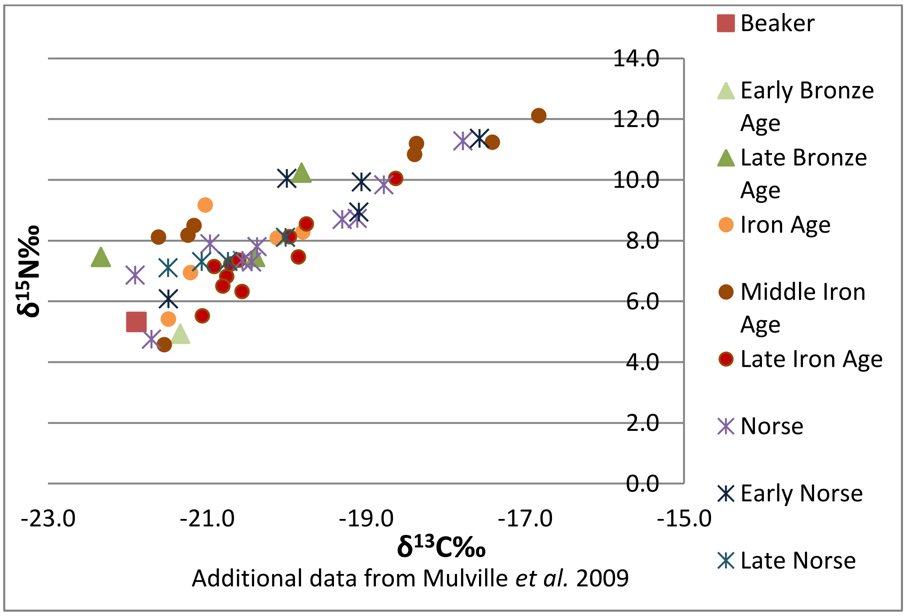


Figure 48: Temporal trends in pig isotopic values: Western Isles

The first real evidence for the consumption of marine protein by fauna is demonstrated in four pig specimens (DV24, DV19, DV23 and DV14) from the site of Dun Vulan (Figure 48). The enriched $\delta^{15}N$ values of ~11-12‰ are indicative of feeding at a higher trophic level, and when combined with the enriched $\delta^{13}C$ values suggest that a diet that included a level of marine protein. Several of the Norse individuals from the sites of Bornais and Cille Pheadair also have isotopic values consistent with marine protein consumption, suggesting that the trend of feeding pigs marine products continued into the Norse period in the Western Isles

Elsewhere isotopic evidence of marine food consumption by pigs is limited to date. Pigs have been observed foraging for shellfish in coastal Brittany (Cocaign 1990), and shellfish have been suggested as potential pig foddering in central Europe (Zvelebil 1995). The values observed in the pigs from the Western Isles are more enriched in $\delta^{15}N$ than would be anticipated than from consuming shellfish (Milner *et al.* 2004). Archaeological pig specimens analysed from 16th century fishing stations in Newfoundland demonstrated evidence of marine food consumption having $\delta^{13}C$ values ranging between -14.42 to -17.75‰, and $\delta^{15}N$ values ranging between 13.5 to 18.2‰, thought to be from the consumption of fish waste, alongside individuals with entirely terrestrial diets (Guiry *et al*. 2012), which are comparable to the values observed in the Western Isles.

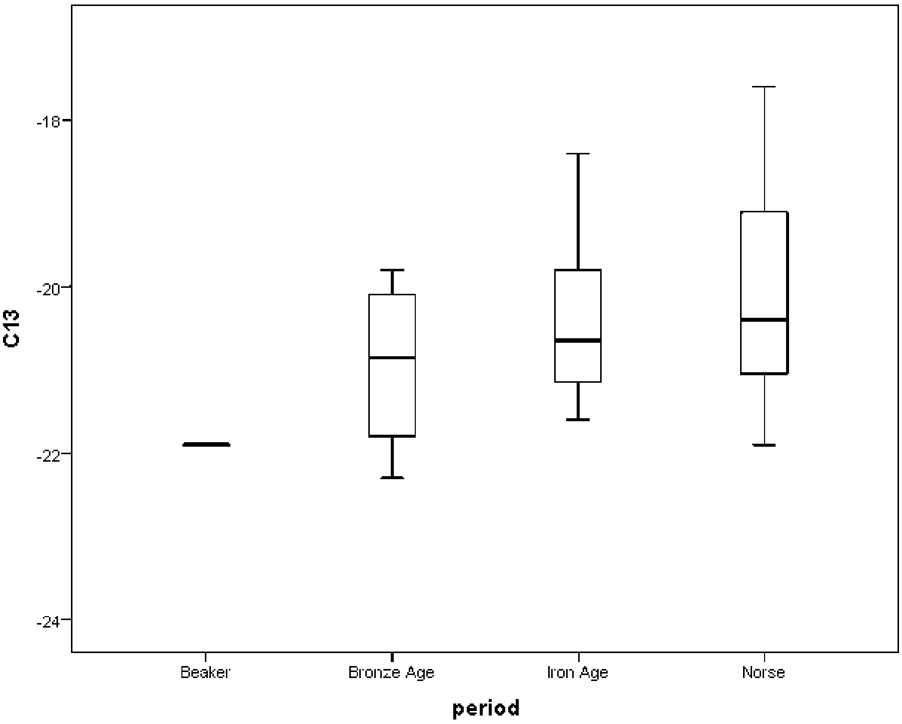


Figure 49: Boxplot showing pig $\delta^{13}C$ values through time: Western Isles

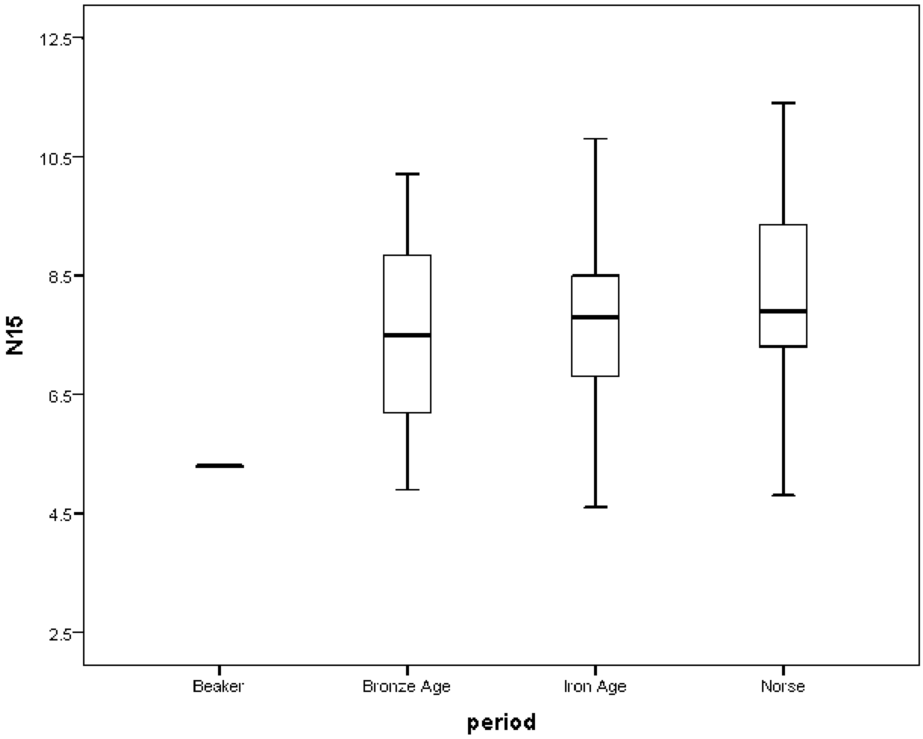
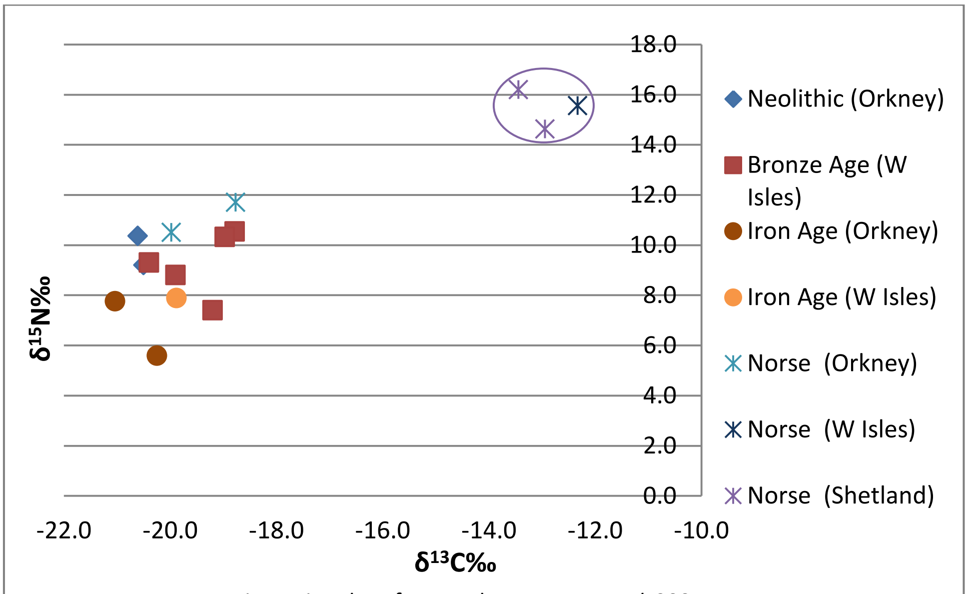


Figure 50: Boxplot showing pig δ^{15}N values through time: Western Isles

North Atlantic Island Dogs



Bronze Age isotopic values from Parker Pearson *et al.* 2005

Figure 51: Dog isotopic values from the North Atlantic Islands

Within the North Atlantic Island dog specimens there are two groups of individuals, one with marine signatures (circled in purple), with all others having diets consistent with the consumption of predominantly terrestrial food sources (Figure 51).

Of the group of non-marine consuming dogs there were extensive differences in the $\delta^{15}N$ observed within the species, indicating variations in levels of protein consumption. One dog from Iron Age Orkney had a $\delta^{15}N$ value of 5.9‰ which is consistent with a predominantly herbivorous diet, whereas another individual has a $\delta^{15}N$ value of 11.7‰, highlighting great variation in protein consumption. Dogs can be omnivorous and therefore the low levels of protein consumption can be indicative of marine protein consumption. Dogs frequently scavenge food; therefore they would have been exposed to food from a variety of different sources, which explains why there are differences in the quantities of protein consumed.

The three Norse dog specimens analysed have enriched $\delta^{13}C$ and $\delta^{15}N$ values (circled in purple), indicative of consumption of large quantities of marine protein to produce such enriched values. Fish, shellfish or even marine mammals must have been commonly available within these settlements in order for dogs to be accessing them as a food source. Two of these individuals were from the site of Jarlshof, Shetland, and one was from the site of Bornais, in the Western Isles. The other two Norse dog specimens from Orkney did not have marine isotope signatures demonstrating that not all dogs were consuming marine products at that time, and suggesting different access to marine resources.

Seals

Few seal specimens were available for analysis isotopically, however it was possible to generate samples from each temporal period. The highly mobile nature of marine mammals results in isotopic signatures that are not reflective of the local environment, but they provide a useful indication of the impact of the consumption of these specimens on human isotopic values. Seals can also provide an insight into carnivorous marine ecosystems, representing geographical differences in oceanic $\delta^{13}C$ levels, as shown in fish specimens (Barrett *et al.* 2011; Szpak 2011).

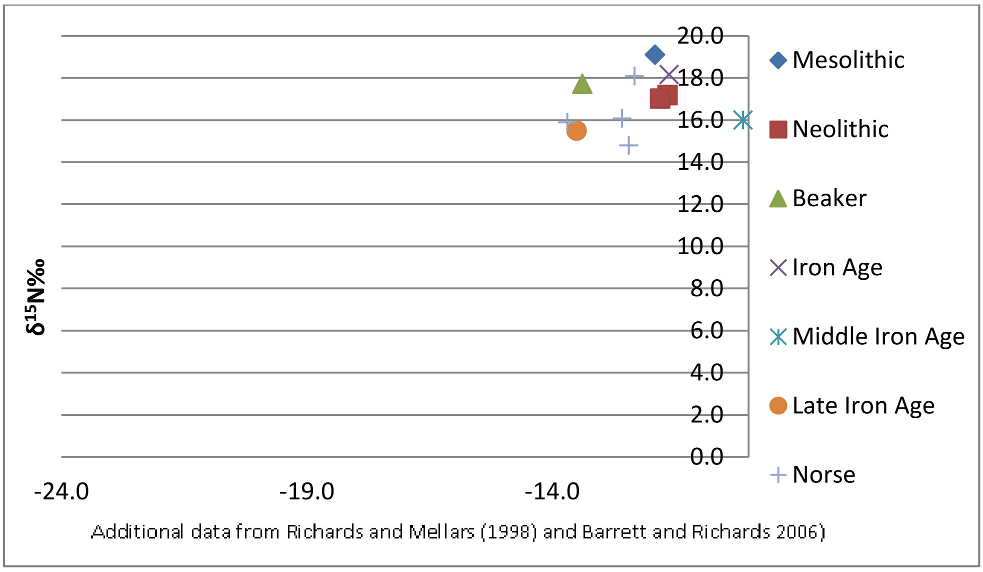


Figure 52: Seal isotopic values through time in the North Atlantic Islands

All of the seals have very enriched δ^{15}N values, indicating large-scale consumption of marine protein (Figure 52). It is stated that there is roughly a 3-5% enrichment in δ^{15}N values with each trophic level (Hedges and Reynard 2007:1243). The values indicate that the seals were feeding at a high level of the food chain.

In comparison analysis of archaeological seal (*Phoca sibirica*) bone collagen from the Late Neolithic and Early Bronze Age in Siberia demonstrated average δ^{13}C values of -22‰ and average δ^{15}N values of 14‰ (Katzenburg and Weber 1999, 655). The seal specimens analysed from the North Atlantic all have relatively enriched carbon values in comparison to their Siberian counterparts. This difference in carbon may be linked to geographical variations in the oceans, suggesting that there is a greater need to explore the impacts of δ^{13}C variations within ocean ecosystems on archaeological marine specimens to further enhance understanding of possible impacts on human isotopic values.

Fish

Unfortunately fish bones were not available from many sites due to difficulties in accessing collections, lack of sieving preventing fish bone retention, and small assemblage sizes. Small bone sizes of certain fish species (e.g. herring) make destructive analysis inappropriate, as individual bones produce very limited quantities of collagen relatively. Fish can migrate over large areas, and using them to provide a local δ^{13}C and δ^{15}N baseline can be problematic as they do not necessarily represent the local marine environment (Barrett *et al.* 2011; Szpak

2011), making baseline fish values challenging to interpret. For these reasons the decision was made to analyse a limited number of fish bones. The fish specimens analysed were all white fish, which are higher up the marine food chain and therefore demonstrate enriched δ^{15}N relative to species that are lower down the food chain such as herring.

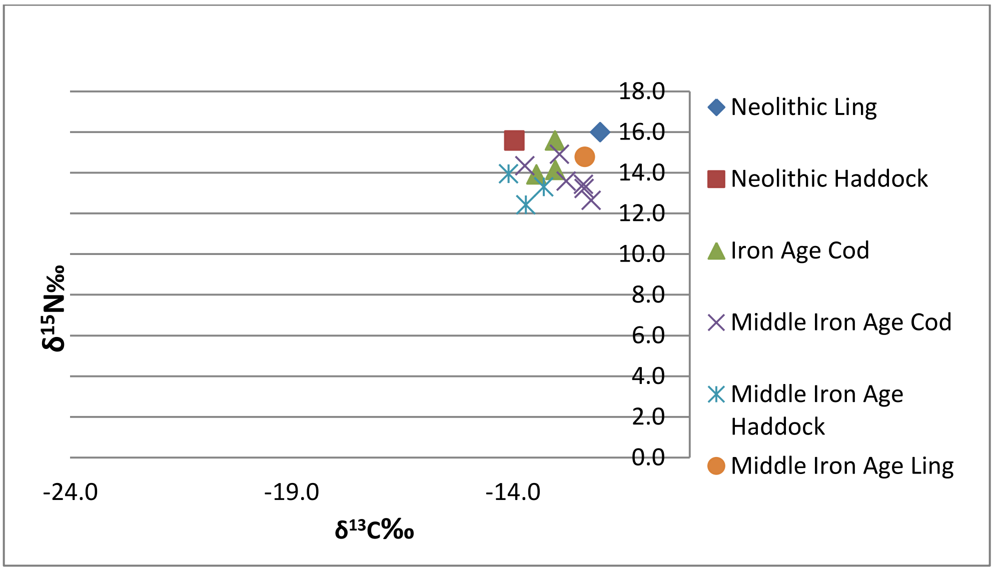


Figure 53: Fish stable isotope values in the North Atlantic Islands

The δ^{13}C values observed in the North Atlantic Islands fish (Figure 53) range from -12‰ to -13.9 ‰, and this is relatively limited compared to other marine consumers analysed (e.g. marine mammals, seabirds). The δ^{15}N values fall within 4‰ of each other (ranging between 12.4 to 16.0‰), indicative of these fish feeding within one trophic level of each other (Hedges and Reynard 2007, 1243). Analysing a greater number of species would be beneficial in understanding isotopic differences between fish occupying different environmental niches, and how they might impact on human values if consumed.

Birds

A total of 57 bird bone specimens were selected for analysis from 7 different sites. For purposes of discussion the bird bone specimens analysed have been split into two groups: marine birds (e.g. gulls, gannets, cormorants, razorbills, guillemots etc.) and non-marine birds (e.g. swans, geese, corvids).

The marine birds analysed all have enriched δ^{15}N and δ^{13}C values indicative of marine food consumption (Figure 54). The limited studies of archaeological bone collagen δ^{13}C values (e.g. Hobson 1987) of Western gulls demonstrated that they had values of roughly −13.6 ± 1.0‰ which is consistent with the gull isotope signatures observed in this study. The δ^{15}N values ranged between 12.0‰ and 16.9‰ showing diversity in the quantities of marine protein consumed by these species. Humans eating considerable quantities of sea birds or their products (e.g. oil, eggs) would therefore be expected to have stable isotope signatures that reflect this marine component in their diet.

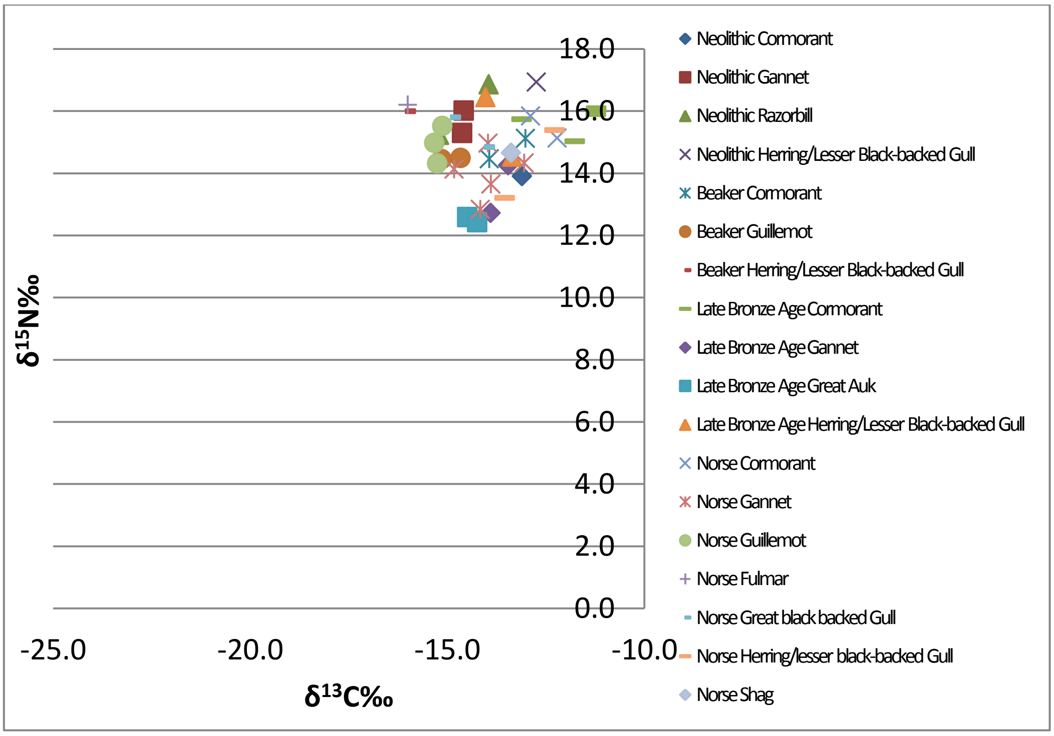


Figure 54: Marine bird isotopic values from the North Atlantic Islands

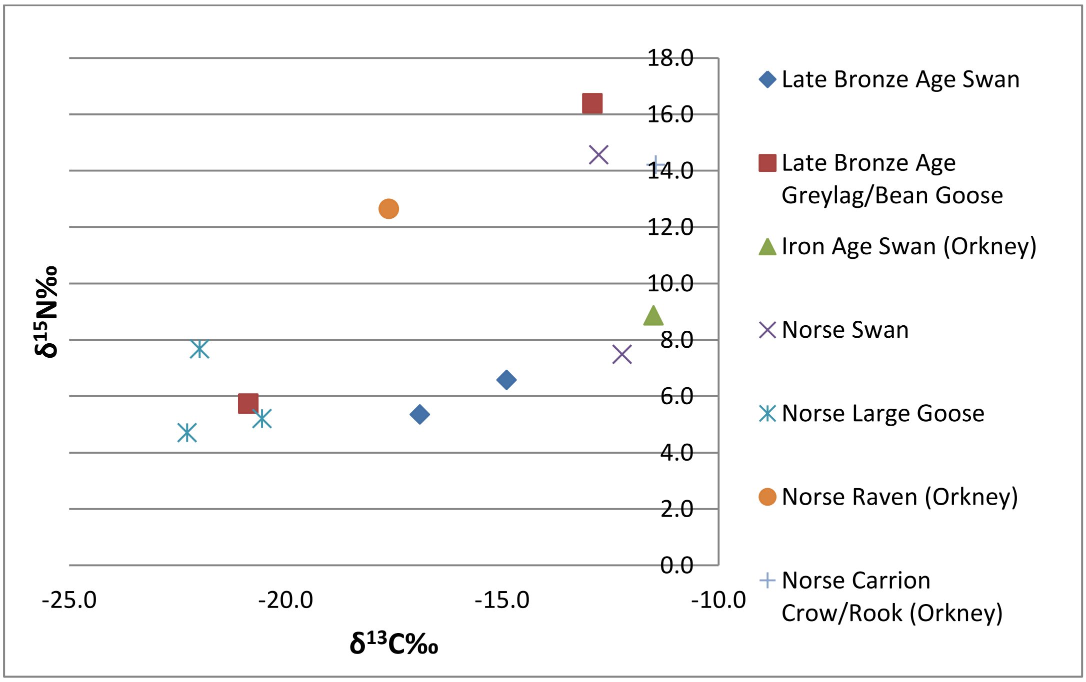


Figure 55: 'Non-marine' based bird species through time in the North Atlantic Islands

There is a high level of diversity in the isotopic values of the typically land-dwelling bird species analysed (Figure 55). Two Bronze Age and one Norse swan, exhibit interesting isotopic patterns. All of the specimens have enriched $\delta^{13}C$ values, which is indicative of a marine carbon source, but the $\delta^{15}N$ values observed for 4 of the 5 swans were within the typical herbivorous range. This suggests that the swans were consuming marine plant foods such as seaweed. A second Norse swan has an enriched $\delta^{15}N$ value (14.6‰), suggesting that this individual had been consuming levels of marine protein.

A raven from Orkney has an enriched $\delta^{13}C$ (-17.6‰) and $\delta^{15}N$ (12.6‰) values consistent with the consumption of marine protein. Ravens are carrion birds, therefore the marine signature indicates that the individual had access to fish or marine mammal carcass. Carrion birds therefore potentially reflect the presence of marine resources in the local environment, and could be utilised as a proxy for the availability of marine species on archaeological sites.

Three goose specimens were analysed. These are typically land dwelling birds, and as would be expected exhibit terrestrial signatures. Speciating geese can be challenging, and it is possible that some of these geese sampled were domestic, and the terrestrial isotopic signatures observed are consistent with the dietary behaviour of domestic geese (Best pers. comm.). The bird isotopic values have formed a minor aspect of this research but there is scope for greater exploration of wider ecological matters related to bird habitat, migration, environments and behaviours.

Summary

Several distinctive animal management practices were identified within the faunal isotopic values (summarised in Table 26). The consumption of marine plants such as seaweed during the Neolithic, Bronze Age, Iron Age and Norse periods in Orkney demonstrates that shorefront resources were an important aspect of animal management in Orkney. There is a great diversity in the isotopic values observed within each temporal period, indicative of different animal management strategies on both an inter-site and intra-site level. The elevated nitrogen values observed in Neolithic, Bronze Age and Iron Age sheep from Orkney could indicate possible penning, or consumption of nitrogen-rich fodder potentially as a result of manuring. The limited isotopic evidence from Shetland suggested that marine plants were being consumed by several of the cattle at Jarlshof. In the Western Isles marine plant consumption was observed in sheep, and during the Iron Age and Norse period this is observed in both sheep and pig specimens. The patterns observed in the data are not observed in every individual analysed, indicating that there were inter-species and even inter-site differences in animal management and foddering. From the Iron Age onwards marine protein forms a key dietary component in pigs from the Western Isles, indicative of an intensification of the use of marine resources during this period. This suggests that marine resources were being utilised in the islands prior to the 'Fish Event Horizon' during the Norse Period. During the Norse period homogeneity in the isotopic values between Orkney and the Western Isles was observed, indicating that similar management practices were being undertaken, possible as a result of land fertilisation to enhance crop productivity.

The results of the isotopic analysis have provided a baseline of faunal isotopic values, utilised to aid with the interpretation of the human isotopic results in the following chapter. In particular the $\delta^{15}N$ difference identified between the islands in the Neolithic, Bronze Age and Iron Age in the islands will be invaluable in interpreting nuances in dietary behaviour.

In the following chapter average faunal values are produced to enable more in-depth interpretation of temporal patterns of human dietary behaviour in the North Atlantic Islands.

Key

Percentage of individuals analysed	
0%	
1-10%	░
11-20%	▒
>20%	█

	Orkney								
	Enriched Carbon (>-20‰)			Marine Protein Consumers			Enriched Nitrogen (>8‰)		
	Cattle	Sheep	Pig	Cattle	Sheep	Pig	Cattle	Sheep	Pig
Neolithic		▒	░					▒	
Bronze Age								█	
Iron Age		░	░					▒	
Norse			█						
	Western Isles								
Neolithic									
Beaker									
Bronze Age		▒	█						
Iron Age		░				█	░	░	
Norse			▒			█	░		
	Shetland								
Iron Age									
Norse	▒								

Table 26: Summary of Possible Isotopic Interpretations observed in each Island Group

Chapter 8: Results and Discussion: Human Stable Isotope Analysis

This chapter discusses all available human isotope data in comparison to the average faunal values for each temporal geographical location and temporal period. Terrestrial faunal species are utilised to provide a baseline of results, with marine species included to provide comparisons when marine signatures are identified in the human bone isotope record. Where two or less values were available for each faunal species, the individual points were plotted (e.g. dog). The raw values for the human stable isotope values used, C:N ratios and bibliographic references for all data are shown in Appendix 5.

To prevent additional destructive sampling of human remains, all existing human stable isotope data for which $\delta^{13}C$ and $\delta^{15}N$ values are available were collated, including values achieved using radiocarbon dating (Chapter 6). Data from 126 individuals were available from North Atlantic Island sites for utilisation in this research.

The following paragraphs discuss the human isotopic values on a period by period basis for each island group. Human specimens were not necessarily available for each island group in each time period.

Interpreting Human Dietary Behaviour

There are several challenges of interpreting past human diet using collagen analysis. Behaviour relating to sex, age, and society can all potentially impact on observed diet. A further factor to consider is population movement, and whether individuals are local to the geographical region that they are buried in, as isotopic values are determined by localised environmental conditions (Hare *et al.* 1991; Van Klinken *et al.* 2000). Finally, chronological blurring can influence interpretations, as human skeletons from the same time period could represent a temporal span of several hundred years, and are therefore not necessarily contemporary, causing challenges when drawing comparisons. These factors are discussed further in chapter 10.

Chronological Human Dietary evidence by Geographical region

Mesolithic Inner Hebrides

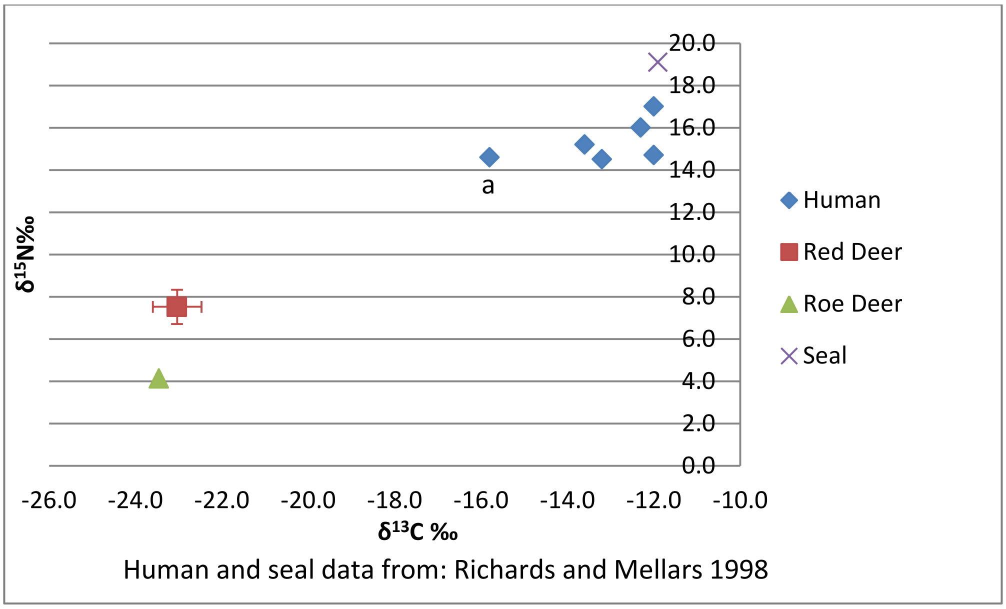


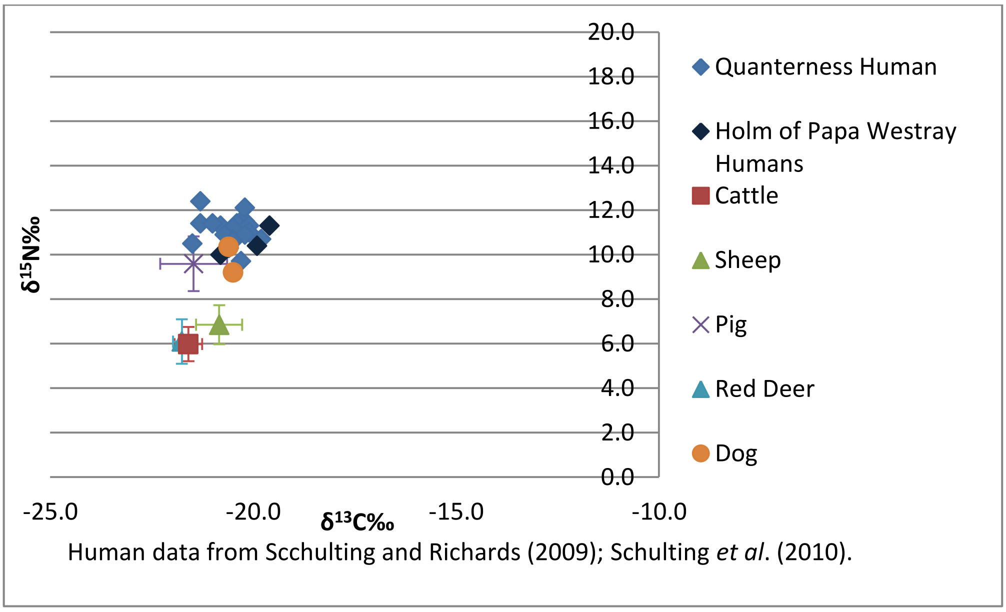
Figure 56: Mesolithic human and animal isotope data: Inner Hebrides

The six Mesolithic humans included in this graph are all from the Inner Hebridean midden sites of Cnoc Coig, Cnoc Sligeach, Caisteal Nan Gillean II (Figure 56). As identified in previous studies these Mesolithic humans have strong marine signatures, suggesting a predominantly marine-based subsistence (Richards and Mellars 1998; Richards *et al*. 2003; Schulting and Richards 2002a).

The $\delta^{15}N$ between individuals are similar, indicating that there was little variation in the protein content of diet consumed between these individuals. The marine signature observed in the human bone demonstrates direct consumption of marine foods, such as shellfish, fish and sea mammals, all of which were identified in the Oronsay midden zooarchaeological assemblages (Grigson and Mellars 1987).

Individual (a) is depleted in $\delta^{13}C$ relative to the other individuals by around 1.2‰, and potentially consumed lower levels of marine foods than the other individuals analysed. Individual (a) may not have been raised in the Oronsay area, and previously subsisted on more terrestrial resources. This has been observed in other isotopic studies of British Mesolithic humans (e.g. Meiklejohn 2011) and may explain why these values are different. The lack of teeth in the Mesolithic Oronsay midden specimens (Schulting and Richards 2002) prevents the use of locational isotopes to further explore the potential of mobility within this population.

Neolithic Orkney

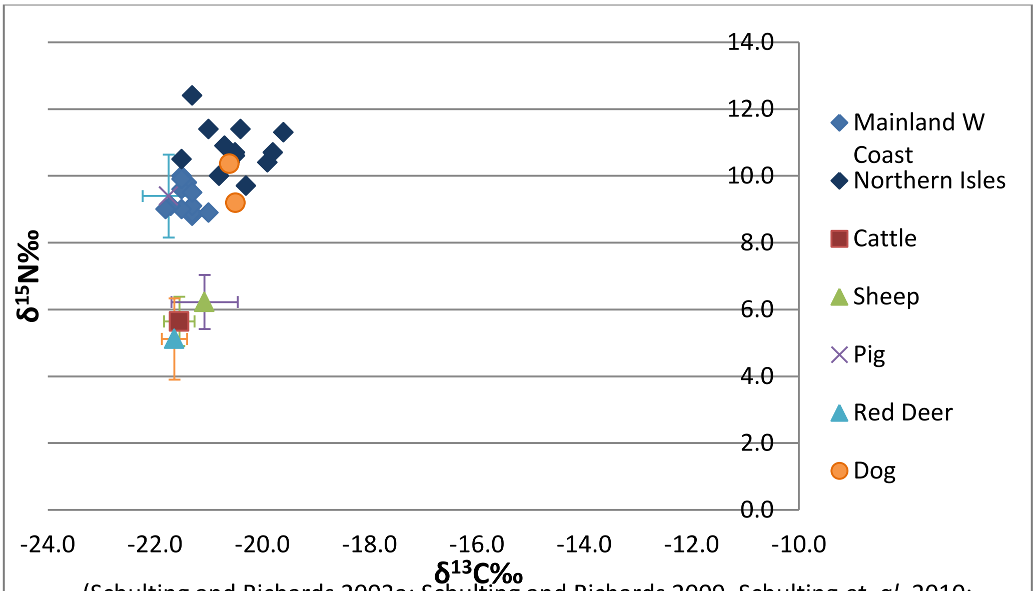


Human data from Scchulting and Richards (2009); Schulting *et al*. (2010).

Figure 57: Neolithic humans values and average faunal Values: Orkney

In Neolithic Orkney the individuals from Quanterness and Holm of Papa Westray plot together (Figure 57) and are isotopically indistinguishable from each other. This suggests that these individuals were consuming very similar diets comprising predominantly terrestrial food. The nitrogen values suggest that protein make an important dietary contribution and these values are all consistent with regular consumption of both meat and milk products. The δ^{15}N values of these skeletons range between 9.7‰ to 12.4‰, indicating that there are differences in the quantities of animal protein consumed by these individuals.

The Neolithic data provide an opportunity to better understand the relationship between human and dog values. Dogs have been used as a proxy for human dietary behaviour (e.g. Clutton-Brock and Noe-Nygaard 1990; Fischer 2007; Schulting and Richards 2002b). Recently the utilisation of dogs as a proxy for human diet in archaeological populations has been debated (Guiry 2012). These data demonstrate that for Neolithic Orkney the humans and dogs plot together in the same region of the graph, indicative of a similar diet that was relatively high in protein. Therefore in this case dogs appear to be an effective proxy for human diet.



(Schulting and Richards 2002a; Schulting and Richards 2009, Schulting *et. al*. 2010; Armit and Shapland pers. comm.)

Figure 58: Neolithic human isotopic values from Orkney and the Inner Hebrides with Orkney faunal average values

As there are no Neolithic human skeletons from the Western Isles the only comparable specimens are from Western Coast of Mainland Scotland (Carding Mill bay and Crarae) (Figure 58). These have previously been characterised by Schulting and Richards (2002a) as having a terrestrial diet. The mainland Scotland samples form a tight cluster, in terms of the $\delta^{13}C$ and $\delta^{15}N$ values exhibited. There is a greater range of human $\delta^{13}C$ values within the specimens from Orkney, indicative of greater range of dietary behaviour within this population. This may be partly due to the fact that the sample size is smaller (13 for Mainland Scotland; 22 for Orkney), and therefore less variation is evident.

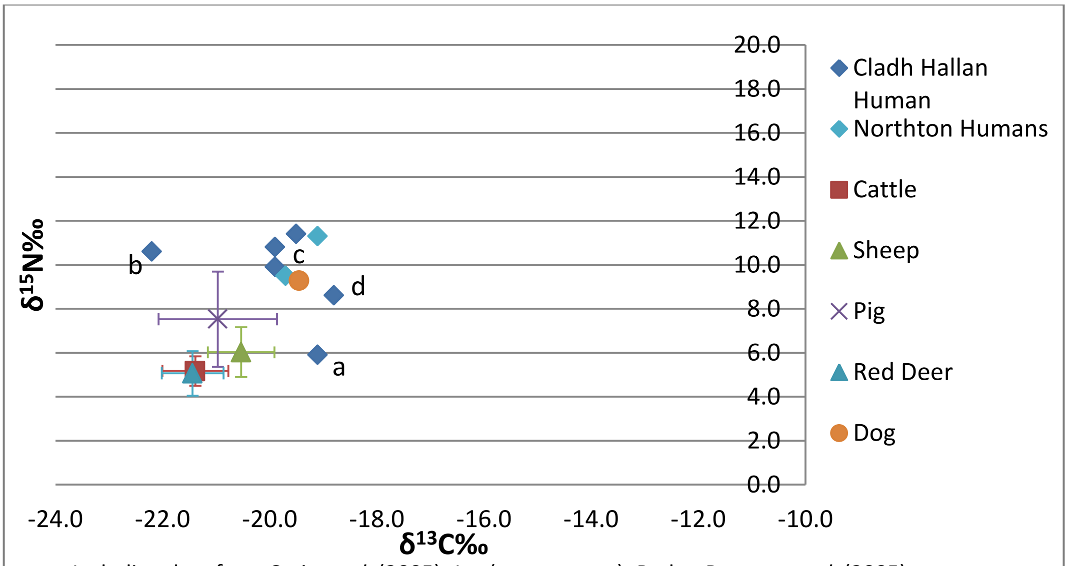
There is enrichment in $\delta^{13}C$ and $\delta^{15}N$ values observed in the humans from Orkney in comparison to the individuals from the West Coast. This could be a result of differences in salinity between these two locations. Orkney and the Western coast of Scotland occupy different geological and environmental niches related to differences in rock type vegetation growth, exposure to salinity, height above sea level, all of which can impact on the dietary behaviour of humans and animals, and the isotopic values observed in the bone collagen record. The differences observed between the Western coast of Scotland and Orkney demonstrate a need to characterise dietary behaviour of populations within each geographically distinct environment to enable more accurate interpretation of past dietary behaviour.

Neolithic Shetland

For Neolithic Shetland no human bone specimens were available for inclusion in this study, but recent analysis focussed on incremental sampling of dentine and enamel of recently excavated Neolithic skeletons from Shetland demonstrated evidence of periods of marine food consumption during times of nutritional stress (Montgomery *et al*. forthcoming). Comparisons to the bone collagen results indicated that these periods of marine food consumption did not influence the bone collagen values, highlighting the sporadic and infrequent nature of marine resource utilisation in Neolithic Shetland.

Bronze Age Western Isles

The only Bronze Age human isotopic values available from the North Atlantic Islands are from Cladh Hallan (Parker Pearson *et al.* 2005; 2007), and Northton (Jay pers. comm.), representing a total of 8 specimens. No Bronze Age human skeletons were available from either Shetland or Orkney. DNA evidence has proved that the Bronze Age mummies are composites created from a minimum of 6 mummified individuals (Hanna *et al*. 2012), confirming the findings of previous osteoarchaeological investigations of the skeletons (Parker Pearson *et al.* 2007).



Including data from Craig *et al*. (2005); Jay (pers. comm.); Parker Pearson *et al.* (2005)

Figure 59: Bronze Age isotope values and faunal baseline: Western Isles

The individuals from Cladh Hallan and Northton all have isotopic values consistent with the consumption of a predominantly terrestrial diet (Figure 59). Marine foods may have been consumed, but not in sufficient quantities to affect the stable isotope signature observed.

The human skeletal elements analysed from Cladh Hallan show a high degree of variation in the isotopic values generated, a characteristic also observed in the Bronze Age faunal remains from Cladh Hallan (Chapter 7).This variable animal management is potentially influencing the human isotopic values observed, causing a greater spread in the isotopic values observed. The degree of variability between different skeletal elements (Balasse *et al.* 1999; O'Connell and Hedges 2002). is not great enough to account for the $\delta^{13}C$ and $\delta^{15}N$ differences observed in the Cladh Hallan specimens, but the composite nature of the mummified remains mean that the bones analysed could potentially represent skeletons from a wide time span encompassing several generations. The temporal scales involved with the generation of the mummies and their later reburials as composite people is not known. Therefore the dietary evidence potentially represents different episodes in time, which may explain this dietary variability.

Excluding individual (a), which will be discussed in the following paragraph, the $\delta^{15}N$ values of the individuals range between 8.1‰ and 11.4‰. Studies of dietary behaviour within modern populations demonstrated that there can be a $\delta^{15}N$ value difference of up to 2.5‰ between animal protein consumers and non-animal protein consumers within tissues with short-term turnover, but this effect is reduced in bone collagen due to the longer turnover rates (O'Connell and Hedges 1999, 422). The Cladh Hallan specimens have a range greater than 2.5‰, indicating that there was a difference of about 1 trophic level between individuals c and d. All of the individuals (excluding a) were consuming a diet that included protein, but some individuals were consuming greater quantities of meat and milk than other individuals. The two Northton individuals have $\delta^{15}N$ within 2.5‰ of each other, suggesting that they were consuming on the same trophic level, with similar dietary protein content. The human dietary evidence from the Bronze Age Western Isles indicates that diets were not homogenous during this period.

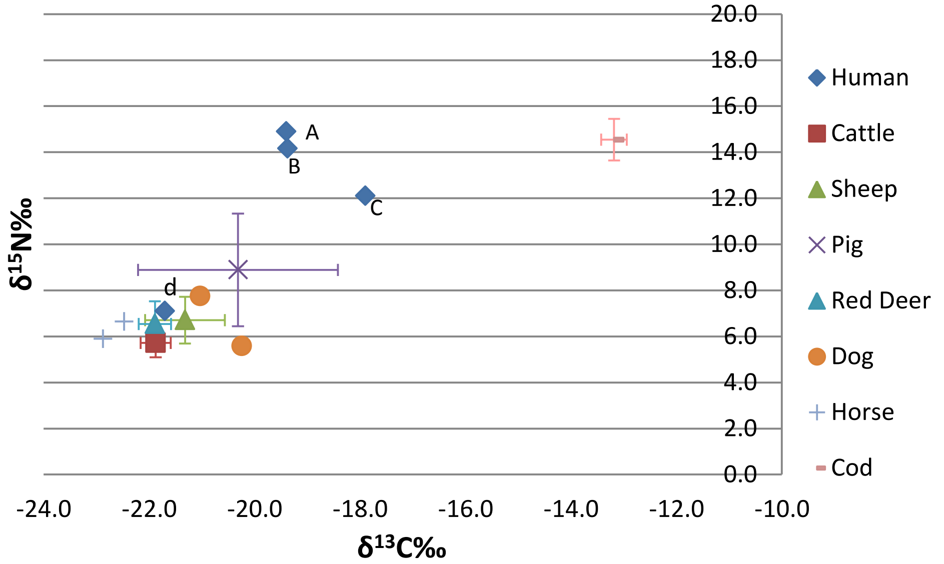
The majority of the Cladh Hallan specimen, and Northton specimens plot with the dog specimen, indicating that in this instance dogs make a good proxy for human diet. The canine $\delta^{15}N$ value is slightly depleted relative to several of the human specimens, but it is still within the range of human values observed.

Individual (a) has a δ^{15}N value of 5.9, which is similar to the values observed for the contemporary herbivorous specimens sampled, indicative of this individual consuming a vegan diet. Isotopic evidence for archaeological veganism is exceptionally limited, and on further analysis is the result of misidentification. For example one Iron Age individual from Wetwang Slack in Yorkshire was initially interpreted as being ‘vegan’, but further protein-based research identified the specimen as being a horse specimen (Jay 2005, 300). Murray and Schlesinger (1988, 8164) analysed a rib bone specimen from a burial at Magdalenska Gora in Slovenia, and it produced values that were in line with herbivores from the site. Potential veganism was observed from hair collagen analysis of the Alpine ‘ice man’ (Macko *et al*. 1999). This situation is not comparable to the bulk isotopic studies, as the hair collagen analysed represents a much shorter span of time, demonstrating shorter-term dietary behaviour, and not typical dietary behaviour. Specimen (a) was listed as part of a human scapula from a burial cist (Parker Pearson *et al*. 2005), and further communication with the site director confirmed that the fragment could potentially be a misidentified animal specimen (Parker Pearson pers. comm.). Given the isotopic value observed for this specimen, and the rarity of true ‘veganism’ in the long-term bone collagen record, this suggests that individual (a) is probably a fragment from a herbivore. This specimen has an enriched δ^{13}C value (-19.1‰), but this could be a product of marine plant consumption, which was also observed on a sheep specimen at the site.

Individual (b) has a depleted δ^{13}C value in comparison to the other humans analysed, and is more depleted than average values for the faunal baseline. This suggests a possible non-local individual that had previously been subsisting on foods originating from more inland environments that are not influenced by sea spray effects that can cause enriched δ^{13}C values of plants and animals in coastal environments.

Iron Age Orkney

The four human specimens from Iron Age Orkney derived from: Broch of Gurness, Lingro, Cross Kirk and Icegarth (Armit and Shapland pers. comm.) and Newark Bay (Richards *et al.* 2006; Schulting and Richards 2004) (Figure 60).



(additional human values from Richards *et al.* (2006), and Armit and Shapland pers. comm.)

Figure 60: Iron Age isotope values and faunal baseline: Orkney

Unusually this small sample shows a high degree of diversity. Individuals (a) from Lingro and (b) from Broch of Gurness had δ^{15}N values of 14.2 and 14.9 respectively, indicative of consumption of high levels of animal protein. The δ^{13}C values for these individuals are slightly enriched, and fall outside of the values observed for the herbivorous specimens, but are within the range of the pig δ^{13}C values. Therefore they could be indicative of consumption of larger quantities of porcine products. The zooarchaeological record suggests that pigs were not being utilised in any great number during this period in Orkney, and the most plausible explanation therefore is that these values are indicative of consumption of low levels of marine foods, which could also explain the enriched δ^{15}N observed.

Individual (c) is a Late Iron Age specimen from the site of Newark Bay and was enriched in δ^{13}C (-17.9) and δ^{15}N (12.1) (Schulting and Richards 2004; Richards *et al.* 2006), indicative of a diet including marine protein. This individual was dated to the Late Iron Age and was from the site of Newark Bay. This suggests that during the Late Iron Age in Orkney marine foods may have been used more frequently.

Individual (d) has a depleted δ^{15}N value and plots in the middle of the faunal specimens. The specimen has a δ^{15}N value of 7.1, and would be traditionally interpreted as indicating a 'vegan' diet. This bone was from the site of Cross Kirk on Orkney and was analysed as part of a project radiocarbon dating unusual Iron Age burial practices (Armit and Shapland 2012).

This artefact is described in written reports as being 'apparently human' (Shapland and Armit 2012, 107; Mackie 2002), and was based on the size of the femoral head fitting within the range for human specimens (Shapland and Armit 2012, 108). The comparative dataset of cattle femoral head measurements utilised is from a relatively small sample of 9 specimens (Shapland and Armit 2012, 108), and therefore may not be representative to use as size comparisons. There is also a possibility that the femoral head could be from another species e.g. red deer. The unusually low δ^{15}N values are interpreted in publications as representing a low dietary protein component, potentially indicating a non-local origin of the individual (Shapland and Armit 2012, 108), but considering the 'vegan' or herbivorous isotopic signature, it is highly likely that this specimen is a herbivorous specimen. This hypothesis can be investigated further by techniques such as proteomics to speciate this specimen (e.g. van Doorn 2011).

Despite the small sample size the one individual with a marine signature, and two individuals with possible marine dietary input, suggest that marine foods were beginning to be consumed in this region, although not to any great extent.

Iron Age Shetland

A single Iron Age individual was available from the site of Jarlshof (Shapland and Armit 2012). Poor bone preservation in Shetland has resulted in few human skeletons being available for analysis.

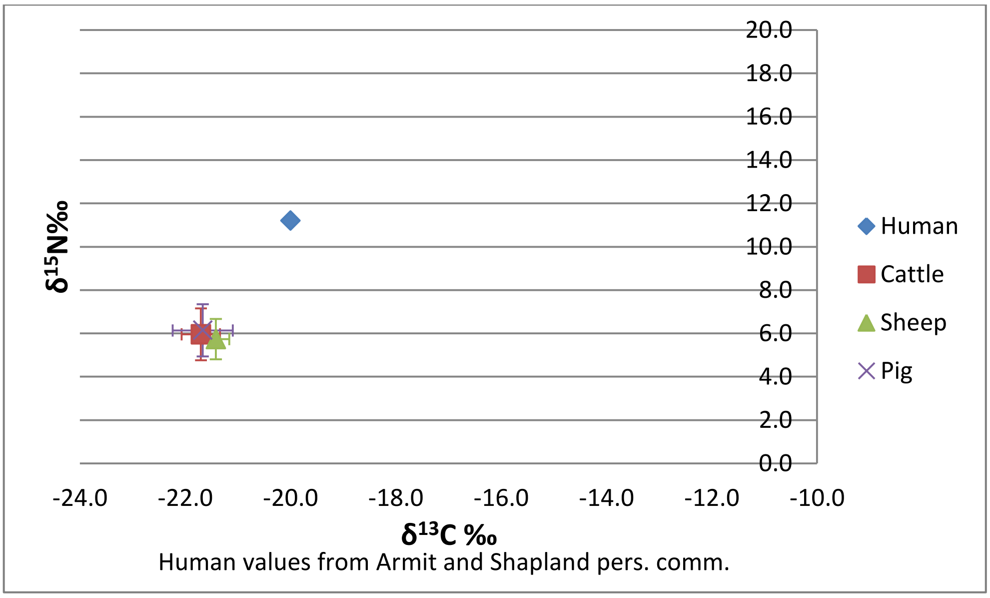
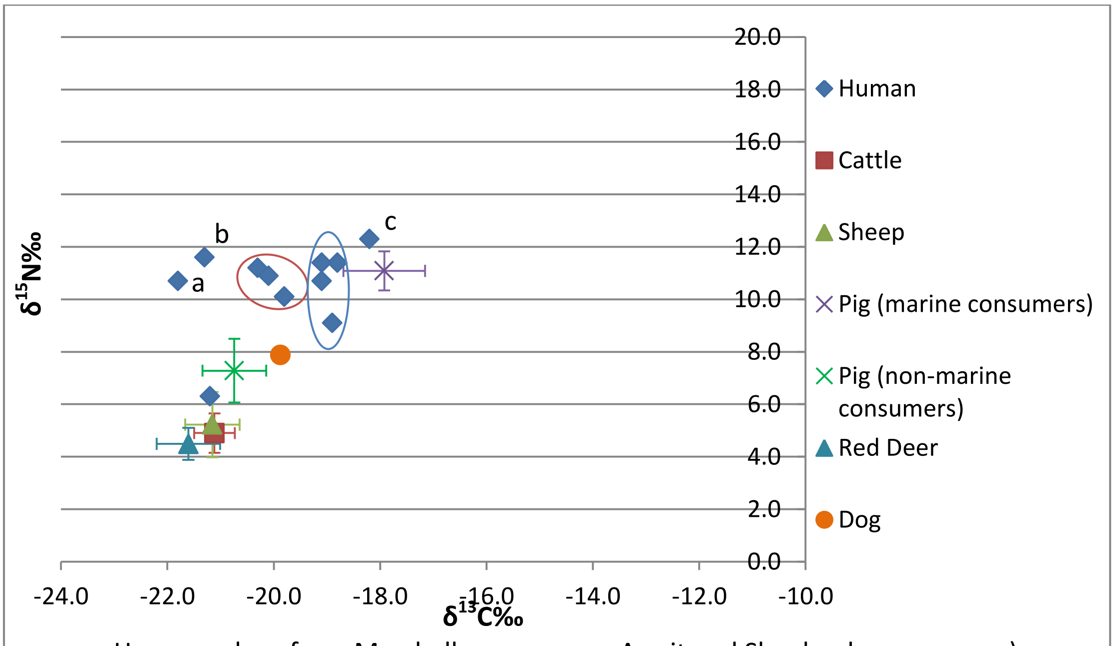


Figure 61: Iron Age Human specimen from Shetland

The individual from Jarlshof dates to the Middle Iron Age, and has an isotopic signature consistent with the consumption of a predominantly terrestrial diet, suggesting that marine food were not a major contributor to dietary protein. This individual has an enriched δ^{15}N value (11‰) compared to the faunal specimens from the site, indicating consumption of animal protein as either meat or milk.

Iron Age Western Isles

Figure 62 shows the 12 human values and the faunal baselines for the Western Isles. As noted in chapter 7 two groups of pigs were identified during the analysis of the faunal isotopic values. Plotting the average value of all of the pigs together would provide a misleading terrestrial baseline signature. Therefore the average values for each of these pig groups have been divided into marine-consuming and non-marine consuming animals to enable more detailed interpretation of the human values. Dividing the pig averages enables more nuanced comparisons with the human specimens sampled from this region.



Human values from Marshall pers. comm. Armit and Shapland pers. comm.)

Figure 62: Iron Age human isotope values for the Western Isles

There is a level of diversity in the dietary behaviour of individuals from the Western Isles. Two individuals stand out; (a) from Cille Pheadair and (b) from Late Iron Age Bornais have isotopic values that are depleted in δ^{13}C relative to the other specimens. Unfortunately no other Iron Age specimens are available from these locations to analyse. These two samples may represent individuals that had at one point been non-local to the region, which would explain why the δ^{13}C are more depleted than generally observed in these island populations. These values were both from radiocarbon dates on isolated pieces of human bone (Marshall pers. comm.). Research into Iron Age disarticulated remains suggests that they may represent non-local individuals, such as ancestors, or rivals (Armit and Ginn 2007), which supports this hypothesis.

The δ^{15}N values of all of the Iron Age individuals from the Western Isles are consistent with the consumption of dietary protein in the form of meat and/or milk products. The cluster of human isotopic results circled in red all have δ^{13}C well within typical ranges expected from consumption of a terrestrial diet, and plot in a similar location on the graph as the individuals from Iron Age Orkney.

Individual (c) is from the Iron Age site of Cnip, a wheelhouse settlement site on the Isle of Lewis (Armit and Shapland 2012). The Cnip individual has a δ^{13}C value of -18.2, and a δ^{15}N value of 12.3‰, indicating that marine foods were being consumed in some capacity. It was not possible to analyse any faunal specimens from Cnip for comparison.

The cluster of individuals circled in blue are from Middle Iron Age at Dun Vulan. These isotopic signatures are consistent with the consumption of marine dietary protein with enriched δ^{13}C and δ^{15}N values, and have similar values to the pig specimens that demonstrated evidence of marine food consumption.

To further explore this dataset Figure 63 plots the Middle Iron Age human specimens from Dun Vulan alongside the individual faunal specimens analysed. The humans analysed from Dun Vulan were all isolated fragments of human remains rather than formal burials, and may have experienced special or different treatment in death, and therefore may represent atypical or possibly non-local Iron Age individuals (Armit and Ginn 2007). The radiocarbon dating results showed that these individuals all date to the Middle Iron Age (Marshall pers. comm.), but little else is known about these who these people were.

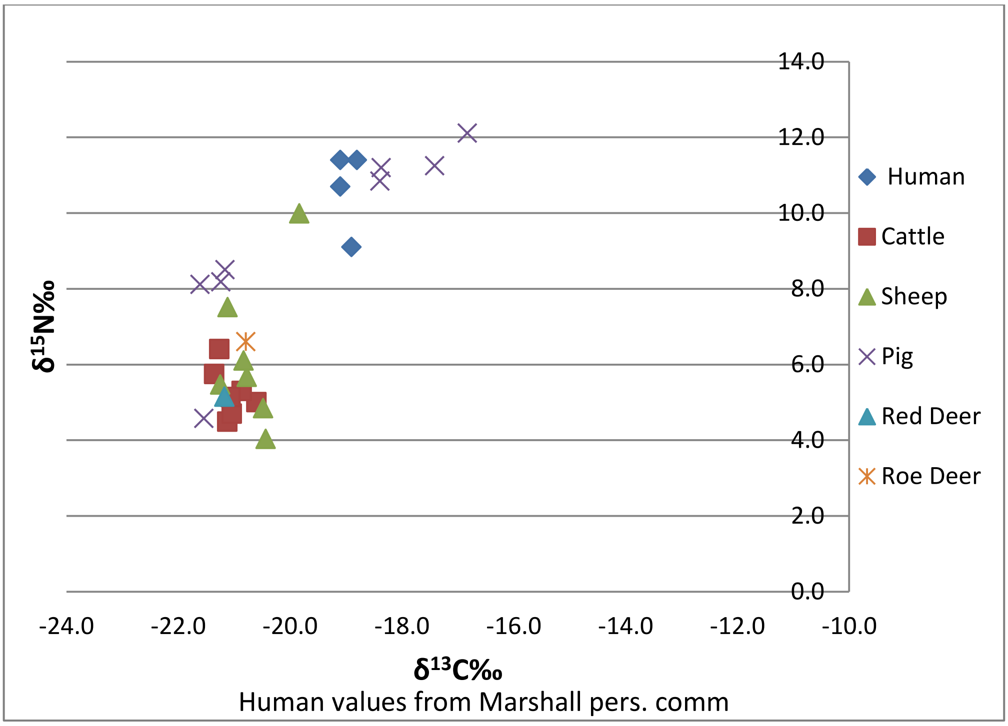


Figure 63: Middle Iron Age Human and animal values from: Dun Vulan

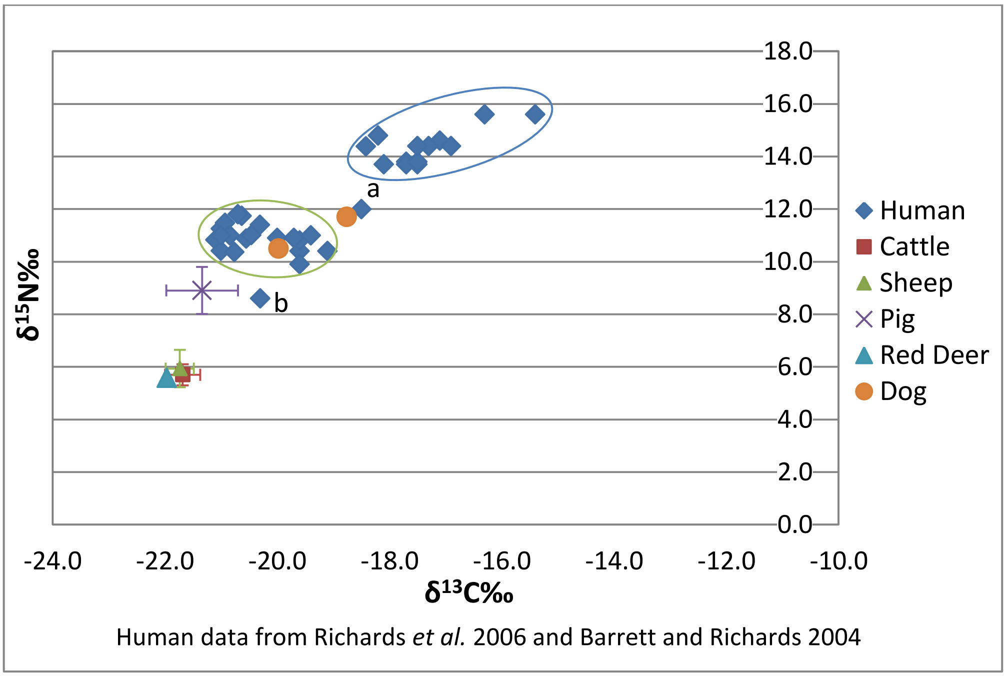
The enriched δ^{13}C and δ^{15}N values observed in the Dun Vulan and Cnip individuals demonstrate that they consumed sufficient quantities of marine foods to enrich the bulk collagen δ^{13}C and δ^{15}N isotopic values. There are two possible explanations for the isotopic values observed; firstly these humans could have been consuming marine foods directly in relatively small quantities, causing low level enrichment in the isotopic values observed. The other possibility is that these individuals were achieving enriched δ^{13}C and δ^{15}N isotopic values from the consumption of animals that had in turn been eating marine foods. In this case the Middle Iron Age pigs from Dun Vulan had marine signatures, and consuming these pigs in sufficient quantities would enrich the human bulk collagen bone record. However if this was the case then a greater enrichment in δ^{15}N is expected than we see, as they should appear to be feeding one trophic level higher than the pigs (producing a 2-3‰ nitrogen increase), which is not observed. The most plausible explanation is that these humans were consuming marine foods in lesser quantities than the pig specimens analysed.

Iron Age Summary

The isotopic signatures consistent with marine protein consumption suggest that the Iron Age marks an increase in marine food consumption compared to the proceeding Neolithic and Bronze Age in the Outer Hebrides. The human isotopic values from Orkney suggest that marine foods had been consumed by one individual in the Late Iron Age. The Middle Iron Age individual from Shetland consumed a terrestrial diet, whereas the individuals from the same period at Dun Vulan had a marine component in their diet. The variability between the two regions may be related to the site type between the higher status broch sites such as Dun Vulan versus relatively typical settlement sites such as Jarlshof, or could be related to differences in burial style, for example formal inhumation burials compared to fragmentary human remains from comingled deposits. The site of Dun Vulan is unusual in other ways; for example it contains greater quantities of pig remains (Parker Pearson *et al.* 1996). There are clearly discrepancies in observed dietary behaviour between the Western Isles and the Northern Isles. The diversity in dietary behaviour is potentially a result of status, site activities, geographical location or even temporal events.

Norse Period Orkney

As stated previously the Orcadian Norse specimens are predominantly from the sites of Newark Bay (Richards *et al.* 2006), and Westness (Barrett and Richards 2004), with one individual analysed from the Broch of Gurness as part of this research (Figure 64).



Human data from Richards *et al.* 2006 and Barrett and Richards 2004

Figure 64: Norse human isotopic data from Orkney

The Norse humans from Orkney cluster into two main categories, one group with marine signatures (circled in blue), and one group with terrestrial signatures (circled in green). Two individuals (a) and (b) from the site of Newark Bay fell outside of these two main groups. Individual (a) had enriched $\delta^{13}C$ and $\delta^{15}N$ values consistent with the consumption of marine foods in lower quantities than the individuals within the blue circle. This isotopic signature could be produced by consistent consumption of marine foods in low relatively intensities, or occasional, infrequent consumption of marine food. Individual (b) has a predominantly terrestrial signature, with a depleted δ^{15}N value, indicating that this individual was consuming less protein than the other specimens analysed, but the isotopic signature is enriched beyond the baseline herbivores such that this individual would have been consuming an omnivorous diet.

The two dog specimens appear to be a rough proxy for Norse diet in Orkney, with one individual plotting with the group of humans consuming terrestrial diets, and the other dog plotting in between the two groups, next to individual (a), suggesting that in this instance dogs can inform on human diet.

To further explore the dataset from Newark Bay and Westness males and females have been plotted separately (Figure 65). Both males and females from Newark Bay have δ^{13}C and δ^{15}N values indicative of marine consumption. In Westness several male skeletons displayed evidence of marine food consumption, whereas none of the female skeletons analysed had consumed a marine diet. In the original paper discussing the Newark Bay data in detail it was proposed that dietary behaviour was linked to sex, with more males than females having marine dietary signatures (Richards *et al.* 2006), which explains some of the dietary differences observed. A further aspect to consider is whether the dietary differences are a product of other demographic considerations such as the age of the individuals concerned (Figure 66).

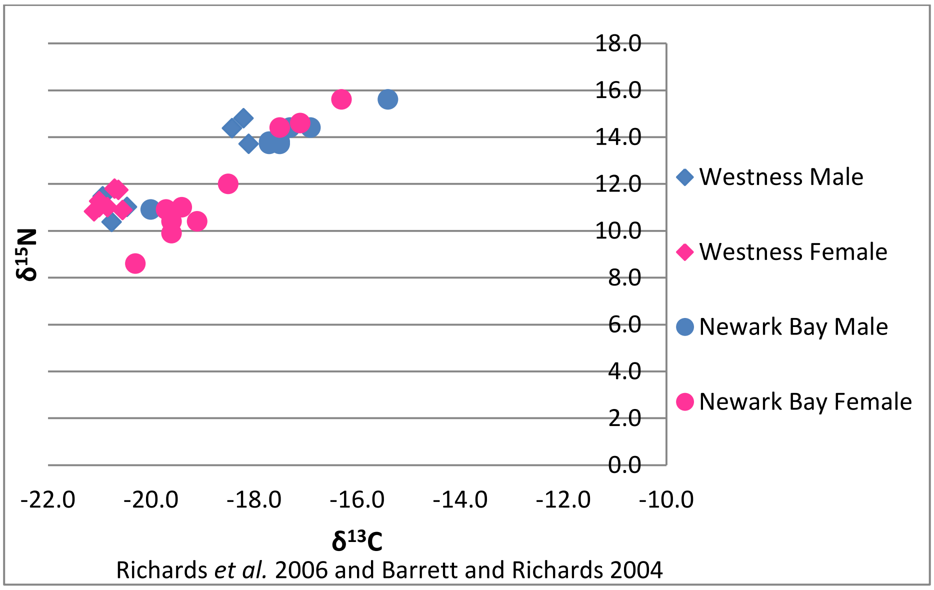
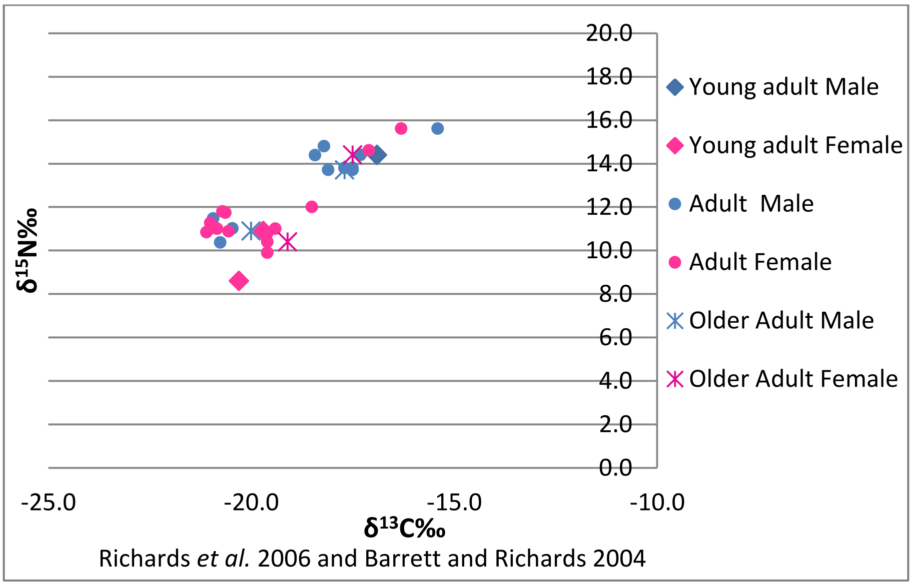


Figure 65: Male and Female isotopic values of skeletons from Norse Newark Bay and Westness: Orkney



Richards *et al.* 2006 and Barrett and Richards 2004

Figure 66: Age and Sex differences in isotopic values of skeletons from Norse Newark Bay and Westness: Orkney

The data from both sites has been plotted by age and sex (Figure 66). The age ranges used are: younger adults, adults, and older adults, as categorised by Richards *et al*. (2006) and Barrett and Richards (2004). Unfortunately no juvenile skeletons were available from either of the sites to explore the dietary behaviour of immature individuals. There is little patterning in the age groups represented, and age appears to be an insignificant factor in the dietary choices made by the Norse populations in Orkney.

Factors influencing Norse Dietary behaviour

As shown in Figure 65 and Figure 66 the age and sex of individuals are not major factors contributing to the dietary behaviour of these individuals. Therefore other factors must be responsible for this dietary difference. One possible explanation is that the two groups of individuals with marine and terrestrial diet behaviour belonged to different socioeconomic groups of people. The choice of foods consumed could potentially be an indicator of status of these individuals. Exploring status within these populations is challenging, as data linking the published isotopic and dating information (Barrett and Richards 2004; Richards *et al*. 2006) with information on grave goods and other social indicators are minimal. Two male skeletons with marine isotopic signatures from Westness contained wealthier grave goods, which led to the suggestion that fish consumption might be a higher status activity (Barrett and Richards 2004, 265). Further detail is needed to determine more about the possible status of these individuals; for example full osteological analysis of the skeletal remains to determine health and pathologies could provide an insight into social stratification within the society.

The differences in dietary behaviour observed may be a result of occupational differences between these groups of people. The Barrett and Richards (2004, 265) model of a 'Fish Event Horizon' and the rise of fishing and fish processing on a commercial scale would have required a workforce in order to catch, process and preserve the fish present, supporting the possibility of occupational links to dietary behaviour. The individuals with strong marine signals may represent the individuals involved with fishing and the fish trade, with the other group of individuals representing non-fishing-related occupations. The consumption of fish remains therefore may be linked to industry and the male and female specimens associated with marine signatures may have been part of the fishing trade observed in the Norse period in the Islands (Barrett *et al.* 2004b).

Another possible explanation is that the skeletons with marine signatures represented non-local individuals, and had retained marine isotopic signatures from consuming marine diets elsewhere. Given the archaeological and historical contexts behind Norse Orkney, with the arrival of the Vikings marking a change in economy, administration and religion in the islands (e.g. Barrett *et al.* 2000b), it is quite plausible that individuals buried in Orkney had not grown up locally. Dietary studies of Norse populations from Greenland have suggested marine foods were consumed in addition to agricultural products (Arneborg *et al.* 2012), and therefore Norse invaders could feasibly have consumed a diet rich in marine foods prior to their arrival in the islands. Locational isotopes are currently being analysed on the teeth from the Newark Bay skeletons to determine whether these individuals were local to Orkney or whether they had travelled from further afield, and initial results indicate that several of the individuals in the cemetery had previously lived in Northern Europe (Montgomery pers. comm.). The dietary differences are therefore linked to possible cultural and geographical differences in diet between these two populations.

Norse Period Outer Hebrides

There are no human skeletons with carbon and nitrogen values were available for the Outer Hebrides, but several dog specimens were available. The Norse dog specimen from Bornais has a very strong marine signature, plotting next to one of the herring gull specimens from the site, indicating very high marine protein content in the diet (and wider economic processes (Figure 67). Dog coprolites from the site of Bornais were found to be rich in fish bones

(Mulville pers. comm.), which is consistent with the findings of the isotopic research. This demonstrates that dogs were consuming marine protein in the Outer Hebrides, and must have had access to marine protein. As discussed further in Chapter 9 zooarchaeological remains from Bornais contained large quantities of fish bones. The dog specimens analysed previously in this study demonstrated that dog isotopic values are consistent with the human isotopic values, suggesting that they can be used as proxy for understanding human diet. It is possible that humans in the Outer Hebrides were consuming marine foods.

One challenge of using dogs as a proxy for human diet is understanding whether marine foods are present as a result of consumption by the population, or whether they are the present as a result of trade. Fish may be processed prior to trade, such as the removal of heads, guts, fins and tails prior to trading which would provide dogs with access to marine resources, without the local human populations ever consuming them. Dog specimens therefore in this scenario would therefore not necessarily be reflective of human dietary behaviour, but instead of wider economic processes.

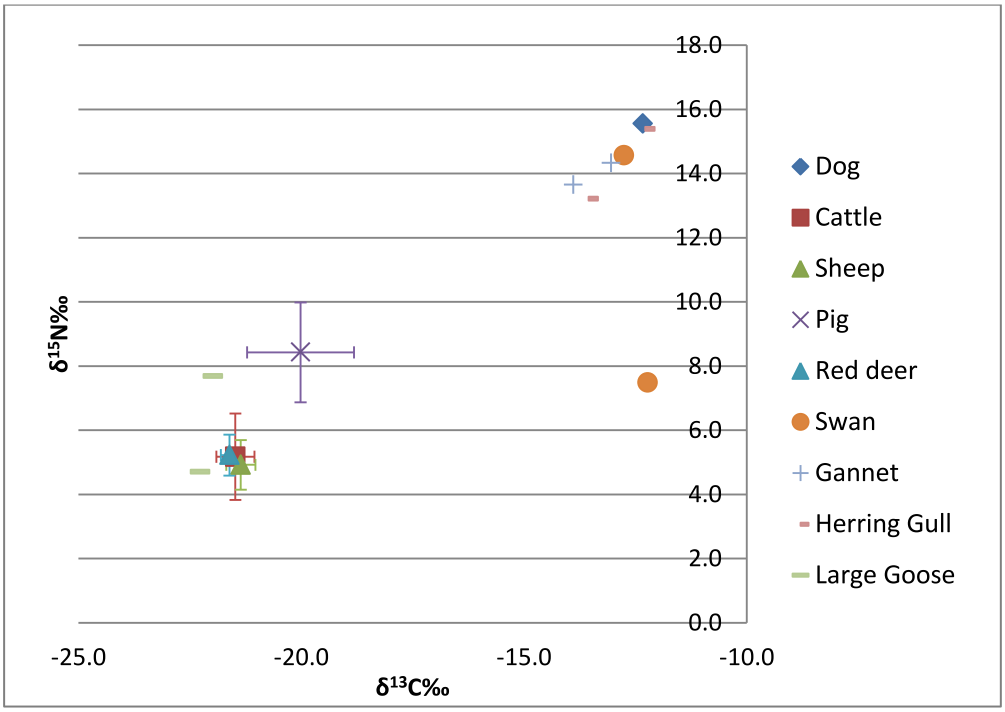


Figure 67: Dog proxy for human diet in the Outer Hebrides

Summary

The human stable isotope information demonstrated that during the Neolithic, there is little evidence for the direct consumption of marine foods. In the Bronze Age there was no evidence of direct consumption of marine foods in the human bone collagen, despite fish being more prevalent within the zooarchaeological assemblages at Cladh Hallan (Chapter 9). Marine foods were therefore not being consumed in sufficient quantities to affect the isotopic signatures observed. The Iron Age human bulk collagen analysis demonstrated that marine foods were being consumed in the Western Isles. In Orkney, there was one individual with an isotopic signature consistent with a marine dietary component. One group of Norse individuals from Orkney had strong marine signatures indicative of consumption of large quantities of marine protein. Another group of individuals had isotopic signatures consistent with a predominantly terrestrial diet. This suggests that marine foods had been consumed by some members of the population but not by all individuals. This was not a result of age or sex differences between these populations, and is potentially due to these individuals not being local to Orkney.

There are limitations with the dataset. For example there are several gaps in the human skeleton record, such as the lack of Beaker period skeletons existing currently from Orkney or the Outer Hebrides, and the lack of Bronze Age Orcadian human skeletons. Several skeletons appear to have been misidentified as being human, and further osteoarchaeological research, and proteomic studies (e.g. van Doorn *et al.* 2011) would be beneficial in order to confirm the identification of these specimens. The human stable isotope evidence provides an understanding of longer-term average dietary behaviour, reflecting direct consumption of food, and therefore is useful for determining average consumption patterns. The following chapter considers the zooarchaeological evidence to further our understanding of dietary and economic behaviour through time in the North Atlantic Islands.

Chapter 9: Results and Discussion: Zooarchaeological Analysis

This chapter presents the results of the zooarchaeological analysis conducted according to the methodological outlines discussed in chapter 4. Broad zooarchaeological patterns are initially discussed comparing trends in the relative proportions of each resource type through time. Trends in the utilisation of terrestrial mammals are then explored, before considering fish, shellfish and sea mammal evidence in turn to provide insights into the relative importance of different species through time, and the implications that this has for dietary and economic behaviour. The methodological techniques used are critiqued to explore how valuable these are when assessing past dietary and economic behaviour.

A summary of the zooarchaeological remains from the Middle Iron Age phases at the site of Dun Vulan is then discussed in greater detail in order to explore potential results behind the findings from the human and faunal isotopic evidence. The chapter concludes by discussing the results of the meat weight analysis conducted for the Outer Hebridean sites to explore the benefits and constraints of utilising this technique when attempting to understand the relative importance of each resource type.

Broad-Scale Analysis

In total 78 different sites with available mammal bone data were available for inclusion in this research, from 122 different temporal phases of occupation. Of these 42 sites (90 phases of occupation) had evidence of fish bone remains, and 13 sites (30 phases) had shellfish evidence. This list represents data that have been published to date, in addition to data soon to be published kindly supplied by the authors (e.g. Mulville and Powell's forthcoming publications on the zooarchaeology at Cladh Hallan, Bornais Mound 2 and 2A and Cille Pheadair). A full list of species resource type NISPs of the sites included in the study is shown in Appendix 6 (Northern Isles) and Appendix 7 (Western Isles).

Correspondence Analysis

Correspondence analysis (CA) comparing the proportions of each zooarchaeological fraction was utilised to explore marine resource between each site (Figure 68).

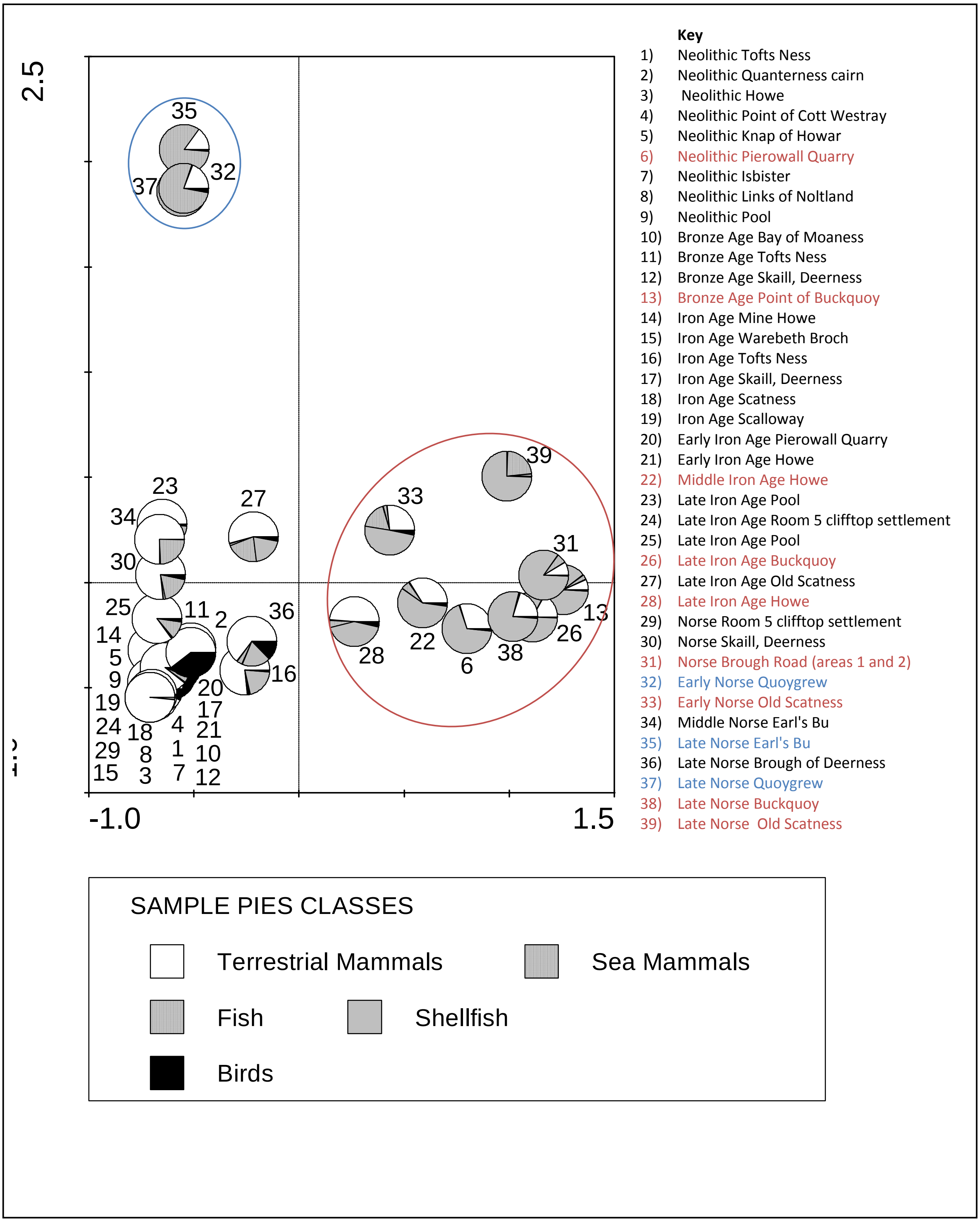


Figure 68: Correspondence analysis of sites in the Northern Isles including shellfish data*

*Blue denotes sites grouped as a result of large quantities of fish identified withing the deposits. Red denotes sites grouped due to large quantites of shellfish identified within the deposits.

The key corresponding characteristics identified by the CA are increased quantities of fish bones present in assemblages (circled in blue), and increased quantities of shellfish present (circled in red). The sites with larger quantities of fish bones present are all Norse sites that were studied intensively for PhD projects such as Quoygrew (Colley 1983; Harland 2006), and therefore had more intensive sampling and recording strategies than other sites. Similarly the shell presence in the assemblages is a product of sampling strategy as shellfish were recorded in few North Atlantic assemblages, and therefore the CA grouped together sites containing shellfish data. The CA is therefore identifying analytical bias in assemblages rather than archaeologically meaningful differences in dietary behaviour between sites.

CA of the same sites excluding shellfish was also undertaken and can be seen in Appendix 9, but the technique continued to link sites with elevated numbers of fish and bird bones, reflective of intensive sampling strategies, rather than providing insights into anthropogenic behaviours of archaeological populations.

CA of individual sites appears to reflect differences in sampling and post-excavation strategies between sites rather than reflections of archaeological dietary variations. To avoid potential over interpretation of false patterning in the data, further utilisation of the technique has not been pursued using this dataset. Differentiating between meaningful patterns resulting from differences in dietary behaviour and patterns resulting from variations in sampling strategies is not possible using this technique. The results of the correspondence analysis highlight the need to generate average values for each time period between each island group to ensure that variations in sampling strategy between sites is diluted within the broader corpus of zooarchaeological data for each time period. Correspondence analysis was not conducted to any greater level of identification in the islands.

Relative Proportions of Resource types Exploited

The average NISP count proportions for each period were calculated to provide an insight into the relative importance of different resource types, based on cumulative totals of resource type use across each temporal period. This averages out inter-site sampling and recording biases. The NISP counts of resource types recorded for each site, in addition to the references where these values came from are included in Appendices 6 and 7.

Orkney

The temporal comparisons of resources utilised in Orkney through time are displayed in Figure 69. NISP proportions for each wider temporal period provide insights into broader dietary trends (Figure 69 a and b) and are the primary focus of discussion. The split temporal periods

(Figure 69 c and d) allow for more detailed understanding of temporal trends in diet. The split temporal comparisons are based on relatively low site frequencies and therefore are potentially reflecting sampling strategies, and have to be viewed with caution. Shellfish account for a large percentage of the total NISPs in the Bronze Age (63%), Iron Age (20%) and Norse Period (46%) (Figure 69 a and c).

The quantification of shellfish remains is a challenge due to the highly fragmentary nature of shells, and considering that shellfish are very small in size, accounting for their true importance in relation to the other species types is not possible to achieve using the current dataset. The following paragraphs focus on the species proportions excluding shellfish (Figure 69 b and d).

The Neolithic dataset is based on 9 assemblages from Orkney, and therefore the average values are based on a relatively large dataset. Fish and marine mammals account for 2% of the total Neolithic zooarchaeological remains (excluding shellfish). The presence of fish and shellfish remains is noteworthy, but the low frequencies in the zooarchaeological assemblages and the low quantities of meat that they would have represented suggest that they made only a minor contribution to diet during the Neolithic period.

In the Bronze Age on Orkney fish bones account for a greater proportion of the zooarchaeological assemblage (8%, excluding shellfish) than observed in the Neolithic. Bird bones are also slightly more common in Bronze Age assemblages, although they still make up around only 9% of the total assemblages. The increase in the representation of fish and bird species in the Bronze Age suggests that they were a more important dietary component during this period. Fish and bird yield less meat per individual than mammalian remains (e.g. Smith 2011; White 1953), and despite being represented more in the zooarchaeological record, would not have made a great dietary contribution in terms of the quantity of meat that they represent.

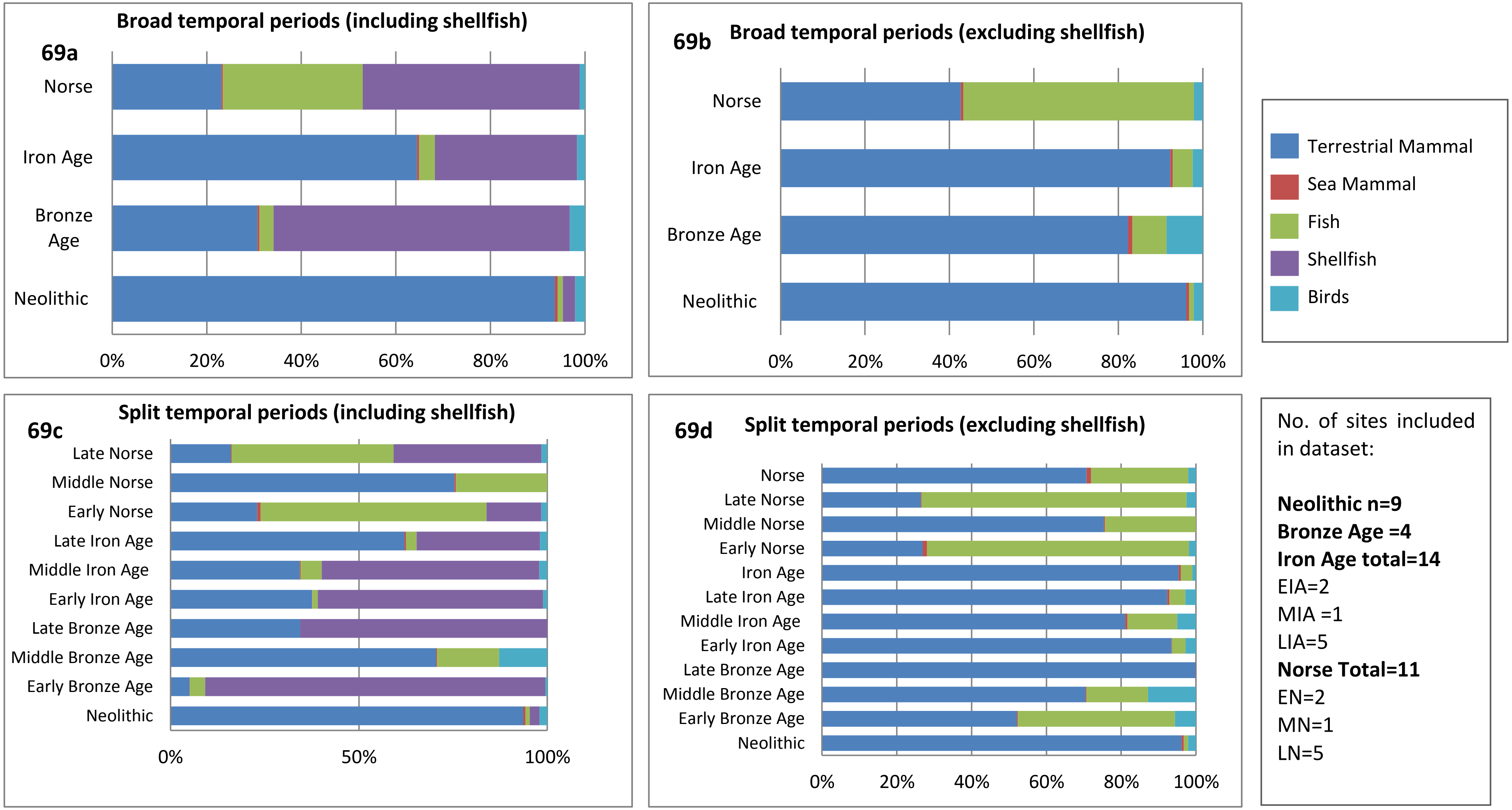
In the Iron Age fish bones account for only 3% of the zooarchaeological remains (excluding shellfish (Figure 69 b and d). This suggests that this resource represented a minor dietary component in comparison to terrestrial faunal species. The NISP values suggest that marine foods were less important in the Iron Age than in the preceding Bronze Age, however this may partially be a product of different sample sizes between these assemblages (Iron Age data based on 14 sites, Bronze Age based on 4).

In the Norse period there is an increase in the proportion of fish bones (29%) relative to other resources found in the assemblages (Figure 69 b and d), demonstrating that fish were being utilised to a greater extent during this period in Orkney, which is consistent with past research conducted into Norse dietary behaviour in the islands (e.g. Barrett 2004; Harland 2006). Fish bones account for a much larger proportion of the faunal remains than in any of the periods prior to this, demonstrating that they were a more important resource at this time.

The relative proportion of marine mammals present in each period is consistent through time, accounting for 1-2% of the total NISPS. Sea mammals are high ranked prey, meaning that one individual provides a substantial quantity of meat (Smith 2011). Therefore despite being less numerous, the quantity of food that they represent is substantial to lower ranked prey species (e.g. fish, shellfish, and terrestrial mammals).

Summary: Trends in Orkney

This review demonstrated that fish and shellfish were not used to any great extent in Orkney during the Neolithic, confirming previous research in the region (e.g. Schulting and Richards 2002a; 2009). In the Bronze Age and Iron Age there is a small increase in the proportion of fish bones present in the assemblage, but the quantity of meat represented by this resource would have been low in relation to the terrestrial species. Greater numbers of shellfish were present in the Bronze Age than in any of the other temporal periods, demonstrating that they were an important resource at this time. In the Norse Period fish bones account for almost a third of the total zooarchaeological NISP (excluding shellfish). Fish were a more important economic resource during the Norse period. This confirms past work investigating Norse subsistence (e.g. Barrett 1995; Barrett *et al.* 1999; Colley 1983; Harland 2006).



No. of sites included in dataset:

Neolithic n=9
Bronze Age =4
Iron Age total=14
EIA=2
MIA =1
LIA=5
Norse Total=11
EN=2
MN=1
LN=5

Figure 69: Comparisons of species NISP proportions in Orkney

Western Isles

The wealth of zooarchaeological data generated by the SEARCH project generated a wealth of detailed zooarchaeological data from the Bronze Age onwards, with detailed collection and analysis of fish bone remains. The Western Isles dataset therefore provides more reliable inter-period comparisons to be drawn than was possible for Orkney.

The proportions of each resource type in terms of the NISPs recorded in the Western Isles do change through time (Figure 70). No shellfish remains are available from the Western Isles in the Neolithic, Beaker Period or Bronze Age (Figure 70 a and c). Shellfish account for a larger proportion of the assemblage during the Iron Age (42% of total assemblage) in the Western Isles. There are relatively low numbers of shellfish in the Norse period (1%). This is partially due to differences in recording strategies; for example shellfish were present in large quantities at Bornais in South Uist (Law pers. comm.) but they are frequently discussed in terms of the species presence (e.g. Sharples 2012) rather than in quantifiable terms and therefore could not be included in this study. This has skewed the shellfish data, resulting in the dataset being more representative of sampling strategy rather than dietary behaviour. The following paragraphs exclude shellfish from the species proportions to ensure visibility in the patterns of fish exploitation (Figure 70 a and c).

The total faunal NISP for the Neolithic Western Isles is 849, and is based on data from just two sites, and so the dataset may not be entirely representative. Fish accounted for less than 1% of the total faunal NISP present, suggesting that they were not a major dietary component at this time.

The Beaker period dataset is similarly limited, based on 3 sites (total combined species NISP 920). The Beaker period also shows relatively small frequencies of fish bones are present, accounting for less than 2% of the total faunal NISP (Figure 70).

This limited dataset suggests that fish were not a major dietary contributor during the Beaker period in the Western Isles, reflecting the patterns observed in the Neolithic. Bird bones account for a slightly higher proportion of the assemblage than observed in the Neolithic (4%), suggesting that birds may have been a more important resource at this time. Due to the low sample sizes for these periods these observations are made tentatively.

In the Bronze Age there is an increase in the proportion of fish bones present in the assemblages accounting for 22% of the total NISP. This suggests that fish were a more important resource during this period. As discussed in Chapter 8 the human remains analysis did not have marine isotopic signatures, demonstrating that they were not consumed in sufficient quantities to affect the bone collagen isotopic signatures. Fish are a relatively low ranked prey, with one individual representing a much smaller quantity of meat compared to terrestrial animals (e.g. sheep, cattle). Therefore despite the increase in NISP, the amount of protein that they represented may not have been substantial.

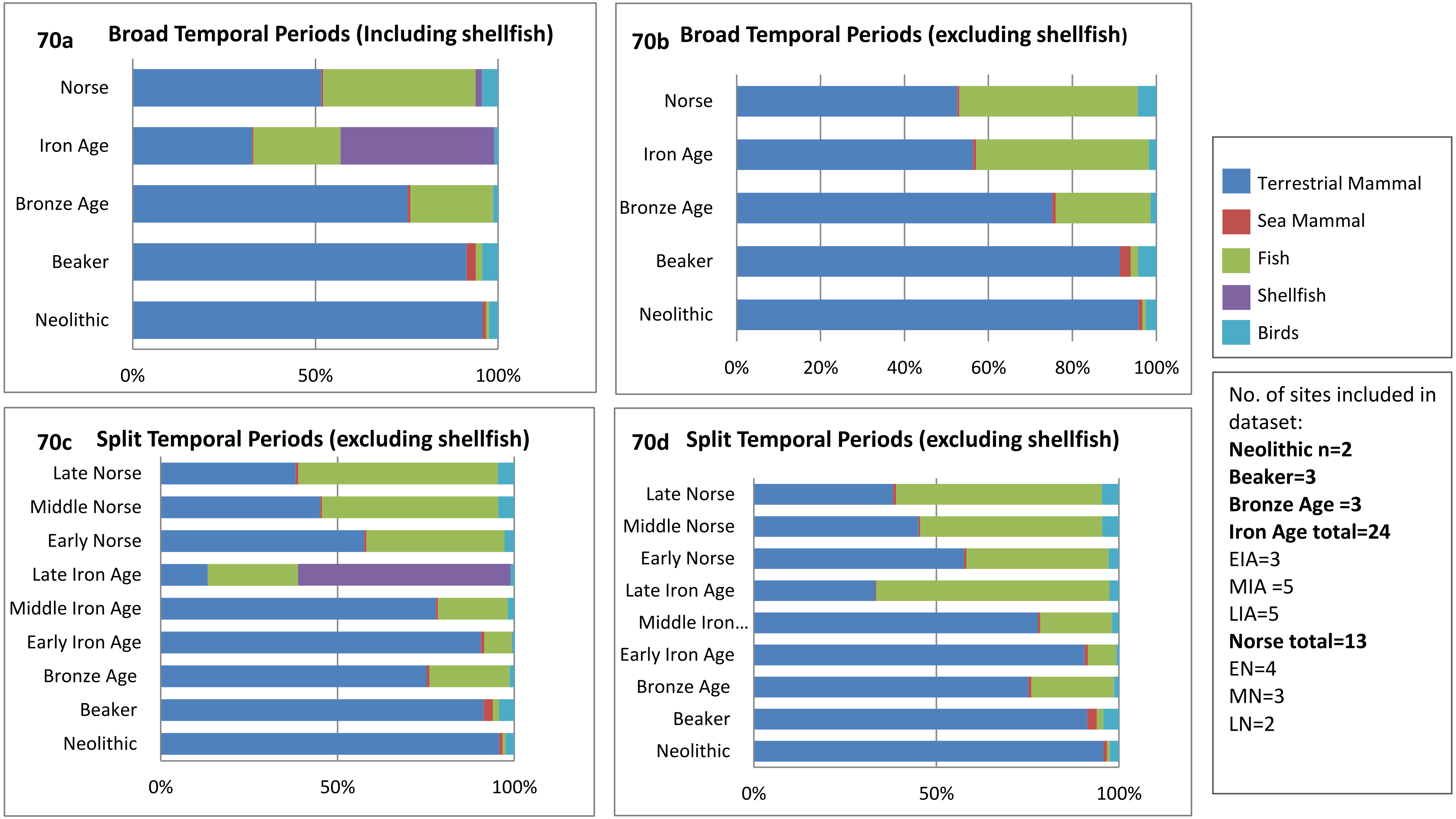
During the Iron Age there is a further increase in the proportion of fish bones present in the assemblage accounting for around 41% of the zooarchaeological remains. This demonstrates a further increase in the importance of this resource from the preceding Bronze Age. This is consistent with the zooarchaeological and human isotopic records, where we begin to see marine signatures appearing in the bone collagen record (Chapters 7 and 8).

In the Norse Period the proportion of fish bones present in the assemblage is similar to the Iron Age, with fish accounting for 42% of the total assemblage, indicating that fish were still economically important at this time, which is consistent with the human and faunal isotopic results achieved.

The relative proportion of sea mammal remains consistent through time. There is a slightly higher proportion of marine mammal bone fragments present in the Beaker period in comparison to the Neolithic and the subsequent period, suggesting that they may have been a more important resource at this time. In general sea mammals appear to have been exploited on a low level, continuously through time.

Summary Western Isles

The zooarchaeological evidence for the Neolithic period in the Western Isles is limited, and conclusions are made tentatively. The low frequency of fish and sea mammal remains indicates that marine resources were not a major economic resource at this time. In the Bronze Age there is an increase in the proportion of fish bones present, suggesting that they were more important at this time. During the Iron Age and Norse period there is a further increase in the proportion of fish bones present, demonstrating that they played an important role in diet. There are increasing numbers of fish bones present in assemblages in the Bronze Age, and Iron Age and Norse period, indicating that fish were being utilised to greater extents through time. Sea mammal and bird remains account for a low number of fragments during each period, indicating that they were utilised at small but relatively consistent levels.



No. of sites included in dataset:
Neolithic n=2
Beaker=3
Bronze Age =3
Iron Age total=24
EIA=3
MIA =5
LIA=5
Norse total=13
EN=4
MN=3
LN=2

Figure 70: NISP proportion temporal comparisons in the Western Isles

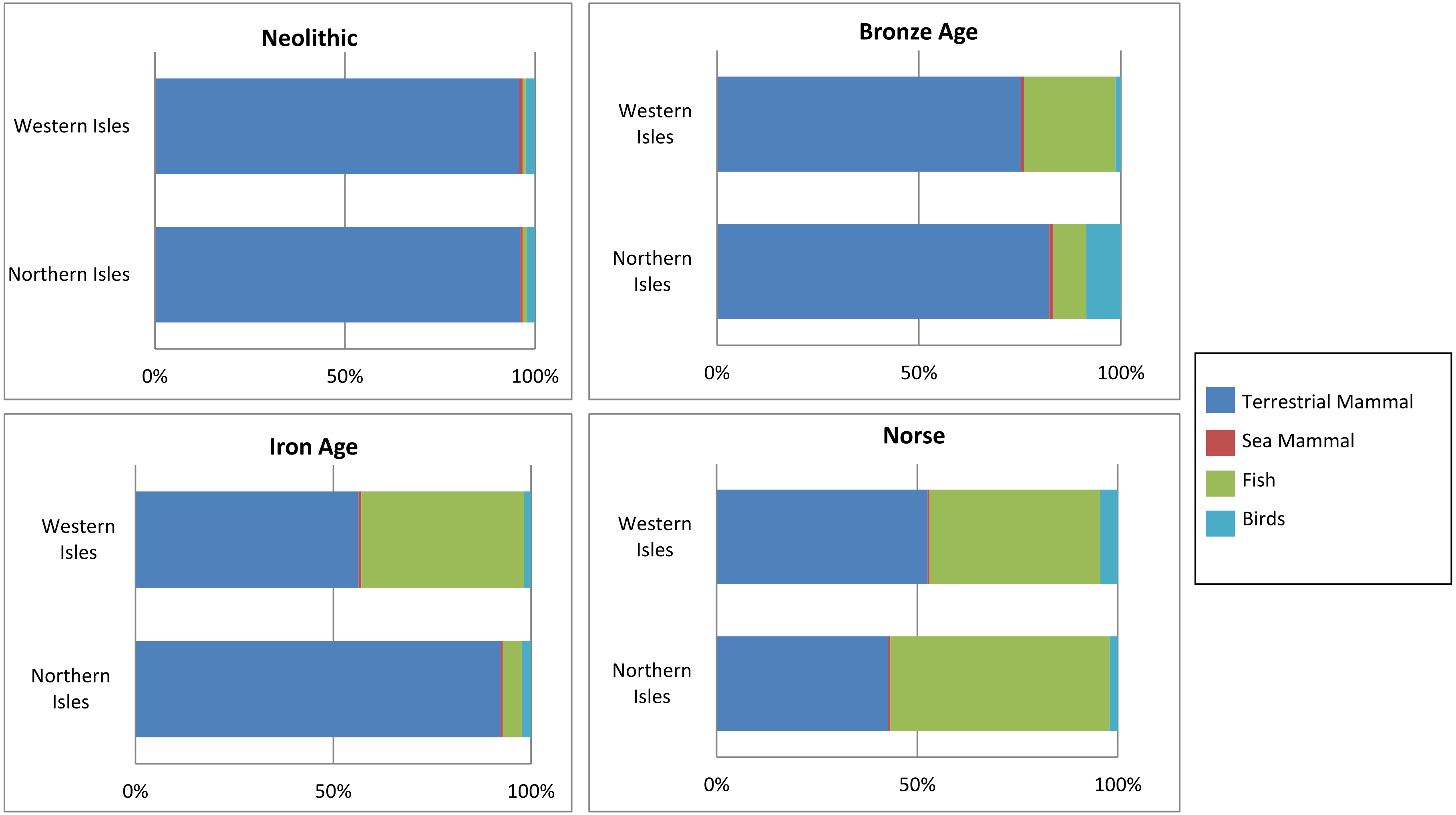


Figure 71: Species NISP proportion comparisons between Orkney and the Western Isles (excluding shellfish)

Geographical Comparisons between Orkney and Western Isles

Temporal comparisons of cumulative NISP values for each resource type in Orkney and the Western Isles are included in Figure 71. Shellfish have been excluded from this dataset due to the biases surrounding the absence of data.

The Neolithic assemblages in both island groups are dominated by terrestrial faunal remains, with few fish, bird or sea mammal bones present in the assemblage, suggesting that marine resources did not make a major contribution to diet in the Neolithic period in either Orkney or the Western Isles.

In the Bronze Age assemblages there is a difference in the use of marine foods between Orkney and the Western Isles. In Orkney fish bones represented only 3% of the faunal remains, and were not a major dietary contributor. In the Western Isles fish accounted for 22% of the total faunal remains. This suggests that fish represented a more important resource for the Bronze Age populations of the Western Isles.

A similar level of fish exploitation in Orkney is observed in the Iron Age, with fish continuing to represent only 3% of the total faunal assemblage. In the Western Isles there is an increase in the proportion of fish used at this time, accounting for 41% of the Iron Age assemblages. This demonstrates a marked increase in the importance of fish at this time, which is not observed in the assemblages from Orkney.

In the Norse Period fish are represented in higher proportions within the assemblages in Orkney (29%), indicating that they start to become a more important resource during this period. In the Western Isles fish bones account for a similar proportion of the faunal assemblage as observed in the Iron Age (42%), indicating that fish continued to be important in this island group.

The proportions of sea mammal remains present are relatively low, but constant in relation to the other resources characterised throughout time in both Orkney and the Outer Hebrides. They were a relatively rare resource, but were a consistently utilised feature of the economy in both island groups through time.

Terrestrial Species Exploitation Patterns

The following section explores the role of the dominant terrestrial species (cattle, sheep, pigs and red deer) through time. Differences in the proportions of each of the major terrestrial food species are discussed for each island group, and comparisons are drawn between the island groups.

Orkney

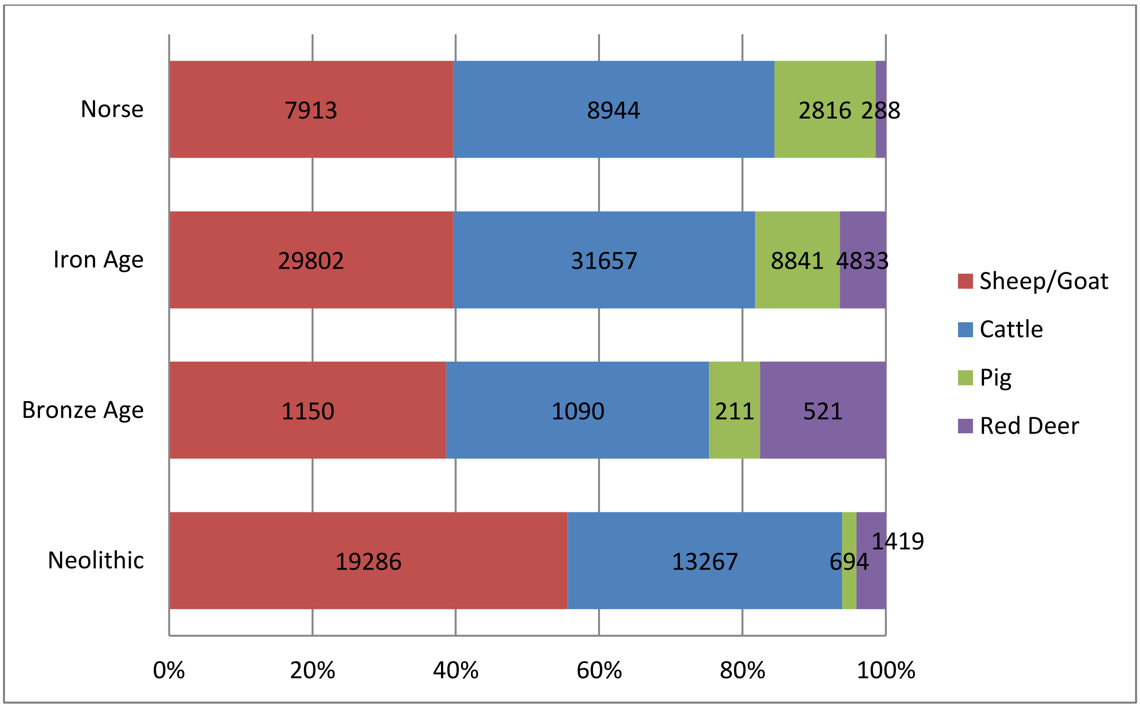


Figure 72: Terrestrial species representation: Orkney (Numbers listed represent NISP values)

The frequency of cattle in Orkney NISPs is relatively consistent for each period within the assemblages (Figure 72). The proportions of sheep bones in the Neolithic are higher than observed in the following periods, suggesting that sheep played a pivotal role in diet during this period. Despite being more numerous in terms of NISP, sheep are considerably smaller than cattle, and would therefore contribute less dietary protein in terms of both meat and dairy products than offered by cattle. Pottery residue analysis demonstrated that dairy fats were present in all Neolithic vessels from the Early Neolithic onwards at the sites of Links of Noltland, Ness of Brodgar, Pool and Skara Brae (Cramp pers. comm.), and would therefore have represented a valuable protein source, as soon as the first domesticates arrived in the region. The number of pig bones present in assemblages is relatively low in the Neolithic (2% of the terrestrial assemblage), and increases slightly during the Bronze Age (7%). Pigs are difficult to rear within island environments, as their action of rooting can be very damaging to fragile soils of the North Atlantic, potentially threatening agriculture (Serjeantson 1990; Mulville 1999). The relatively low proportion of pigs within the assemblages during the Neolithic and Bronze Age is potentially a reflection of this. During the Iron Age and Norse period pig bones are represented more commonly in the assemblages (11%, then 14%), indicating that they increased in importance during these periods. It is possible that pig management techniques such as penning were being employed at this time, allowing greater numbers of pigs to be raised without risking damage to crops.

Assessing the role of red deer in the North Atlantic Islands can be challenging as they are often identified in 'special' deposits; for example at the site of Links of Noltland in Orkney 15 articulated red deer skeletons were identified in a burial deposit (Armour-Chelu 1992). Similarly caches of deer (MNI 6) were identified at the site of Howe (Orkney), interpreted as being evidence of roasting and consuming whole carcasses (Smith 1994, 149). At the site of Northton in the Outer Hebrides a cache of 8 cast antlers was recovered alongside 5 fragments of antler removed from skulls (Finlay 2006, 174). Red deer is also a common feature of chambered cairns in the Scottish Islands (Morris 2005). Deer are utilised for a range of purposes in the islands. Therefore their presence in archaeological deposits is not necessarily related to subsistence, and is not always predictable within assemblages.

The proportion of red deer specimens identified increases through time in Orkney. This is possibly a result of red deer populations on Orkney becoming better established by the Bronze Age, resulting in a larger population being available for hunting (Mulville 2010, 45). The Neolithic and Iron Age red deer assemblage at Pool represented a wide range of skeletal elements and ages of deer (Bond 2007, 214), suggesting that deer were being hunted locally rather than exchange of specific body parts. Red deer become extinct in Orkney during the Norse period as demonstrated by the decline in the frequency of bones observed within the assemblages, and the body parts available from later periods are commonly traded antler and cranial fragments (Mulville 2010).

Western Isles

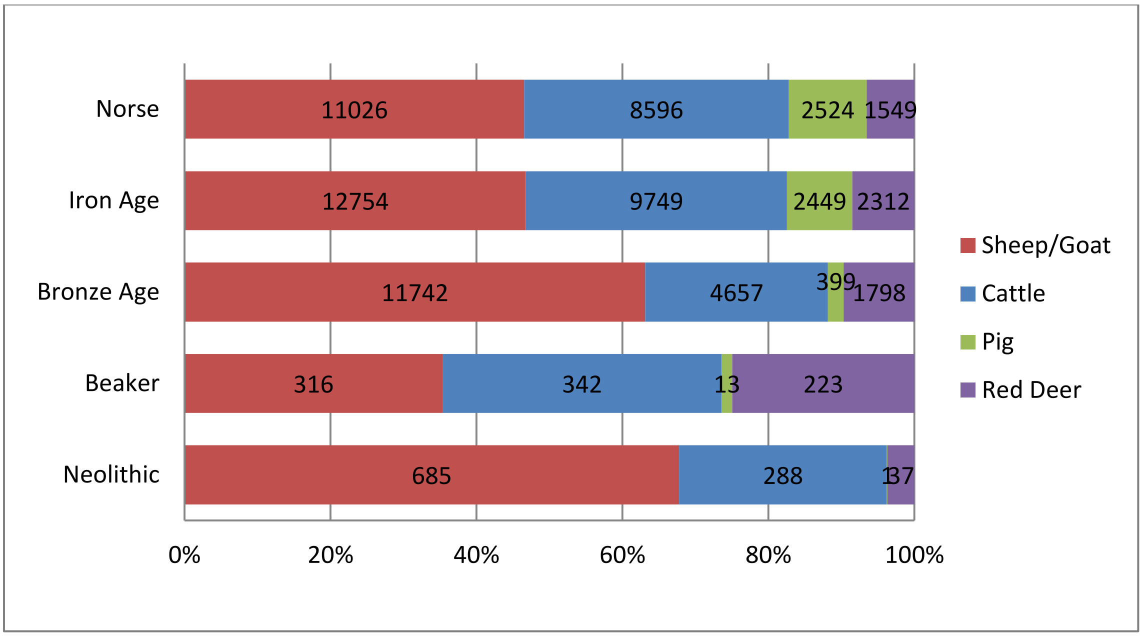


Figure 73: Terrestrial species representation: Western Isles

The temporal patterning of terrestrial species exploited in the Western Isles (Figure 73) is similar to that observed in Orkney. The proportions of sheep in the Neolithic are high in comparison to the number of cattle bones, suggesting that sheep played an important role in Neolithic diet in this region. Cattle bones are represented in similar proportions through time, indicating that they were consistently important across time. As observed in Orkney, pottery residues from Neolithic vessels from the sites of Bharpa Langais and Eilean Domhnuill demonstrated that dairy fats were present at this time, and would therefore have represented a valuable resource (Cramp pers. comm.).

Pigs are a minor resource in the Neolithic, Beaker Period, and Bronze Age. The proportion of pigs within the assemblages increases in the Iron Age and Norse Period. Pigs are present in greater proportions in the Western Isles than observed in Orkney during the later periods, suggesting that they were a more important resource in the Western Isles during these periods.

There is an increase in red deer bone specimens in the Beaker Period in the Western Isles. The vast majority of the Neolithic and Beaker period specimens were from the site of Northton and were recorded by the same zooarchaeologist, and were subjected to the same analytical and sampling strategies (Finlay 1984; 2006), indicating that this increase is an accurate reflection of their increased utilisation during this period. As previously discussed red deer occupy an unusual role in Scotland, and their utilisation is not necessarily economic, but influenced by a range of social and cultural factors (Morris 2005; Sharples 2000). Red deer are present in similar proportions throughout the Bronze Age, Iron Age, and Norse period, suggesting that they maintained their importance throughout this time, which is a different pattern to that observed in Orkney, where red deer decrease in numbers from the Iron Age onwards.

Shetland

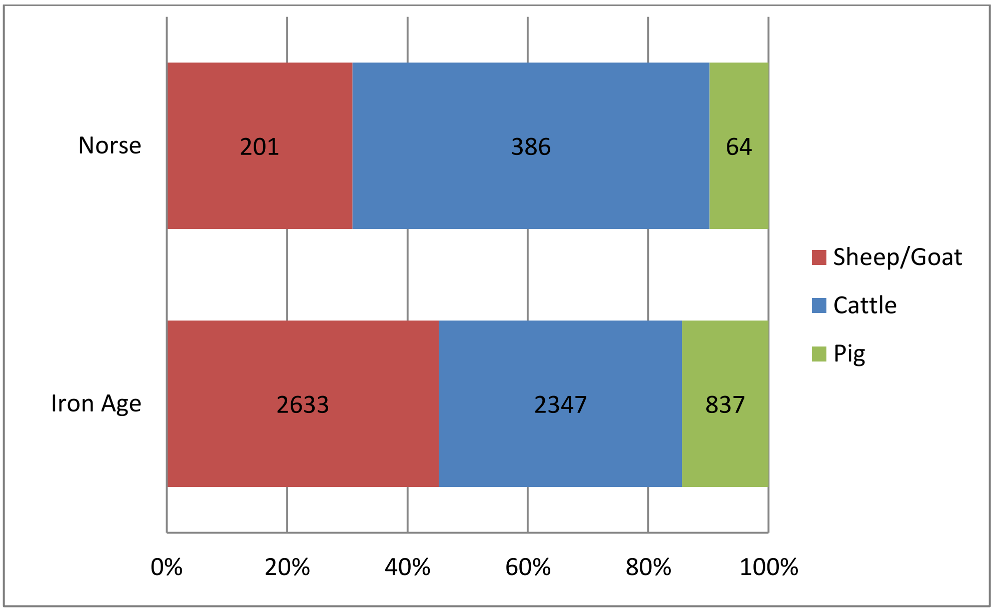


Figure 74: Terrestrial Species representation: Shetland

Poor preservation conditions have limited the number of faunal assemblages available for analysis. Therefore the Shetland evidence is based on much smaller sample sizes than was available for Outer Hebrides and Orkney, and these datasets are all viewed with caution. Data from future excavations would provide a valuable addition to the corpus available to date, and would enable more nuanced comparisons between the island groups within each time period to be achieved.

The Neolithic assemblage from Scord of Brouster comprised only 17 identifiable bones (Noddle 1986), and therefore was too small an assemblage to be considered a representative sample. The Shetland terrestrial species are therefore based on the Iron Age phases of Scatness, Scalloway, and the Norse faunal remains are all from Scatness (Figure 74).

There is an increase in the proportion of cattle bones represented in the terrestrial faunal assemblages from the Iron Age to the Norse period, with cattle accounting for a larger proportion of the assemblage than observed in the Western Isles and Orkney.

Counter to the findings in the Western Isles and Orkney the number of pig bones identified decreases between the Iron Age and Norse Period in Shetland. Red deer are not commonly found in the zooarchaeological assemblages in Shetland, and predominantly occur within the artefactual assemblages such as the fragment of antler listed in the worked animal bone collections at Iron Age Scalloway (O'Sullivan 1998, 91).

Trends in Shellfish Exploitation

Information on shellfish remains was only available from 24 sites across the North Atlantic Islands. Further work is being conducted on the shellfish assemblages by Matthew Law at Cardiff, including assemblages from Mound 2 and 2a in Bornais. Only four sites in the Outer Hebrides contained data relating to shellfish remains: Bostadh Beach (Late Iron Age and Norse periods), Bornais M3 (Norse Period), and Cnip (Iron Age). Bronze Age shellfish from the sites of Ardnave (Cerón-Carrasco *et al.* 2006) and Killelan Farm (Ritchie 2005) were included in this analysis to provide an insight into earlier Hebridean shellfish exploitation patterns. A further 18 sites from Orkney provided shellfish assemblages.

The fragmentary nature of shellfish remains means that NISP values frequently overestimate the proportion of shellfish remains present, and so these values have to be viewed with caution. Speciation of shellfish within assemblages varies, with some analysts identifying shellfish as 'winkles' but others providing a greater degree of speciation, which affects some of the patterning observed in this analysis.

Figure 75 presents patterns in shellfish exploitation through time in Orkney and the Western Isles. The Neolithic period is represented by relatively low numbers of shellfish remains, generated from three sites on Orkney (Isbister, Pierowall Quarry, and Tofts Ness). This can tentatively be interpreted as relatively low utilisation of these resources. No Neolithic shellfish remains were available from the Western Isles, which partially is a product of the low density of Neolithic sites.

One of the most striking aspects of the marine shell assemblages is the dramatic increase in the number of marine shells recorded in the assemblages through time, from a combined total of 960 fragments in the Neolithic to 43637 in the Bronze Age, 75519 in the Iron Age, and 123924 in the Norse period. As these totals represent the cumulative sums of all sites of that period, the effect of differing sampling and excavation strategies is diminished; however, the increasing levels of shellfish can be broadly attributed to greater intensity of marine mollusc use.

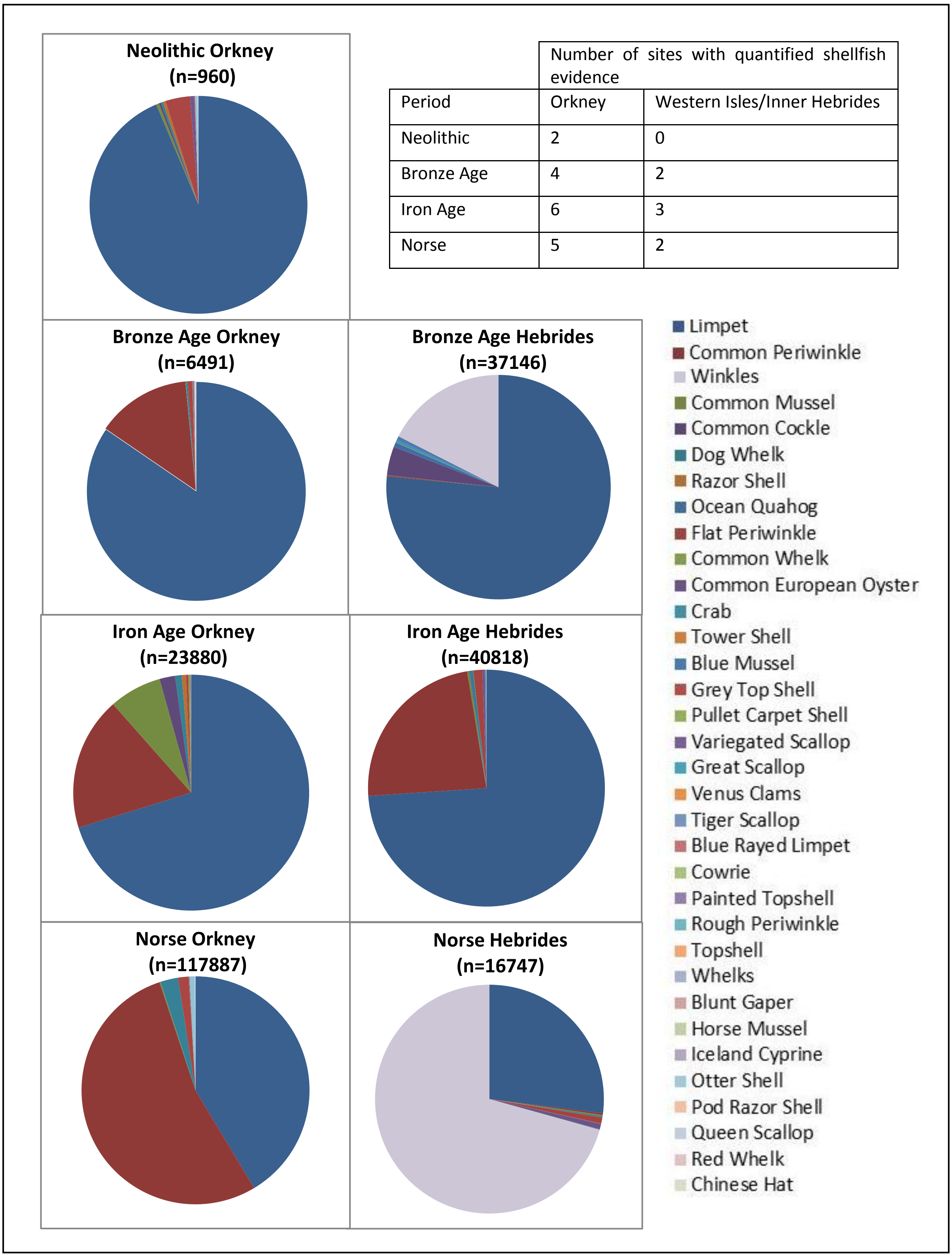
In each time period the most important species in the assemblages are limpets and periwinkles, with other species accounting for less than 4% of the assemblages in each period. The Neolithic shellfish species represent 10 different species, compared to 20 for the Bronze Age assemblages, 27 for the Iron Age assemblages, and 20 for the Norse assemblages. The diversity in the taxa represented is related to the sieving and sampling strategies employed, so the greater the level of sieving strategies the greater the number of species that will be encountered (O'Connor 2000). The detailed sampling and analytic strategies employed at the Bronze Age site of Cladh Hallan and at Norse sites such as Quoygrew (Harland 2007), and Bornais (Sharples 2012; 2005) has resulted in a greater degree of species visibility in these assemblages.

The shellfish in Neolithic Orkney are dominated by limpets representing 94% of the total shellfish NISP, with common periwinkles being the next most exploited species. In the Bronze Age in both island groups, limpets continue to dominate the shellfish assemblages accounting for 85% of total assemblage from Orkney and 77% of the assemblage from the Western Isles. Winkles are the next most commonly exploited species in both island groups. In the Western Isles the only other notable species are common cockles, which accounted for 4% of the shellfish assemblage.

In the Iron Age limpets are still the most commonly exploited species, they account for a smaller proportion of the total assemblage (70% in Orkney, 74% in the Western Isles), demonstrating a decline in their usage at this time. Winkles continue to be the second most dominant species, and in Orkney common whelks were also exploited (representing 7% of the total assemblage).

During the Norse Period there is a rise in the dominance of winkle species present within assemblages, and they overtake limpets in terms of shellfish representation within the assemblages, accounting for 54% of the shellfish NISP in Orkney and 71% of the shellfish NISP in the Western Isles. Limpets are the next most commonly exploited resource in the islands (41% of assemblage in Orkney, 27% in the Western Isles).

In terms of general trends in species exploitation limpets dominate the assemblages from the Neolithic period onwards until the Norse period, when winkles take over as the dominant resource. This is observed in both Orkney and the Western Isles. The implications of this change in shellfish exploitation strategy are discussed in greater detail in chapter 11.



	Number of sites with quantified shellfish evidence	
Period	Orkney	Western Isles/Inner Hebrides
Neolithic	2	0
Bronze Age	4	2
Iron Age	6	3
Norse	5	2

Figure 75: Shellfish remains from the North Atlantic Islands

Fish Species Exploitation

Identifying patterns in fish species patterns provides insights into past fishing strategies, and changes in exploitation patterns in the North Atlantic. The following graphs show only fish that could be positively identified to species (not families e.g. gadid), and so the numbers of each species present is likely to be affected by differences in the ease of fish species recognition by the analysts. Only species with 10 or more fragments identified in at least one of the island groups are displayed to enable the key trends to be more easily identified (excluding Neolithic Western Isles, where the total assemblage was 3 fragments). Each period is listed and discussed to compare trends in fish species use through time within the islands.

Neolithic Fish remains

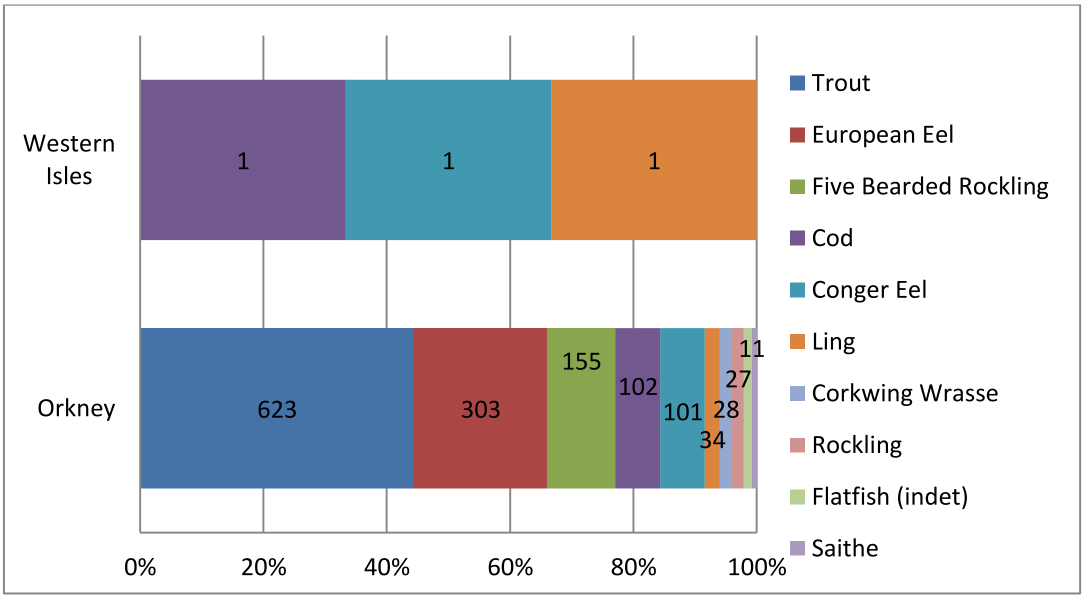


Figure 76: Fish species exploitation in Orkney and Western Isles: Neolithic

Figure 76 illustrates the fish species present in the Northern and Western Isles during the Neolithic. Trout bones and European eel were the most commonly represented fish species in the Neolithic period in Orkney, and were predominantly from the settlement site of Skara Brae (Cerón-Carrasco *et al.* 2006). Unfortunately further contextual evidence is not available to date as the site is currently being written up, and little information is publically available for this site.

The frequency of fish bones in Neolithic Orkney is low, and assessing the quantity of fish represented by the 623 trout bones identified at Skara Brae was not possible as MNI values, skeletal representation or fish size information was not available. There are numerous bones in the skeleton of a fish, and so 623 bones could theoretically represent only a handful of individuals. Work on the Skara Brae material to explore seasonality of the fish remains would be beneficial in identifying whether these remains reflect a seasonal pattern of exploitation. There are also assemblages of fish bones from the recent excavations at the links of Noltland on Orkney which to date have not been analysed and published (Fraser pers. comm.). When these remains have been studied they will enhance the debate of Neolithic fish exploitation patterns further.

There are few Neolithic sites in the Outer Hebrides, and out of those only Eilean Domhnuil (Armit 1986), and Northton (Finlay 1984) contained zooarchaeological data. Neolithic fish remains are scarce in the Western Isles, with only 4 fish bone fragments identified to species, and fishing strategies cannot be reconstructed. The general paucity of Neolithic faunal remains from the Western Isles makes assessing the importance of marine foods challenging.

Beaker Period Fish remains

Only 15 fragments of fish bone from the Beaker period phases at Northton were identified in the North Atlantic Islands. Of these, 10 were identified as ling, and potentially represent a single individual. The small assemblage size from only one site raises questions as to the representativeness and reliability of the sample. As a result further investigation of fish in this period has not been pursued.

Bronze Age Fish remains

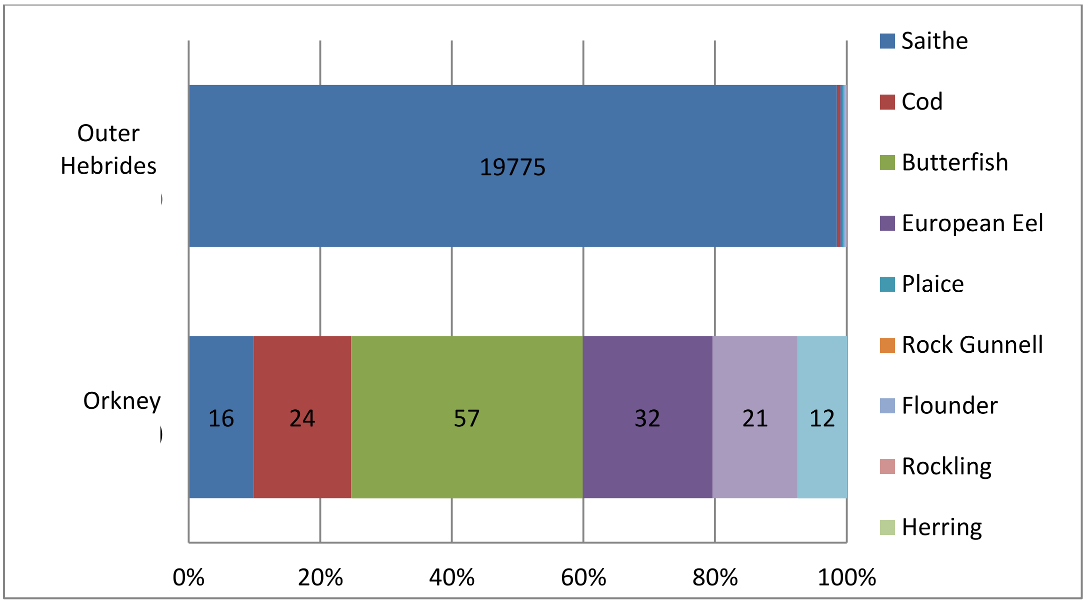


Figure 77: Fish species exploitation in Orkney and Western Isles: Bronze Age

The Bronze Age assemblage for Orkney was limited, with fish evidence only available from Tofts Ness and Point of Buckquoy, there was a larger assemblage of fish remains available from the Outer Hebrides (Figure 77). Butterfish are the most commonly represented species, but these related to only 57 fragments of bone; other species present included cod, saithe, conger eel, European eel and corkwing wrasse. The diversity of fish present in very similar quantities in the assemblage suggests broad-spectrum fishing strategies, with exploitation being somewhat more ad hoc perhaps based on chance encounters. The Bronze Age fish bones from the Outer Hebrides are dominated by saithe bones and these account for roughly 98% of the total fish bone remains. The large quantities of saithe present in the assemblages from the Western Isles suggest that targeted exploitation strategies were being undertaken, demonstrating a degree of specialisation in the fishing techniques practiced.

Iron Age Fish Remains

The percentages of each fish species exploited in the cumulative Iron Age assemblages for each of the island groups are displayed in Figure 78. The total number of fish bones for each of the major species has been noted to give an indication of sample sizes, and therefore representativeness of the fish bone assemblages available.

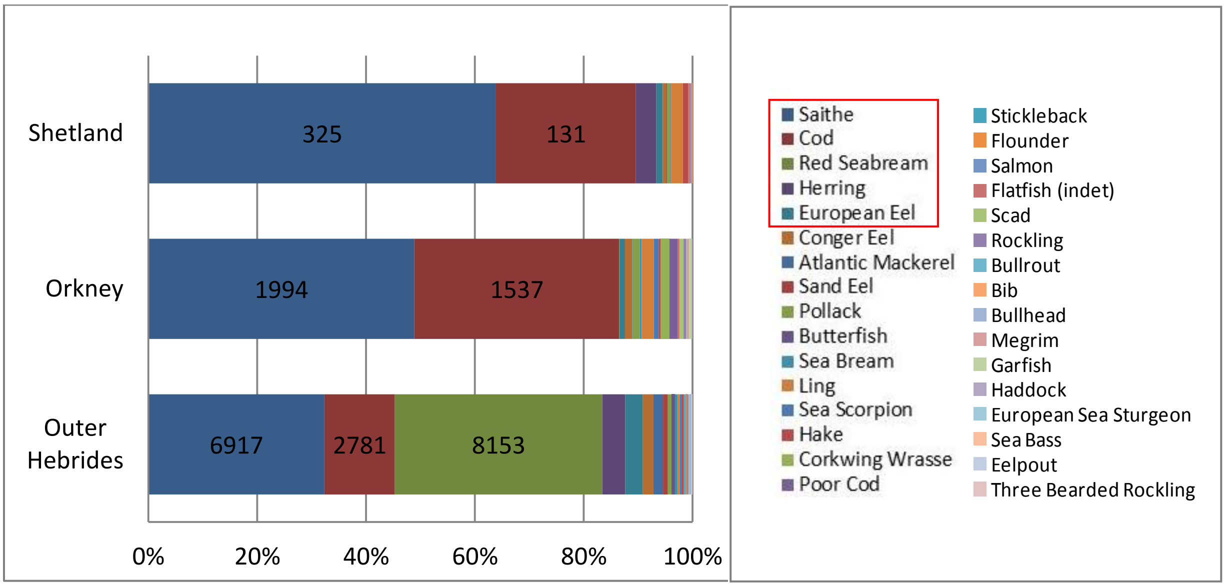


Figure 78: Fish species exploitation in Orkney and the Western Isles: Iron Age

Saithe and cod dominate the Iron Age assemblages in Shetland and Orkney, in addition to accounting for a large proportion of the zooarchaeological fish remains found in the Outer Hebrides. The most commonly represented species in the Iron Age Outer Hebrides is red seabream. The bulk of these specimens are from the Iron Age deposits at the site of Bostadh Beach, accounting for 7823 fragments. This species is also present in lesser numbers in the Iron Age deposits at Dunan Ruadh on the Isle of Pabbay, totalling 330 bone fragments. Red sea bream are not present in the Iron Age assemblages from Orkney or Shetland. The predominance of red seabream in the assemblages from the Outer Hebrides is potentially linked to environmental conditions in the islands, with the aquatic environments surrounding the Outer Hebrides better suited to the environmental niches required by red seabream. This will be explored further in chapter 11.

Norse Period Fish Remains

There is a great wealth of fish bone evidence available from the Norse period assemblages from the North Atlantic Islands (Figure 79). A total of 26864 identifiable fragments were present in Orkney, 2151 from Shetland, and 44485 from the Outer Hebrides.

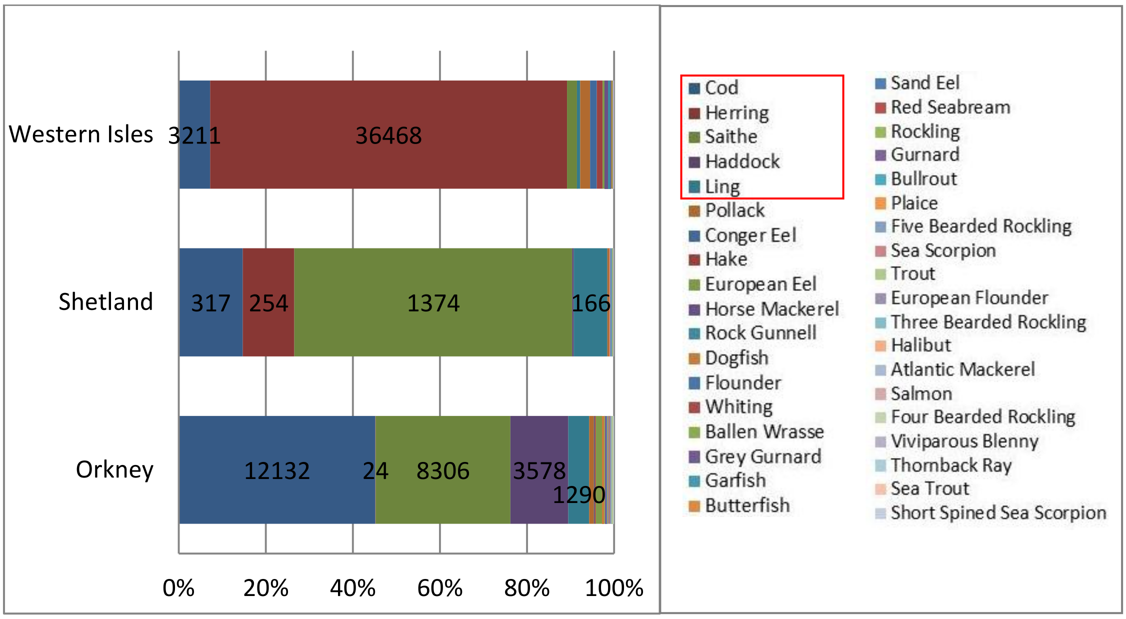


Figure 79: Fish species exploitation in Orkney and the Western Isles: Norse Period

The economy in the Northern Isles of Shetland and Orkney during the Norse Period is heavily dominated by white fish. Cod is the species most commonly represented within the fish bone evidence from Orkney, and saithe is more common in the Shetland assemblages, although both species are represented. Ling were also present in greater proportions in the Northern Isles. Cod are present within the Western Isles assemblage, but account for only 7% of the total NISP. Herring dominate the fish bone assemblages in the Western Isles, accounting for 82% of the total assemblage. Herring are the third most commonly represented species in Shetland. Differences in species exploitation between the island groups suggest that different economic practices were being employed between these regions.

Understanding the importance of these species between the islands using NISP is challenging. Comparing NISP (and MNI) values between different species can be misleading, as herrings are much smaller in size than larger white fish species such as cod, and saithe, and so very different quantities of meat would be represented by an identical NISP. However, the presence of large quantities of herring in comparison to other fish species represented in the zooarchaeological assemblages from the Western Isles indicates that they were an important resource in this island group.

Different fishing practices would need to be employed to catch these two different types of fish, suggesting differing marine exploitation strategies between the island groups. This is discussed further in chapter 11.

Fish Exploitation Summary

The NISP analysis provides an understanding of the different types of fish being exploited, and the diversity in exploitations strategies being undertaken in the North Atlantic Islands. In the Neolithic fish bones are scarce, but the presence of 600 trout bones from Skara Brae in Orkney demonstrates that they were being used at the site. In Bronze Age Orkney fish remains are still limited, and there are a range of species represented indicative of a less targeted fishing strategy. In the Outer Hebrides there is a wealth of fish bone evidence, and saithe were the main species exploited. In the Iron Age saithe and cod dominate the zooarchaeological assemblages in Shetland and Orkney, and account for a large proportion of the fish bones evident in the Outer Hebrides. The main species exploited in the Outer Hebrides is red seabream. During the Norse period we see a divergence in the economic strategies used between the two island groups, with evidence from Orkney and Shetland showing a continued exploitation of saithe and cod, and the Outer Hebridean evidence demonstrating a preference for herring. Comparing fish species NISPs provides a crude understanding in fish exploitation strategies through time, but more detailed data relating to MNI of each species, fish size and available fish seasonality evidence would be invaluable in enhancing our understanding of fish exploitation strategies in the islands.

Abundance Indices and the Importance of Marine Mammals

Abundance indices can be used to determine the relationship between larger bodied (high ranked) prey such as marine mammals to the other smaller bodied resources (low ranked prey) found at sites (Chapter 4). Abundance indices are ranked between 0 and 1, with values of 0 suggesting that there the large bodied prey were less important, and values of 1 being indicative of large bodied prey being very important within the assemblage (Betts and Friesen 2006).

Figure 80 shows the abundance index comparing the sea mammals to the total fish, shellfish, and terrestrial mammal remains from each period to assess the importance of sea mammals as a resource over time.

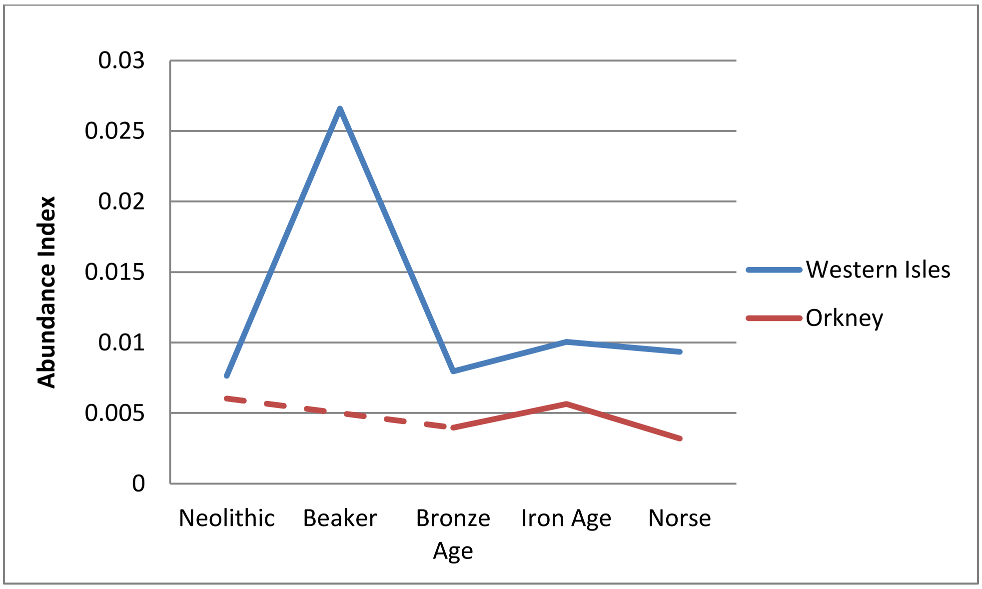


Figure 80: Sea Mammal: fish/terrestrial mammal index in Orkney and the Western Isles

Overall the abundance indices for both island groups are low, generally being below 0.01, indicating that marine mammals were not a major resource in either island group. For each of these broad temporal periods the abundance index for marine mammals is higher in the Western Isles in relation than the Northern Isles. This could be a result of greater levels of sea mammal exploitation in the Western Isles, or could be a reflection of differences in sea mammal bone identification between analysts. During the Beaker Period there is an increase in the marine mammal abundance index, which suggests that they may have been exploited more intensively in this period.

There is an increase in the relative abundance of marine mammals during the Iron Age in the Western Isles. The largest body of marine mammals combined in this period is from the sites of Cnip (McCormich 2006), Dun Vulan (Mulville 1999; and A'Cheardach Bheag (Finlay 1984). There is also a peak in marine mammal abundance in the Early Iron Age Northern Isles, with a large assemblage identified from the site of Howe (Smith 1994; Locker 1994). The zooarchaeological report from Howe states that juvenile sea mammal bones are commonly represented (Smith 1994), which may suggest that these individuals were more easily targeted by people procuring these remains. The presence of juvenile sea mammals would have provided an opportunity for easy culling of this resource, which could explain their high frequency at that site.

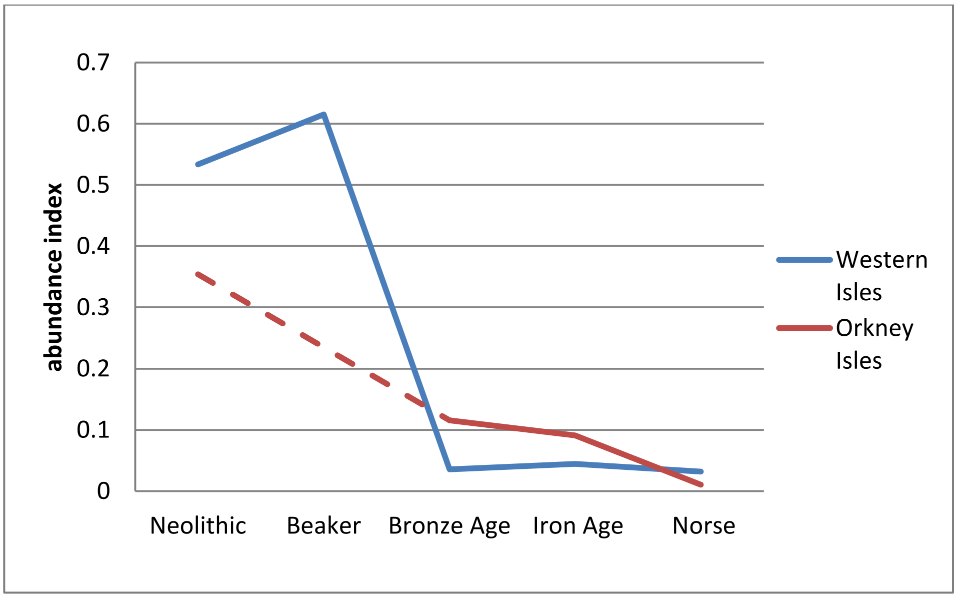


Figure 81: Sea Mammal: fish abundance index in Orkney and the Western Isles

When abundance indices are calculated comparing marine mammal in relation to fish bone evidence a slightly different pattern emerges (Figure 81). In the Neolithic (and Beaker period in the Western Isles) the abundance of marine mammals in comparison to fish bone is very high, demonstrating that marine mammals presented a greater resource. This is not surprising given the low frequency of fish bones in the Neolithic assemblages. As anticipated, with the increase in the presence of fish bones in the zooarchaeological assemblages, there is a decline in the abundance of sea mammals from the Bronze Age onwards in both island groups. This demonstrates that despite the high rank of sea mammals, in terms of the quantity of meat represented by one individual, they were not as important as fish during these periods, confirming the findings of the NISP analysis.

Sea Mammal Species Exploitation

Many of the fragments were not identified to species, and are listed as being seal, whale, or a size class of sea mammal such as medium/large cetacean, or small cetacean. Occasional fragments of common seal, Atlantic seal and grey seal were identified in the assemblages in low frequencies (Figure 82 and Figure 83).

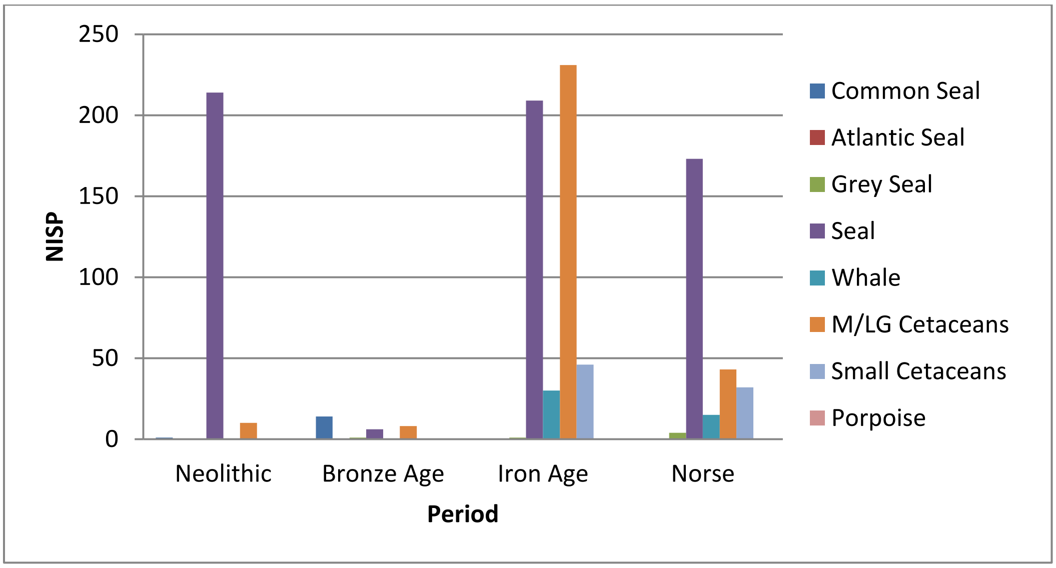


Figure 82: Sea mammal species exploited in Orkney

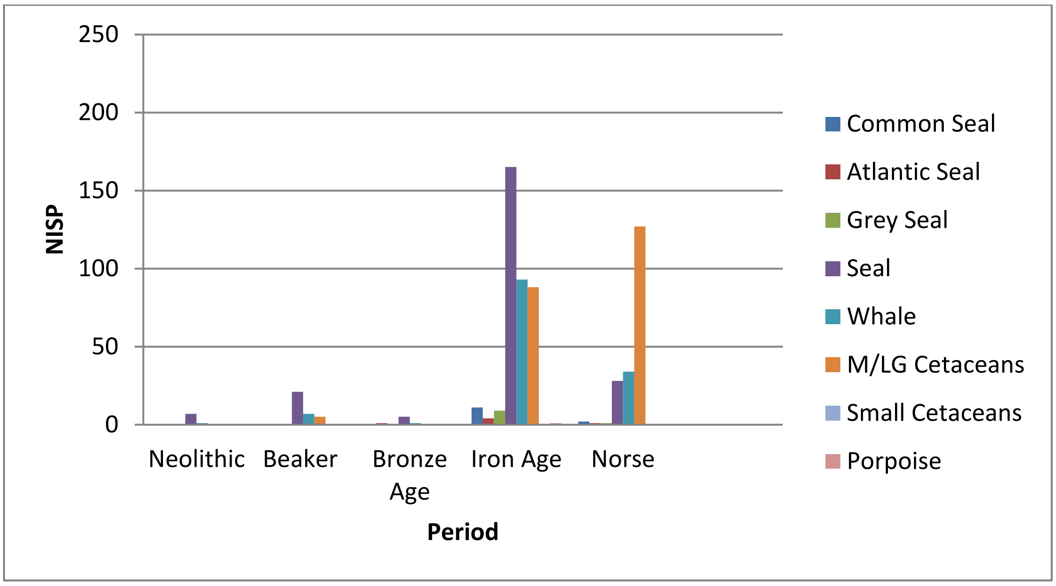


Figure 83: Sea Mammal species exploited in the Western Isles

In Neolithic Orkney the predominant species exploited is seal, with 214 fragments identified. Seal is also present in lower frequencies in the Neolithic Western Isles assemblages. The Beaker assemblage from the Outer Hebrides contains whale bone in addition to seal bone. Seal and whale NISPs are low in the Bronze Age in both Orkney and the Western Isles, and both assemblages are composed entirely of seal. During the Iron Age in Orkney and the Western Isles whale bone appears in greater frequencies, with seal bones being commonly represented in the assemblages. During the Norse period whale and seal bones are identified in both Orkney and the Western Isles.

Due to the highly fragmentary nature of the whale and cetacean bones found at these sites very few specimens could be positively identified to species. This prevents some interpretational difficulties when assessing sea mammal procurement, as species exploitation can provide an indication of scavenging of beached animals versus active hunting.

Sea Mammal Summary

Abundance indices can provide a broad insight into the relative importance of large bodied prey in relation to other resources available at the time, but they provide very similar information to simple NISP comparisons. A challenge of assessing the importance of marine mammals using abundance indices is that they assume that marine mammals were being consumed, which is not necessarily accurate. Marine mammals have been utilised in the North Atlantic as architectural materials and for the creation of artefacts (Mulville 2002), which can explain the presence of some of these remains on archaeological sites. Overall the abundance indices provide a useful indication of broad trends in the utilisation of marine mammals, but they need to be considered in the light of other archaeological and contextual evidence.

Resource use in Middle Iron Age Dun Vulan

The Middle Iron Age human and faunal isotopic evidence from Dun Vulan demonstrated evidence of marine consumption. Exploring the Middle Iron Age faunal remains in greater detail can enhance our understanding of the isotopic signatures observed in the human and animal remains.

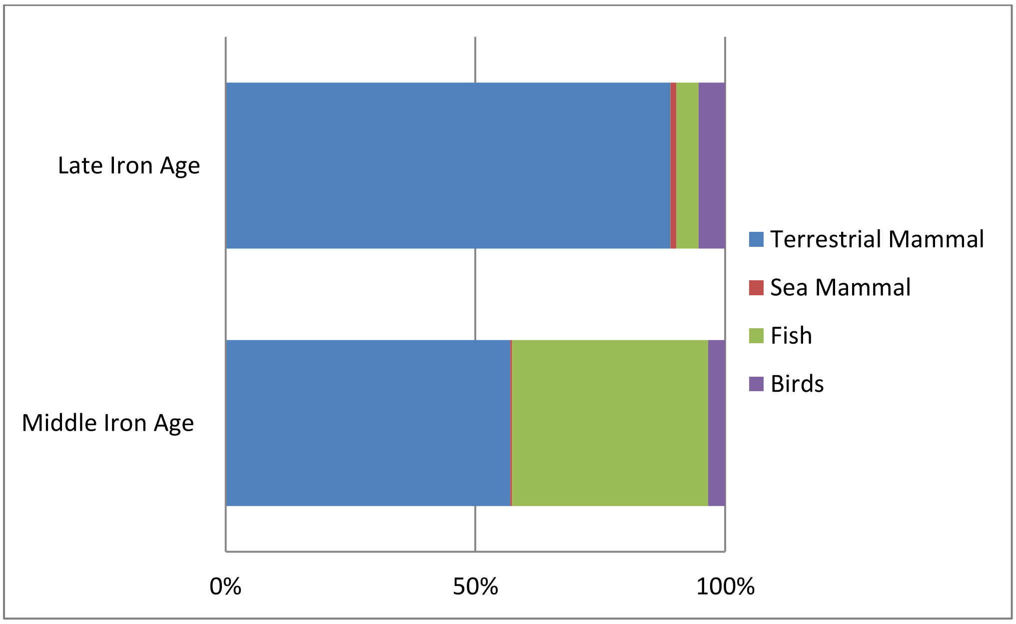


Figure 84: Phase comparison of NISP proportions at Dun Vulan

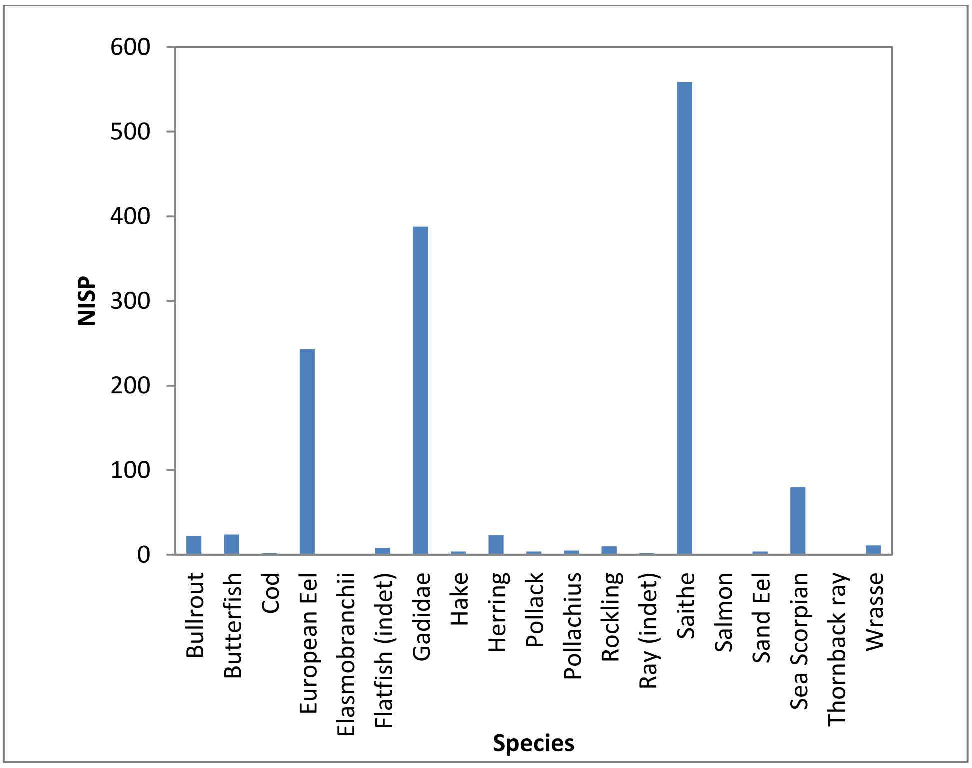


Figure 85: Fish species NISP from Middle Iron Age Dun Vulan

There is a greater number of fish bones present in the Middle Iron Age deposits at Dun Vulan in comparison to the late Iron Age (Figure 84). Saithe, European eel and gadid are the most commonly represented species in terms of NISP in the Middle Iron Age phases at Dun Vulan (Figure 85). Sea scorpion, bull-rout, butterfish and herring also represented in small numbers within the assemblage. These fish are generally found in rocky shores, and tidal pools, and whilst they could have been collected by humans, other interpretations for the presence of these species are that they may have been accumulated by otters (Cerón-Carrasco 1999, 276). Otters are present in the Dun Vulan assemblages, interpreted as being utilised for skin rather than naturally occurring on the site (Mulville 1999). These remains could be a product of processing otter pelts at the sites.

Unfortunately MNI values are not available for the fish species present at Dun Vulan, and so assessing the quantity of meat represented by these fish bones is not possible. The presence of fish in the Dun Vulan assemblage supports the stable isotope results that fish were being utilised at the site during the Middle Iron Age. Shellfish remains are not discussed within the published Dun Vulan report, and cannot be included in this investigation.

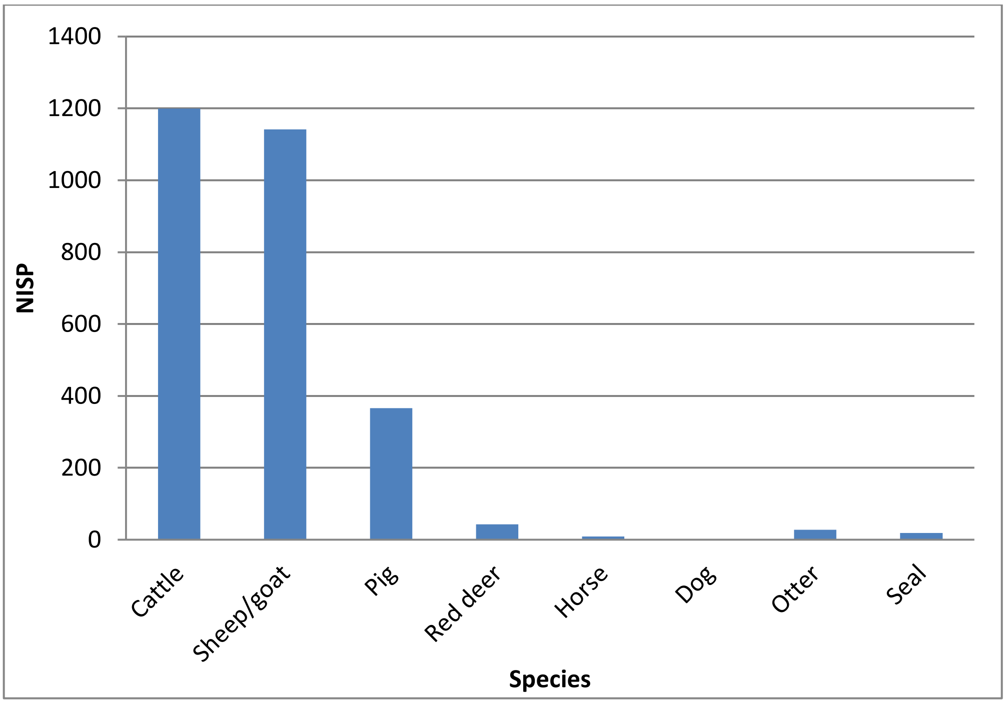
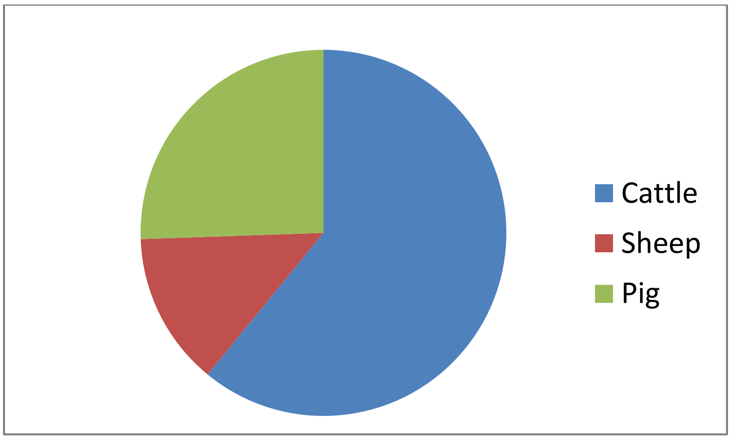


Figure 86: Faunal remains from Middle Iron Age Dun Vulan

Of the mammalian species exploited, cattle and sheep are the most commonly represented species, with cattle providing the greatest quantity of meat, although there are large quantities of sheep/goat. Pig bones are represented in greater numbers at Middle Iron Age Dun Vulan, despite their playing only a minor role in many contemporary Iron Age settlement sites such as Cnip (McCormick 2006): Northton (Finlay 1984); and A' Cheardach Mhor (Clarke 1960). Some rough meat weight calculations (Figure 87) suggest that pig represent the second most important species in terms of the quantity of meat they potentially provided. These calculations assume that all pigs were adults. The pig mortality profiles for Dun Vulan suggested that pigs were killed as immature individuals for meat and fats, with few reaching maturity (Mulville 1999, 250). Therefore the meat weights for this species provide an over estimation of the quantity of meat that these pigs would have provided. Based on the MNI and NISP values, and the faunal stable isotope values (Chapter 7), it is undeniable that pigs played an important role at the site of Dun Vulan.



Species	MNI	KG usable meat	Meat weight Value
Cattle	4.5	226.796	1020.582
Sheep	12.5	18.1437	226.79625
Pig	5.5	77.791091	427.8510005

Figure 87: Meat weight percentage proportions of domestic species at Middle Iron Age Dun Vulan

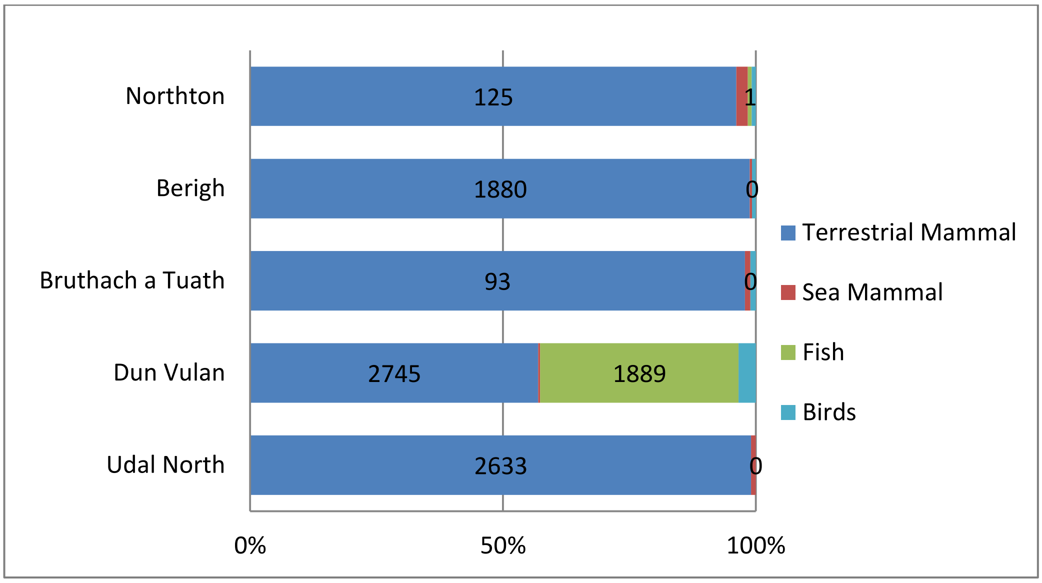


Figure 88: Middle Iron Age NISP proportions by site in the Outer Hebrides

Dun Vulan has greater numbers of fish bones present in the faunal assemblages than the other Middle Iron Age assemblages in the Outer Hebrides (Figure 87). This suggests that Dun Vulan is somewhat unusual in comparison to contemporary sites. Dun Vulan has previously been interpreted as a higher status site, reflected in the higher proportion of pig remains (Parker Pearson *et al.* 1998). The greater use of fish at Dun Vulan suggests that the site is unusual.

Summary Dun Vulan

Dun Vulan appears to be an unusual assemblage in comparison to other Middle Iron Age assemblages in that it contains greater numbers of fish bones and pig bones than other contemporary sites, a characteristic identified during the original analysis of the assemblage (Parker Pearson *et al.* 1996; Mulville 1999). The implications for the patterning in the zooarchaeological and isotopic data are explored further in chapter 11.

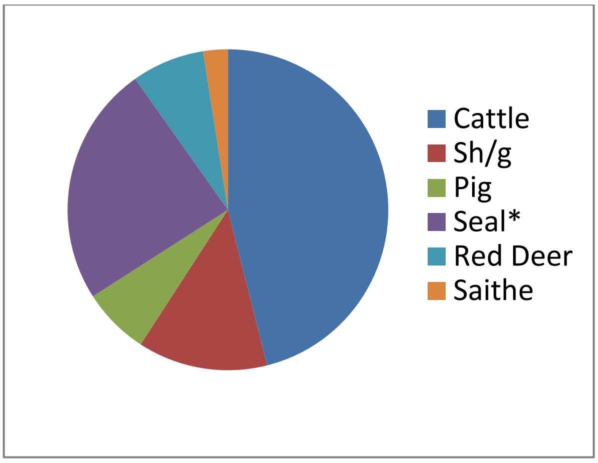
Understanding the Importance of Marine Resources: Meat Weight Analysis in South Uist

Meat weight analysis was conducted using the methodology outlined in chapter 4. By generating meat weight values it is possible to achieve an understanding of the quantity of food represented by each of the different resource types, providing a better indication of the actual quantities of food represented by these resources.

Figure 89 and Figure 90 show the meat weight analysis for Cladh Hallan. The NISP analysis (Figure 70) demonstrated that larger quantities of fish bone were present in the Bronze Age. When we consider the minimum number of fish represented in the Bronze Age phases at Cladh Hallan the number is very limited and comparing the quantity of meat represented by these fish bones in relation to the other species investigated, fish represent a minor resource in terms of the quantity of protein. This value does under-represent the quantity of meat available due to the nature of MNI calculations.

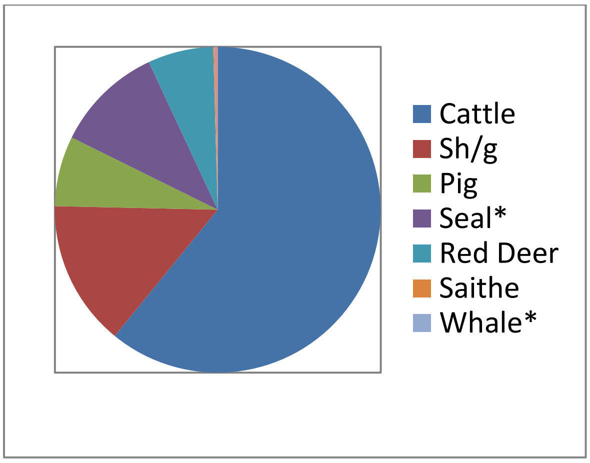
Cattle NISP values were lower than sheep NISP values at Cladh Hallan, but they provided a much greater quantity of meat to the Bronze Age populations (Figure 89 and Figure 90). Cattle would also have provided a valuable source of protein in the form of milk, and so their total dietary contribution would have been even greater.

The use of seal NISP rather than MNI for the meat weight calculations may have artificially inflated these values.



Cladh Hallan Middle Bronze Age Meat Weight		
Species	**MNI**	**Meat Weight (KG)**
Cattle	**49**	**11113**
Sheep/goat	**174**	**3157**
Pig	**21**	**1634**
Seal*	***39***	**5850**
Red Deer	**39**	**1769**
Saithe	**152**	**599**
Whale*	***0***	**0**
Bird	**0**	**0**
* Calculations based on NISP rather than MNI		

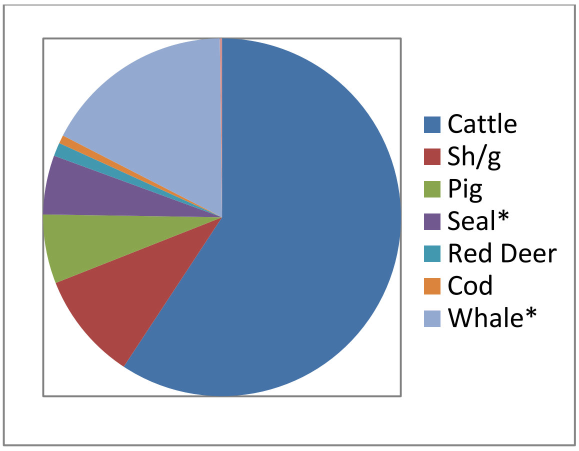
Figure 89: Meat Weight Analysis at Cladh Hallan: Middle Bronze Age



Cladh Hallan Late Bronze Age Meat Weight		
Species	**MNI**	**Meat Weight (KG)**
Cattle	**30**	**6804**
Sheep/goat	**89**	**1615**
Pig	**10**	**778**
Seal*	***8***	**1200**
Red Deer	**16**	**726**
Saithe	**3**	**12**
Whale*	***0***	**0**
Bird	**49**	**39**
* Calculations based on NISP rather than MNI		

Figure 90: Meat Weight Analysis at Cladh Hallan: Late Bronze Age

The meat weight analysis from Norse Cille Pheadair (Figure 24) demonstrates similar patterns to Cladh Hallan. Cattle, despite having lower NISP values than sheep, accounted for the largest proportion of meat. As for Cladh Hallan the sea mammal species are likely to appear over-exaggerated due to the use of NISP rather than MNI. Sheep, pig, and red deer appear to have contributed similar quantities of meat. Saithe appear to have made a minor contribution to diet. Unfortunately herring MNI values had not been calculated for this site, which prevented them from being included in this analysis, and so the quantity of fish meat available is likely to be under-represented.



Norse Cille Pheadair Meat Weight calculations

Species	**MNI**	**Meat Weight (KG)**
Cattle	**88**	***19958***
Sheep/goat	**181**	***3284***
Pig	**27**	***2100***
Seal*	**12**	***1800***
Red Deer	**9**	***408***
Cod	**64**	***252***
Whale*	***7***	***5807***
Birds	**99**	***68***

***Calculations based on NISP rather than MNI**

Figure 91: Meat Weight analysis for Cille Pheadair: Norse

Summary: Meat Weight Analysis

The meat weight analysis has demonstrated that even with datasets with known collection and analytical strategies assessing the relative importance of different resource types is still challenging. Many of the concerns of calculating meat weights are centred on the accuracy of MNI values (as discussed in chapter 4), in addition to the challenges of identifying accurate approximations for the quantity of usable meat represented by carcasses identified. The meat weight values achieved do not allow for insights into the contributions of secondary products such as milk or even the value of non-consumable resources.

Shellfish were not possible to include in the meat weight analysis as MNI values for this dataset had not been generated, so accessing information relating to their relative importance was not possible. The importance of sea mammal bones is over-exaggerated in the meat weight analysis as NISP had to be utilised due to the absence of MNI values as identifying sea mammal skeletal elements from homogenous bone fragments is not possible.

Another limitation is that MNI values had not been generated for every fish species present in the assemblages, and the relative importance of fish is under-estimated using meat weight calculations. It was possible to combine fish from the same family (e.g. gadid), but other smaller species could not be included in the analysis. The technique also does not take into account faunal remains that have been identified only to species class level.

Meat weights can provide an interesting approximation of the relative importance of each resource type, but the number of possible biases affecting the values generated is great, and there are questions as to how valuable these calculations are in understanding the contributions made by different dietary resources.

Summary: Zooarchaeological Analysis

The zooarchaeological analysis has provided a broad overview of the relative proportions of each zooarchaeological fraction present. Assessing the quantity of marine foods consumed is challenging when integrating data from a range of different sites is challenging due to differing levels of preservation, sampling and analytical biases. Broad trends in the number of bones from each species can be identified, and provide a general understanding of the relative importance of each resource type utilised. Broad period comparisons provide comparable datasets to the human stable isotopic investigations, but this does not provide any scope for individuality in the dietary behaviours practiced between different archaeological sites, and is a potential area for future exploration.

The presence of remains in a zooarchaeological assemblage is not necessarily evidence of consumption, as resources can be used or cultural purposes (e.g. whale bone in architecture (Savelle 1997; Mulville 2002), which is a factor that needs considering during interpretation. Similarly the absence of certain resources (e.g. shellfish at Norse Bornais) may be a reflection of recording biases rather than lack of utilisation.

Assessing quantity of foods represented by resources is complex to achieve. Meat weights can give a broad indication of the quantity of meat represented by different resources, but cross-comparing fish, sea mammals and terrestrial mammals is heavily influenced by the preservation and recording biases between these resource types. Determining the relationship of the marine resources to terrestrial resources is a challenge using solely the zooarchaeological remains, but when considering these lines of evidence in light of the stable isotope data from humans and animals it is possible to achieve a more detailed understanding of changes in marine resource use through time. The following chapter discusses some of the benefits and constraints of attempting to integrate these two very different lines of dietary evidence in order to understand past marine resource consumption patterns.

Chapter 10: Discussion: Integrating and Interpreting Stable Isotopes and Zooarchaeological data

Stable isotopes analysis and traditional zooarchaeological analysis are valuable techniques for understanding dietary and economic behaviour in archaeological human and animal populations. In the North Atlantic Islands there has been wealth of archaeological studies based solely on isotopic analysis to understand past diet in the islands (e.g. Barrett *et al.* 2004; Barrett and Richards 2006; Mulville *et al.* 2009; Madgwick *et al.* 2012b, Richards and Mellars 1998; Schulting and Richards 2002a; Schulting and Richards 2009). Similarly, even since the widespread application of isotopic analysis to answer dietary and economic questions, the majority of studies exploring past economies have concentrated primarily on zooarchaeological evidence (e.g. Bond 2007; McCormick 2006; Mulville 1999; Mulville and Powell 2012; Nicholson and David 2007). Criticisms of the Schulting and Richards (2002a) study of the Mesolithic-Neolithic transition in Scotland included the lack of integration of the available zooarchaeological evidence with isotopic evidence (Milner *et al.* 2004), yet despite this critique, few archaeological studies, both within the North Atlantic, and beyond have been undertaken to accomplish this integration.

Further afield in Europe few research projects have integrated isotopic and zooarchaeological data. For example, Boric *et al*. (2004) utilised isotope analysis of both human and animal remains alongside more traditional zooarchaeological methods when exploring the Mesolithic-Neolithic transition in the Danube gorges. Similarly stable isotopic data alongside more traditional zooarchaeological techniques was used to explore dietary behaviour and earlier Neolithic husbandry practices in Northwest Europe (Tresset 2003; Tresset 2000). The dearth of studies integrating these dietary indicators is potentially a reflection of difficulties in reconciling the scales of analysis provided by these different datasets, sample representativeness, data availability, and time/funding limitations. The following paragraphs explore some of the benefits and limitations of using these different lines of evidence, and the methodological approaches that can be used to enhance our understanding of dietary and economic behaviour. The chapter then moves on to explore dietary and economic evidence that cannot be accessed using this methodology, offering potential solutions to the interpretive challenges faced by using these datasets. Understanding the limitations of these datasets is crucial when interpreting past dietary and economic behaviour.

Integrating datasets– temporality

Carbon and nitrogen stable isotope analysis and zooarchaeological evidence relate to different aspects of past dietary behaviour. Stable isotope analysis of bone provides evidence of direct consumption of foods averaged over 10-15 years, the time taken for bone to regenerate (Chisholm *et al.* 1982; Lovell 1986) and is therefore good at identifying longer-term dietary trends (Chisholm *et al.* 1982; Lovell 1986). Zooarchaeological data, on the other hand, provide indirect evidence of consumption patterns but can be highly variable in the temporal resolution represented (Amorosi *et al.* 1996; Meadow 1980). For example zooarchaeological assemblages can represent individual consumption events (e.g. Chomoko 1991), or can be a product of food debris accumulating over extended periods of time (e.g. Grigson and Mellars 1987). Importantly, assemblages can provide an indication of infrequent or occasional uses of marine (or other) resources where isotopic methods are not sensitive enough to do so (Milner *et al.* 2004; Barberena and Borrero 2005). These datasets are therefore complementary in terms of the dietary information that they record, informing on different aspects of past diet.

Unfortunately the benefits of accessing information at these two scales of analysis can also make integration of these datasets difficult as they both represent different aspects of dietary behaviour, and are not necessarily comparable (Richards and Schulting 2006). Indeed some of the insights often appear to be contradictory, and interpretation can be challenging. To facilitate the collating and comparison of a range of archaeological sites from each temporal period over a larger span of time this research has averaged the zooarchaeological assemblages. In doing this it becomes impossible to assess the importance of infrequent consumption of resources. A potential solution is to analyse zooarchaeological assemblages in relation to contextual information, with isotopic values from humans and animals on a site by site basis, to enhance understanding of the relationship between these two datasets. Equally comparative analysis on a phase by phase basis would be invaluable in determining the importance of different resources on a temporal basis. It only by understanding the relationship between these dietary indicators on an individual site level that it is possible to apply these techniques to characterising broader trends in dietary behaviour over wider geographical regions.

Interpreting Stable Isotope Data

How Representative is Bone of Long-Term Diet?

Drawing comparisons between individuals is complex due to differences in the length of time dietary behaviour is recorded in the bone collagen. Bone collagen turnover differs depending on the skeletal element sampled. Studies have demonstrated that in adults between 20-60 years old, ribs have a turnover rate of 4.7% per year, compared to 2% in cortical bone (Snyder *et al.* 1975, 75). Similarly trabecular bone regenerates at a faster rate than cortical bone (Klepinger 1984, 75). Isotopic values achieved from different skeletal elements have potentially different temporal spans, and are therefore not necessarily directly comparable. Studies demonstrate that despite there being a strong correlation between isotopic values observed between different skeletal elements (Sealy *et al.* 2005), which could still account for differences in dietary behaviour when cross-comparing dietary behaviour between individuals (both human and animal specimens), which needs to be considered during analysis.

A further complicating factor is that bulk collagen values represent different periods of time due to differences in bone collagen turnover between different age groups, which can make inter-individual comparisons complex. Small-scale forensic investigations demonstrated that bone turnover for individuals within their 20s was approximately 20 years, whereas for individuals in their 30s turnover was extended to 30 years (Wild *et al.* 2000). Bone turnover rates within younger children are also much higher (100%-200% in their first year of life) (Snyder 1975, 75). A further consideration is that bone collagen is predominantly set down in adolescence, so that changes in dietary behaviour during adulthood are not necessarily represented in the bone collagen record (Hedges 2004). The isotopic record for humans and animals also represents different temporal periods, making direct comparisons between the datasets complex. Similarly fauna in general have much shorter life spans than humans, as they are frequently culled for consumption, and the bulk collagen values of animals will represent a much shorter time span than human isotopic values, making cross-comparisons between species difficult to achieve.

There are a complex range of factors affecting the bulk collagen record, and the temporal scales involved, making comparing isotopic values between individuals complex to achieve. One solution to this difference in turnover rates in future studies would be to undertake compound specific isotopic analysis. Compound specific analysis of amino acids has been recently utilised in archaeological studies as a more enhanced method of investigating past diet to a much finer degree of resolution. Compound specific analysis works by isolating and analysing individual amino acids, counteracting the averaging effect that results from bulk collagen analysis (e.g. Corr *et al.* 2005; Styring *et al.* 2012; 2010; Naito *et al.* 2013). This technique would require additional destructive sampling of human skeletal remains, but it could potentially allow for a more in-depth understanding of marine resource consumption between individuals.

How Representative are Bone samples of Individuals?

The archaeological processes of recovering human remains are highly influenced by burial and mortuary practices, and the visibility of these in the archaeological record. There is great diversity in mortuary practices in the British Prehistoric context. For example the formal act of burial is a mortuary practice that is not bestowed upon every member of a population, and can be linked to the status or hierarchy of the individual concerned (e.g. Milner *et al.* 2004; Parker Pearson 2005; Shanks and Tilley 1982). Similarly disarticulated or co-mingled human remains can be present within archaeological assemblages due to a range of different factors including defleshing, trophy hunting, display, cannibalism, and sometimes taphonomic processes (Outram *et al*. 2005, 1699). Additionally some bone is treated prior to burial. For example, in Britain cremation is practiced from the Neolithic onwards (Barrett 1990). Intense heating alters the C:N ratios (DeNiro 1985) and can cause destruction of collagen, making cremated bone unsuitable for bulk collagen isotopic analysis. This inability to characterise the dietary isotopes of cremated individuals means that part of the population is missing from our isotopic datasets. There are therefore a range of factors affecting the preservation, recovery and analysis introduced by the variations in how human remains are disposed of. Different individuals within a population may have consumed different diets, and analysing just one or two individuals from a given population may not necessarily provide a representative sample, and interpreting diet based on this would not necessarily be accurate.

How Representative are Human Samples of the Population as a Whole?

A critique of using human stable isotope data to explore dietary behaviour is the degree to which any individual specimen available for analysis is representative of the population as a whole (e.g. Milner *et al.* 2004). Formal burial practices, such as the Neolithic individuals placed in tombs such as Holm of Papa Westray (Schulting and Richards 2009) and Quanterness (Schulting *et al*. 2010), have their own challenges. Understanding who exactly was buried in these tombs in terms of the status, ideological beliefs, and identity of these individuals, is a question constantly explored by archaeologists (e.g. Edmonds 1999; Parker Pearson 1999; Shanks and Tilley 1982; Whittle 2003), Chambered tombs potentially reflect only elite members of society (Hedges and Reynard 2007) or individuals buried in Neolithic tombs may represent curated body parts related to ancestral traditions (Edmonds 1999, 61), and therefore may not represent typical dietary behaviour local to the tombs (or even within the islands). If individuals are not local then any comparisons to local faunal baselines, and zooarchaeological assemblages would not be appropriate. Exploring isotopic and zooarchaeological evidence from sites with human remains buried within settlements would allow direct comparisons to be drawn between these dietary indicators. This approach was utilised where possible (e.g. Cladh Hallan; Dun Vulan). However, there is no reason to assume that these individuals were local either, for example the Cladh Hallan composite mummies (Hannah 2012; Parker Pearson *et al.* 2005), and the disarticulated burial of the young boy at Hornish Point (Barber *et al.* 1989), could represent individuals from further afield buried at the sites, which could explain the highly unusual nature of these burials.

Ethnographic accounts have demonstrated that dietary practices can differ depending on social factors. For example in the Tlingit communities of Northwest America high status individuals were discouraged from consuming shellfish, with further variation noted in relation to gender and age (Moss 1993). Determining age and sex from fragmentary human remains is not always possible, so linking whether dietary behaviour is a result of demographics can be difficult. Even within spatially close burials of confirmed adults the individuals analysed are not necessarily contemporaneous, and there may be generational differences in dietary behaviour observed.

Understanding the sector of the population represented by the isotopic analysis of human remains is not always possible, and an appreciation that the dietary behaviour observed may not be representative of dietary behaviour across the entire time period is necessary. Where possible sampling human remains from a range of depositional contexts would enable greater insights into different sectors of the population, and will help to balance out possible biases resulting from taphonomic processes.

How Representative are Faunal Isotopic Samples?

There are similar limitations affecting the representativeness of the faunal specimens selected for isotopic analysis, for example age and sex. To avoid issues relating to age differences, where possible only mature individuals were sampled to prevent enrichment of δ^{15}N values resulting from weaning signatures. This appears to have generally been successful with all unusually enriched nitrogen values on examination deriving from potentially juvenile specimens, normally from radiocarbon dating samples. Whilst this approach enabled geographical characterisation of local δ^{13}C and δ^{15}N values, these values do not help in the reconstruction of human diet if these past populations subsisted on large numbers of juvenile animals. Zooarchaeological evidence from the sites of Cladh Hallan and Bornais suggested that juvenile cattle and deer played an important role in the diet of the communities living at these sites (Mulville and Powell 2012, 247; forthcoming a), so it is possible that any human remains from these sites would be consuming animals with elevations in δ^{15}N values of individuals at the site. Counter to this is the fact that juvenile animals are generally much smaller in size than fully mature animals, and even consumed in greater numbers than fully mature animals their contribution in terms of the quantity of meat that they represented would be lower, and would have less of an impact on the human bone collagen isotopic record. A further aspect to characterise is the importance of milk use on isotopes. Slaughter patterns of animals can be generated to assess the contribution of milk to diet using the zooarchaeological record (Davis 1987; O'Connor 2000; Reitz and Wing 2008). Unfortunately the effect of milk consumption on isotopic values within adult populations is unknown, and interpretations are commonly based on mixed protein diets based on meat and milk consumption (e.g. Richards *et al.* 2006). Comparing pottery residues and animal slaughter patterns with human isotopic values on an intra-site basis would allow inferences about past milk consumption to be made.

A further issue in isotopic analysis is the assumption of full knowledge of the potential range of food species available spatially and temporally when interpreting the isotopic results (Schwarcz 2004). This research draws up zooarchaeological data alongside the isotopic analysis to determine the range of animal food species available to the North Atlantic populations but other food groups have not been considered. Whilst many plants do not have a significant effect on isotopic carbon and nitrogen signatures, the increased consumption of protein-rich plants such as legumes and cereals can result in enriched δ^{15}N being observed within consumers (Southgate 2000a, 336) and full integration with archaeobotanical evidence would therefore be beneficial in understanding the suite of resources potentially impacting on the isotopic record to enhance future analysis.

Characterising Intensity and Duration of Marine Resource Consumption

Understanding the Impact of Marine Foods on Isotopic Signatures

Quantifying the impact of marine foods on the isotopic signature in the bulk collagen record has not yet been achieved. Whilst Milner *et al.* (2004) hypothesise that a diet of up to 20% marine foods can be consumed without any effect being observed in the bulk collagen isotopic record this figure remains only an estimate. Several controlled diet experiments within modern populations have (e.g. Ambrose and Norr 1993; O'Connell 2001; Tieszen and Fagre 1993) enhanced general understanding of the relationship between body tissues and the expression of diet isotopically but do not provide insights into the duration/intensity of marine food consumption required to produce isotopic signatures in the longer-term dietary record. Longer-term feeding experiments would be especially useful for investigating marine consumption on bone collagen $\delta^{13}C$ and $\delta^{15}N$ values. Recent research investigating the effects of diet on longer-term tissues has been conducted by Evershed (pers. comm.) to explore the weaning signature of pigs, and the effects of fish consumption on collagen output. When completed, the results of this experiment will provide a valuable dataset to aid with the interpretation of isotopic analysis. Unfortunately at present it is only possible to estimate the importance of different resources using these techniques.

This research provides an excellent opportunity to reconcile both zooarchaeological and isotopic information. For example, in the Bronze Age deposits, predominantly represented by the site of Cladh Hallan in the Western Isles, fish accounted for around 20% of the total zooarchaeological NISP, but no marine signature was observed in the contemporary human remains from the site. If we accept that all the human remains are chronologically and geographically related to the deposits from which these fish were recovered then fish consumption must have been below the threshold to produce a marine isotopic signature. In the absence of accurate estimates of relative protein contributions of the different food groups it is only possible to state that a fish NISP of over 20% is needed to be consumed in order to produce a marine isotopic signature. Later during the Iron Age in the Western Isles fish bones accounted for around 40% of the total zooarchaeological NISP, and the human isotopic values from Dun Vulan display a small enrichment in $\delta^{13}C$ and $\delta^{15}N$ values. Again given the problems with estimating protein input this research indicates that on sites with a fish NISP of 40% the isotopic signatures observed start to be affected. Further modelling of zooarchaeological and isotopic data within individual sites would be beneficial in characterising the relationship between marine species NISP values and bone collagen values.

Characterising Mixed Diets

Interpreting mixed diets that include marine protein, marine plants and terrestrial protein using the bulk collagen isotopic record can be complex due to the various isotopic inputs (Figure 7 in Chapter 6). Mixing models have been produced that aim to help with the isotopic interpretation of dietary behaviour (e.g. Bocherens *et al.* 2005; Newshome 2004) but criticisms of mixing models are that it can under-represent more commonly consumed foods, and over-represent less commonly resources (Philips 2001, 167). Another concern is that model diets of mixed plant and animal products can be inaccurate due to unequal fractionation of carbon and nitrogen from foods derived from plant and animal tissues by the body (Phillips 2001, 167). Similarly consuming diets that are rich in carbon or nitrogen (e.g. protein-rich diets) can skew the isotopic values observed (Phillips and Koch 2002) which would obviously impact the interpretation of past dietary behaviour. As a result mixing models have the potential to cause inaccurate interpretations of data.

In order to enhance understanding of mixed diets, considering zooarchaeological and archaeobotanical data alongside isotopic data can aid with understanding the contribution of different resource types in diet. Zooarchaeological techniques make it possible to determine the relative proportions of different species present within zooarchaeological assemblages, but relating the zooarchaeological remains to the quantity of protein represented is difficult to achieve (Chapter 9). Meat weight quantifications were attempted however; as previously discussed, calculations based on MNI values are heavily affected by body part representation and can underestimate the importance of each resource type within zooarchaeological assemblages (e.g. Grayson 1973; 1979; Lyman 2008; O'Connor 2000). Meat weight values based on these figures can therefore cause inaccuracies in estimating the available protein available from different species, and their applications in understanding dietary behaviour are restricted to providing insights into general trends in diet.

Also faunal remains are indirect dietary indicators, and the presence of these resources does not necessarily mean that they were being consumed; for example, whale bone can be used to create artefacts, or structures (Savelle 1997; Mulville 2005b; Monks 2005) whilst feathers from birds are also a valuable resource (Bramwell *et al.* 1981). Comparing deposits including non-consumption-based resources with isotopic data that is directly related to consumption can cause inaccuracies, but as broad temporal analysis was used in this period this effect will be diminished, although as discussed previously this technique also has associated challenges.

Relating Archaeological datasets

Relating Inter-site and intra-site data

As discussed in Chapter 4 there are methodological concerns associated with sample representativeness within zooarchaeological assemblages. It is rare that entire sites are excavated, and zooarchaeological assemblages will be skewed as a result of excavation strategies employed (O'Connor 2000, 28; Davis 1987, 29), and are therefore not necessarily representative of the economy at the site. Generating average values of faunal remains for each temporal period enabled a greater degree of comparability within the longer-term isotopic bone collagen record, but this technique dilutes aspects of site individuality, and any unusual or occasional deposits of marine foods would not be visible. A method of solving this challenge would be to analyse individual phases and deposits from sites in order to characterise specific resource use practices. Cross-comparisons between sites would not be possible due to methodological and preservation differences between sites (Chapter 4), although it would be a beneficial technique for providing insights into infrequent, occasional or unusual dietary and economic behaviour. Calculating the densities of each type of zooarchaeological resource in relation to the volume of archaeological deposits would be invaluable in allowing inter-site and intra-site comparisons between datasets to be achieved.

As demonstrated above, analysing human and animal isotopic data in tandem with published accounts of zooarchaeological remains from the same sites to characterise the interplay between diet and isotopic signature is ideal. Unfortunately it is rare that all three datasets are available at any one site due to the highly variable nature of the archaeological record. For example in the North Atlantic Islands, many sites where human burials had been analysed did not have extensive assemblages of faunal remains for isotopic or zooarchaeological analysis. The sites of Westness and Newark Bay highlight this issue. Both are cemeteries, and whilst occasional fragments of animal bones had been sampled to provide an insight into the baseline values (Barrett and Richards 2004; Richards *et al*. 2006), the animals are not necessarily representative of the foods consumed as they are from a funerary, rather than a domestic context. Likewise there were no domestic refuse assemblages from these sites available for traditional zooarchaeological analysis, preventing integration of these datasets. Many of the large zooarchaeological assemblages with a high standard of recording, with good collagen preservation of faunal specimens, did not have any associated human remains available for analysis (e.g. Bornais, Cille Pheadair). Therefore multi-scale analysis was not possible at these sites, and instead period-wide analysis had to be used to allow interpretations to be used. This enabled a suite of isotopic and faunal data to be achieved for cross comparisons. Ultimately it has only been possible to work with the human and zooarchaeological datasets and assemblages currently available, but data from newly excavated sites can be incorporated into this study to further enhance our understanding of past diet and economies.

Applications of Archaeological Residues and Pottery Analysis

There is a high potential for pottery residue analysis to provide further evidence of different resource use alongside available bone collagen isotopic and zooarchaeological data. Residues have been used to trace the development of dairying (Copley *et al.* 2003; Craig *et al.* 2005; Evershed *et al.* 2008), vessel use (e.g. Copley *et al.* 2001; Evershed *et al.* 2003), and more recently to understand the presence of marine foods in pottery (Craig *et al.* 2011; Cramp and Evershed 2013). As part of the wider project organic and absorbed lipid residues were analysed using GC-IRMS from a suite of North Atlantic Island sites from the Neolithic period to the Norse Period as a method of exploring dietary behaviour further (Cramp and Evershed 2013). In particular research focussed on identifying evidence of marine food processing and use of ruminant products. Pottery samples were taken from sites with associated faunal and human remains to enable comparability between datasets (e.g. Skara Brae, Cladh Hallan, Dun Vulan, Jarlshof, Bornais).

Initial results indicate that ruminant dairy fats were present in all pottery vessels, suggesting that milk was a ubiquitously used resource across time (Cramp pers. comm.). Marine residues were limited within pottery vessels, and no Neolithic pots analysed provided evidence of processing in vessels. Marine residues were identified in Norse vessels from Jarlshof and Bornais, demonstrating that aquatic resources were being processed in ceramics at this time (Cramp pers. comm.), supporting the findings from the isotopic and zooarchaeological findings.

A potential problem is that the presence of marine residues in pottery does not mean that marine foods were being consumed and vice versa. For example fish oil could be used to waterproof pottery and ethnographic studies have demonstrated that fish can be smoked or sun-dried on racks, boiled in wooden bowls, and baked prior to consumption (Thoms 2008, 448). Indeed the smaller herring that dominate the faunal assemblages at Bornais have evidence of processing (Ingrem pers. comm.) and could potentially have been smoked prior to consumption and/or traded further afield, as observed in 14th Century Britain (Cuttincy 1955, 71). Unlike the European Ertebølle period, where pottery existed prior to the Neolithic period, with evidence that marine foods were cooked in ceramic vessels (Craig *et al.* 2011), pottery in the North Atlantic Islands was a Neolithic development. Pottery therefore represented a new technological advancement. One could speculate that pottery was only associated with the new foods that were introduced at the same time, and so marine species may never have been processed in Neolithic vessels. Residues from milk, a product that was newly introduced in the Neolithic at the same time as pottery, are ubiquitously found in Neolithic pots (Cramp and Evershed pers. comm.), which supports this possibility.

Another consideration when analysing pottery residues is that different pottery vessel shapes may have been used for the processing of different residues, so the absence of residues may be related to the functional use of pots sampled rather than these foods not being consumed. Sampling a wide range of pottery vessels would be beneficial in characterising resource uses further.

As with isotopic and zooarchaeological techniques, lipid residues only demonstrate a presence or absence of marine resource use, and whilst the use intensity of individual vessels can be demonstrated this does not inform on the quantity, duration or intensity of marine resource use overall. Despite these challenges lipid residue analysis provides an important additional dimension in the understanding of the utilisation of marine resources, and of trends in dietary behaviour, and when combined with zooarchaeological and isotopic results can help with understanding the changing importance of marine resource use in the islands.

Expanding Interpretations of Dietary and Economic Behaviour

Understanding Economic Behaviour

Assessing economic behaviour such as trade can be difficult to access using isotopic and zooarchaeological techniques. The trade of marine foods could have potentially played a role in the North Atlantic Island economies and is crucial to consider, particularly in Norse period Orkney, as some humans did not have marine isotope signatures (Chapter 8), despite fish accounting for around 60% of the total faunal NISP (Chapter 9). The lack of marine signatures in some Norse humans, despite the presence of large quantities of marine foods on archaeological sites, suggests that the North Atlantic Norse populations from Orkney were not all eating these foods, and therefore may have been traded these products instead, which would explain the isotopic and zooarchaeological patterns observed.

Recognising trade using only NISP species proportions by zooarchaeological and isotopic methods is difficult to achieve, and other methodological processes would be valuable in identifying instances of trade. Detailed zooarchaeological studies looking at body part representation, and butchery evidence could be invaluable in identifying possible instances of preparation for export. For example, Barrett (1997) identified head removal prior to salting or preserving, in Norse period Caithness and Orkney. However many species and processes prior to trading do not leave such signatures; for example smoking or pickling and smaller fish may not provide this part representation signature as fish can be processed whole (e.g. herring smoked as kippers), and so they may never be present on archaeological sites as the entire skeleton would leave the site during trade. Historical documents have been used in previous studies to investigate trade in fish products (e.g. Barrett *et al.* 2004; Perdikaris and McGovern 2009), but this technique only works for historic periods, where documentary evidence exists, and therefore has limited archaeological applications. In prehistoric contexts the presence of fishing apparatus such as fish hooks, traps, or net weights, such as the fishing weight identified in block 7.1 at Scalloway (Sharples 1998, 186), could suggest fish trade, in the absence of actual fish bone remains. Alternatively evidence of trade could be potentially identified within prehistoric sites. Identifying traded products could also be a valuable proxy to recognise trade of fish products; for example the presence of non-local materials or artefacts could provide evidence for trade links. Considering the wider corpus of archaeological data would enhance understanding of possible trade of goods further.

Identifying the Importance of Non-Protein Products and Fats

As noted above the isotopic and zooarchaeological methodologies employed in this thesis provide an indication of the importance of marine species and protein to human and animal diets, but they provide little understanding of low or non-protein consumption, for example the role of carbohydrates, plants and fats in diet.

Plant proteins only account for a small proportion of bone collagen protein and are easily masked by the more potent effects of animal proteins such as meat and milk on isotopic values (e.g. Ambrose and Norr 1993; Hedges and Reynard; Howland *et al.* 2003; Tieszen and Fagre 1993). Some plants have the potential to have a greater influence on the bone collagen record. For example pulses are comparatively high in nitrogen, and could potentially produce an enriched $\delta^{15}N$ signature (Fraser 2011), but plants are generally invisible in the isotopic record. Archaeobotanical studies in the islands (e.g. Colledge and Smith 2012) have demonstrated the importance of crop plants, providing insights into the use of carbohydrates that is not possible to access isotopically.

Full integration of zooarchaeological and isotopic evidence with archaeobotanical evidence would therefore provide a more complete understanding of total diet, and the full range of resources exploited by past populations. This requires full interaction between specialists to enable a full assessment of resource use to be achieved. Similar studies have allowed broad economic patterns to be observed in the islands by comparing archaeobotanical and zooarchaeological data with other resources (e.g. Parker Pearson and Sharples 1999; Sharples 2005; 2012; forthcoming), providing a valuable model to work with, and expanding such studies to include isotopic evidence from humans and animals would provide greater insights into past dietary and economic behaviour.

The role of fats in diet using broad zooarchaeological and isotopic methodologies is also not possible. More detailed zooarchaeological analysis can be beneficial in characterising possible consumption patterns. Analysis of faunal assemblages considering bone features such as fragmentation patterns, and fracture freshness (Outram 2001) can and provide information on the use of bone marrow fats, which is not possible to determine using NISP analysis or isotopic evidence. Quantifying the importance of these resources is more difficulties. Meat and fat utility indices can be calculated from bone fragments (e.g. Outram and Rowley-Conwy 1998), providing insights into the quantity of fats available within assemblages, and would enable the importance of dietary fats to be assessed. Similarly, as previously mentioned pottery residue analysis provided evidence of ruminant dairy fat rendering in ceramic vessels, and can also be used to inform on rendering of no dairy fats (Cramp pers. comm.).

Identifying Foddering

Detailed sampling of domestic species has provided information on foddering strategies and valuable information on coastal grazing, in addition to temporal and geographical differences in foddering strategies of animal specimens. Interpreting these signatures using only bone collagen results can be difficult, and a greater understanding of localised environments within the islands to determine possible foddering locations and animal movement strategies is desirable. Sampling a variety of different plant remains for carbon and nitrogen analysis would enable a greater understanding of the contribution of plant food resources to the diets of humans and animals at the sites and inform on the speculated manuring of crops. The approach undertaken by Stevens *et al.* (2013; 2010) analysing terrestrial plant $\delta^{13}C$ and $\delta^{15}N$ values to define locational 'isozones' has demonstrated the potential for plant isotopic analysis to determine where animals were grazing, and would be invaluable in understanding past animal movements in this study. Similarly isotopic analysis of plant remains can be used to understand more about past agricultural processes such as manuring and fertilisation (Bogaard *et al.* 2007; Senbayram *et al.* 2008). Isotopic sampling of plants would be invaluable in aiding with the understanding of past animal management and agricultural techniques.

Assessing the role of marine plants can be achieved using carbon isotopes as marine plants have enriched $\delta^{13}C$ values from seawater carbon sources. Previous isotopic studies have demonstrated evidence of seaweed consumption by Neolithic sheep in Orkney (Balasse *et al.* 2005; 2006; 2009) and in a single Late Iron Age red deer specimen from the Outer Hebrides (Mulville *et al*. 2009). Similarly enriched $\delta^{13}C$ values were observed within herbivorous mammal species as part of this study, and have been interpreted as possible seaweed consumption. Determining if these animals were intentionally fed seaweed as fodder (Balasse *et al*. 2005; 2006; 2009) or were grazing in areas where seaweed was available is not possible to determine using isotopic, zooarchaeological or archaeobotanical methods. Additionally identifying seaweed consumption within species that have a mixed diet, such as omnivores (i.e. pigs and humans), is not necessarily possible, as any enrichment in $\delta^{13}C$ due to marine plants would be diluted by the consumption of other types of resources. As a valuable natural fertiliser there is a further complication in that seaweed can enter the isotopic record indirectly. Further isotopic analysis of plant remains would help to identify whether seaweed was being used as a crop fertiliser. The use of seaweed has been identified by the presence of marine mollusc remains from seaweed-dwelling species, (e.g. *Littorina littoralis* or *Patina pellucida),* within cultural deposits (Bell 1981, 123; Smith 1994). Also dental microwear studies have the potential to clarify whether animals were directly consuming seaweed (e.g. Mainland 2006; 2000). A multi-proxy approach would be invaluable in identifying both direct and indirect marine plant utilisation by animals and humans.

Shellfish Utilisation in the Archaeological and Isotopic Record

Differentiating between the consumption of shellfish and marine protein from fish remains isotopically is very difficult to achieve. Modern reference proteins analysed demonstrated that there was an overlap in the $\delta^{13}C$ values of marine fish, gastropods and bivalves (Cramp and Evershed 2013). Mollusc $\delta^{13}C$ ranges can span -23‰ to -14‰, but nitrogen values are less enriched (Milner *et al.* 2004, 16), and little is known about the effect of these values on human isotopic values. Shellfish have a very low meat/calorific return in relation to the other marine species per individual (Smith 2011), and therefore larger quantities of shellfish would need to be consumed in order to influence the isotopic signature of consumers. Shellfish would have to be eaten in great quantities to produce an isotopic signature.

Characterising prehistoric shellfish use from zooarchaeological remains is also complex. Firstly shellfish use varies dramatically between human populations due to differences in cultural behaviours and environmental conditions (Claassen 1986; Erlandson 1988). Secondly there are a range of taphonomic factors that can affect the presence or absence of shellfish on an archaeological site including both deliberate aggregation resulting from human activity such as consumption, or decoration, such as the perforated shells found at Skara Brae interpreted as shell necklaces (Clarke and Shephard forthcoming), or natural accumulation (e.g. Coles, 1971; Woodman *et al.* 1999). As shellfish of the North Atlantic assemblages are predominantly found within cultural deposits on archaeological sites (e.g. Sharples 2005; 2012; Thoms 2004), their presence in the Outer Hebrides can be directly attributed to human activity.

With regards to consumption, shellfish can be eaten or processed at their location of collection with the shell discarded. Ethnographic evidence from the Meriam, a population of modern shellfish consumers of the Torres Straits in Australia, demonstrated that this group often processed shellfish at 'dinner camp', either eating the shellfish immediately, or transporting the pure meat back to the main settlement sites (Bird and Bliege Bird, 2000, 42; Bird *et al.* 2002, 461). Shellfish deposits can also be a mix of various processes. Interpretations of the Mesolithic site of Isle of Portland suggested that only the larger shells were identified as representing consumption of the organism, with the smaller shells being used for decorative purposes (Mannino and Thomas 2001, 1108). Detailed analysis of shellfish in archaeological deposits can determine whether live shellfish were being specifically targeted as a food source, or if dead beach-deposited shellfish were being utilised for decorative purposes (Thomas 1981). For example valve pairing can be utilised to differentiate between these processes, as freshly collected shells should have roughly the same number of left and right valves (Thomas

1981). Methodologies such as valve pairing would be beneficial in enabling more accurate quantification of shellfish resources.

In the North Atlantic Islands the understanding of shellfish use was impeded by the lack of assemblages analysed. Conducting full analysis of existing shellfish assemblages will be invaluable in calculating shell NISP and MNI values that are currently lacking for many sites across the North Atlantic Islands. Assessing seasonality of shell use would also aid with understanding the role of shellfish to past populations.

Seasonality of Resource Use

Understanding seasonal uses of different resources would be invaluable in furthering the characterisation of past diet and economies in the North Atlantic. Seasonality is useful for understanding trends in shellfish use, to determine if molluscs were being consumed at certain times of the year when other resources were scarce. Shell seasonality can be determined by conducting $\delta^{18}O$ stable isotope analysis to determine the season of death of the limpets (Mannio *et al.* 2003). This as yet has not been conducted for many of the North Atlantic Island assemblages, and would be beneficial in future research in the islands to explore dietary behaviour.

In the Bronze Age Western Isles marine foods accounted for around 20% of the total faunal assemblage, yet none of the skeletons demonstrated evidence of marine food consumption, and it is possible that marine resources were consumed infrequently or occasionally, possibly on a seasonal basis. Exploring seasonal use of resources would be invaluable in aiding with the interpretation of past economic and dietary behaviours. Fish seasonality can be assessed using incremental growth of vertebrae (e.g Noe-Nygaard, 1983; Desse 1983) and otoliths (e.g. Higham and Horn 2000; Smith 1983; Van Neer *et al.* 1993). Assessing the sizes of fish to inform on shoal compositions, could provide insights into seasonality based on spawning seasons (e.g. Ingrem 2005). Further zooarchaeological studies to explore these characteristics within existing archaeological assemblages would be invaluable in determining whether fish were being exploited on a seasonal basis.

Birds can also be exploited on a seasonal basis; for example, sea birds can come to shore to nest, providing a source of meat and eggs for human populations to exploit (Serjeantson 1998; 2009). Evidence of seasonality in birds is available in the form of medullary bone, a calcium-rich deposit found within bird bone cavities during the laying period (Serjeantson 1998; 2009). The presence of juvenile bones can also provide insights into seasonality of exploitation within archaeological sites. New techniques can be used to speciate eggshell using proteomics (Stewart *et al*. 2013), which when combined with knowledge of nesting patterns can provide insights into seasonality of exploitation at archaeological sites. Within the zooarchaeological and environmental assemblages within sites there is extensive scope for additional analysis to explore possible seasonal uses of different dietary resources.

Conclusions

Integrating isotopic and zooarchaeological data is a valuable technique for understanding past diets on both long- and short-term temporal scales. Reconciling isotopic evidence with more traditional zooarchaeological techniques is a significant challenge due to a range of concerns such as sample comparability, differing temporal resolutions, invisibility of certain resources (e.g. plants, carbohydrates and fats), sample representativeness, and analytical biases, among many more challenges. It also remains impossible to accurately quantify the utilisation of marine resources present in human and animal diets using either isotopic or zooarchaeological methods. Despite this challenge, there are several methodological approaches that can be used to enhance understanding.

There are several new lines of enquiry that can be pursued to enhance understanding past dietary behaviour such as feeding studies, isotopic analysis of plant remains, and dental microwear studies. In addition to this in-depth analysis of archaeological deposits from discrete temporal resolutions at individual sites could characterise the frequency and intensity of marine resource consumption; for example analysing contexts within middens, pits and other archaeological features would allow insights into occasional or infrequent patterns of resource consumption.

Exploring archaeobotanical data in terms of the species represented would enhance understanding of the role of plant foods and carbohydrates in diet. Isotopic analysis of wild and domestic plant species would be invaluable in characterising ‘isozones’ to further enhance understanding of foddering locations in the landscape, in addition to manuring practices.

Expanding analysis of existing shellfish datasets to calculate MNI and NISP values will expand knowledge of their use through time, as well as further analysis of zooarchaeological assemblages to explore fragmentation patterns, and possible bone marrow exploitation by past populations. Seasonality of resource use is a further area to explore, particularly when considering use of fish, shellfish, and birds as a resource.

Despite the challenges associated with drawing comparisons between these lines of evidence the integrated approach allows resource use on broad scales and short-term or occasional use to be identified. The following chapter draws these datasets together to explore dietary and economic behaviour further in light of the considerations of integrating these datasets.

Chapter 11: Discussion: Changing trends in Diet and Economy through time in the North Atlantic Islands.

This chapter combines the results of the human and animal stable isotope data with the zooarchaeological analysis relating to the main terrestrial and marine species exploited. Key dietary trends in each temporal period in each island group are drawn together and possible explanations for the patterning observed in the data explored. Due to the low, but consistent utilisation of marine mammals and bird resources through time in the North Atlantic Island assemblages these resources are discussed at the end of this chapter.

Neolithic Marine Resource Use

Orkney

The human skeletal isotope data from Orkney indicates that marine foods were not being routinely consumed during the Neolithic. The zooarchaeological evidence also reflects this, with few fish bones and shellfish remains present within the assemblages. These results are consistent with previous research proposing that marine resources cease to be consumed following the arrival of domesticates to the region (Schulting and Richards 2002a; 2009) and in coastal Britain in general. Domestic cattle and sheep are the main food species in Neolithic Orkney. Ageing evidence from cattle in the Neolithic phases at Pool in Orkney suggests that a non-intensive form of dairying is likely to have been practiced (Nicholson and Davies 2007, 224), therefore both milk and meat would have provided valuable protein sources to these past populations, which is reflected in the human $\delta^{15}N$ values. The differences in $\delta^{15}N$ values between individuals demonstrated that there were differences in the quantity of protein consumed by individuals.

The proportion of fish bones present was small (total NISP 623, 1% of faunal assemblage), but indicate that aquatic resources were utilised in Neolithic Orkney, if only on an infrequent or occasional basis. The fish bones were predominantly from the site of Skara Brae. Trout (*Salmo trutta*) was the most commonly exploited fish species exploited at Skara Brae but could be one of two varieties commonly identified in NW Europe: sea trout and brown trout (Wheeler 1969). These two species are skeletally indistinguishable using morphological traits (Wheeler 1969), and therefore it is not possible to know which species of trout are present from the zooarchaeological remains from Skara Brae. Sea trout and brown trout can be differentiated by their behavioural habits (Wheeler 1969). Sea trout migrate to the sea in the spring to achieve greater growth (Cerón-Carassco 2005, 21), whereas brown trout reside in freshwater habitats, occupying rivers, lakes, locks, streams and burns in Scotland (Mills 1980). Historically sea trout in the Scottish Islands were captured during times of migration using paraphernalia such as nets and traps, such as the tidal traps built over estuaries in South Harris to capture salmon and trout (Calderwood 1906). Seasonal exploitation of migratory fish species during the Neolithic by the early farmers in Europe has been hypothesised by Clark (1948), and it is possible that this was being practiced at the site of Skara Brae. Assessing fish seasonality using techniques such as otolith studies, and vertebral growth (Chapter 10) could be applied to the trout remains from Skara Brae to determine whether fish were being used seasonally as a supplementary protein source at Skara Brae. Occasional or seasonal use of these fish would not necessarily impact on the isotopic signature in the bone collagen stable isotope values of human remains from Orkney.

Marine mammals were present in low frequencies in the zooarchaeological assemblages, and if whale and seal meat was being consumed this was not in sufficient quantities to produce a marine signature in the human bone collagen isotopic record. At Skara Brae the whale bone fragments mostly represent the remains of architectural materials and artefacts (Mulville 2002), which could contribute to the lack of marine isotopic signature in the human bone collagen isotopic values. Excavations during the 2012 field season at the Neolithic site of Links of Noltland on Orkney revealed an in situ beam manufactured from a 7ft long fragment of whale bone (Rice pers. comm.), demonstrating that whale bone was being utilised as a building material elsewhere in Neolithic Orkney. Pottery analysis of lipid residues and surface residues from Skara Brae, Ness of Brodgar, and Quanterness tomb (Cramp pers. comm.) did not provide any evidence of aquatic biomarkers. Thus, even if eaten, marine resources were not being processed in pottery vessels.

Enriched $\delta^{13}C$ values were observed in two sheep specimens and one pig specimen which suggests that these animals may have had access to marine plants (the low $\delta^{15}N$ precludes these signatures from being indicative of marine protein consumption), either being fed them directly, or grazing in areas where marine plants were available. Fine-grained analysis of dental $\delta^{13}C$ and $\delta^{18}O$ isotopic values has revealed seasonal winter seaweed consumption in 5 Neolithic sheep from Holm of Papa Westray (Balasse *et al.* 2006), and a single Neolithic sheep from Point of Cott, Westray (Balasse *et al.* 2009) in Orkney. This practice at more than one site suggests that marine grazing was a common practice in the North Atlantic Islands. The shorefront appears to have been used as a resource by the past populations of Orkney, but only a small proportion of sheep displayed evidence of marine food consumption, suggesting a seasonal use of this coastal resource.

Western Isles

Evidence for marine resource consumption in the Neolithic Western Isles at this time is more limited with zooarchaeological evidence available from just two sites, Northton and Udal North, and no human bone evidence was available. Human isotopic data available from the Inner Hebridean sites of Crarae and Carding Mill Bay suggest that marine foods were not being consumed in quantities sufficient to produce a marine stable isotope signature (Schulting and Richards 2002a). Similarly the faunal isotopic data from the Western Isles indicated that none of the animals analysed were feeding on marine products on a regular basis. Due to the limited datasets it was not possible to accurately assess the importance of marine foods from the zooarchaeological remains, and the low frequencies of fish in the assemblages are potentially a reflection of poor preservation.

The absence of marine biomarkers in pottery residues on Neolithic vessels from Bharpa Langais tomb, and Eillean Domnhuil (Loch Olabhat) in the Outer Hebrides (Cramp pers. comm.) indicates that, as for Orkney, marine foods were not being processed in these vessels and when combined with isotopic and zooarchaeological evidence, suggests that marine foods were not being regularly or intensively exploited in the Western Isles during the Neolithic.

The Use of Terrestrial Mammals

Domestic species, sheep and cattle, dominate the zooarchaeological assemblages in Orkney and the Western Isles. There were higher NISP counts of sheep in both island groups, but when taking into account the relative size of cattle in relation to sheep in terms of the meat represented by each individual, and the evidence from lipid residue analysis of ruminant dairy products in Neolithic North Atlantic Island pottery vessels from the Early Neolithic onwards (Cramp pers. comm.), it is highly likely that cattle would have made an important dietary contribution despite being less numerous. The presence of dairy residues and the implied milking strategies is *contra* Sherratt who suggested that the animal management strategies required for milk production were too advanced for earliest farming populations (1981; 1983). Following the relatively late arrival of the Neolithic to Britain from Europe (Whittle *et al.* 2011), agriculture may have already arrived in Britain in an advanced state, with dairying being a typical aspect of the economy (Copley *et al.* 2005c, 523). The utilisation of dairy products would have provided both a substantial form of dietary protein, during the summer season following a spring birthing pattern (Mulville and Outram 2005), and during these months there would have been little need to exploit alternative resources such as shellfish and fish.

The zooarchaeological evidence also demonstrates that the utilisation of wild resources during the Neolithic on Orkney and the Outer Hebrides is limited; for example, there are lower frequencies of the main wild food species, red deer, observed in this period relative to subsequent periods. The red deer specimens that are observed in the islands during the Neolithic are frequently identified in unusual contextual settings such as the articulated burials at Links of Noltland (Armour-Chelu 1992) and the chambered cairns of Midhowe (Platt 1934) and Blackhammer (Platt 1937a), indicative of utilisation of red deer for possible ritual purposes (Chapter 9). This suggests that wild resources were not necessarily used for food, but played an important non-dietary role, with the Neolithic North Atlantic Island populations having a special relationship with wild mammal resources, using them infrequently, and often for purposes other than consumption. Of the other wild terrestrial mammal species analysed there were 3 otter bones identified within the Neolithic deposits at Tofts Ness (Nicholson and Davies 2007); a further 2 otter bones the Links of Noltland assemblage were identified (Armour-Chelu 1992), with pine marten also being present in the Pierowall Quarry deposits (McCormick 1984). These species are interpreted as being fur-bearing species, used by archaeological populations in the islands for pelts (Fairnell and Barrett 2007), which supports the idea that wild species had an important non-dietary function.

Neolithic Discussion

The observation that compared to their Mesolithic forbears the Neolithic Island communities of the North Atlantic had “turned their backs on the sea to face the land” (Schulting and Richards 2002a, 155) is consistent with the findings of this research with sparse zooarchaeological or isotopic evidence for the utilisation of marine products. Despite being surrounded by a plentiful supply of marine species, the Neolithic people of the North Atlantic Islands appear to have used marine resources on an infrequent basis, subsisting predominantly on the terrestrial domestic species. This change in diet in the islands is linked to the change in lifestyle from nomadic hunter-gatherer-fishers to being farmers, dwelling in permanent settlements, building monuments, and using pottery (e.g. Armit and Finlayson 1992). The reasons behind this change in diet are linked to much wider themes in Neolithic archaeology relating to the nature of the Neolithic transition in Britain, population movements and social change, which are outside the primary scope of this thesis. The evidence in this research can provide insights into dietary and economic behaviour of the Neolithic populations of the islands, but it is not possible to understand the nature of the transition in the islands using this evidence alone, and in-depth analysis of archaeological remains evidence is essential in attempting to address these questions. The following paragraphs therefore introduce some of the wider themes in British Neolithic archaeology, viewing the economic and dietary evidence in light of these arguments.

The British Neolithic is characterised by the emergence of permanent settlements (e.g. Skara Brae), the creation of monuments (e.g. Stonehenge; the Ring of Brodgar), stone tombs (e.g. West Kennet, Maeshowe), new technologies such as pottery and the origins of farming in the form of domesticated plant and animal species (Thomas 2008). The Neolithic therefore marks a distinctive change in economy and lifestyle. The nature of the adoption of agriculture in Europe and the associated dietary and cultural developments in Britain are hotly debated (e.g. Collard *et al.* 2010; Sheridan 2010; Thomas 2004; 2008; Whittle *et al.* 2011).

There is extensive debate as to how the process of Neolithisation in Britain occurred. Bayesian radiocarbon dating of enclosures has suggested that the Neolithic was initiated with small groups of people arriving in southeast Britain from the 4-5th century cal. BC, followed by an increase in the pace of the transition from c. 3,800 cal. BC (Whittle *et al.* 2011). Sheridan (2010) presents a model of Neolithisation based on arrival of settlers from Brittany to the Western Atlantic Façade, based on pottery evidence and artefactual evidence. Further models based on radiocarbon dating evidence of Neolithic sites in Britain have suggested that the transition to agriculture was rapid and expanded from the South of Britain (Collard *et al.* 2010). Despite these differing models of Neolithisation, these scenarios all provide plausible evidence to suggest that the arrival of the Neolithic in the Islands was swift. The change in dietary evidence observed at this time supports the hypothesis of Neolithic populations arriving directly to the islands as suggested by Sheridan (2010). New dating evidence is currently being generated for Orkney to trace the emergence of Grooved Ware pottery, to determine more about settlement, aggregation, and cultural change in the islands (Whittle pers. comm.). This new dating evidence will provide a valuable understanding of the nature of the transition to agriculture in the islands, and will enhance interpretations of past economic and subsistence behaviour.

The dietary evidence from the North Atlantic Island populations makes it possible only to speculate as to how the dietary trends relate to the wider arguments about the Mesolithic-Neolithic transition in Britain. It is possible that the change in dietary behaviour observed is related to economic factors, social factors, ideological beliefs or population movement, as discussed in the following paragraphs.

Economic Factors

A number of economic factors have been identified as affecting Neolithic populations, including changes in the production of homes/tombs, subsistence strategies and population size. The Neolithic in the North Atlantic Islands marks a very distinctive change in the nature of the archaeology represented, from small and fragile lithic scatters of the Mesolithic (Mithen 2000; 2001), or shell mounds such as on Oronsay (Mellars 1987), to the large-scale permanent monuments dominating the landscape as observed in the Stenness and Brodgar region of Orkney (Richards 1996). Neolithic monuments such as Callanish stone circle and Bharpa Langais tomb in the Outer Hebrides, and the Ring of Brodgar, Maeshowe, Isbister and Quanterness in Orkney all provide evidence of large-scale construction works. Building monuments such as these would have required extensive manual labour, and feeding the workforce would have required a surplus to be generated in order to feed the workforce (Case 1969). Sherratt (1990, 149) suggests that large labour forces (potentially 15-20 individuals) would have been required to complete each agricultural cycle of land preparation, crop growing and harvesting, and the breeding and rearing of livestock. In order to produce the agricultural surpluses required to feed a workforce of monument builders, time and energy would need to have focussed on maintaining agricultural productivity. Compared to hunting/gathering/fishing, agriculture provides a maximised return, in addition to minimising food shortage risks (Cohen 2009). The adoption of agriculture in Neolithic communities has been linked to an increase in the size of the population (e.g. Carneiro and Hilse 2008; Kuijt 2000) and a need to maintain production of sufficient quantities of food to feed this increased population. Crops and animals need to be carefully managed and maintained to generate sufficient yields to sustain populations (Bellwood 2005). Therefore there needs to be a level of commitment to agriculture in order for the venture to be successful, and to maximise yields (Sherratt 1990, 149), which may limit the opportunity to undertake activities such as hunting and gathering or fishing. The predominance of domestic species within the Neolithic assemblages from the North Atlantic Islands supports the possibility that agriculture was used in preference to hunting, gathering and fishing to provide the surplus of resources needed to allow the creation of monumental architecture.

Social Changes

The term ‘Neolithic Revolution’, as coined by Gordon Childe (1936), implies that the origins of farming marked a dramatic change in lifestyle. The word ‘revolution’ has connotations of progress and advancement, and it is possible that the North Atlantic communities were immersed in this new way of life, and there was a desire to leave behind the old ways and to embrace the new technology of farming. The creation of monuments has been suggested as a new way of interacting with and viewing the environment, with Neolithic people having an altered perception of the world in relation to their Mesolithic counterparts (Bradley 1998). Exploiting only domestic species may have been a method used by the Neolithic farmers of affirming this new cultural identity. The utilisation of domestic species in Neolithic Europe is potentially linked to the "social value of exotic foods" (Barker 2006, 390), with domestic species being viewed as a new and exciting form of cuisine. The sheep and goats that were common domesticates in the Neolithic did not have an ancestor in Europe (Vigne 2008, 186), and therefore these species would have been exotic in terms of the resources available in the North Atlantic, and therefore utilising these new and 'exotic' species may have been a method of affirming this new found way of living based on agriculture, and permanent settlement. It is possible that there may even have been a perceived stigma against being a hunter-gatherer-fisher in a world where agriculture provided opportunity and progress. Assessing this theory is not possible using only dietary evidence in the islands, and a wider consideration of the archaeological evidence is required, but the switch to almost entire reliance on domestic species could be evidence of social changes at this time, as previously suggested (Barker 2006).

Ideology and food taboos

The lack of aquatic resource exploitation has led some authors to suggest they were the focus of a taboo (Thomas 1993, 70). Taboos have been linked to changed perceptions of the sea resulting from new trends of burying bodies in rivers and the sea and with the consumption of marine products having negative associations with the process of death and aquatic environments (Thomas 1993). On a practical level food taboos are often linked to ideas of hygiene and contamination. Ethnographic case studies indicate that in some coastal communities such as in Fiji certain marine species are considered a taboo for pregnant and lactating women and are probably related to the reduction of levels of potentially harmful toxins in the population (Henrich and Henrich 2010). Food taboos and prohibitions are observed ethnographically within populations, and have been identified as a luxury that can only be afforded in populations that have a plentiful supply of protein (Ross 1978). The zooarchaeological, isotopic and pottery residue analysis from the North Atlantic Islands all suggest that domestic species were providing substantial quantities of meat and milk resources, which would provide sufficient protein supply to enable taboos to be put into practice. However, research suggests that several children from West Voe in Shetland may have suffered from periods of malnutrition, and through using incremental isotopic sampling of teeth, determined that during these times they consumed marine foods (Montgomery pers. comm.); this demonstrates that marine foods were not entirely avoided. The presence of trout bones within the assemblages at Skara Brae also suggests that fish were not necessarily viewed as a ‘taboo’. The zooarchaeological and isotopic evidence therefore does not support the hypothesis that marine food avoidance was the result of a food taboo (Thomas 2003).

Change in Population

The dramatic shift in dietary behaviour may be a result of a change in the Neolithic population with new people settling on islands during this period (Sheridan 2010), a phenomenon hypothesised to be happening in mainland Europe at this time (Tresset 2003; Schulting *et al.* 2002a). Rather than the indigenous populations adopting the new cultural and technological developments associated with the Neolithic, new populations inhabiting the islands from elsewhere may have utilised their pre-existing knowledge and experience of farming (Sheridan 2010). Incoming farming populations may not have had the experience or inclination to exploit marine resources, unlike the previous inhabitants of the islands. The arrival of Norse settlers in Greenland provides a parallel to the Neolithic, as the arrival of this new population coincided with an increase in the use of marine foods in Greenland (Arneborg *et al.* 2012). In the case of the Neolithic the arrival of a new population marks a decline in the use of marine resources in the North Atlantic Islands. Radiocarbon dating of Neolithic sites in Orkney is currently being undertaken by Whittle (pers. comm.), which will provide invaluable insights into the early farming populations in the islands. Combining this information with locational isotopes (e.g. δ^{87}S and δ^{18}O) will further enlighten our understanding of the early populations of the islands. Studies of locational isotopes in Britain from skeletal remains from Monkton-up-Wimbourne in Dorset demonstrated that one individual had moved from the Mendips (Montgomery *et al.* 2000), indicating that there was a degree of mobility in Neolithic British populations.

The most compelling explanation for the shift in dietary behaviour observed in the Neolithic is that the marked change in dietary behaviour in the islands is a result of a change in the populations inhabiting the North Atlantic Islands (Sheridan 2010). Despite the method of Neolithisation in Britain being disputed (Collard *et al.* 2010; Sheridan 2010; Whittle *et al.* 2011), these models suggest that there was an influx of people to Britain during the Neolithic, bringing knowledge of new agricultural techniques. The North Atlantic Islands evidence supports this possibility. For example the immediate presence of ruminant dairy fat residues in the pottery from the earliest Neolithic phases (Cramp pers. comm.) suggests that farming was relatively advanced in the islands at this time. When we combine this evidence with the appearance of monuments and pottery (Sheridan 2010) and lack of continuity in occupation from the Mesolithic, an influx of population during the Neolithic is a highly plausible explanation for the patterns in dietary behaviour observed. The intensity of analysis of pottery residues over such as small geographical area makes for a more compelling argument for the impact of dairying on the early Neolithic populations in the islands than is possible to reconstruct for mainland Britain.

There are a wealth of complex arguments concerning the Neolithic transition in Britain, based on radiocarbon dating, material culture and site densities. The dietary changes observed in the Neolithic could be linked to a new population arriving in the islands (Sheridan 2010), social change, or economic pressure. Understanding these factors requires a thorough understanding of the archaeological evidence available, and the patterns in economic and dietary behaviour are just one aspect of a much wider set of factors.

Beaker Period

Evidence from the Beaker period was limited to Western Isles assemblages from the sites of Northton, Sligenach, and Udal North and no human specimens were available for isotopic analysis to characterise dietary behaviour. So the representativeness of these samples need to be borne in mind. The small numbers and/or low proportion of fish, shellfish, and marine mammal remains at this time indicate that marine foods were not being widely consumed in the Beaker period in the Western Isles. There was also no isotopic evidence of marine food consumption by domestic fauna in the Outer Hebrides, demonstrating that marine foods were not being consumed by animal populations.

As for the Neolithic, sheep and cattle dominate the terrestrial fauna, but with greater proportions of red deer identified in the Beaker assemblages. The larger quantities of red deer identified in the Beaker Period in relation to the proceeding Neolithic Period may be a reflection of red deer having become established in the Western Isles by the Beaker Period, and available in greater numbers to hunt (Mulville 2010), and they may have become a more important dietary component or were increasingly culturally significant. The increase in red deer at this time suggests that wild resources may have been more important during this period. Unfortunately the limited Western Isles assemblages for the Neolithic and Beaker period limit the possibility of drawing comparisons between these periods.

Beaker Period Discussion

The Beaker period in the Outer Hebrides is characterised by the appearance of new decorated pottery vessels in archaeological assemblages (Parker Pearson 2005), but despite this change in material culture, the economic strategies appear to demonstrate a continuation of tradition in of the dietary resources utilised in the Neolithic. As for the Neolithic, there is debate as to whether Beaker activity in Britain is a product of population movement or the transference of artefacts or cultural ideas (e.g. Anthony 1997; Burmeister 2000; Chapman and Hamerow 1997). The archaeological evidence from the North Atlantic Islands is extremely limited, and it is not possible to contribute to this debate with the evidence available. The excavation and analysis of further Beaker period assemblages would be beneficial in aiding with characterising the role of marine resources during this period in the North Atlantic Islands.

Bronze Age

Orkney

The few Bronze Age zooarchaeological assemblages available from Orkney demonstrated that fish were present in limited quantities during this period, and were not a major dietary component. There were greater quantities of shellfish present in the Bronze Age assemblages from Orkney, in comparison to the Neolithic faunal assemblages from Orkney, accounting for around 50% of the total zooarchaeological NISP (Figure 69). The quantity of meat represented by each individual shellfish specimen is small, so that it is very easy to exaggerate the importance of shellfish as a resource based on their occurrence on archaeological sites (Bailey 1975, 45; Meighan 1969).

No human remains were available for isotopic analysis and of the faunal remains sampled three sheep had enriched $\delta^{13}C$ consistent with the consumption of marine plants. Again this suggests that sheep were either independently grazing along the seashore or were being deliberately foddered on marine plants in sufficient quantities to affect the bone collagen record of these individuals. As observed in the Neolithic the shorefront and its resources appear to have played a valuable role in animal management.

Western Isles

The Bronze Age Outer Hebridean zooarchaeological assemblages contained greater numbers of fish bones than observed in Orkney. Accounting for roughly 25% of the total NISP count, fish were a more important resource during this period than in the preceding Neolithic period. The meat weight calculations for Cladh Hallan suggested that fish contributed minimally to the total dietary protein content observed, accounting for only 3% of the total available meat for Middle Bronze Age phases, and less than 1% in the Late Bronze Age deposits. Human specimens analysed from Cladh Hallan had $\delta^{13}C$ and $\delta^{15}N$ values consistent with consumption of terrestrial diets. The presence of fish bones on site, combined with the absence of a marine signature in the human specimens, suggests that marine foods were not being consumed in great enough quantities to produce a marine signature in the bulk collagen isotopes.

One hypothesis for the presence of marine species in the zooarchaeological assemblages in the absence of a human marine isotope signature is that they were used as animal fodder (Schulting *et al.* 2004; Schulting and Richards 2009), for example direct feeding of fish and shellfish to livestock. This is not confirmed by the Bronze Age dataset as none of the fauna sampled in this study showed evidence of a marine protein signature from $\delta^{13}C$ and $\delta^{15}N$. Several of the faunal specimens had enriched $\delta^{13}C$ values consistent with the consumption of plants inhabiting saline environments (e.g. seaweed). This is not observed in all individuals, indicating that different sheep management strategies were being practiced, possibly linked to the age of individuals, seasonal resource availability, or location of sites. This is supported by the great diversity in the isotopic values observed within the sheep specimens analysed. Comparisons of this pattern of animal management to wider Bronze Age animal management in mainland Britain are explored in Chapter 12.

A second possibility is that fish were consumed in small amounts on a regular, infrequent or seasonal basis and this would account for the lack of marine signature (Schulting *et al.* 2004), despite the presence of great quantities of fish bones in the zooarchaeological assemblage. Metrical analysis of Late Bronze Age saithe from Cladh Hallan indicated that they were from smaller specimens, indicative of younger individuals up to 4 years of age (Ingrem pers. comm.). These would typically be caught from shallower coastal areas using line and rod methods (Cerón-Carrasco 2005; Ingrem 2012). Whilst saithe would have been available all year round, the younger saithe are more plentiful in the late summer/early autumn months (Ingrem 2012) and their abundance potentially represents seasonal exploitation of this resource.

If saithe were being fished and consumed directly at this time of year then the implication is that these deposits represent seasonal utilisation of resources. If milking was being practiced in the summer months, assuming a spring birthing season (Mulville and Outram 2005), the exploitation of saithe during the late summer/early autumn breeding season would help to fill the dietary protein gap at the end of the milking season. Another possibility is that fish were caught during summer and early autumn to take advantage of the seasonal availability of the resources, but were preserved and stored (such as by drying) to utilise in the future, and would therefore represent an emergency resource. As for the Neolithic, fish seasonality studies would help to clarify whether fish were being consumed seasonally, or as infrequent consumption events. The large fish bone datasets available from Cladh Hallan would provide a valuable opportunity for further investigations of seasonality in the islands, for example the large assemblage at Cladh Hallan would provide a valuable dataset for fish otolith studies or analysis or growth rings of vertebrae as previously mentioned.

Bronze Age Discussion

Terrestrial cattle and sheep continue to dominate the zooarchaeological assemblages, suggesting that they were the major contributors of dietary protein. The age profiles of the Bronze Age cattle showed that a high predominance of neonatal cattle and older adults is also indicative of a potential milking economy (Mulville *et al.* 2005, 173). The presence of ruminant dairy fats in the Bronze Age pottery in the Northern and Western Isles (Craig *et al.* 2005; Cramp pers. comm.) confirms that dairy products continued to play an important role in the diet of the Bronze Age populations, supporting the findings of the zooarchaeological analysis.

Marine resources were not commonly used in either of the island groups during the Bronze Age. In the Western Isles fish account for a greater proportion of the animal bone assemblage in comparison to Orkney. Whilst overall this pattern is partially a product of increased sample size due to rigorous sampling and analysis of faunal remains at the Bronze Age site of Cladh Hallan, the evidence from this site provides a more in-depth understanding of marine food utilisation during this period. The example of Cladh Hallan therefore highlights the advantages of utilising rigorous sampling and analytical strategies in order to enhance understanding of marine resource use.

Despite the challenges of identifying the total quantity of protein represented by marine resources the presence of almost 20,000 saithe bones from the site of Cladh Hallan demonstrates that fish were utilised to a degree in the Western Isles during the Bronze Age. The absence of a marine signature in the human remains is potentially related to the averaging effect of utilising bulk collagen analysis, so there is a need to utilise techniques such as intra-tooth sampling for isotopic analysis to explore shorter terms in dietary behaviour, such as the recent methodology applied at West Voe (Montgomery *et al.* pers. comm.). The absence of a marine signature in the pottery vessels analysed from Cladh Hallan (Cramp pers. comm.) demonstrates that fish were not being processed in pottery vessels, but this may be a result of non-pottery-based cooking methods being employed. Further work needs to be conducted in order to explore further the fish consumption being practiced at Cladh Hallan during the Bronze Age.

Iron Age

Orkney

Fish remains from Iron Age Orkney are rare. They account for a minor proportion of the total NISP values generated, suggesting they were not a major dietary component. What is of interest is the first isotopic evidence for human marine consumption in a single specimen from Late Iron Age levels at Newark Bay. It is possible that towards the end of the Iron Age there was a move towards the consumption of marine foods and that this individual was not local to the islands. Within the faunal dataset two pigs and one sheep had enriched $\delta^{13}C$ typical of consuming marine plants (e.g. seaweed). This suggests that the shore continued to be utilised in animal management to provide fodder, as observed in the Neolithic and Bronze Age. Overall the evidence for Iron Age marine resource utilisation in Iron Age Orkney is minimal.

Shetland

For the first time it is possible to provide comparisons with Shetland. Here the Iron Age dietary evidence was extremely limited, with little zooarchaeological evidence available to explore the role of marine foods in diet and no human specimens available for analysis to determine dietary consumption patterns. The available zooarchaeological evidence indicated that dietary behaviour in Iron Age Shetland was predominantly focussed on terrestrial resources whilst the few faunal isotopic samples showed no evidence of marine food consumption. Given the dearth of information regarding prehistoric Shetland, future research generating any skeletal material excavated would be invaluable in providing a greater understanding of the role of marine resources in the lives of the Shetlanders.

Western Isles

The evidence for marine food consumption in the Iron Age Western Isles is more compelling and provides an interesting comparison to the Orkney Isles. There is an increase in the proportion of fish bones present in the zooarchaeological assemblages (accounting for roughly 40% of the total NISP count), indicating that fish were a more important resource during this period. Isotopic analysis demonstrated that both humans and animals were consuming marine protein, providing the first direct evidence for consumption in this period in the Western Isles.

Within the mammalian fauna several of the pig specimens from Dun Vulan displayed enriched $\delta^{13}C$ and $\delta^{15}N$ values consistent with the consumption of marine protein. The pig specimens analysed were from the Middle Iron Age broch site of Dun Vulan. This site is situated on a promontory leading out into the sea (Parker Pearson *et al.* 2004; Parker Pearson *et al.* 1999) and the proximity to the sea would provide readily available marine foods for the human and animal communities residing there.

The marine protein signatures may be a result of pigs consuming shellfish, either through self-selection or deliberate foddering. The practice of pigs consuming shellfish and fish has been observed in the islands of Brittany (Cocaign 1999), and has been suggested as a potential food source of wild pigs in the Baltic Mesolithic (Zvelebil 1995). No shellfish data were published for Dun Vulan, but tens of thousands of limpet fragments were recovered from the site (Mulville pers. comm., Sharples 2005a), and could have viably been consumed by pigs. Hedges (2003, 35) suggests shellfish consumption would have a lesser impact on the bulk collagen values observed in individuals, and so the pigs from Dun Vulan would have had to consumed substantial quantities of shellfish to leave behind an isotopic signature.

Molluscs are also hypothesised as having $\delta^{13}C$ values ranging between -23 to -14 due to absorbing elements of terrestrial carbon (Milner *et al.* 2004, 16). Shellfish values therefore are relatively enriched in $\delta^{13}C$ in comparison to other marine species, and consumption of shellfish may not necessarily be reflected in bulk collagen from diet. The enriched $\delta^{15}N$ values observed in the individuals from Dun Vulan in combination with the enriched $\delta^{13}C$ values are therefore indicative of a consumption of food sources higher up the food chain such as fish. Pigs may have been fed waste products such as fish heads, elements that are commonly discarded, but as fish body parts represented at Dun Vulan showed that 49% are from the body, and 51% are from the head (Cerón-Carrasco and Parker Pearson 1999, 281), this seems unlikely based on body part representation. If the pigs were consuming fish then they could potentially have been consuming entire fish skeletons, which would explain the patterning observed in the zooarchaeological assemblages.

In addition to the Iron Age pig specimens with marine signatures there were four human specimens from Dun Vulan, and one human from Cnip with marine signatures as well. The enriched $\delta^{13}C$ values could be either a direct result of humans consuming marine foods, or could relate to human consumption of pigs that had been foddering on marine foods. Gadid species, in particular saithe, dominated the fish bone assemblages at Dun Vulan, and these could have been caught using line and hooks in the vicinity of the broch (Cerón-Carrasco and Parker Pearson 1999, 281). The zooarchaeological evidence is consistent with the findings from the isotopic research, demonstrating that marine foods were being utilised.

Mulville and Powell (2012, 233) on studying Late Iron Age deposits at Bornais suggest that farming practices would have been well developed, with careful animal management needed to protect the limited pastures available on the island of South Uist. Suggested dairying strategies at Bornais are relatively involved, for example keeping milk producing cows near to settlements as a source of milk, whilst keeping the bulk of the herd further away (Mulville and Powell 2012, 233). These involved dairying strategies suggest that agricultural techniques were relatively sophisticated at this time. It is therefore unlikely that Iron Age inhabitants of the Western Isles were eating marine foods purely for survival. Unfortunately there is no evidence from human remains regarding the health of the population, so it is necessary to explore other possible explanations for the increased consumption of marine resources in the Western Isles during this period.

The increased evidence of fish consumption during the Middle Iron Age phases at Dun Vulan may be linked to the function and status of this broch site. The role of brochs in Iron Age society has, particularly in reference to semi-subterranean wheelhouses, been hotly debated by archaeologists, as to whether they were typical domestic dwellings (Armit 2005), or more hierarchical structures (Parker Pearson *et al*. 1998; Sharples 2012). It is only possible to infer the status of the site using dietary evidence but the increased numbers of pigs at the site of Dun Vulan (Mulville 1999; Parker Pearson *et al.* 1998), and the utilisation of marine resources indicate that the site can be differentiated from typical Middle Iron Age wheelhouse sites, and possibly indicative of hierarchical behaviour.

The Iron Age brochs have great social significance in landscapes, as they promote networks of social boundaries within a community (Sharples 2012, 337). Brochs have been identified as possible high status locations in the landscape (Parker Pearson *et al.* 1996), The utilisation of marine foods during the Middle Iron Age at Dun Vulan is potentially an expression of status at the site, as signified by the marine isotopic signatures observed in the bone collagen of humans and animals, and by the presence of marine foods in the bone collagen. Contra to this theory is the marine signature of a single individual from the wheelhouse site at Cnip (Armit and Shapland pers. comm.). It is therefore possible that the individuals analysed at these sites were not necessarily individuals permanently occupying these locations, but instead may have been more mobile fish eaters, which would explain why marine isotopic signatures are not consistently observed in all of the Iron Age individuals from the Western Isles. The human remains from these sites were isolated fragments of human remains, and may not necessarily have been local to the sites, potentially representing non-local individuals, outsiders, or ancestors (Armit and Ginn 2007), which could explain why these individuals exhibit different dietary behaviour.

The use of marine resources in the Outer Hebrides may be a reflection of the Iron Age inhabitants making the most of locally available resources. This is further demonstrated by the presence of large quantities of red seabream at the Late Iron Age site of Bostadh Beach during the Late Iron Age (NISP 7823), though elsewhere red seabream play a minor role in other zooarchaeological assemblages. This strange predominance may indicate that the coast surrounding Great Bernera provided an ecological niche well suited to red seabream. Red seabream spawn between August and October and live as young fish close to the shore in depths of up to 40m (Wheeler 1969; Lythgoe and Lythgoe 1971) and would be a straightforward resource to exploit regularly on a seasonal basis during spawning season. It is possible that the presence of these red seabream are a result of one or more highly successful fishing trips over a relatively short span of time, representing a one-off procurement strategy and consumption event. Further analysis of fish seasonality or size-based ageing techniques would be beneficial in identifying possible capture timeframes and techniques. The isotopic and zooarchaeological evidence demonstrates that marine foods played an important role in the lives of some of the Iron Age inhabitants of the Western Isles.

Iron Age Discussion

The Iron Age is suggestive of the beginnings of divergent dietary behaviour, in particular in the utilisation of marine foods, between the Northern and Western Isles. Where evidence for marine resource use and consumption was available, fish gained importance from at least the Middle Iron Age in the Western Isles. Whilst fish were being also utilised in Orkney and Shetland, they appeared to have made a more minor contribution to long-term diet, due to the lack of marine signatures observed in the isotopic record at the site.

In both the Outer Hebrides and Orkney, the pig isotopic values were highly diverse in comparison to the other periods. The broad ranges of $\delta^{13}C$ and $\delta^{15}N$ values are indicative of a highly varied diet. This is potentially a result of pigs being kept on a small-scale possibly even on a household level, in dwellings away from the broch site, before being taken to Dun Vulan, to be consumed, and being deposited together in the midden assemblage. Pigs have been suggested as a high-status feasting food during the Iron Age (Parker Pearson 1999b), and could plausibly have been reared separately and brought together for specific occasions. Pig have the potential to be highly destructive of the fragile machair environments of the Outer Hebrides (Serjeantson 1990), and keeping pigs away from agricultural land would be would be beneficial in protecting crops growing on the more fragile soils.

These divergent economic strategies employed between the islands could be a result of environmental differences and the seasonal or local availability of certain resources (e.g. red seabream use at Bostadh Beach), or could be cultural differences linked to status and hierarchy. These issues will be discussed further in chapter 13 in relation to wider patterns of dietary behaviour observed in Britain.

Norse Period

Orkney

The zooarchaeological evidence for the exploitation of white fish such as cod, ling and saithe, in Orkney during the Norse period is extensive (e.g. Harland 2006; Barrett *et al.* 2007; Colley 1983a). Despite these large quantities of fish bones present in the zooarchaeological assemblage, only 11 out of the 29 human skeletons analysed from Westness and Newark Bay demonstrate evidence of marine food consumption. A further 18 individuals consume predominantly terrestrial diets. The difference in dietary behaviour between individuals in the Norse period is potentially linked to some individuals being new settlers to the region, and others representing the existing population (Montgomery pers. comm.), suggesting a social element to the patterns in food consumption observed (Chapter 8).

These large quantities of fish bones present, coupled with the absence of a marine signature within some of the individuals from Orkney, may result from extensive trade of fish. Preparation of fish for trade can result in head bones being present within the zooarchaeological assemblages (Barrett 1997). Trade of fish could explain the absence of marine isotopic signatures in humans analysed, despite the presence of large quantities of marine foods in the zooarchaeological assemblage. There is extensive evidence for the trade of dried fish in Norse Orkney based on fish body parts representation (Barrett 1997). The use of fish for domestic consumption has also been identified in Orkney; for example Harland (2006: 591) demonstrated that at Quoygrew the middens contained evidence of fishing for domestic use in addition to waste from commercial processing. Thus not all fish remains were being utilised for trade. Further work comparing the body part representation of fish identified at Norse sites in Orkney similar to the methodologies applied by Barrett *et al*. (2004a; 1999), and Harland (2006) would be beneficial in identifying potential instances of trade versus domestic utilisation of fish remains.

Shetland

There was little scope for analysis of assemblages both zooarchaeologically and isotopically in Shetland due to the poor bone preservation. The presence of a strong marine signature in the bone collagen of the single Norse dog from Jarlshof demonstrated that fish were present at the site. The minimal zooarchaeological evidence from Shetland suggests that marine resources were being utilised during this period due to the presence of fish bones within the assemblages. There is however potential for the dataset for Shetland to be expanded further to include results from recently excavated sites, such as the Norse site at Sandwick on Unst excavated by Glasgow University (Lelong 2007), and the Viking settlements excavated at Hamar, Underhoull and Belmont (Bond *et al.* 2008) contained zooarchaeological remains, which on analysis will provide a valuable dataset for future comparisons.

Western Isles

Zooarchaeological data from the Western Isles demonstrate there was an increase in the number and/or proportion of fish bones present in the Norse assemblages compared to the Iron Age and suggest that fish were a significant resource for the Norse. There was no human isotopic data available from this period, but dogs from both Bornais and Cille Pheadair had strong marine signatures indicating that these individuals had consumed marine protein. As discussed above, this is indicative of fish being plentifully available.

At Bornais Mound 1 larger herring, probably from their third year of growth, dominate the assemblage, with a few smaller individuals being present (Ingrem 2012, 226). As mature herring frequent deeper water (Wheeler 1969) offshore fishing would have been practiced to capture these specimens. Ethnographic accounts indicate that herring are typically caught at night using drift nets and require a team of people, waiting for variable amounts of time, ranging from several days to weeks to capture a shoal (Martin 1995). Thus herring fishing was a significant investment of time and resources with groups of people working together to harvest the herring (Ingrem 2012, 226). Careful scheduling and planning of the herring hunting trips would be crucial to ensure that crops or livestock could be suitably cared for over this period. Ingrem (2012, 226) suggests that the larger white fish represented at the Western Isle sites were caught during the herring capturing expedition, maximising the potential resource output from the trip. This is corroborated by the change in saithe size from the Late Iron Age to the Norse period, indicating a shift from shallow water exploitation towards fishing in deeper waters as part of a bigger group. Further exploration of herring size and age would be beneficial in achieving a more thorough understanding of herring capture and exploitation methods.

The pig isotopic evidence demonstrated that they were consuming marine products, and were potentially being fed fish processing waste. This was observed in several pig specimens from Bornais and Cille Pheadair. The presence of marine-consuming pigs at two different sites suggests that the foddering of pigs on marine foods was not a practice occurring at just one site. Fish must have been available in sufficient quantities for them to have been included into the diet of pigs. Other pigs at these sites had terrestrial omnivorous isotopic signatures, suggesting that different animal management practices were being employed at these sites.

Summary Norse Period

The ‘fish event horizon’ identified by (Barrett *et al.* 2004) as coinciding with the arrival of the Vikings is supported by the zooarchaeological and isotopic datasets, with a great quantity of fish resources being utilised in the Norse period. Human stable isotope data demonstrated that fish were not being consumed by all members of the population. The data presented here indicate that the transition from the Iron Age to the Norse period was not as dramatic as suggested by Barrett *et al.* (2004). In the Western Isles fish were being utilised in greater proportions from the Iron Age onwards, but there is a significant increase in the use of marine resources during the Norse Period.

Similar proportions of fish bones were present in the zooarchaeological assemblages from both Orkney and the Western Isles, demonstrating that fish were an important resource in both of these regions. There are differences in the fishing strategies practiced between the islands, with Orkney having a cod, saithe and pollock focus, with herring being the most predominant species consumed in the Western Isles (e.g. Parker Pearson *et al.* 2005, 145, Ingrem 2005, Barrett *et al*. 2001). This suggests that, as observed in the Iron Age, there are divergent economies employed in these two island groups. There may have been a seasonal element to the fish exploitation strategies used in the islands. Herring are thought to shoal on the edge of the continental shelf to the west of the Outer Hebrides, and in the Minch on the east edge of South Uist during the spring/summer months (Harden Jones 1968). Cod, however, would have been plentiful all year round (Lee and Ramster 1981). The difference in fish species exploited may be linked to seasonal activities, with herring fishing in the Outer Hebrides being focussed on shoal capture during the spring and summer months, and cod exploitation in Orkney potentially being undertaken all year round.

There were also changes in agriculture in the form of greater quantities of pig bones present in zooarchaeological assemblages, suggesting that they were a more important resource at this time, possibly due to more advanced animal management techniques, allowing greater numbers of pigs to be reared without damaging the agricultural land.

As well as changes in animal species there are changes in land management in the Norse period reflected indirectly in the faunal isotopic record and directly in changes in plant species. Isotopic baseline evidence suggests that there is a homogenisation of nitrogen values between the islands. This may be indicative of addition of manure to the soil to increase soil fertilisation and increase productivity in the islands (Jones *et al.* 2012) as discussed in chapter 7. This is mirrored in archaeobotanical evidence across the North Atlantic Islands. At the Norse site of Bornais newly introduced plants such as oats and flax are present in the plant assemblages, which in addition to the evidence from weed taxa suggests that soils were more enriched (Summers and Bond 2012, 339). Similarly Pool in Orkney indicates that flax was being introduced during the Norse Period (Bond and Hunter 1987). These characteristics imply that during the Late Iron Age and Early Norse period agricultural practices were intensifying, and manuring of crops aided the expansion of agriculture during the Norse Period.

In both the Western Isles and Orkney the zooarchaeological data demonstrate there is a change in the shellfish exploitation strategies with the predominant species changing from limpets in the Iron Age to winkles in the Norse period (Figure 75, Chapter 9). There are several possible explanations for this phenomenon ranging from over-exploitation to cuisine preferences to usage.

Milner *et al*. (2007) argue that over-exploitation of limpets occurred in Orkney between the Late Iron Age and Norse period, based on the decrease in limpet size between these two periods. This decrease in limpet size is evident in the Late Iron Age and Norse period assemblages at Buckquoy (Evans and Spencer 1977), and in the 13th-15th centuries limpets were identified at Bornais M3 (Sharples 2005). The decrease in the number of limpets in the zooarchaeological assemblages could be linked to over-exploitation, shifting the focus from limpets to winkles.

Limpets can be used as bait for line fishing, a practice observed historically in Scotland (Fenton 1978). The presence of limpets in earlier assemblages may be linked to their use as fishing bait, but if they were being used as a bait in the Norse period we would not expect to see such a decline in their use during the Norse Period, when there is an increase in fish use. Sharples (2005, 159) argues that ethnographical evidence indicates that waste shells from fishing bait are generally crushed and as there are complete limpet shells at the site of Bornais this suggest they were not used for this purpose and instead were consumed. As it is unnecessary to transport limpets between the settlement sites and the sea shore for use as bait, the large quantities of limpet shells at Bornais (Sharples 2005; 2012; Law pers. comm.), also suggests consumption (Sharples pers. comm.). Additionally as the most commonly represented fish species was herring, which would have been caught using nets (Ingrem 2012; 2005; Martin 1995) it is unlikely that limpets were being used as fishing bait in the Norse period.

The role of shellfish in prehistoric coastal communities has been the subject of great debate, with authors suggesting that they represent a dietary last resort (e.g. Bailey 1975, 1978;

Osborn 1977), and others suggesting that they were a viable option given favourable environmental conditions, with an important role culturally for past communities (e.g. Glassow and Wilcoxon 1988; Perlman 1980; Wickham Jones 2003). The evidence for the utilisation of shellfish remains is restricted in the North Atlantic Islands by the archaeological record and analytical biases, but it is likely that shellfish were being consumed. The dramatic change from the use of limpets to the use of winkles may be related to a change of tastes with the arrival of the Scandinavian settlers during the Norse period. Winkles may have been considered a more palatable resource, and may have been utilised in preference over limpets by the Norse settlers.

The changes in dietary behaviour observed in the Norse period can be attributed to the arrival of the Scandinavian settlers to the previously occupied settlements in the North Atlantic would have presented challenges in terms accommodating new bodies of people in the islands, and managing/introducing new economic strategies in addition to conflict and rivalry between the old and new settlers (Morris and Rackham 1992, Smith and Mulville 2002 and Gammeltoft 2004).

The use of Alternative Resources

The role of Birds through Time

As demonstrated chapter 9 bird bones represent a minor resource for the archaeological populations of the North Atlantic Islands. Wild bird species such as seagulls would represent a low ranking prey item in terms of the meat yielded, and therefore would not have made an extensive contribution to diet. The presence of both domestic and wild species within many of the North Atlantic Island assemblages suggests active procurement of wild species. Large quantities of eggshell were also recovered from the sites of Bornais and Cladh Hallan and have been identified as being from both wild and domestic species (Stewart 2013). Eggs from wild birds provide a valuable source of dietary protein, especially during the nesting season (Baldwin 2009).

Whilst evidence of cut marks suggests that birds were consumed by the past North Atlantic Island populations (Best 2013; Best and Cartledge forthcoming; Best and Powell forthcoming), they have value beyond just consumption and provide a wealth of resources. The historic island community of St Kilda represents a population that relied on bird resources, with a number of accounts exploring the relationship of these populations with sea birds, as they provided a valuable resource for nutrition, clothing, and medicines amongst other uses (Harman 1997; Maclean 1977). The reliance on sea birds observed in St Kilda provides an extreme example of specialised sea bird utilisation, and the archaeological evidence from the North Atlantic Islands demonstrates that unlike the example from St Kilda, they were not being exploited extensively, and only accounted for a small proportion of the zooarchaeological remains through time. Understanding the contribution of marine birds to the diet using stable isotopes would not be possible as many of the sea birds had stable isotope signatures that are very similar to marine fish so are therefore hard to isolate. Zooarchaeological information provides the best insights into bird use in the North Atlantic Islands, and this is the basis for Best (2013) exploring the procurement and utilisation of birds through time in the islands.

The Role of Sea Mammals through Time

Sea mammals are represented in similar minor proportions throughout the entire zooarchaeological record in the islands. The NISPs of whale and seal bones remain consistent throughout time in both Orkney and the Western Isles. Where higher numbers of marine mammals occur (e.g. greater abundance of marine mammals in the Outer Hebrides in comparison to Orkney), these are potentially reflective of analytical sampling methodologies and analytical biases rather than being archaeologically meaningful. The absence of evidence for enrichment in both $\delta^{13}C$ and $\delta^{15}N$ in humans suggests that the whale and seal meat was not consumed on a regular basis, but they may have been an occasional addition to the diet, in addition to being utilised for non-food purposes.

Despite the low frequencies of sea mammal bones identified throughout the North Atlantic Islands, the high rank of whales in terms of the meat yielded by one individual would realistically provide a great quantity of meat for a community. It has been suggested that a sperm whale could provide roughly 25 tons (metric) of meat (Smith and Kinahan 1984, 95), representing a substantial quantity of protein. Aside from having dietary importance, whale bone can be used as a building material, and can be easily worked into artefacts (Mulville 2005, 161; Mulville 2002, 40).

Historically whale bone was used in the Faroe Islands as an alternative fuel source to peat (Annandale 1905), and would have potentially been a valuable source of fuel in the islands given the scarcity of wood. Burnt deposits of whale bone have been found in hearth settings at sites such as A’ Cheardach Mhor, and were interpreted as having fulfilled a functional purpose (Clarke 1960). The importance of marine species is therefore not necessarily linked to consumption of these species. Within zooarchaeological assemblages in the North Atlantic the percentage of burnt whale bone is high, and is frequently associated with hearth deposits (Mulville 2002, 44). The role of sea mammals in the lives of the North Atlantic coastal communities therefore is multi-faceted, and simply determining consumption patterns only goes part way towards reconstructing past uses of marine mammals as a resource.

Marine Mammal Procurement

Determining whether the past communities were actively whaling rather than scavenging carcasses washed up on the shore is challenging given the range of different uses of sea mammals, and the archaeological invisibility of whales on archaeological sites. In the absence of evidence in the form of hunting paraphernalia (e.g. Monks *et al.* 2001), or graphical depictions of hunting scenes (e.g. McCartney 1980), it is difficult to assess if whales were being caught using active or passive methods in the North Atlantic Islands.

Understanding the species present on site can provide insights into active versus passive whaling as certain whale species are more prone to being stranded than others (Mulville 2002). As noted by Mulville (2002) many of the fragments of whale found in the North Atlantic Islands cannot be speciated due to the fragmentary nature of the remains, as demonstrated in Figure 82 and Figure 83 (Chapter 9). New methodologies have been developed to extract DNA from whale bones using relatively small sample sizes (Sinding *et al.* 2012). Similarly Buckley (pers. comm.) can determine sea mammal species from bone fragments using proteomics. Applying these methodologies to whale bone assemblages would be valuable in determining the species of whale present, and therefore would prove to be a useful line of research to explore in the future.

Sea mammals could easily have been procured via beach combing. Trees were, and continue to be, scarce in the North Atlantic Islands (chapter 1). There are few sources of wood for use as building materials and fire, meaning that driftwood would have been the major source of wood, as suggested in the Outer Hebrides (Gale 2005). Beaches would have provided much sought after resources such as drift wood, and whale bone, as noted above, which would have been a valuable architectural material considering the scarcity of trees on the Outer Hebrides, and therefore beach combing would have proved to be a beneficial activity (Sharples 2012). If beach combining was occurring on a regular basis, and marine mammals were being encountered on occasion, this would explain the low but consistent proportions of marine mammals in the zooarchaeological record. Encounter rates of sea mammals on the beach are a regular but infrequent occurrence; for example, in 1990 seven cetacea were found stranded on Lewis and Harris (Angus 1993). The shore would provide resources in the form of marine mammals and drift wood, and scheduling regular reconnaissance trips following such periods would undoubtedly be fruitful.

Summary and Conclusions

The dietary and economic behaviour of past populations changes through time in the North Atlantic Islands, particularly the utilisation of marine resources. Marine mammals, fish and shellfish are present in each temporal period in the islands but there is great diversity in the practices involved with utilising and procuring marine resources. During the Neolithic there is little evidence for the utilisation and consumption of marine foods, suggesting that that they played a minor economic role. During the Bronze Age there is an increase in the utilisation of white fish in the Western Isles, although consumption was below the threshold needed to produce a marine isotopic signature in human bone collagen. Evidence for fish consumption in the Iron Age is more compelling, with pigs and humans in the Western Isles displaying isotopic signatures that provide direct evidence of marine food consumption, supported by increased numbers of fish bone remains in the zooarchaeological remains. Evidence for marine consumption in Iron Age Orkney is more limited, indicating the beginnings of diverging economic strategies between these two regions. During the Norse Period, zooarchaeological evidence suggests that marine foods were being extensively exploited in both the Northern Isles and the Western Isles. The isotopic evidence suggests that some individuals consumed marine food, whereas others did not. There are different economic strategies being practiced between these islands, with white fish (e.g. saithe, cod) being utilised in Orkney, and herring being exploited more in the Western Isles. The utilisation of marine products changes over time. There are differences in how marine resources are utilised in the islands through time, and in the different species of food being consumed, which is potentially a result of differing social, economic, or ideological factors between these two locations. The following chapter compares these patterns in dietary behaviour to those observed in Mainland Britain and Europe, to consider how far the patterns observed are determined by the insular location of these islands.

Chapter 12: Exploring Diet and Economy through time: Wider Regional Comparisons

This chapter takes a chronological approach towards discussing the key themes in marine resource use, animal management, and subsistence identified in this thesis in relation to the wider geographical setting of Britain and Europe. By drawing comparisons to mainland Britain and Europe it is possible to contextualise the patterns observed in the North Atlantic Islands and to understand the impact of environmental and social factors in influencing the dietary and economic practices of past populations.

This discussion is guided by the use of brief case studies from a range of environmental niches within Europe to provide both inland and island comparisons to the North Atlantic, to provide insights into the influence of geographical setting on economic and dietary behaviour. Whilst there are a range of suitable island groups around Britain and Europe that can provide interesting comparisons to the North Atlantic Islands (e.g. Ireland, the Isle of Man), these locations do not always provide zooarchaeological and/or isotopic evidence as a comparison. The following paragraphs therefore centre on a series of studies with comparable datasets to the North Atlantic Islands to explore the diversity in dietary and economic practices between these regions.

Southern mainland Britain is used as a case study to provide an indication of dietary and economic behaviour of inland populations to explore how far dietary behaviour is influenced by the island locations proffered by the North Atlantic. Similarly the populations of mainland Europe are compared to the North Atlantic Islanders to explore the diversity of dietary behaviour observed in the Neolithic, and the breadth of economic practices undertaken at this time. The islands and coastal sites of Brittany are examined, because of their Atlantic location, which would have provided island locations with a similar resource base to the Scottish Atlantic Island populations. Similarly the Northern Atlantic Islands of Scandinavia offer similar resource bases to the North Atlantic populations, and present interesting comparisons for the dietary and economic practices employed at these sites. These brief case studies guide the wider discussion providing comparative datasets to explore how the dietary and economic patterns in the North Atlantic Islands fit with the processes observed elsewhere in Britain and Europe.

Firstly dietary behaviour and marine resource use across the Mesolithic-Neolithic transition in mainland Britain is discussed, to explore how typical the patterns observed in the North Atlantic Islands are, before drawing comparisons to the Mesolithic-Neolithic transition in

Europe, to understand whether the Neolithic marine food avoidance is a product of the environmental challenges of inhabiting island locations, or whether these patterns are a product of the environment niches associated with island inhabitation. Comparisons are then drawn between Bronze Age subsistence and marine resource use in Britain, comparing evidence of marine product consumption, and animal management strategies. Bronze Age island populations of the Isles of Scilly are considered to explore economic strategies between these island groups. The chapter then considers the role of fish in Iron Age British populations, to explore whether there is a link between broch hierarchy, status and control with marine resource use, and whether theories of British Iron Age marine food avoidance (Dobney and Ervynck 2007) are appropriate. The chapter concludes by focussing on the Norse fishing trade and intensification of agricultural practices within other Norse populations based in Britain and Scandinavia. This comparison provides evidence on the extent to which economic strategies practiced in Scandinavia were introduced to the islands or if new strategies tailored to the distinctive environments offered by the North Atlantic Islands were adopted.

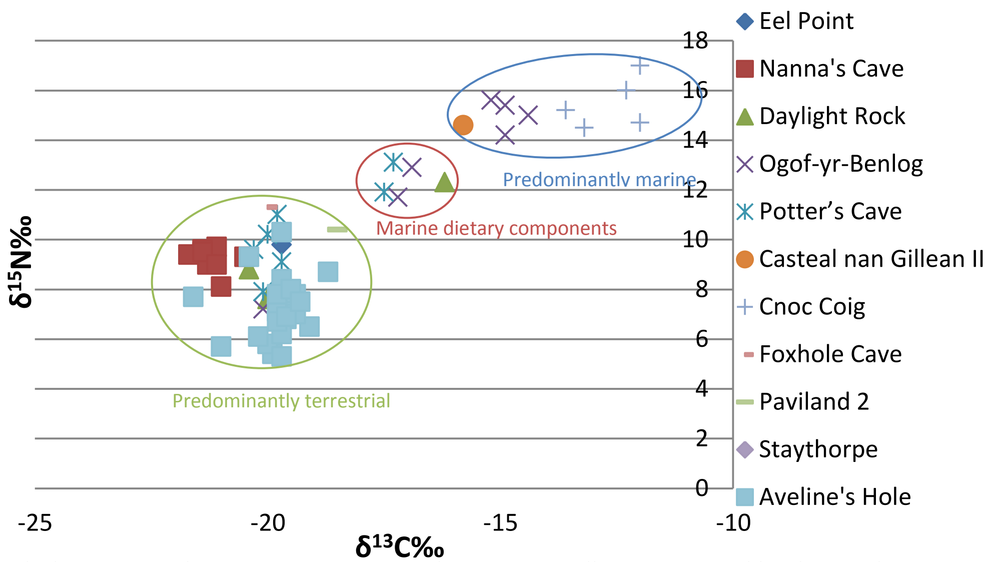
The Mesolithic-Neolithic transition in Britain

Traditionally it has been argued that the Mesolithic population in the North Atlantic Islands were consuming diets rich in marine foods (Grigson and Mellars 1987; Richards and Mellars 1998). The shift towards a predominantly terrestrial diet with the origins of agriculture in the region during the Neolithic therefore marked an abrupt change in diet (Schulting and Richards 2002a). The research conducted as part of this thesis corroborates this argument, with zooarchaeological remains, isotopic evidence and residue analysis indicating that marine foods playing a minor role in Neolithic diet in the North Atlantic Islands. Comparing Mesolithic and Neolithic dietary behaviour within Britain provides an indication of whether the trends observed are localised patterns observed in the North Atlantic Islands or can be observed across Britain.

British Mesolithic Dietary Behaviour

Characterising dietary behaviour during the British Mesolithic is crucial in understanding dietary changes following the introduction of agriculture in the Neolithic, and how representative the ‘marine food avoidance’ model is (Schulting and Richards 2002a). Mesolithic dietary behaviour across Britain has been explored using stable isotope analysis and the results demonstrated that diet was by no means uniform with extensive variation in the proportions of marine and terrestrial foods consumed (e.g. Meiklejohn *et al.* 2011; Richards 2001; Schulting 2005).

Isotopic values of the British Mesolithic skeletons were collated from a range of coastal and inland locations (Figure 92). The dietary behaviour observed falls into three main categories: individuals that consumed predominantly terrestrial diets (circled in green); individuals that consumed predominantly marine diets (circled in blue); and individuals consuming diets including some marine protein (circled in red). This demonstrates that dietary behaviour in Britain during the Mesolithic was highly diverse, with a variety of different diets being consumed. The isotopic values existing from coastal and mainland Britain demonstrate that there was no 'typical' Mesolithic dietary behaviour.



Schulting and Richards 2002a;2002c; Richards and Mellars 1998; Meiklejohn *et al.* 2011;Richards 2001; Schulting 2005

Figure 92: Mesolithic Human Isotopic values: Britain

The individuals with $\delta^{13}C$ and $\delta^{15}N$ values consistent with a diet rich in marine foods (blue circle) were all from skeletons found buried near coastal or island locations, suggesting a focus of resource use in the immediately local area, exploiting fish. The Oronsay midden specimens exhibit the most enriched $\delta^{13}C$ and $\delta^{15}N$ values, indicating high levels of marine food consumption. These values reflect the zooarchaeological composition of the middens associated with the human remains which were composed of huge mounds of shell and sea mammal remains, interspersed with red deer bones (Grigson and Mellars 1987). Four other coastal specimens from the Welsh sites of Ogof-yr-Benlog (Schulting and Richards 2002c) have $\delta^{13}C$ and $\delta^{15}N$ indicative of the consumption of predominantly marine diets. No associated zooarchaeological remains were available for a comparison.

There is a cluster of five individuals (circled in green) from the inland site of Aveline's Hole, and the island site of Nanna's Cave, with stable isotope signatures consistent with the consumption of a predominantly terrestrial diet (Meiklejohn *et al*. 2011). The Aveline's Hole values (Schulting 2005) are depleted in δ^{15}N in comparison to the other Mesolithic samples. These samples were affected by analytical error and are subsequently being reanalysed by the original authors of this research (Schulting pers. comm.). If any marine foods were being consumed by these individuals, it was not in sufficient quantities to affect the isotopic values.

The final group of individuals from Potter's Cave, Daylight Rock and Ogof-yr-Benlog (circled in red) (Schulting and Richards 2002c) all located on Calday Island in Pembrokeshire appear to have consumed diets that included a marine component. Despite their island location the individuals buried in these caves did not have isotopic signatures enriched to the same extent as the Oronsay midden individuals, indicating that they were consuming lesser quantities of marine foods. This could be a result of these individuals regularly moving from coastal locations to terrestrial locations, perhaps guided by the seasonal availability of food sources.

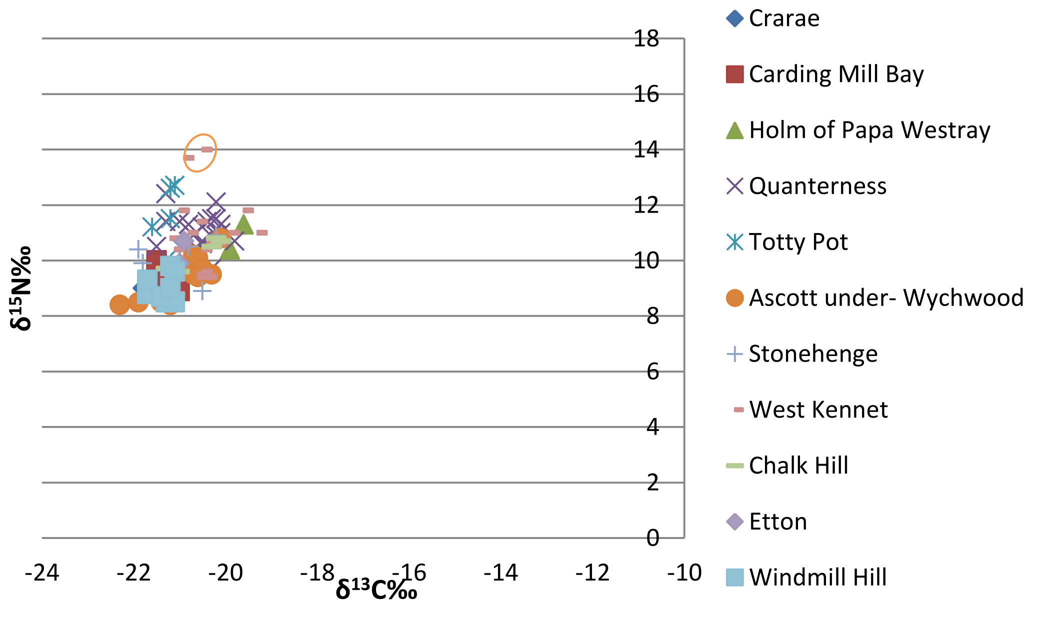
There were differences in dietary behaviour observed between individuals buried at the same site. For example whilst there is a cluster of individuals from Potter's Cave with terrestrial dietary signatures two individuals have isotopic signatures demonstrative of marine consumption. Similarly several individuals from Nanna's Cave also on Caldey Island have isotopic signatures consistent with the consumption of a predominantly terrestrial diet, with other individuals at the site having strong marine signatures. Schulting and Richards (2002b) interpret these individuals as belonging to different social groups, favouring the exploitation of different food sources, which would explain the differences in dietary behaviour observed. These examples highlight the diverse nature of diet in the Mesolithic, with individuals that are buried together exhibiting very different average diets.

Thus, the Mesolithic-Neolithic dietary dichotomy observed in the North Atlantic Islands (Schulting and Richards 2002a; Richards and Mellars 1998) is not applicable to all of Britain. Some Mesolithic individuals were consuming terrestrial products, some were consuming diets intensive in marine foods, and other individuals were consuming small quantities of marine foods. Interestingly several individuals buried in island locations (e.g. Nanna's cave on Calday Island), consumed predominantly terrestrial diets, suggesting that diet in the Mesolithic was highly flexible. The Schulting and Richards (2002a) model is highly specific to the North Atlantic Island, and British Mesolithic diet was much more diverse, potentially reflecting the exploitation of seasonal resources, and foods available in the localised environment. The Mesolithic evidence from the North Atlantic Islands is dominated by the faunal assemblages from Oronsay, and therefore potentially represents just this group's behaviour, and is not necessarily representative of dietary behaviour across the North Atlantic Islands. Recently Mesolithic sites at Tràigh na Beirigh, Northton, and Teampuil Bágh, Cnip (Blake *et al.* 2011a; 2011b) have been investigated, which has the potential to further inform on Mesolithic dietary behaviour in the Western Isles.

British Neolithic Dietary Behaviour

The arrival of agriculture in the British Isles dramatically changes dietary behaviour observed in both the zooarchaeological and isotopic records. The introduction of domestic species identified at sites across Britain (e.g. Serjeantson 2011) provided a brand new set of resources used in preference over wild species that had previously dominated diet in the preceding Mesolithic.

The existing Neolithic human δ^{13}C and δ^{15}N values available from Britain demonstrate that dietary behaviour is in general more homogenous than in the preceding Mesolithic period (Figure 93), with all individuals exhibiting terrestrial diets. Additionally all of the individuals with isotopic data available from Neolithic Britain have isotopic signatures consistent with the consumption of an almost entirely terrestrial diet. There is no distinctive difference in the isotopic values of the North Atlantic Island populations in relation to the rest of Britain, suggesting that similar dietary practices were being undertaken in the North Atlantic Islands alongside mainland Britain.



(Bayliss *et al.* 2007;Hamilton and Hedges 2011; Hedges *et al.* 2003; Hedges et al. 2007; Meiklejohn *et al.* 2011; Parker Pearson *et al.* 2010; Schulting and Richards 2002; Schulting and Richards 2009;)

Figure 93: Neolithic Human Isotopic values: Britain

There are differences in the $\delta^{15}N$ values observed between individuals, indicative of variability in the quantities of protein consumption within the Neolithic population of Britain. For example, the individuals from Totty Pot were consuming more protein that the individuals from Ascott-under-Wychwood. The two individuals from West Kennet (circled in orange) with enriched $\delta^{15}N$ values, were juvenile skeletons (Bayliss *et al.* 2007), and may be affected by nursing signatures.

The Neolithic populations of the North Atlantic Islands have isotopically similar diets to specimens analysed from mainland Britain, subsisting predominantly on terrestrial products. The predominance of domesticates in the faunal assemblages in Southern Britain (e.g. Serjeantson 2011; Tresset 2003), suggests that dietary behaviour was predominantly focussed on farmed animals, rather than wild species, a pattern consistent with that in the North Atlantic Islands. The predominant difference in dietary behaviour in the Neolithic relates to differences in protein consumption between individuals, demonstrated by the difference in nitrogen values between individuals.

The importance of Domestic Species

Of the domestic species represented in the North Atlantic Islands sheep and cattle dominate the assemblages, indicating that they made a major contribution to diet. Pottery residue analysis suggests that dairying formed an important part of subsistence in the Neolithic in Southern Britain (Copley *et al.* 2005c). This characteristic was also observed in the Neolithic vessels from the North Atlantic Islands (Cramp pers. comm.) and demonstrates that milk and milk products were an important protein source across the British Isles.

Pigs represent a less important resource in the North Atlantic Islands compared to mainland Britain. The zooarchaeological evidence (chapter 9) demonstrated that in the islands pigs accounted for the minor proportion of domestic species in the Neolithic period (<1%). In Southern Britain pigs are identified as a common feature of Neolithic assemblages (Tresset 2003), and account for around 20% of the main domesticates during the Early-Middle Neolithic (Serjeantson 2011, 26). Similarly lipid residues from Grooved Ware pottery in Southern Britain contained high quantities of porcine fats, indicative of pigs being processed in these vessels (Mukherjee *et al.* 2008). In contrast pottery analysed from Neolithic Orkney contained no evidence for porcine processing in the vessels, suggesting that pigs were less important in the islands than observed elsewhere in Britain (Mukherjee *et al.* 2008). The lower levels of pig exploitation could be related to the fragile agricultural environments of the islands being more susceptible to damage from rearing pigs (Serjeantson 1990), which could explain why they were not used to the same degree as mainland Britain.

Neolithic Atlantic Island Comparisons

Comparisons to other island groups can help to determine how far dietary behaviour is determined by the insular locations that they occupy. Evidence of Neolithic dietary behaviour in British island populations is limited and as mentioned above the earliest substantive evidence for faunal exploitation comes from Early Bronze Age assemblages on the Isles of Scilly (Johns *et al.* 2012). It is therefore necessary to consider dietary evidence from Neolithic islands in Europe to determine whether the marine food avoidance observed in the Scottish North Atlantic Islands is typical of early farmers inhabiting insular environments. These comparative dietary studies in Europe are also limited in scope, although there is dietary evidence available from island groups in Brittany and Scandinavia to enable comparisons to the North Atlantic Islands.

Isotopic studies have been undertaken to investigate Mesolithic and Neolithic dietary behaviour in the islands of Hoëdic and Téviec off the coast of Brittany, with some individuals demonstrating evidence of marine food consumption (Schulting and Richards 2001). Challenges in dating resolution prevented the Mesolithic and Neolithic skeletons from being differentiated and it was not possible to determine which individuals were consuming marine products (Schulting and Richards 2001). The isotopic evidence is therefore inconclusive, and there is scope for further analysis of the skeletons from Hoëdic and Téviec in the future.

Zooarchaeological evidence from coastal Brittany provides a clearer understanding of dietary behaviour during the Neolithic. Faunal assemblages from the island site of Ponthezières, and the nearby coastal site of La Sauzaie in Brittany were dominated by terrestrial faunal remains, accounting for between 80-90% of the total faunal assemblage (Braguier 2000; Laporte *et al*. 1998), indicating that marine foods were not being commonly utilised at these sites despite their insular and coastal locations, which is consistent with the zooarchaeological and isotopic from the North Atlantic Islands. A possible explanation for this pattern in resource explanation during the Neolithic is that populations were occupying some coastal locations for purposes other than the exploitation of marine resources. Coastal and island sites provide natural barriers for the containment of animals, and potentially allow for greater control of animal ownership (Schulting *et al.* 2004).

In contrast faunal remains from the island site of Er Yoh in Southern Brittany terrestrial species dominate the zooarchaeological assemblage, with sheep and cattle alone accounting for 80% of the faunal remains, but seal bones were present in greater numbers, accounting for approximately 9% of the faunal remains present. This suggests that in addition to agricultural techniques, these populations were specialising in the exploitation of seal at the site (Boyle

2002). This specialisation was not observed at the sites of Ponthezières or La Sauzaie despite their proximity to Er Yoh, suggesting that there is a high degree of variability between small geographical regions. This demonstrates that whilst domestic resources were the predominant food source across the region, the population of Er Yoh were maximising their resource base, exploiting seals alongside domestic stock. Marine resources were being used by some Atlantic Island populations during the Neolithic, and the Scottish Island populations are not necessarily typical of dietary behaviour across Europe.

To the North of the Scottish Islands, dietary evidence from the larger islands off the coast of Scandinavia show different patterns in dietary behaviour emerging within Neolithic populations. Isotopic analysis of Pitted-Ware burials from the site of Västerbjers on Gotland demonstrated that these Neolithic individuals were exploiting seal meat in addition to practising agricultural and pastoral techniques (Erikkson 2004), suggesting that these two very different economic strategies were being practiced successfully at the same time. Similarly isotopic analysis of skeletal remains from the island of Öland demonstrated that marine foods were being consumed during the early Neolithic, but by the Late Neolithic isotopic evidence indicated an almost entirely terrestrial diet (Erikkson *et al.* 2008). The evidence from Öland suggests that marine foods continued to be utilised until farming had become fully established in the island. These two examples demonstrate that despite having the capability to rear animals and to produce crops these island populations chose to subsist by exploiting marine resources in addition to utilising domestic species. The Mesolithic-Neolithic boundary is blurred in parts of Europe, and whilst domestic species are exploited, several island groups demonstrate evidence of marine exploitation.

The dietary behaviour in Atlantic Europe is highly complex, and over a relatively small geographical area there is great diversity in the economic strategies practiced during the Neolithic. There are two main economic strategies evident within the Neolithic island populations of Europe; the Scottish Islands and several of the coastal and island sites in Brittany demonstrate limited utilisation of marine resources, whereas on the Scandinavian islands, and at Er Yoh in Brittany there is evidence of specialisation in marine food exploitation alongside more traditional agricultural strategies. This could be related to the timing of the arrival of agriculture to the North Atlantic Islands, as the ‘Neolithic package’ appears in Britain much later than in parts of mainland Europe with some of the earliest domestic cattle and sheep identified in mainland Britain at Ascott-under-Wychwood at around 4000-3900 cal. BC (Whittle *et al.* 2011, 870), compared to 5400 cal. BC in temperate Europe (Bellwood 2005, 74). Complex agricultural techniques such as milking may have already been developed (Copley *et* *al.* 2005c; Salque *et al.* 2012), and there would have been less of a necessity to continue to exploit marine resources.

Mesolithic-Neolithic transition in Mainland Europe

Dietary behaviour across the Mesolithic-Neolithic transition has been a major focus of interest in Europe resulting in a wide range of isotopic studies being conducted. Pioneering isotopic studies such as the work by Tauber (1981) analysing human δ^{13}C values of human skeletons demonstrated that Neolithic individuals from coastal Denmark were consuming terrestrial foods, with their Mesolithic counterparts consuming a diet of predominantly marine foods. More recently this Mesolithic-Neolithic dichotomy has been challenged (e.g. Borić *et al.* 2004; Craig *et al.* 2011), and a greater complexity in dietary behaviours within Mesolithic and Neolithic populations is emerging.

Studies have suggested that in mainland Europe the Mesolithic-Neolithic transition was an extended process, with gradual acculturation by the indigenous Mesolithic communities to the new ways of farming (Tresset 2003, 19). This concept of more gradual acculturation has been observed in patterns of dietary behaviour, for example analysis of lipid residues from Neolithic Northern Europe has demonstrated that fish were being processed in pottery vessels (Craig *et al*. 2011). This indicates that marine resources were being utilised at some level in this region even after the adoption of agriculture.

Isotopic analysis of Mesolithic and Neolithic individuals in Southern Sweden demonstrated that within both time periods both terrestrial diets and marine diets were being consumed (Lidén *et al.* 2004, 31). The fluidity in the dietary behaviour observed in Southern Sweden has been attributed to the geographical locations inhabited by these populations, rather than resulting from any cultural or temporal affiliations (Lidén *et al.* 2004, 31). This interpretation would explain the patterning of marine resources observed throughout Europe, where different cultural groups of Mesolithic and Neolithic people have been observed to be both consumers and non-consumers of marine resources. Traditional interpretations of fish exploitation patterns in the Neolithic are that these populations took advantage of the seasonal spawning of different species (Cerón-Carrasco 1998). The trout bone assemblage identified at Skara Brae (Chapter 9) is potentially indicative of seasonal exploitation of aquatic resources, albeit on a much smaller scale than observed in mainland Europe. The pattern of gradual adoption of agriculture is not restricted to Northern Europe. For example δ^{13}C and δ^{15}N analysis of humans and fauna in the Danube gorges demonstrated that Neolithic individuals from Lepenski Vir had isotopic signatures consistent with the consumption of freshwater fish (Borić *et al.* 2004; Cook *et al.* 2001). Zooarchaeological evidence from the same site demonstrated that freshwater fish were present in large quantities within the assemblages with catfish, pike and carp identified in Mesolithic and Neolithic horizons at Lepenski Vir (Bartosiewicz *et al.* 2008, 46). More recently $\delta^{34}S$ isotopes confirmed that aquatic foods were being consumed by the Neolithic populations of the Danube Gorges (Nehlich *et al.* 2010). The distinctive environmental niche of the Danube gorges region would have provided valuable resources in the form of freshwater fish, and their ready availability would have made this food source an attractive food source to these people. The zooarchaeological and isotopic evidence from Lepenski Vir demonstrates evidence of hunter-gatherer populations adopting elements of the Neolithic lifestyle, whilst retaining a predominantly 'Mesolithic' lifestyle. Strontium evidence from Lepenski Vir has demonstrated that there was a degree of mobility during the Early Neolithic (Borić and Price 2013), which is counter-intuitive to typical perceptions of settled Neolithic lifestyles, potentially explaining this exploitation of wild resources.

The dietary choices made by Mesolithic and Neolithic populations in Europe appear to be closely linked to their geographical situation and the localised resources offered by these environments. Agriculture provides a more secure diet than hunting, gathering and fishing which is heavily affected by seasonality and weather conditions, and results in less flexibility in dietary behaviour, but provides a greater security in diet (Helms 2004). The Neolithic inhabitants of the North Atlantic Islands therefore may have focussed on agriculture to provide greater dietary stability. Ethnographically there are examples of North Atlantic Island populations integrating farming with procurement and utilisation of wild resources. The populations of St Kilda in the Outer Hebrides made extensive use of bird resources, and actively fished, despite farming being part of the lifestyle of the islanders (Maclean 1977). The St. Kilda example demonstrates that it was possible to exploit wild and domestic resources successfully in the environments of the North Atlantic. The change of diet observed in the Neolithic populations of the islands is therefore more likely to be a product of social or cultural factors, rather than being influenced by the environment.

Mesolithic-Neolithic transition Summary

Neolithic dietary behaviour is observed differently across Europe. The North Atlantic Islands populations cease to utilise marine resources during the Neolithic, but in many areas of Europe marine foods continued to be utilised alongside agricultural processes. Borić (2005, 17) suggests that the term transformation is more suitable than transition when considering the change between Mesolithic and Neolithic identities, as it suggests a more dynamic, multi-directional process rather than traditional opinions of progression and enhancement, providing a better description of the events observed in Neolithic Europe. In the North Atlantic

Islands, however, the process of change between the Mesolithic and Neolithic is much more abrupt, with a distinct change in dietary behaviour between these two periods.

Beaker Period

The dietary evidence from the Outer Hebrides suggests that there was an element of continuity in dietary behaviour between the Neolithic and the Beaker Period. Beaker period dietary evidence in Britain to date is limited. A series of individuals are currently under analysis as part of a wider project investigating dietary behaviour in Britain during the Beaker Period, and initial results indicate that the British Beaker specimens have typically terrestrial diets (Jay pers. comm.). This is consistent with the zooarchaeological evidence from the Outer Hebrides, which was predominantly terrestrial.

Evidence of Beaker activity is not consistently observed in Europe, and Beaker-associated artefacts appear sporadically at sites (Price *et al.* 2004). Trade, population movement, and transference of cultural ideas are all possible explanations for the appearance of Beaker vessels (Anthony 1997; Burmeister 2000; Chapman and Hamerow 1997). The evidence of Beaker diet is therefore limited, and it is only possible to hypothesise as to the role of North Atlantic diet in the wider Beaker migration and cultural transfusion debate. The dietary evidence from the Outer Hebrides supports the hypothesis that the presence of Beaker evidence was a result of transmission of material culture; for example the faunal isotopic values were consistent between the Neolithic period and the Beaker period, indicative of similar animal management strategies being employed in these two groups. The similarities in the zooarchaeological assemblages between these two periods also suggests that diet between these two periods was virtually identical, indicating that there is little diversity in the economic strategies being practiced between these periods, and potentially outside influences were minimal.

Bronze Age

The Role of Marine foods in Bronze Age Britain

In the Outer Hebrides fish bone remains accounted for around 20% of the total zooarchaeological NISP observed, but they were not being consumed in sufficient quantities to influence the bone collagen isotopic values of humans analysed. Comparable regional studies of diet in Bronze Age diet are limited, but zooarchaeological research investigating general trends in Southern Britain demonstrated that fish were only present in 21% of Bronze Age assemblages (Hambleton 1998, 24). No further quantification of remains was available;

however, the low frequency of occurrences of marine species at these sites suggests that fish were not a common dietary feature. Of the sites with fish remains present, those situated inland contained a predominance of riverine species, and coastal sites were predominantly utilising marine species (Hambleton 1998, 24), indicating that these populations were using locally available resources, which is consistent with the use of saithe in the Outer Hebridean assemblages from the Outer Hebrides. The low occurrence of marine foods at archaeological sites in southern Britain is more consistent with the assemblages from Orkney, where fish remains accounted for less than 10% of the total NISP. The Outer Hebridean assemblages, however, indicate that fish made a greater dietary contribution in this region.

The presence of fish bones on the Bronze Age sites could be a result of fish consumption during times of hardship, for example when crops failed, or if animals were not thriving, and would explain why they make a minor contribution to the assemblage, although if this was the case we would not expect this pattern to be observed in earlier periods also, suggesting that other explanations may be more feasible. Another possibility is that fish were only utilised on special occasions, such as during feasts or celebrations, but were not necessarily a common feature of diet. Fish consumption on a ceremonial level has been identified in archaeological populations (e.g. Fiore and Zangrando 1996), and is a plausible explanation for the patterning observed in the fish bone evidence from Bronze Age Britain. Further exploration of fish seasonality, and in depth analysis of the archaeological contexts surrounding fish remains would be beneficial in enhancing understanding of the circumstances surrounding the utilisation of mariner resources, and why they are present on archaeological sites without impacting on the human bone collage isotopic values.

Bronze Age British Island comparisons

Comparative zooarchaeological data from Bronze Age Island sites in Britain are also limited. Dietary information was available from the site of Nor-nour in the Scilly Isles and this provides a useful comparison to the North Atlantic Islands of insular economic practices in Britain.

Zooarchaeological remains from the Late Bronze Age and Early Iron Age phases from Nor-nour demonstrated that marine species are thought to account for less than 20% of the total protein content of diet (Johns *et al.* 2012; Turk 1978). Seal bones outnumber the number of cattle bones identified, with burning observed on high proportions of the seal specimens, indicating that they may have been utilised as a fuel on account of the high fat content of blubber (Turk 1978). Grey seal are thought to have been hunted during the autumn when they came to shore during the breeding season, with occasional cetacean being recovered from beach stranding (Johns *et al.* 2012), seal therefore may have been exploited seasonally.

The faunal remains from Nor-nour suggest that the importance of marine mammals at the site was potentially related to their value in providing oil, and seals were being actively hunted at the site for this purpose. In contrast at the North Atlantic Island sites sea mammals are utilised in consistently low frequencies, indicative of stranding rather than active procurement of marine mammals, with whale bone been utilised to make artefacts (e.g. Mulville and Powell 2012; Mulville 2002). Breeding populations of grey seals are present in North Rona in the Outer Hebrides, (Twiss *et al.* 1994), and around Oronsay and Colonsay (Hewer and Backhouse 1960) among other areas of the Scottish coast, demonstrating that the difference in exploitation between the two British island sites is not a result of resource availability. The function of seal as fuel resource appears to have been the driving mechanism behind exploitation in the Scilly Isles, whereas in the North Atlantic Islands the populations were not as dependent on the use of sea blubber as a fuel, and therefore did not exploit them to the same extent. These island groups both have similar resource bases. The differing resource exploitation patterns appear to be a result of the intended function or purpose of marine species. These two island groups are very different in size, and have differing opportunities for agriculture, which influences the dietary and economic processes undertaken by these past populations. The site of Nor-nour appears to have been a specialist sealing site, focussing on the exploitation and use of seal. This is not observed in other Bronze Age assemblages within the Isles of Scilly; for example at the site of Halangy Down was dominated by domestic species, with some fish and bird remains evidence (Locker 1983). Despite being from the same island group at Halangy Down, seals were not being to any great extent, suggesting that the site of Nor-nour was specialising in seal exploitation. The seal exploitation patterns observed at the site of Nor-nour are similar to the Neolithic Island site of Er Yoh in Brittany which also focussed on the exploitation of seal in addition to domestic species (Boyle 2002).

European Island Comparisons

Few dietary studies of Bronze Age island sites for comparison in Europe exist to provide an additional comparison. The analysis of Bronze Age individuals from the sites of Kalleguta, Vickleby, Torsborg, Resmo and Algutsrum on the island of Öland revealed isotopic signatures consistent with the consumption of predominantly terrestrial proteins (Erikkson *et al.* 2008). This is consistent with the Bronze Age isotopic evidence from the sites of Cladh Hallan and Northton. Unfortunately zooarchaeological analysis at the Öland island sites has not been conducted, so further comparisons with Scottish North Atlantic Islands are not possible.

Bronze Age Animal Management Practices in Britain

One of the striking aspects of the Bronze Age faunal isotopic analysis from the North Atlantic islands was the diversity in the values observed, indicative of variability in the foddering strategies practiced. In the only review of faunal isotopic studies available from the Late Bronze Age, the sites of Potterne and Llanmaes in Southern Britain demonstrated diverging foddering strategies within both sites, and this was observed in both omnivorous and herbivorous species (Madgwick *et al.* 2012). The Bronze Age animals analysed from the Outer Hebrides displayed a similarly broad range of isotopic values in both the herbivorous and omnivorous species analysed.

The diversity in Bronze Age faunal isotopic values observed suggest that there is little consistency in the foddering choices at this time. Such diversity in isotopic values would not be expected from specialist production of larger herds (Madgwick *et al.* 2012), suggesting animal management was taking place on a smaller scales. The animal management practices observed could be linked to animal ownership, with different people foddering their animals in different locations, resulting in broader ranges of dietary behaviour, and thus a greater level of variation between the isotopic values observed. This has possible social implications for the organisation of Bronze Age societies, implying localised practices of animal management.

Elsewhere isotopic investigations of Bronze Age sheep specimens from the Severn Estuary demonstrated that these individuals were being grazed on salt marshes (Britten *et al.* 2008). The isotopic values of several of the sheep from Cladh Hallan suggested that they too had access to marine plants, potentially foddering in coastal locations such as the shore front. The practice of foddering animals in coastal pastures was therefore not a feature specific to the North Atlantic Islands, but was being followed in other areas of Britain (e.g. Britten *et al.* 2008). Salt marsh grazing and coastal pasturing could have been practiced as a method of keeping control of livestock, with the natural barrier of the coast to prevent animals straying too far afield. Animals may have been grazed on coastal pastures deliberately to alter the taste of the animals, much as salt marsh-grazed lamb is a speciality of populations today.

Iron Age

Marine Foods in Iron Age Britain

General accounts of subsistence in Iron Age Britain based on zooarchaeological evidence suggest that marine foods were not being utilised to any great extent during this time period (e.g. Champion and Collis 1996; Dobney and Ervynck 2007; Green 1992; Green 1992; Cunliffe 1995). The absence of fish bones on many Iron Age British sites in the North Sea region has been attributed to ideological beliefs or taboos held by these populations (Dobney and Ervynck 2007). This is supported by isotopic data exploring dietary behaviour from a range of coastal and inland sites in England indicated that the individuals analysed had isotopically similar diets, with little or no marine input (Jay and Richards 2007; 2006; Jay 2005; 2008). Evidence from the Western Isles, however, indicated that humans and animals did consume marine foods.

Both stable isotope evidence from the human and animal populations analysed from the Outer Hebrides and the zooarchaeological evidence suggested that marine foods were being consumed in the North Atlantic Islands during the Iron Age. The evidence from the Western Isles counteracts the traditional Iron Age fish-avoidance consumption models (Dobney and Ervynck 2007). The difference in dietary behaviour between the islands and the mainland suggests that dietary behaviour in the Iron Age is highly localised, and is not necessarily typical of Iron Age Britain as a whole. The Iron Age populations of the North Atlantic Islands were culturally distinct from their counterparts in neighbouring Britain. Whereas the inhabitants of Southern and Eastern Scotland constructed timber buildings and hillforts, as observed in mainland Europe, the Iron Age populations dwelling on the Atlantic coast constructed stone-built round houses (Armit 1990, 436). The North Atlantic Island populations also only adopted aspects of material culture as observed in mainland Britain during the 3-4th Century BC (Sharples 2012, 19). This cultural difference could explain the differences in dietary behaviour observed between these regions. If cultural taboos were in place in Iron Age Britain as suggested by Dobney and Ervynck (2007), they were not a set of beliefs subscribed to by the populations of the Western Isles. Similarly the individual from Bryher, known as the 'Bryher sword burial', on the Isles of Scilly had an isotopic signature (δ^{13}C -18.9‰, δ^{15}N 10.7‰) consistent with the consumption of marine foods in low quantities (Johns 2002), similar to the pattern observed in the Western Isles. Evidence of Iron Age marine food consumption, at least on a low level, is therefore evident in two different island groups, suggesting that Iron Age dietary behaviour in the islands does not conform to past models of Iron Age marine food taboos (Dobney and Ervynck 2007).

The Role of Diet in expressing Status and Hierarchy

The utilisation of fish and increased numbers of pig specimens in the Iron Age Western Isles assemblages may be linked to concepts of feasting. The production of surpluses has long been suggested as a mechanism for controlling trade, securing a hierarchical position and maintaining status (e.g. Sharples 1991; Haselgrove 1999; Cunliffe 1991). van de Veen (2007, 121) suggests that grain surpluses were produced in the Middle Iron Age to use for feasting as a method of demonstrating hierarchy and encouraging social cohesion, and as incentive building or maintenance projects. It is possible that feasting on marine products was utilised as a technique to construct the impressive broch structures such as Dun Vulan. Pigs have been suggested as a high-status product utilised for feasting in Scottish Iron Age societies (Parker Pearson 1999b, 46; Parker Pearson *et al.* 1996), and it is possible that marine foods were being deliberately fed to pigs intended for feasting purposes. The difference in behaviour between Orkney and the Western Isles therefore may be linked to local hierarchies between the islands utilising different resources and different in order to manage populations. The fact that there are no wheelhouses present on Orkney (Sharples 2012) emphasises this difference in identity between the individuals from Orkney and the Western Isles. If marine foods and pigs were being used specially for feasting in exchange for loyalty or labour then these consumption events must have been occurring frequently in order for the marine signatures to be observed in the human bone collagen.

The comparability of these datasets needs to be considered to determine whether these dietary differences are a result of sampling biases. The mainland British Iron Age human remains analysed by Jay (2005; Jay and Richards 2006; 2007) were all formal burials within a cemetery, whereas disarticulated remains (potentially resulting from excarnation) are an equally typical form of burial practice in the Iron Age (Carr and Knüsel 1997; Madgwick 2008; Redfern 2008), and so the diets of the individuals analysed may only represent a sub section of the population. Typically North Atlantic Island burials are disarticulated in nature, with few inhumation burials identified (Shapland and Armit 2012), a feature also observed in Mainland Britain at this time (Cunliffe 1991; 1995). Comparing disarticulated remains with humans interred in the North Atlantic Islands with the formal burials previously analysed in Britain (e.g. Jay 2005; Jay and Richards 2006; 2007) is not necessarily comparable. Further analysis of disarticulated human remains from mainland Britain would be beneficial in furthering our understanding of dietary behaviour between these regions.

Norse Period

The arrival of the Vikings marked a major turning point in Britain, with key developments such as market economies, increased resource production, Christianity and centralised authorities all being identified during this period (Barrett *et al.* 2000b). As observed in the Neolithic, the arrival of new populations to the islands results in a distinctive change in the observed zooarchaeological and isotopic record, marked by a decline in the use of marine species in relation to the preceding Mesolithic period. Conversely the arrival of Norse populations coincides with an increase in the presence of fish in zooarchaeological and isotopic records in addition to enhanced agricultural techniques. In the North Atlantic Islands the increase in the proportion of fish bones in the zooarchaeological assemblages and the marine isotopic signatures observed in some of the humans analysed indicates that marine foods were more important during this period. There is a difference in the species of fish exploited between the islands, with herring being the predominant fish species present in the Western Isles assemblages, and cod being the most commonly exploited species in the Northern Isles.

Trade of Fish

The presence of increased numbers of fish represented within the zooarchaeological record, combined with the absence of a marine isotopic signature within individuals from the Norse populations, suggests that marine foods were not necessarily being consumed by the islands' inhabitants. It has been suggested that the utilisation of marine resources in the North Atlantic Islands is potentially linked to the concept of economic growth, and the emergence of trade (Barrett *et al*. 2000b). Theories have suggested that the need for trade in the Norse Period, and the increase in fish consumption was linked to rapid population growth, requiring a greater quantity of resources to feed this larger population (Dyer 2002; Hoffman 1996). Trading of resources would explain why not all individuals were consuming marine foods, despite their abundance in the archaeological record. Historical documentary evidence has been used to suggest that Norse sites in Iceland and Orkney contributed to the wide-scale trade of cod in the form of 'klipfisk', with fish being gutted and dried to be stored and traded (Perdikaris and McGovern 2009). The predominance of gadids in the assemblages from Orkney and Shetland could be explained by the trading of these resources in dried form, although identifying this using the zooarchaeological record is challenging. Interpretations of Norse fishing and trade have been suggested in Norse Orkney and Caithness based on evidence from historical sources such as Sverri's Saga, with archaeological evidence of trade predominantly being based on the goods that had been imported (Barrett 1995). Dried fish would be an invaluable commodity for the provisioning of armies and towns, and had the potential to be a lucrative business for the populations involved with trading (Perdikaris and McGovern 2009). Evidence of the fish trade is challenging to positively identify, but analysis of fish bones has demonstrated potential for trade. For example, at the site of Quoygrew on Orkney, evidence of fish drying was identified in several contexts (Harland 2007, 230). Fish drying could suggest on-site storage, or could be indicative of the preparation of resources for trade. Accounts suggest that smoked herring were being marketed in England during the 14th century, and being preserved in such a manner as would enable transportation over great distances (Cuttincy 1955, 71). It is therefore plausible that the large quantities of herring recovered from Bornais were linked to the trade of this commodity.

The trading of marine foods in the Norse period has been interpreted as a method of exerting and maintaining chiefly authority, enabling centralised markets to be developed (Perdikaris 1999). The evidence from the North Atlantic Islands supports this hypothesis, and the trade of different fish resources in Orkney and the Western Isles is potentially an expression of control, with different authorities exploiting different gaps in the economic market.

Inter-Regional Comparisons of Isotopic Studies

In Sweden isotopic investigations at the site of Ridanäs in Gotland demonstrated that all of the Norse individuals analysed at the site were consuming marine foods in addition to animal protein and C3 plant material (Kosiba *et al.* 2007). These findings are interesting in the light of those from Norse Orkney, where half of the individuals displayed evidence of marine food consumption. It is possible that the 'fish eating' individuals had potentially relocated to Orkney from Scandinavia as suggested by recent strontium analysis (Montgomery pers. comm.). Indeed differences identified via dietary analysis may have the potential to be used as an indicator of migration or population movement. Unfortunately zooarchaeological remains from this site are not available to provide further insights into patterns in dietary behaviour.

In Ireland dietary analysis of Norse skeletons from Dublin demonstrated that variable quantities of marine products were being consumed within the population (Knudson *et al.* 2012). Strontium evidence demonstrated that the majority of the skeletons analysed from Dublin were local to the area, and the adoption of some marine foods into diet has been interpreted as acculturation (Knudson *et al.* 2012). The situation in Ireland is consistent with isotopic studies in Greenland, where there is a gradual enrichment of carbon and nitrogen isotopic values through time, following initial settlement in the region, demonstrating an increase in the importance of marine foods (Arnebourg *et al.* 2012). This effect is not observed in the North Atlantic Islands, as one group of individuals did not have a marine signature, indicating that acculturation via consumption practices was not taking place everywhere that the Norse settlers inhabited.

Agriculture and Pastoralism

Foddering in the North Atlantic during the Norse period is interpreted as a highly political issue. The production of fodder and the ability to keep animals over the winter months were paramount to the success of Norse farming economies. For example, farmsteads in Iceland were ranked depending on their ‘fodder reserve value’, which determined the ability to keep animals over the harsh winter months (Amorosi *et al.* 1998).

The isotopic evidence for manuring of fodder observed in the faunal specimens in the Northern and Western Isles indicates that farming techniques were enhanced, increasing the productivity of fodder in order to maintain animal populations over the winter period. Isotopic investigations of δ^{15}N values of faunal remains from two Norse settlements in Greenland demonstrated differences in the foddering practices between the two sites (Nelson *et al.* 2012), and zooarchaeological evidence from Greenland demonstrated that from 11560AD animal pastures were less viable, with evidence of over-grazing occurring (Mainland 2006). These examples all demonstrate that animal husbandry practices during the Norse period was highly localised on a site by site level, with each population following different foddering and pasturing practices. This is potentially linked to farming in the Norse Period being more commercial in nature, with producers employing different techniques to try to maximise the yield of their produce.

Analysis of faunal and archaeobotanical assemblages from the Greenland site of Gården Under Sandet indicated that manure collected from cattle barns was utilised as a fertiliser for the crops (Ross and Zutter 2007). This pattern was observed isotopically in the Western Isles of Scotland with Norse faunal remains all showing enriched δ^{15}N indicative of manuring. The process of fertilisation is clearly practiced in Norse populations within Europe, demonstrating that efforts were being made to enhance agricultural productivity. This enhancement may be linked to the idea of population increase, and the need to increase food production in order to maintain a larger population.

Summary

The dietary behaviour of the North Atlantic populations is not necessarily reflective of processes being practiced in mainland and coastal/island Britain, or the rest of Europe. During the Neolithic the North Atlantic Island populations did not use marine foods to any great extent. This is a trend consistently observed throughout coastal and mainland Britain, where further isotopic studies have demonstrated that average human and animal diets observed are predominantly terrestrial. Further afield in Europe, however, there is evidence of insular marine food consumption alongside the consumption of domestic species (e.g. Gotland and Ørland), demonstrating that not all islands had the same attitude towards diet. During the Bronze Age marine resources are identified in the zooarchaeological assemblages from the Western Isles in greater quantities, but they were not consumed in sufficient quantities to influence the isotopic values observed in the North Atlantic Island specimens, and the same pattern is not observed on Orkney. Bronze Age zooarchaeological remains from Nor-nour in the Scilly Isles demonstrated a higher use of marine mammals, potentially as a fuel source (Turk 1978), suggesting diversity in the relationship that British Bronze Age island populations had with the sea. During the Iron Age marine resources appear to play a more important role in diet in the Western Isles, which contradicts the patterns of dietary behaviour observed in Orkney and mainland Britain, where traditionally arguments have suggested that even at coastal sites around the North Sea marine foods were not being consumed (e.g. Dobney and Ervynck 2007; Jay 2005; 2008). With the arrival of Scandinavian settlers in the Norse Period fish remains become a common feature of zooarchaeological assemblages, although human isotopic values demonstrate that marine resources were not necessarily being consumed by all members of the population. Fish, however, were economically valuable as a commodity and were potentially used for trading at this time.

The following chapter concludes this thesis by outlining the key findings of this thesis, and highlighting further areas for future investigation and analysis to expand this research further to provide a more detailed insight into the role of marine resources in the lives of North Atlantic Island populations.

Chapter 13: Conclusions and Further Research

The primary aim of this research was to understand the changing importance and uses of marine resources through time in the North Atlantic Islands using a combination of stable isotope analysis and more traditional archaeological methods. Generating a suite of faunal isotopic values across time was essential in characterising animal diets and human diets, to assess husbandry strategies, and to provide a baseline for enhancing interpretation of human values. A further aim was to explore methodologies of quantifying marine resource using zooarchaeological techniques, and to determine the extent to which we can integrate these results with the isotopic results achieved. The isotopic analysis also aimed to explore geographical and environmental variations in isotopic values linked to soil types and vegetation in the islands. The following paragraphs present the conclusions of these aims thematically, before identifying areas for potential future research that would be beneficial in characterising the dietary and economic behaviours of the past North Atlantic Island populations, starting with human dietary behaviour from isotopic and zooarchaeological data.

Temporal trends in Human Diets in the Islands

During the Mesolithic in the Inner Hebrides there is evidence for extensive evidence of marine resource use, with sea mammals accounting for around 45% of the total mammalian NISP in the Oronsay midden sites (Grigson and Mellars 1987) (fish bones from these assemblages have not currently been analysed). The isotopic evidence from human remains demonstrated that these individuals were consuming large quantities of marine foods (Richards and Mellars 1998). The isotopic evidence of marine food consumption from Neolithic Orkney suggested that marine foods were not being consumed in sufficient quantities to produce a marine isotopic signature. Extensive assemblages of faunal remains from Neolithic Orkney demonstrated that marine foods accounted for a minor proportion of the economic resource utilised in the island, accounting for only 1.7% of the total faunal remains. The zooarchaeological and isotopic record for the Western Isles was more limited, and the absence of evidence prevents conclusions on dietary behaviour from being drawn, but isotopic evidence from the Inner Hebrides indicates that marine foods were not being consumed in any great quantity in the Neolithic (Schulting and Richards 2002a). Thus these new extended insular datasets corroborate the conclusions drawn by (Schulting and Richards 2002a, 155) that during the Neolithic period the populations of the North Atlantic “turned their backs on the sea to face the land”. These changes are a result of a series of cultural changes, possibly driven by population movements, including the introduction of farming as a developed and successful economic strategy to the region. This rapid change in dietary behaviour is supported by the evidence from the pottery residue analysis, demonstrating ruminant dairy utilisation in the earliest Neolithic vessels (Cramp pers. comm.), providing a valuable protein source. In the North Atlantic Islands, the arrival of farming in the Neolithic marks a distinctive change in diet, away from a reliance on marine species, and towards domestic species, that are utilised for both meat and milk. Conversely in mainland Europe, there is a greater diversity in the dietary behaviour observed in the zooarchaeological and isotopic record (see chapter 12). There is more fluidity in the nature of the Mesolithic-Neolithic transition, with some populations practising agriculture and fishing techniques, indicating different processes of Neolithisation between these regions. In the North Atlantic fish bone evidence exists at the site of Skara Brae, with 623 trout bones present, suggesting that fish were being used, if only to a minimal extent in the islands.

During the Bronze Age isotopic evidence from the individuals analysed at Cladh Hallan and Northton in the Western Isles demonstrated that marine foods were not being consumed in sufficient quantities to produce a marine isotopic signature, but the fish remains, predominantly based on Cladh Hallan, accounted for approximately 20% of the total NISP count (excluding shellfish), which is an increase from the preceding Neolithic. This suggests that marine resources were being utilised to a greater extent in this period in the Western Isles. The absence of a marine isotopic signature in the human remains at the site suggests that these foods were not being consumed in great quantities. No human skeletons were available from Bronze Age Orkney, and dietary evidence was limited to zooarchaeological evidence from only 4 sites, with a combined total NISP of under 4,000 fragments. Fish bones were present in the assemblage, and accounted for 8% of the faunal NISP (excluding shellfish), indicating that fish were not being utilised same extent as in the Outer Hebrides. Marine foods therefore may have been consumed on a seasonal or occasional basis.

Bronze Age subsistence is linked to localised environmental and geographical considerations. In mainland southern Britain marine species were not being used to any great extent in the Bronze Age (e.g. Hambleton 2008), but evidence from the island site of Nor-nour in the isles of Scilly demonstrated that seals were being exploited alongside domestic species. There is therefore no ‘typical’ model of Bronze Age diet in Britain. Domestic species are the major contributor to subsistence in Bronze Age Britain, with localised differences in the use of supplementary resources such as seals or fish.

In the Iron Age dietary evidence was more plentiful in the North Atlantic with zooarchaeological data available from a large range of sites. In total there are 24 sites from the Western Isles and 14 from the Northern Isles, with human isotopic data available from 12 individuals from the Western Isles and the West coast of Scotland and 3 individuals form the Northern Isles. There was a greater diversity between sites, with differing exploitation patterns and isotope values observed.

Evidence for marine resource utilisation in the Western Isles was extensive, with fish bones accounting for approximately 40% of the total assemblage NISP for this period. Human Isotopic values of individuals from Cnip and Dun Vulan were indicative of consuming a diet that contained marine protein, and pigs at Dun Vulan were also consuming marine protein. Thus, marine resources were being utilised by the Iron Age populations of the Western Isles. In comparison fish accounted for only 5% of the total NISP assemblage in Orkney, indicating that they were less commonly utilised. One late Iron Age individual with a marine signature consistent with minimal consumption of marine food suggest that marine foods were consumed, but not in any great quantity. Evidence of marine food consumption in Iron Age Orkney is limited, suggesting that they were not a major economic or dietary resource at this time.

This difference in marine exploitation strategies between the two regions at this time could be related to social factors, local hierarchies or environmental conditions influencing resource choice. The best example of this is the abundance of red seabream in the zooarchaeological assemblage at the site of Bostadh Beach which potentially relates to the localised environments of Great Bernera. The evidence from the Western Isles contradicts recent theories on Iron Age marine food avoidance in Britain (Dobney and Ervynck 2007); rather than simply avoiding fish the populations of the North Atlantic Islands were responding to a different set of social rules.

During the Norse period marine resources are utilised to a much greater extent in both the Western Isles and Northern Isles, marking quite a distinct change in dietary and economic behaviour. Zooarchaeological assemblages from the Western Isles included greater proportions of fish bones, and isotopic evidence for marine resource exploitation from a number of pigs and a single dog indicates that marine foods were being utilised by this population. In Orkney human isotopic values also demonstrate that marine foods were being consumed, again corroborated by greater proportions of fish identified in the zooarchaeological assemblages. Different fish species were exploited in the island groups, as observed for the Iron Age, with white fish being the main focus of attention in the Northern Isles, and herring being the predominantly utilised species in the Western Isles. The differences in fish species exploited suggest that the populations of the islands were specialising in the trade of resource types.

The human isotopic record demonstrated that not all Norse individuals were consumers of marine foods. Initial explorations based on the Orcadian human remains using locational isotopes suggested that individuals with marine signatures are not local, and potentially derive from Scandinavia whereas the humans without marine signatures were local to the islands (Montgomery pers. comm.). This suggests that on Orkney at least humans were potentially not consuming increasing quantities of marine foods, and instead may have been using them for trade. Trade of white fish in Norse Period Orkney has been suggested in previously studies (e.g. Barrett *et al*. 2004a; 2004b), and the isotopic and zooarchaeological record from Orkney and the Western Isles supports this hypothesis.

Across time sea mammals are present consistently within the zooarchaeological assemblages, with sea mammal NISP proportions remaining consistently at around 1% in each time period, and within each island group. Sea mammals whilst a valuable food source were also potentially being utilised for architectural purposes, creating artefacts, or as fuel (Mulville 2002; Savelle 1997). The occasional, but persistent, utilisation of sea mammals through time reflects infrequent or occasional exploitation, possibly using beach-combing as a procurement strategy.

In summary, domestic species dominate the faunal spectrum from the Neolithic onwards, but marine foods increase in importance through time in the North Atlantic Islands. Fish are utilised in greater numbers from the Bronze Age, but it is in the Iron Age onwards that we begin to see evidence of marine food consumption in the longer-term bone collagen record in the Western Isles. By the Norse period fish are being used in greater proportions in both Orkney and the Western Isles but this is not evident in all human residents in the islands.

Palaeoenvironmental Modelling

A further aim of this research was to generate detailed faunal baselines to characterise background levels of $\delta^{13}C$ and $\delta^{15}N$ for each temporal period in Orkney and the Western Isles. This research demonstrated a difference in $\delta^{15}N$ between Orkney and the Western Isles in the Neolithic, Bronze Age and Iron Age, probably resulting from localised environmental condition relating to soil type. This information is important for the interpretation of human values, and in explaining the enrichment in $\delta^{15}N$ between humans analysed from the West Coast of Scotland and Orkney. Aside from small-scale differences between the diets of individual species in each time period, no statistically significant temporal shifts in $\delta^{13}C$ and $\delta^{15}N$ were identified in the North Atlantic Island fauna that would influence the isotopic values observed in this region.

The intensive sampling of faunal remains employed in this research has provided a wealth of information on background $\delta^{13}C$ and $\delta^{15}N$ values for each time period and for each geographical location concerned. It would be beneficial to analyse plant remains from the sites where animal bones were sampled to enhance interpretations of these values. Recent studies by Stevens *et al.* (2010; 2013) at the Iron Age settlement of Danebury demonstrated the benefits of analysing archaeological plant remains in order to enhance interpretations of faunal baseline values. Bogaard *et al.* (2007; 2013) have investigated the applications of plant stable isotopic analysis to explore the effects of charring, irrigation and manuring on past plant isotopic values and have been able to identify that soil enrichment via manuring has an effect on n values in plants. Sampling of plant macro-remains for $\delta^{13}C$ and $\delta^{15}N$ isotope analysis will allow different environments to be characterised, in addition to identifying local changes resulting from land and crop management strategies, and would be a valuable area of research for future North Atlantic studies.

Characterising past animal management practices and dietary behaviour

The bulk collagen analysis of faunal specimens from the North Atlantic Island assemblages demonstrates it is possible to identify differences that relate to animal management strategies employed in the North Atlantic Islands. Several of the $\delta^{13}C$ values observed indicate that a proportion of the animals in Orkney and the Western Isles were consuming marine plants, possibly resulting from the use of the shorefront as a pasture, or possibly even the use of marine plants as a fertiliser, a process attested both ethnographically and historically on the Outer Hebrides, with seaweed used as a fertiliser in the islands to enhance agricultural productivity, in addition to being applied to crops for foddering (Smith 2012; 1994). Further exploration of faunal isotopes can provide additional insights. Elsewhere analysis of tooth apatite for $\delta^{13}C$ and $\delta^{18}O$, has proved to be a valuable technique to explore faunal dietary behaviour within coastal populations, revealing seaweed consumption within Neolithic individuals (e.g. Balasse *et al.* 2006; 2009). Also dental microwear analysis has been beneficial in the identification of seaweed foddering in Orkney (Mainland 2000), and could be applied to more of the North Atlantic Island assemblages. Combining isotopic and microwear approaches would clarify the role of marine plants in the diet of fauna and expand our understanding of past animal management strategies in the North Atlantic Islands.

Future research

Enhancing Isotopic methodologies

Whilst it was possible to achieve an understanding of dietary trends in the islands using combined isotopic and zooarchaeological methodologies there are several areas that could be expanded upon. The bulk collagen analysis utilised in this study provided an understanding of broad trends in diet within the human populations, but infrequent or occasional uses of marine resources is not possible to access using the methodology. There are two main areas of future research that would be beneficial in aiding with our understanding of infrequent marine resource utilisation in the islands. Firstly enhancing our understanding of bulk collagen analysis and the quantity and regularity of marine food consumption required to influence the bulk collagen record. Understanding consumption based on shorter-time spans would allow us to determine infrequent or occasional consumption of marine resources and help with characterising the relationship that the North Atlantic Island populations had with the sea.

Whilst juveniles were avoided, the range of nitrogen values observed within the faunal specimens suggests that some weaning individuals were analysed, with rogue values observed indicative of younger individuals. Whilst the weaning signatures have been identified within bone collagen values (e.g. Richards *et al.* 2006; Schurr 1997; 1998), as yet little research has been conducted into characterising the suckling signature, and the length of time that the milk signature remains within the bone collagen of younger animals. Detailed sampling of mandibles from a variety of age ranges, and sampling long bones from each fusion age, would be beneficial in helping to characterise weaning signatures further.

Characterising the impact of frequency, intensity and duration of marine food consumption on bulk collagen values would be invaluable in determining more about marine food consumption, for example the quantity of marine foods needed to be consumed to leave a marine isotopic signature in the bulk collagen record. The pig-feeding experiments conducted by Evershed (pers. comm. see chapter 10) will be invaluable in further understanding characterising marine food input and the values expressed in the bone collagen values.

Recently there have been several advancements in the isotopic analysis that could be applied to the North Atlantic Island assemblages to enhance our understanding of changes in human marine resource consumption through time. New techniques in isotopic analysis have been developed to explore dietary behaviour on a micro scale (Montgomery pers. comm.). The technique involves incremental sampling of human dentine, similar to the technique used by Balasse *et al.* (2005; 2006; 2009) on animal populations, and was able to reveal that marine foods were consumed by Neolithic individuals in Shetland during times of nutritional stress, coinciding with incidents of enamel hypoplasia (Montgomery *et al.* pers. comm.). Employing intra-tooth sampling techniques would enable a greater resolution of consumption patterns within human populations to be achieved, providing a much detailed insight into the dietary behaviour of these populations to be observed. This technique relies on teeth being preserved and available for analysis, which would be a limitation for some sites in the North Atlantic Islands.

Other isotopic indicators can also be utilised to explore past diet. Bromine isotopic analysis has been used alongside δ^{15}N analysis as an additional indicator of marine versus terrestrial diets (Dolphin 2013), and sulphur has also been employed as a technique to identify marine diets, such as applied to skeletons from the Danube Gorges (Nehlich *et al.* 2010). Utilising additional isotopic investigations alongside δ^{13}C and δ^{15}N analysis could potentially enhance understanding of past marine resource use in the islands as an additional indicator alongside to understand more about past diet. Compound-specific amino acid analysis removes the effects of dietary averaging (Styring *et al.* 2010), and therefore could be used to provide a more detailed understanding of animal and human dietary behaviour during each period. Some of these techniques would require further destructive sampling of bones and teeth, and may not substantially enhance our understanding; therefore caution must be employed before deciding to undertake any further analysis on this material.

Pottery Residue Analysis

The pottery residue analysis conducted as part of the wider research project successfully identified marine biomarkers in pottery vessels from the Norse Period (Cramp and Evershed 2013), demonstrating that the newly developed marine markers based on reference deposits have potential for reconstructing past marine resource use. Further expansion of lipid residue analysis to the strategic sampling of a range of different pottery vessel types would eliminate possible biases in the assemblages relating to vessel form. Analysis also demonstrated that milk residues are present in pots from the Early Neolithic (Cramp pers. comm.), suggesting that milk was an important resource for the early farming populations in the islands. Developing further techniques to separate dairy fats originating from cattle and sheep individually would aid with furthering our understanding of animal husbandry and management in the Neolithic of the North Atlantic Islands.

Enhancing zooarchaeological methodologies

A major challenge of this thesis has been the integration of zooarchaeological datasets from different sites. Re-analysis of the zooarchaeological assemblages using the same recording methodology would allow for more successful integration of zooarchaeological assemblages; however, there would still be biases as a result of the archaeological process (e.g. differences in sampling and sieving strategies). Calculating densities per volume of soil of each resource type would be beneficial in further understanding the relative importance of fish, marine mammals and shellfish within discrete deposits. Micro analysis of individual contexts or features would also enable dietary and economic behaviour to be characterised in a more detailed way.

Enhancing access to data would be beneficial in allowing greater comparisons in the use of different resources between sites. Digital archiving and online access to raw datasets is an area that can be beneficial in enabling successful data integration. Projects such as the MARES database (Cerón-Carrasco 2006) accumulated data from a range of different projects, but not all of the sites were included in the database, and terrestrial data from many of these sites were lacking, preventing comparisons to other resources. Individual site reports with raw data are now more commonly published online allowing access to data prior to formal publication (e.g. Drew 2006; Hardy and Wickham-Jones 2007), enhancing the data available for inclusion in cross comparative studies. The Archaeology Data Service ('ADS', WWW5) provides access to site archives and raw data tables allowing access to a wealth of information. If more sites provided their raw data online it would enable better access to grey literature to include in future studies of dietary behaviour.

There have been some attempts to allow access to large datasets for inter-site comparisons. Organisations such as the 'Alexandria Archive Institute' (WWW3) organisation undertakes projects to maximise open access of data from archaeological projects. A recent project by Arbuckle and Kansa (2013) worked to accumulate all of the existing Neolithic faunal data from across Anatolia to allow researchers to compare metrics, fusion, and species representations between sites. The datasets achieved by Arbuckle and Kansa (2013) were standardised where possible to enhance comparisons across sites, and provide a valuable model to base North Atlantic Island datasets. Obtaining funding to create a digital archive of all existing zooarchaeological and isotopic data from the North Atlantic Islands would allow future researchers to utilise the data gathered for future dietary studies utilising new techniques. Publishing raw data in an open access format enables greater comparisons in dietary behaviour to be achieved.

Understanding fish Use

This research has demonstrated that even when combining the long-term evidence of bulk collagen isotopic analysis with the zooarchaeological evidence it is not possible to clearly characterise marine resource use. In addition to utilising the suggested more detailed isotopic techniques such as intra-tooth sampling to investigate infrequent and occasional consumption of resources, zooarchaeological techniques can be employed in future studies to understand fish exploitation strategies. Assessing fish seasonality would be beneficial in determining whether fish bone assemblages such as the collection of red seabream at Bostadh (Thoms 2004), the trout remains from Skara Brae (Cerón-Carrasco *et al*. 2006) or the saithe bone assemblages from Cladh Hallan (Ingrem forthcoming a) were a result of seasonally targeted exploitation of this resource or occasional and ad hoc exploitation. This could be achieved by analysing fish otoliths, which grow on a seasonal basis, making it possible to identify the season that fish were being caught (Colley 1990). If caught and eaten on a seasonal basis, would help to explain the absence of a marine signature from fish consumption in the bone collagen stable isotope values. Another line of inquiry would be to consider the ages of the fish present in shoals to access information about fishing strategies employed, and insights into fish utilisation practices. This approach has been utilised to an extent for the site of Bornais M3 by Ingrem (2005), where the ages of fish were used to determine that entire shoals of herring were being captured by nets.

Understanding shellfish use

Shellfish are infrequently recorded within the North Atlantic Island assemblages. Research into molluscan evidence is currently being undertaken by Matt Law at Cardiff University, and will provide a valuable insight into shellfish exploitation. The analysis of existing archives of shellfish remains will also be invaluable in determining the role of this resource. Shellfish seasonality could be explored to determine whether they were being utilised on a seasonal basis or all year round (Chapter 10). Shellfish growth-ring studies to explore seasonality were successfully applied to the Mesolithic shell middens at the site of Morton in Fife (Deith 1983), and could potentially be applied to the North Atlantic shellfish assemblages. Similarly oxygen isotope analysis of shell assemblages has been successful utilised to explore seasonality on shell middens identified in Southern Britain (Mannio *et al*. 2003), and could also be applied to the North Atlantic Island assemblages to enhance understanding of the nature of shellfish exploitation in the islands.

Conclusion

Past models of subsistence in the North Atlantic Islands have been highly generalised, centering on the decline of marine food consumption in the Neolithic (Schulting and Richards 2002a), and increase in marine food consumption in the Norse period (Barrett *et al.* 2004). The integrative approach comparing zooarchaeological evidence with human and animal isotopic values has demonstrated that the relationship of these past populations with marine resources had was much more nuanced than previously thought, increasing in importance from the Bronze Age onwards, with direct consumption of marine foods clearly identified in the Iron Age Western Isles. The Norse Period marks an expansion in the use of fish remains, and marine resources appear to be used for land and animal management.

The two major changes in diet that occur in the North Atlantic Islands are linked to the arrival of new settlers. The decline in marine resource use in the Neolithic occurs at the same time as the arrival of farming populations to the islands. Similarly the expansion of marine food use in the Norse Period is then linked to the arrival of the Vikings to the islands, and the establishment of trading connections, that continue to exist in the islands today.

Occasional or infrequent marine resource use in the Western Isles is observed in the Bronze Age, with an increase in intensity of use in the Iron Age, whilst in Orkney the evidence is more limited. This highlights the importance of considering these regions independently, when investigating past archaeological behaviour. Considering zooarchaeological information alongside isotopic data from the North Atlantic Islands provides a valuable model for enhancing our understanding of marine resource use, and agricultural techniques on a temporal and regional scale. Integration of isotopic analysis of human and animal with zooarchaeological techniques is complex, but it is an invaluable technique for interpreting past economic strategies, and here has been demonstrated to have revolutionised our understanding of dietary behaviour in archaeological populations.

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Appendix 1- Faunal stable isotope samples and value

Site	Island	Period	Species	Element	Fusion	$\delta^{13}C$	$\delta^{15}N$	C:N	Sample no	Reference
Casteal nan Gillean II	Inner Hebrides	Mesolithic	Seal			-11.9	19.1	3.2		Richards and Mellars 1998
Caisteal Nan Gillean II	Inner Hebrides	Mesolithic	Red Deer	Phal II	Fused	-22.8	4.4	3.3	CN02	Jones 2013
Caisteal Nan Gillean II	Inner Hebrides	Mesolithic	Red Deer	Femur	Fused	-22.9	4.5	3.4	CN04	Jones 2013
Caisteal Nan Gillean II	Inner Hebrides	Mesolithic	Red Deer	Metatarsal		-22.2	4.2	3.5	CN05	Jones 2013
Caisteal Nan Gillean II	Inner Hebrides	Mesolithic	Red Deer	Metatarsal		-23.8	4.6	3.3	CN06	Jones 2013
Cnoc Sligeach	Inner Hebrides	Mesolithic	Roe Deer	Scapula	Fused	-23.5	4.1	3.3	CS03	Jones 2013
Cnoc Sligeach	Inner Hebrides	Mesolithic	Red Deer	Metacarpal	Fused	-23.6	3.7	3.4	CS04	Jones 2013
Cnoc Sligeach	Inner Hebrides	Mesolithic	Red Deer	Metatarsal	Fused	-23.4	3.9	3.3	CS05	Jones 2013
Cnoc Sligeach	Inner Hebrides	Mesolithic	Red Deer	Metatarsal	Fused	-23.4	3.4	3.3	CS06	Jones 2013
Priory Midden	Inner Hebrides	Mesolithic	Red Deer	Metatarsal		-23.1	4.5	3.4	PR01	Jones 2013
Risga	Inner Hebrides	Mesolithic	Red Deer	Metatarsal	Fused	-22.1	2.6	3.4	RS01	Jones 2013
Risga	Inner Hebrides	Mesolithic	Red Deer	Humerus	Fused	-23.0	5.7	3.7	RS06	Jones 2013
Tofts Ness	Orkney	Early Neolithic	Cattle	Metacarpal	Fused	-21.8	6.7	3.3	TN01	Jones 2013
Tofts Ness	Orkney	Early Neolithic	Sheep	Humerus	Fused	-21.5	7.0	3.4	TN04	Jones 2013
Tofts Ness	Orkney	Early Neolithic	Pig	Metapodial	Fused	-19.7	10.4	3.4	TN05	Jones 2013
Tofts Ness	Orkney	Early Neolithic	Sheep	Tibia		-21.0	7.5	3.4	TN06	Jones 2013
Tofts Ness	Orkney	Early Neolithic	Sheep	Tibia		-20.2	8.2	3.3	TN08	Jones 2013
Tofts Ness	Orkney	Early Neolithic	Cattle	Metacarpal	Fused	-22.0	6.4	3.3	TN09	Jones 2013
Tofts Ness	Orkney	Early Neolithic	Sheep	Metacarpal	Fused	-20.7	7.9	3.4	TN12	Jones 2013
Tofts Ness	Orkney	Early Neolithic	Red Deer	Metatarsal	Fused	-21.7	6.8	3.4	TN13	Jones 2013
Tofts Ness	Orkney	Early Neolithic	Sheep	Humerus		-21.9	7.1	3.3	TN15	Jones 2013
Tofts Ness	Orkney	Early Neolithic	Pig	Humerus	Fused	-20.2	10.9	3.3	TN16	Jones 2013
Tofts Ness	Orkney	Early Neolithic	Sheep	Femur	Fused	-20.3	9.2	3.4	TN30	Jones 2013
Tofts Ness	Orkney	Early Neolithic	Sheep	Radius	Fused	-21.3	6.7	3.4	TN32	Jones 2013
Tofts Ness	Orkney	Late Neolithic	Pig	Radius	Fused	-21.9	9.9	3.4	TN25	Jones 2013
Skara Brae	Orkney	Neolithic	Red Deer	Radius	Fused	-21.9	5.5	3.3	SB02	Jones 2013
Skara Brae	Orkney	Neolithic	Red Deer	Radius	Fused	-21.7	4.6	3.3	SB03	Jones 2013
Skara Brae	Orkney	Neolithic	Red Deer	Radius	Fused	-21.9	5.7	3.3	SB04	Jones 2013
Skara Brae	Orkney	Neolithic	Red Deer	Radius	Fused	-21.9	5.9	3.3	SB05	Jones 2013
Skara Brae	Orkney	Neolithic	Red Deer	Tibia	Fused	-22.1	6.8	3.3	SB06	Jones 2013
Skara Brae	Orkney	Neolithic	Red Deer	Tibia	Fused	-21.6	5.5	3.3	SB07	Jones 2013
Skara Brae	Orkney	Neolithic	Sheep	Radius	Fused	-20.5	7.2	3.3	SB08	Jones 2013
Skara Brae	Orkney	Neolithic	Sheep	Radius	Fused	-21.1	6.0	3.3	SB09	Jones 2013
Skara Brae	Orkney	Neolithic	Sheep	Radius	Fused	-20.3	6.2	3.2	SB10	Jones 2013

Site	Island	Period	Species	Element	Fusion	$\delta^{13}C$	$\delta^{15}N$	C:N	Sample no	Reference
Skara Brae	Orkney	Neolithic	Sheep	Radius	Fused	-20.6	6.0	3.3	SB11	Jones 2013
Skara Brae	Orkney	Neolithic	Sheep	Radius	Fused	-21.0	6.5	3.3	SB12	Jones 2013
Skara Brae	Orkney	Neolithic	Sheep	Radius	Fused	-21.1	6.1	3.4	SB13	Jones 2013
Skara Brae	Orkney	Neolithic	Sheep	Radius	Fused	-20.8	7.6	3.3	SB14	Jones 2013
Skara Brae	Orkney	Neolithic	Pig	Humerus	Fused	-21.8	7.9	3.3	SB15	Jones 2013
Skara Brae	Orkney	Neolithic	Pig	Humerus	Fused	-21.9	8.1	3.4	SB16	Jones 2013
Skara Brae	Orkney	Neolithic	Pig	Humerus	Fused	-21.7	8.4	3.4	SB17	Jones 2013
Skara Brae	Orkney	Neolithic	Red Deer	Radius	Fused	-21.8	6.5	3.3	SB01	Jones 2013
Skara Brae	Orkney	Neolithic	Pig	Radius	Fused	-22.3	9.8	3.5	SB21	Jones 2013
Skara Brae	Orkney	Neolithic	Pig	Pelvis		-21.3	11.1	3.3	SB18	Jones 2013
Skara Brae	Orkney	Neolithic	Pig	Pelvis		-21.9	8.7	3.3	SB19	Jones 2013
Skara Brae	Orkney	Neolithic	Pig	Tibia	Fused	-21.4	9.7	3.3	SB20	Jones 2013
Skara Brae	Orkney	Neolithic	Dog	Humerus	Fused	-20.6	10.4	3.4	SB22	Jones 2013
Skara Brae	Orkney	Neolithic	Dog	Femur	Fused	-20.5	9.2	3.3	SB23	Jones 2013
Links of Noltland	Orkney	Neolithic	Red Deer	Metatarsal	Fused	-21.5	7.3	3.5	LN02	Jones 2013
Links of Noltland	Orkney	Neolithic	Red Deer	Radius	Fused	-21.5	6.5	3.3	LN03	Jones 2013
Links of Noltland	Orkney	Neolithic	Red Deer	Metacarpal	Fused	-21.4	5.0	3.4	LN04	Jones 2013
Links of Noltland	Orkney	Neolithic	Red Deer	Tibia	Fused	-21.8	5.5	3.5	LN06	Jones 2013
Links of Noltland	Orkney	Neolithic	Red Deer	Metapodial		-22.0	7.7	3.3	LN07	Jones 2013
Links of Noltland	Orkney	Neolithic	Sheep	Humerus	Fused	-20.3	6.2	3.5	LN08	Jones 2013
Links of Noltland	Orkney	Neolithic	Sheep	Humerus	Fused	-21.8	6.5	3.5	LN11	Jones 2013
Links of Noltland	Orkney	Neolithic	Sheep	Humerus	Fused	-21.2	5.5	3.4	LN12	Jones 2013
Links of Noltland	Orkney	Neolithic	Sheep	Humerus	Fused	-21.5	6.8	3.5	LN14	Jones 2013
Links of Noltland	Orkney	Neolithic	Cattle	Humerus	Fused	-21.5	5.2	3.3	LN15	Jones 2013
Links of Noltland	Orkney	Neolithic	Cattle	Humerus	Fused	-21.7	5.0	3.5	LN17	Jones 2013
Links of Noltland	Orkney	Neolithic	Cattle	Humerus	Fused	-21.8	5.6	3.5	LN18	Jones 2013
Links of Noltland	Orkney	Neolithic	Cattle	Humerus	Fused	-21.5	6.0	3.4	LN19	Jones 2013
Links of Noltland	Orkney	Neolithic	Cattle	Humerus	Fused	-21.3	5.2	3.4	LN20	Jones 2013
Links of Noltland	Orkney	Neolithic	Cattle	Humerus	Fused	-21.6	5.1	3.5	LN21	Jones 2013
Eilean Domhnuill	Uist	Neolithic	Sheep	Tibia	Fused	-22.4	6.4	3.3	ED01	Jones 2013
Eilean Domhnuill	Uist	Neolithic	Cattle	Femur		-21.6	4.9	3.3	ED02	Jones 2013
Eilean Domhnuill	Uist	Neolithic	Sheep	Femur		-21.6	5.5	3.5	ED03	Jones 2013
Eilean Domhnuill	Uist	Neolithic	Sheep	Metacarpal	Fused	-22.1	5.7	4.0	ED04	Jones 2013
Eilean Domhnuill	Uist	Neolithic	Cattle	Metacarpal	Fused	-21.7	5.5	3.3	ED06	Jones 2013
Ness of Brodgar	Orkney	Neolithic	Cattle	Tibia	Fused	-21.6	6.0	3.3	NOB01	Jones 2013
Ness of Brodgar	Orkney	Neolithic	Cattle	Tibia	Fused	-21.6	6.0	3.4	NOB02	Jones 2013
Ness of Brodgar	Orkney	Neolithic	Cattle	Tibia	Fused	-22.1	7.0	3.4	NOB04	Jones 2013

Site	Island	Period	Species	Element	Fusion	$\delta^{13}C$	$\delta^{15}N$	C:N	Sample no	Reference
Ness of Brodgar	Orkney	Neolithic	Cattle	Tibia	Fused	-21.8	6.8	3.4	NOB05	Jones 2013
Ness of Brodgar	Orkney	Neolithic	Cattle	Tibia	Fused	-21.8	5.8	3.5	NOB06	Jones 2013
Ness of Brodgar	Orkney	Neolithic	Cattle	Tibia	Fused	-21.9	6.9	3.4	NOB08	Jones 2013
Ness of Brodgar	Orkney	Neolithic	Cattle	Tibia	Fused	-21.8	5.0	3.4	NOB09	Jones 2013
Ness of Brodgar	Orkney	Neolithic	Cattle	Tibia		-21.8	6.8	3.4	NOB10	Jones 2013
Ness of Brodgar	Orkney	Neolithic	Sheep	Tibia		-21.3	7.0	3.4	NOB11	Jones 2013
Ness of Brodgar	Orkney	Neolithic	Sheep	Femur		-21.1	6.0	3.4	NOB12	Jones 2013
Northton	Lewis/Harris	Neolithic	Red Deer	Metatarsal	Fused	-21.4	4.4	3.4	NT28	Jones 2013
Northton	Lewis/Harris	Neolithic	Red Deer	1st Phalanx	Fused	-21.7	3.5	3.3	NT30	Jones 2013
Northton	Lewis/Harris	Neolithic	Red Deer	Metatarsal		-21.4	6.0	3.2	NT31	Jones 2013
Northton	Lewis/Harris	Neolithic	Red Deer	Metatarsal		-21.4	4.7	3.4	NT33	Jones 2013
Northton	Lewis/Harris	Neolithic	Red Deer	Metapodial		-21.9	4.0	3.4	NT34	Jones 2013
Northton	Lewis/Harris	Neolithic	Red Deer	Metapodial		-21.4	4.0	3.3	NT35	Jones 2013
Northton	Lewis/Harris	Neolithic	Red Deer	Metapodial		-21.4	3.8	3.3	NT36	Jones 2013
Northton	Lewis/Harris	Neolithic	Sheep	Radius	Fused	-21.5	5.3	3.3	NT37	Jones 2013
Northton	Lewis/Harris	Neolithic	Sheep	Radius	Fused	-21.4	5.6	3.3	NT38	Jones 2013
Northton	Lewis/Harris	Neolithic	Sheep	Radius	Fused	-21.4	5.1	3.2	NT39	Jones 2013
Northton	Lewis/Harris	Neolithic	Sheep	Radius	Fused	-21.5	5.6	3.2	NT40	Jones 2013
Northton	Lewis/Harris	Neolithic	Sheep	Tibia	Fused	-21.3	7.4	3.3	NT41	Jones 2013
Northton	Lewis/Harris	Neolithic	Sheep	Tibia	Fused	-21.5	5.8	3.3	NT42	Jones 2013
Northton	Lewis/Harris	Neolithic	Sheep	Tibia	Fused	-21.4	5.4	3.4	NT43	Jones 2013
Northton	Lewis/Harris	Neolithic	Sheep	Femur	Fused	-21.4	4.6	3.3	NT44	Jones 2013
Northton	Lewis/Harris	Neolithic	Cattle	Scapula	Fused	-21.4	5.3	3.3	NT46	Jones 2013
Northton	Lewis/Harris	Neolithic	Cattle	Metacarpal		-20.9	4.9	3.2	NT48	Jones 2013
Northton	Lewis/Harris	Neolithic	Cattle	Metatarsal		-21.1	4.3	3.2	NT49	Jones 2013
Northton	Lewis/Harris	Neolithic	Cattle	Metatarsal		-21.3	5.1	3.4	NT50	Jones 2013
Northton	Lewis/Harris	Neolithic	Cattle	Femur		-21.2	5.5	3.3	NT51	Jones 2013
Northton	Lewis/Harris	Neolithic	Seal	Radius	Unfused	-11.8	17.0	3.3	NT77	Jones 2013
Northton	Lewis/Harris	Neolithic	Seal	Scapula	Fused	-11.6	17.2	3.3	NT78	Jones 2013
Links of Noltland	Orkney	Neolithic	Pig	Maxilla		-22.0	11.7	3.8	LON22	Jones 2013
Links of Noltland	Orkney	Neolithic	Pig	Maxilla		-21.3	10.0	3.3	LON23	Jones 2013
Links of Noltland	Orkney	Neolithic	Pig	1st Phalanx	Fused	-21.0	9.7	3.3	LON25	Jones 2013
Links of Noltland	Orkney	Neolithic	Pig	1nd Phalanx	Fused	-22.6	8.3	3.4	LON26	Jones 2013
Links of Noltland	Orkney	Neolithic	Sheep	Metacarpal	Fused	-20.8	7.4	3.4	LON28	Jones 2013
Links of Noltland	Orkney	Neolithic	Sheep	Radius	Fused	-21.3	6.1	3.3	LON29	Jones 2013
Links of Noltland	Orkney	Neolithic	Sheep	Radius	Fused	-19.9	6.1	3.3	LON30	Jones 2013
Links of Noltland	Orkney	Neolithic	Sheep	Radius	Fused	-20.3	6.7	3.2	LON31	Jones 2013

Site	Island	Period	Species	Element	Fusion	δ^{13}C	δ^{15}N	C:N	Sample no	Reference
Links of Noltland	Orkney	Neolithic	Sheep	Tibia	Fused	-20.4	6.2	3.3	LON32	Jones 2013
Links of Noltland	Orkney	Neolithic	Sheep	Tibia	Fused	-19.7	8.3	3.3	LON33	Jones 2013
Links of Noltland	Orkney	Neolithic	Cattle	Metacarpal	Fused	-21.2	6.4	3.4	LON35	Jones 2013
Links of Noltland	Orkney	Neolithic	Cattle	Humerus	Fused	-21.7	4.8	3.3	LON36	Jones 2013
Links of Noltland	Orkney	Neolithic	Cattle	Metacarpal	Fused	-21.3	5.5	3.2	LON38	Jones 2013
Links of Noltland	Orkney	Neolithic	Cattle	Metatarsal	Fused	-21.3	6.2	3.4	LON40	Jones 2013
Links of Noltland	Orkney	Neolithic	Ling	Cleithrum		-12.0	16.0	3.2	LON41	Jones 2013
Links of Noltland	Orkney	Neolithic	Haddock	Vertebra		-14.0	15.6	3.5	LON42	Jones 2013
Links of Noltland	Orkney	Neolithic	Ballan Wrasse	Dentary		-14.6	13.6	3.2	LON43	Jones 2013
Skara Brae	Orkney	Neolithic	Cattle	Humerus		-21.2	6.4	3.3	14683	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Phalanx		-21.7	6.9	3.6	14684	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Tibia		-21.5	5.9	3.9	14685	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Tibia		-21.3	6.1	3.2	14686	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Talus		-21.3	6.3	3.4	14687	Clarke and Marshall pers. comm..
Skara Brae	Orkney	Neolithic	Cattle	Phalanx 3		-21.5	5.9	3.4	14688	Clarke and Marshall pers. comm..
Skara Brae	Orkney	Neolithic	Cattle	Talus		-21.9	6.0	3.4	14689	Clarke and Marshall pers. comm..
Skara Brae	Orkney	Neolithic	Cattle	Phalanx		-22.1	5.3	3.4	14690	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Metatarsal		-21.2	5.3	3.5	14691	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Phalanx		-21.9	6.8	3.5	14692	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Phalanx 1		-21.8	6.9	3.5	14693	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Phalanx 1		-21.8	8.3	3.4	14694	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Phalanx 1		-21.9	6.9	3.3	14695	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Phalanx 1		-21.7	7.0	3.4	14696	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Metacarpal		-21.5	6.2	3.7	14697	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Metatarsal		-21.5	6.2	3.5	14698	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Metacarpal		-21.3	6.3	3.3	14699	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Phalanx 1		-21.7	6.5	3.6	14700	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Radius		-21.6	5.3	3.7	14701	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Calcaneum		-21.8	7.0	3.6	14702	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Phalanx 1		-21.9	6.8	3.5	14703	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Humerus		-21.7	6.4	3.4	14704	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Metatarsal		-21.3	5.4	3.4	14705	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Humerus		-21.2	5.1	3.4	14706	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Acetabulum		-21.4	5.7	3.3	14707	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Sacrum		-21.2	5.6	3.3	14708	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Metacarpal		-21.3	6.4	3.3	14709	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Talus		-22.0	6.0	4.1	14710	Clarke and Marshall pers. comm.

Site	Island	Period	Species	Element	Fusion	$\delta^{13}C$	$\delta^{15}N$	C:N	Sample no	Reference
Skara Brae	Orkney	Neolithic	Cattle	Metacarpal		-21.8	6.0	3.5	14711	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Metatarsal		-21.6	7.6	3.5	14712	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Phalanx 3		-21.7	6.4	3.5	14713	Clarke and Marshall pers. comm..
Skara Brae	Orkney	Neolithic	Cattle	Scapula		-21.4	6.1	3.4	14714	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Patella		-22.1	5.3	3.7	14715	Clarke and Marshall pers. comm..
Skara Brae	Orkney	Neolithic	Cattle	Metatarsal		-21.7	5.7	3.3	14716	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Phalanx 1		-21.6	5.6	3.4	14717	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Humerus		-21.5	5.1	3.6	14718	Clarke and Marshall pers. comm..
Skara Brae	Orkney	Neolithic	Cattle	Tibia		-21.5	3.5	3.9	14719	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Patella		-22.5	6.4	3.8	14720	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Phalanx 2		-21.6	6.1	3.3	14721	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Radius		-21.8	5.4	3.3	14722	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Phalanx 2		-21.8	5.2	3.5	14723	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Metatarsal		-22.0	5.4	3.5	14724	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Phalanx 1		-21.9	5.8	3.2	14725	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Radius		-21.4	5.7	3.3	14726	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Talus		-21.9	4.9	3.4	14727	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Phalanx		-21.9	5.5	3.5	14728	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Talus		-20.7	5.5	3.4	14729	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Phalanx 3		-21.2	5.0	3.4	14730	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Phalanx 3		-21.4	4.0	3.5	14731	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Metacarpal		-22.1	6.5	3.8	14732	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Metatarsal		-21.1	5.0	4.1	14733	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Phalanx 1		-21.4	6.7	3.8	14734	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Radius		-21.4	7.3	3.5	14735	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Tibia		-20.8	5.7	3.7	14736	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Phalanx 1		-21.3	5.6	3.5	14737	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Metatarsal		-21.4	5.3	3.6	14738	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Metatarsal		-22.5	5.4	3.8	14739	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Metatarsal		-21.8	6.1	3.7	14740	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Radius		-21.5	5.9	3.4	14741	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Radius		-20.7	6.6	3.3	14742	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Ulna		-20.6	6.7	3.3	14743	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Metacarpal		-21.4	6.0	3.2	14744	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Tibia		-21.7	5.7	3.6	14745	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Metatarsal		-21.5	7.4	3.5	14746	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Ulna		-21.1	5.6	3.4	14747	Clarke and Marshall pers. comm.

Site	Island	Period	Species	Element	Fusion	$\delta^{13}C$	$\delta^{15}N$	C:N	Sample no	Reference
Skara Brae	Orkney	Neolithic	Cattle	Metacarpal		-21.6	5.3	3.2	14748	Clarke and Marshall pers. comm..
Skara Brae	Orkney	Neolithic	Cattle	Humerus		-21.6	6.1	3.3	14749	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Humerus		-21.6	6.2	3.5	14750	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Metacarpal		-21.7	6.0	3.4	14751	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Atlas		-21.7	6.9	3.3	14752	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Metacarpal		-21.9	5.3	3.5	14753	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Talus		-21.9	6.0	3.4	14754	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Phalanx		-21.8	6.6	3.3	14755	Clarke and Marshall pers. comm.
Skara Brae	Orkney	Neolithic	Cattle	Phalanx		-21.7	6.5	3.6	14756	Clarke and Marshall pers. comm.
Northton	Lewis/Harris	Neolithic	Cattle	Scapula		-21.9	4.8	3.5	NT45	Jones 2013
Northton	Lewis/Harris	Neolithic	Cattle	Radius		-21.6	6.3	3.4	NT47	Jones 2013
Northton	Lewis/Harris	Neolithic	Herring / Lesser black-backed gull	Tibio-tarsus	Fused	-12.7	16.9	3.2	NT90	Jones 2013
Northton	Lewis/Harris	Neolithic	Gannet	Humerus	Fused	-14.6	16.0	3.3	NT91	Jones 2013
Northton	Lewis/Harris	Neolithic	Gannet	Ulna	Fused	-14.6	15.3	3.3	NT92	Jones 2013
Northton	Lewis/Harris	Neolithic	Cormorant	Carpometa.	Fused	-13.1	13.9	3.3	NT93	Jones 2013
Northton	Lewis/Harris	Neolithic	Razorbill	Humerus	Fused	-13.9	16.9	3.2	NT94	Jones 2013
Northton	Lewis/Harris	Neolithic	Razorbill	Humerus	Fused	-15.2	15.2	3.4	NT95	Jones 2013
Sligenach	Uist	Beaker	Cattle			-20.9	5.8	3.3	1318	Mulville *et al.* 2009
Sligenach	Uist	Beaker	Cattle			-22.4	5.3	3.3	1344	Mulville *et al.* 2009
Sligenach	Uist	Beaker	Cattle			-20.7	4.2	4.2	1392	Mulville *et al.* 2009
Sligenach	Uist	Beaker	Sheep			-21.1	4.8	3.3	1396	Mulville *et al.* 2009
Sligenach	Uist	Beaker	Sheep			-21.3	3.7	3.7	1615	Mulville *et al.* 2009
Northton	Lewis/Harris	Beaker	Red Deer	Radius	Fused	-21.8	4.0	3.5	NT01	Jones 2013
Northton	Lewis/Harris	Beaker	Red Deer	Tibia	Fused	-22.1	3.8	3.3	NT02	Jones 2013
Northton	Lewis/Harris	Beaker	Red Deer	Tibia	Fused	-21.9	4.2	3.2	NT03	Jones 2013
Northton	Lewis/Harris	Beaker	Red Deer	Humerus	Fused	-21.7	4.0	3.3	NT04	Jones 2013
Northton	Lewis/Harris	Beaker	Red Deer	Metacarpal	Fused	-21.9	4.1	3.5	NT06	Jones 2013
Northton	Lewis/Harris	Beaker	Sheep	Tibia	Fused	-21.1	3.6	3.3	NT11	Jones 2013
Northton	Lewis/Harris	Beaker	Sheep	Tibia	Fused	-21.0	4.6	3.2	NT12	Jones 2013
Northton	Lewis/Harris	Beaker	Sheep	Humerus	Fused	-20.7	3.5	3.2	NT13	Jones 2013
Northton	Lewis/Harris	Beaker	Sheep	Humerus	Fused	-21.4	5.3	3.4	NT14	Jones 2013
Northton	Lewis/Harris	Beaker	Sheep	Tibia	Fused	-21.5	4.1	3.4	NT15	Jones 2013
Northton	Lewis/Harris	Beaker	Sheep	Tibia	Fused	-20.9	4.5	3.2	NT16	Jones 2013
Northton	Lewis/Harris	Beaker	Sheep	Metacarpal	Fused	-21.1	3.5	3.3	NT17	Jones 2013
Northton	Lewis/Harris	Beaker	Sheep	Metatarsal	Fused	-21.4	4.7	3.2	NT18	Jones 2013
Northton	Lewis/Harris	Beaker	Sheep	Radius		-21.2	2.7	3.3	NT19	Jones 2013
Northton	Lewis/Harris	Beaker	Cattle	Metacarpal	Fused	-21.4	4.9	3.4	NT20	Jones 2013

Site	Island	Period	Species	Element	Fusion	$\delta^{13}C$	$\delta^{15}N$	C:N	Sample no	Reference
Northton	Lewis/Harris	Beaker	Cattle	Metatarsal	Fused	-21.6	5.1	3.4	NT23	Jones 2013
Northton	Lewis/Harris	Beaker	Cattle	Metatarsal	Fused	-21.4	4.4	3.3	NT24	Jones 2013
Northton	Lewis/Harris	Beaker	Cattle	Radius		-21.4	3.9	3.4	NT25	Jones 2013
Northton	Lewis/Harris	Beaker	Cattle	Humerus		-21.4	4.4	3.4	NT26	Jones 2013
Northton	Lewis/Harris	Beaker	Pig	Scapula		-21.9	5.3	3.4	NT60	Jones 2013
Northton	Lewis/Harris	Beaker	Otter	Humerus	Fused	-11.1	16.8	3.3	NT68	Jones 2013
Northton	Lewis/Harris	Beaker	Otter	Humerus	Fused	-12.8	17.4	3.3	NT69	Jones 2013
Northton	Lewis/Harris	Beaker	Otter	Humerus	Fused	-11.4	17.0	3.3	NT70	Jones 2013
Northton	Lewis/Harris	Beaker	Seal	Humerus	Fused	-13.4	17.7	3.4	NT79	Jones 2013
Northton	Lewis/Harris	Beaker	Red Deer	Metacarpal		-22.2	5.0	3.5	NT09	Jones 2013
Northton	Lewis/Harris	Beaker	Cattle	Metatarsal		-22.2	4.9	3.6	NT22	Jones 2013
Northton	Lewis/Harris	Beaker	Great Auk	Humerus	Fused	-16.1	12.4	3.4	NT84	Jones 2013
Northton	Lewis/Harris	Beaker	Cormorant	Femur		-13.9	14.5	3.4	NT85	Jones 2013
Northton	Lewis/Harris	Beaker	Guillemot	Coracoid	Fused	-14.7	14.5	3.3	NT86	Jones 2013
Northton	Lewis/Harris	Beaker	Cormorant	Humerus	Fused	-13.0	15.1	3.3	NT87	Jones 2013
Northton	Lewis/Harris	Beaker	Guillemot	Humerus	Fused	-15.1	14.5	3.3	NT88	Jones 2013
Northton	Lewis/Harris	Beaker	Herring / Lesser black-backed gull	Scapula	Fused	-16.1	16.0	3.3	NT89	Jones 2013
Sligenach	Uist	Early Bronze Age	Sheep	Mandible		-21.2	4.5	3.5	SL04	Jones 2013
Sligenach	Uist	Early Bronze Age	Sheep	Metatarsal	Fused	-21.6	3.2	3.4	SL05	Jones 2013
Sligenach	Uist	Early Bronze Age	Pig	Radius	Fused	-21.3	4.9	3.5	SL06	Jones 2013
Sligenach	Uist	Early Bronze Age	Sheep	Metatarsal	Fused	-21.7	4.5	3.3	SL01	Jones 2013
Sligenach	Uist	Early Bronze Age	Cattle	Ulna	Fused	-22.1	5.1	3.4	SL11	Jones 2013
Sligenach	Uist	Early Bronze Age	Red Deer	Metacarpal		-22.2	4.8	3.3	SL15	Jones 2013
Sligenach	Uist	Early Bronze Age	Cattle	Radius		-22.1	4.0	3.3	SL17	Jones 2013
Sligenach	Uist	Early Bronze Age	Sheep	Metatarsal		-20.9	6.2	3.3	SL18	Jones 2013
Sligenach	Uist	Early Bronze Age	Red Deer	Metatarsal		-22.1	3.5	3.3	SL19	Jones 2013
Cladh Hallan	Uist	Bronze Age	Cattle			-22.3	4.7			Craig *et al.*2005
Cladh Hallan	Uist	Bronze Age	Cattle			-22.1	4.6			Jones 2013
Cladh Hallan	Uist	Bronze Age	Cattle			-21.7	5.8			Jones 2013
Cladh Hallan	Uist	Bronze Age	Cattle			-21.7	4.1			Jones 2013
Cladh Hallan	Uist	Bronze Age	Cattle			-21.9	4.9			Jones 2013
Cladh Hallan	Uist	Bronze Age	Cattle			-21.8	5.2			Jones 2013
Cladh Hallan	Uist	Bronze Age	Cattle			-21.7	4.7			Jones 2013
Cladh Hallan	Uist	Bronze Age	Cattle			-22.1	4.2			Jones 2013
Cladh Hallan	Uist	Bronze Age	Cattle			-21.1	5.5			Jones 2013
Cladh Hallan	Uist	Bronze Age	Cattle			-21.7	5.8			Jones 2013
Cladh Hallan	Uist	Bronze Age	Cattle			-20.6	4.4			Jones 2013

Site	Island	Period	Species	Element	Fusion	$\delta^{13}C$	$\delta^{15}N$	C:N	Sample no	Reference
Cladh Hallan	Uist	Bronze Age	Cattle			-21.1	5.8			Jones 2013
Cladh Hallan	Uist	Bronze Age	Cattle	Lumbar Vert		-20.8	4.9	3.4	14173	Jones 2013
Cladh Hallan	Uist	Bronze Age	Cattle	Phalanx		-20.5	6.2	3.3	14211	Jones 2013
Cladh Hallan	Uist	Bronze Age	Cattle	Femur		-21.1	6.3	3.4	14213	Jones 2013
Cladh Hallan	Uist	Bronze Age	Cattle	Femur		-20.1	5.0	3.5	14214	Jones 2013
Cladh Hallan	Uist	Bronze Age	Cattle	Astragalus		-20.9	4.4	3.4	14167	Jones 2013
Cladh Hallan	Uist	Bronze Age	Red Deer	MP		-20.7	6.6	3.3	14216	Jones 2013
Cladh Hallan	Uist	Bronze Age	Red Deer	Metacarpal		-20.7	6.2	3.2	14209	Jones 2013
Cladh Hallan	Uist	Bronze Age	Red Deer	Tibia		-22.2	6.0	3.5	14218	Jones 2013
Cladh Hallan	Uist	Bronze Age	Red Deer	Tibia		-21.2	3.5	3.5	14220	Jones 2013
Cladh Hallan	Uist	Bronze Age	Red Deer			-21.2	4.5			Jones 2013
Cladh Hallan	Uist	Bronze Age	Red Deer			-21.2	5.3			Jones 2013
Cladh Hallan	Uist	Bronze Age	Sheep	Phalanx		-20.1	6.4	3.3	14172	Jones 2013
Cladh Hallan	Uist	Bronze Age	Sheep	Metatarsal		-20.5	4.6	3.6	14171	Jones 2013
Cladh Hallan	Uist	Bronze Age	Sheep	Radius		-20.3	5.0	3.2	14168	Jones 2013
Cladh Hallan	Uist	Bronze Age	Sheep	Tibia		-20.4	6.0	3.5	14219	Jones 2013
Cladh Hallan	Uist	Bronze Age	Sheep	Carpal		-20.6	6.8	3.4	14212	Jones 2013
Cladh Hallan	Uist	Bronze Age	Sheep	Humerus		-21.2	6.0	3.8	14215	Jones 2013
Cladh Hallan	Uist	Bronze Age	Sheep	Vertebra		-19.7	6.8	3.6	14217	Jones 2013
Cladh Hallan	Uist	Bronze Age	Sheep	Tibia		-20.2	6.4	3.2	14221	Jones 2013
Cladh Hallan	Uist	Bronze Age	Sheep	Astragalus		-21.0	7.3	3.2	14222	Jones 2013
Cladh Hallan	Uist	Bronze Age	Sheep	Scap		-21.0	7.5	3.3	14223	Jones 2013
Cladh Hallan	Uist	Bronze Age	Sheep	Femur		-19.0	7.2	3.5	14329	Jones 2013
Cladh Hallan	Uist	Bronze Age	Sheep			-20.4	5.4			Jones 2013
Cladh Hallan	Uist	Bronze Age	Sheep			-19.9	6.3			Jones 2013
Cladh Hallan	Uist	Bronze Age	Dog	Ulna		-19.9	8.8	3.2	14170	Jones 2013
Cladh Hallan	Uist	Bronze Age	Dog	Rib		-19.2	7.4	3.3	14169	Jones 2013
Cladh Hallan	Uist	Bronze Age	Dog			-18.8	10.5			Jones 2013
Cladh Hallan	Uist	Bronze Age	Dog			-19.0	10.3			Jones 2013
Cladh Hallan	Uist	Bronze Age	Dog	Metatarsal		-20.4	9.3	3.2	14210	Jones 2013
Cladh Hallan	Uist	Bronze Age	Cattle			-20.1	4.9			Jones 2013
Cladh Hallan	Uist	Bronze Age	Cattle	Femur		-20.7	5.1	3.3	14208	Jones 2013
Cladh Hallan	Uist	Bronze Age	Red Deer			-20.2	7.1			Jones 2013
Cladh Hallan	Uist	Bronze Age	Red Deer			-21.4	4.6			Jones 2013
Cladh Hallan	Uist	Bronze Age	Sheep			-21.1	5.3			Jones 2013
Tofts Ness	Orkney	Bronze Age	Sheep	Radius	Fused	-20.4	8.4	3.4	TN17	Jones 2013
Tofts Ness	Orkney	Bronze Age	Cattle	Metacarpal	Fused	-21.7	6.0	3.3	TN19	Jones 2013

Site	Island	Period	Species	Element	Fusion	δ^{13}C	δ^{15}N	C:N	Sample no	Reference
Tofts Ness	Orkney	Bronze Age	Sheep	Ulna	Fused	-20.5	7.5	3.2	TN21	Jones 2013
Tofts Ness	Orkney	Bronze Age	Cattle	Metacarpal	Fused	-21.8	7.0	3.3	TN22	Jones 2013
Tofts Ness	Orkney	Bronze Age	Cattle	Metacarpal	Fused	-21.7	6.8	3.3	TN23	Jones 2013
Tofts Ness	Orkney	Bronze Age	Red Deer	Metacarpal		-21.5	9.7	3.4	TN24	Jones 2013
Tofts Ness	Orkney	Bronze Age	Pig	Femur		-21.8	8.3	3.4	TN27	Jones 2013
Tofts Ness	Orkney	Bronze Age	Pig	Humerus	Fused	-21.1	5.4	3.3	TN28	Jones 2013
Tofts Ness	Orkney	Bronze Age	Cattle	Scapula	Fused	-21.7	6.7	3.4	TN33	Jones 2013
Tofts Ness	Orkney	Bronze Age	Sheep	Tibia		-20.3	8.9	3.3	TN35	Jones 2013
Tofts Ness	Orkney	Bronze Age	Sheep	Metacarpal	Fused	-21.0	5.9	3.2	TN36	Jones 2013
Tofts Ness	Orkney	Bronze Age	Cattle	Humerus		-21.5	6.3	3.4	TN37	Jones 2013
Cladh Hallan	Uist	Late Bronze Age	Great Auk	Humerus	Fused	-14.2	12.4		JJ68	Jones 2013
Cladh Hallan	Uist	Late Bronze Age	Great Auk	Humerus	Fused	-14.5	12.6		JJ69	Jones 2013
Cladh Hallan	Uist	Late Bronze Age	Cormorant	Humerus	Fused	-11.2	15.9		JJ70	Jones 2013
Cladh Hallan	Uist	Late Bronze Age	Cormorant	Humerus	Fused	-13.1	15.7		JJ71	Jones 2013
Cladh Hallan	Uist	Late Bronze Age	Gannet	Ulna	Fused	-13.5	14.3		JJ72	Jones 2013
Cladh Hallan	Uist	Late Bronze Age	Gannet	Ulna	Fused	-13.9	12.7		JJ73	Jones 2013
Cladh Hallan	Uist	Late Bronze Age	Greylag/Bean Goose	Humerus	Fused	-12.9	16.4		JJ74	Jones 2013
Cladh Hallan	Uist	Late Bronze Age	Greylag/Bean Goose	Humerus	Fused	-20.9	5.7		JJ75	Jones 2013
Cladh Hallan	Uist	Late Bronze Age	Swan	Tibio-Tarsus		-14.9	6.6		JJ76	Jones 2013
Cladh Hallan	Uist	Late Bronze Age	Swan	Tibio-Tarsus		-16.9	5.4		JJ77	Jones 2013
Cladh Hallan	Uist	Late Bronze Age	Herring Gull	Tibio-Tarsus		-14.0	16.5		JJ78	Jones 2013
Cladh Hallan	Uist	Late Bronze Age	Herring Gull	Tibio-Tarsus		-13.4	14.5		JJ79	Jones 2013
Bornais Mound 2	Uist	Late Bronze Age	Cormorant	Humerus	Fused	-11.2	16.1		JJ80	Jones 2013
Bornais Mound 2	Uist	Late Bronze Age	Cormorant	Humerus	Fused	-11.8	15.0		JJ81	Jones 2013
Cladh Hallan	Uist	Late Bronze Age	Red Deer	Metacarpal	Fused	-21.3	5.4	3.3	CHJ02	Jones 2013
Cladh Hallan	Uist	Late Bronze Age	Red Deer	Scapula	Fused	-21.8	4.4	3.3	CHJ03	Jones 2013
Cladh Hallan	Uist	Late Bronze Age	Red Deer	Humerus	Fused	-21.3	4.3	3.3	CHJ04	Jones 2013
Cladh Hallan	Uist	Late Bronze Age	Red Deer	Radius	Fused	-21.3	5.0	3.4	CHJ05	Jones 2013
Cladh Hallan	Uist	Late Bronze Age	Red Deer	Tibia	Fused	-21.4	5.1	3.3	CHJ06	Jones 2013
Cladh Hallan	Uist	Late Bronze Age	Red Deer	Tibia	Fused	-21.5	4.3	3.3	CHJ07	Jones 2013
Cladh Hallan	Uist	Late Bronze Age	Red Deer	Tibia	Unfused	-22.4	6.2	3.4	CHJ09	Jones 2013
Cladh Hallan	Uist	Late Bronze Age	Sheep/goat	Radius	Fused	-20.2	6.8	3.3	CHJ10	Jones 2013
Cladh Hallan	Uist	Late Bronze Age	Sheep/goat	Tibia	Fused	-20.9	6.8	3.3	CHJ11	Jones 2013
Cladh Hallan	Uist	Late Bronze Age	Sheep/goat	Ulna	Fused	-20.1	6.6	3.3	CHJ12	Jones 2013
Cladh Hallan	Uist	Late Bronze Age	Sheep/goat	Tibia	Fused	-20.1	5.6	3.3	CHJ13	Jones 2013

Site	Island	Period	Species	Element	Fusion	$\delta^{13}C$	$\delta^{15}N$	C:N	Sample no	Reference
Cladh Hallan	Uist	Late Bronze Age	Sheep/goat	Radius	Fused	-20.7	6.7	3.4	CHJ14	Jones 2013
Cladh Hallan	Uist	Late Bronze Age	Sheep/goat	Tibia	Fused	-20.7	4.9	3.3	CHJ15	Jones 2013
Cladh Hallan	Uist	Late Bronze Age	Sheep/goat	Ulna	Unfused	-19.9	7.9	3.4	CHJ16	Jones 2013
Cladh Hallan	Uist	Late Bronze Age	Cattle	Metacarpal	Fused	-21.6	5.3	3.2	CHJ18	Jones 2013
Cladh Hallan	Uist	Late Bronze Age	Cattle	Metacarpal	Fused	-21.5	5.2	3.3	CHJ19	Jones 2013
Cladh Hallan	Uist	Late Bronze Age	Cattle	Metatarsal	Fused	-21.5	5.3	3.2	CHJ20	Jones 2013
Cladh Hallan	Uist	Late Bronze Age	Cattle	Metatarsal	Fused	-21.7	6.3	3.3	CHJ22	Jones 2013
Cladh Hallan	Uist	Late Bronze Age	Cattle	Metatarsal	Fused	-21.7	5.8	3.3	CHJ24	Jones 2013
Cladh Hallan	Uist	Late Bronze Age	Cattle	Radius	Fused	-21.3	6.0	3.3	CHJ25	Jones 2013
Cladh Hallan	Uist	Late Bronze Age	Pig	Humerus	Unfused	-19.8	10.2	3.2	CHJ26	Jones 2013
Cladh Hallan	Uist	Late Bronze Age	Pig	Metapodial	Fused	-20.4	7.5	3.2	CHJ27	Jones 2013
Cladh Hallan	Uist	Late Bronze Age	Pig	Femur		-22.3	7.5	3.2	CHJ28	Jones 2013
Cladh Hallan	Uist	Late Bronze Age	Red Deer	Radius	Fused	-21.9	4.5	3.3	CHJ29	Jones 2013
Sligenach	Uist	Early Iron Age	Sheep	Pelvis	Fused	-20.3	5.7	3.2	SL02	Jones 2013
Sligenach	Uist	Early Iron Age	Red Deer	Scapula	Fused	-21.2	4.7	3.3	SL07	Jones 2013
Sligenach	Uist	Early Iron Age	Sheep	Pelvis	Fused	-21.3	5.8	3.4	SL08	Jones 2013
Howe	Orkney	Early Iron Age	Cattle	Tibia	Fused	-21.7	5.9	3.4	HO02	Jones 2013
Howe	Orkney	Early Iron Age	Cattle	Radius	Fused	-21.8	5.8	3.2	HO05	Jones 2013
Howe	Orkney	Early Iron Age	Pig	Humerus	Fused	-21.3	6.7	3.3	HO06	Jones 2013
Howe	Orkney	Early Iron Age	Sheep	Radius	Fused	-20.4	5.4	3.3	HO07	Jones 2013
Sligenach	Uist	Early Iron Age	Cattle	Femur		-21.8	5.0	3.3	SL14	Jones 2013
Sligenach	Uist	Early Iron Age	Sheep	Femur		-21.0	5.6	3.3	SL16	Jones 2013
Sligenach	Uist	Early Iron Age	Sheep	Tibia		-20.8	6.7	3.3	SL20	Jones 2013
Sligenach	Uist	Early/Middle Iron Age	Cattle			-20.4	5.4	3.3	1656	Mulville *et al.* 2009
Sligenach	Uist	Early/Middle Iron Age	Cattle			-20.5	4.7	3.3	1660	Mulville *et al.* 2009
Sligenach	Uist	Early/Middle Iron Age	Cattle			-20.4	6.3	3.3	1632	Mulville *et al.* 2009
Sligenach	Uist	Early/Middle Iron Age	Cattle			-20.6	5.9	3.4	1642	Mulville *et al.* 2009
Sligenach	Uist	Early/Middle Iron Age	Red Deer			-20.9	4.7	3.3	1648	Mulville *et al.* 2009
Sloc Sabhaidh	Uist	Iron Age	Sheep			-20.9	5.1	3.4		Armit and Shapland pers. comm.
Baleshare	Uist	Iron Age	Sheep			-20.9	5.1	3.4	24964	Dawson pers.comm.
Baleshare	Uist	Iron Age	dog	Femur	Fused	-19.9	7.9		JJ54	Jones 2013
Baleshare	Uist	Iron Age	Pig	mandible		-19.8	8.3		JJ55	Jones 2013
Baleshare	Uist	Iron Age	Pig	mandible		-21.2	7.0		JJ57	Jones 2013
Baleshare	Uist	Iron Age	Cattle	metacarpal	Fused	-21.6	4.3		JJ58	Jones 2013
Baleshare	Uist	Iron Age	Cattle	metacarpal	Fused	-21.1	5.4		JJ59	Jones 2013
Baleshare	Uist	Iron Age	Cattle	metacarpal	Fused	-20.9	5.2		JJ60	Jones 2013
Baleshare	Uist	Iron Age	Cattle	metacarpal	Fused	-21.3	4.9		JJ61	Jones 2013

Site	Island	Period	Species	Element	Fusion	$\delta^{13}C$	$\delta^{15}N$	C:N	Sample no	Reference
Baleshare	Uist	Iron Age	Cattle	metacarpal	Fused	-21.0	4.6		JJ62	Jones 2013
Baleshare	Uist	Iron Age	Sheep	metatarsal	Fused	-20.8	4.8		JJ63	Jones 2013
Baleshare	Uist	Iron Age	Sheep	metatarsal		-20.5	6.2		JJ64	Jones 2013
Baleshare	Uist	Iron Age	Sheep	metatarsal	Fused	-21.1	7.5		JJ65	Jones 2013
Baleshare	Uist	Iron Age	Sheep	metatarsal	Fused	-21.0	4.5		JJ66	Jones 2013
Baleshare	Uist	Iron Age	Sheep	metatarsal	Fused	-20.7	5.9		JJ67	Jones 2013
Baleshare	Uist	Iron Age	Seal	Ulna	Fused	-11.6	18.2		JJ82	Jones 2013
Baleshare	Uist	Iron Age	Red Deer	Ulna	Fused	-21.9	4.5		JJ84	Jones 2013
Baleshare	Uist	Iron Age	Pig	mandible		-21.5	5.4		JJ85	Jones 2013
Baleshare	Uist	Iron Age	Pig	Humerus	Fused	-21.0	9.2		JJ86	Jones 2013
Baleshare	Uist	Iron Age	Pig	Occipital		-20.1	8.1		JJ87	Jones 2013
Baleshare	Uist	Iron Age	Sheep	metatarsal	Fused	-21.2	4.7		JJ88	Jones 2013
Baleshare	Uist	Iron Age	Sheep	metatarsal	Fused	-21.4	5.4		JJ89	Jones 2013
Mine Howe	Orkney	Iron Age	Pig	Radius	Fused	-20.6	8.6	3.4	MH01	Jones 2013
Mine Howe	Orkney	Iron Age	Pig	Scapula	Fused	-21.8	6.6	3.4	MH02	Jones 2013
Mine Howe	Orkney	Iron Age	Cattle	Astragalus	Fused	-22.1	5.9	3.3	MH03	Jones 2013
Mine Howe	Orkney	Iron Age	Cattle	Tibia	Fused	-21.8	6.3	3.3	MH04	Jones 2013
Mine Howe	Orkney	Iron Age	Sheep	Metacarpal	Fused	-22.1	6.9	3.3	MH05	Jones 2013
Mine Howe	Orkney	Iron Age	Cattle	Humerus	Fused	-21.6	5.9	3.4	MH06	Jones 2013
Mine Howe	Orkney	Iron Age	Cattle	Humerus	Fused	-22.4	4.9	3.6	MH07	Jones 2013
Mine Howe	Orkney	Iron Age	Red Deer	Tibia	Fused	-21.8	6.3	3.4	MH08	Jones 2013
Mine Howe	Orkney	Iron Age	Cattle	Tibia	Fused	-21.4	5.1	3.3	MH09	Jones 2013
Mine Howe	Orkney	Iron Age	Red Deer	Metacarpal	Fused	-21.6	6.6	3.3	MH10	Jones 2013
Mine Howe	Orkney	Iron Age	Red Deer	Metacarpal	Fused	-21.6	6.2	3.3	MH11	Jones 2013
Mine Howe	Orkney	Iron Age	Red Deer	Metacarpal	Fused	-21.7	4.3	3.3	MH12	Jones 2013
Mine Howe	Orkney	Iron Age	Red Deer	Radius	Fused	-22.0	6.6	3.2	MH13	Jones 2013
Mine Howe	Orkney	Iron Age	Red Deer	Metatarsal	Fused	-21.9	7.2	3.3	MH14	Jones 2013
Mine Howe	Orkney	Iron Age	Red Deer	Radius	Fused	-22.3	6.4	3.7	MH15	Jones 2013
Mine Howe	Orkney	Iron Age	Red Deer	Humerus	Fused	-21.8	6.0	3.3	MH16	Jones 2013
Mine Howe	Orkney	Iron Age	Sheep	Femur	Fused	-21.4	6.0	3.4	MH17	Jones 2013
Mine Howe	Orkney	Iron Age	Sheep	Metapodial	Fused	-22.2	8.1	3.3	MH18	Jones 2013
Mine Howe	Orkney	Iron Age	Pig	Humerus	Fused	-20.6	9.6	3.3	MH19	Jones 2013
Mine Howe	Orkney	Iron Age	Swan	Radius	Fused	-11.5	8.9	3.3	MH20	Jones 2013
Mine Howe	Orkney	Iron Age	Cattle	Tibia	Fused	-22.0	6.7	3.3	MH21	Jones 2013
Mine Howe	Orkney	Iron Age	Cattle	Tibia	Fused	-21.7	5.0	3.3	MH22	Jones 2013
Mine Howe	Orkney	Iron Age	Pig	Scapula	Fused	-19.9	8.8	3.3	MH23	Jones 2013
Mine Howe	Orkney	Iron Age	Sheep	Scapula	Fused	-22.4	9.0	3.3	MH24	Jones 2013

Site	Island	Period	Species	Element	Fusion	$\delta^{13}C$	$\delta^{15}N$	C:N	Sample no	Reference
Mine Howe	Orkney	Iron Age	Sheep	Metacarpal	Fused	-21.8	6.7	3.3	MH25	Jones 2013
Mine Howe	Orkney	Iron Age	sheep	Metacarpal	Fused	-22.4	8.5	3.3	MH26	Jones 2013
Mine Howe	Orkney	Iron Age	Sheep	Metatarsal	Fused	-22.1	7.0	3.3	MH27	Jones 2013
Mine Howe	Orkney	Iron Age	Red Deer	Metacarpal	Fused	-21.7	5.3	3.3	MH28	Jones 2013
Mine Howe	Orkney	Iron Age	Pig	Scapula	Fused	-21.0	11.0	3.4	MH29	Jones 2013
Mine Howe	Orkney	Iron Age	Cattle	Tibia	Fused	-21.7	7.1	3.3	MH30	Jones 2013
Mine Howe	Orkney	Iron Age	Red Deer	Tibia	Fused	-22.0	7.3	3.3	MH32	Jones 2013
Mine Howe	Orkney	Iron Age	Red Deer	Humerus	Fused	-22.0	6.9	3.3	MH33	Jones 2013
Mine Howe	Orkney	Iron Age	Pig	Skull		-21.9	8.8	3.3	MH34	Jones 2013
Mine Howe	Orkney	Iron Age	Red Deer	Metatarsal	Fused	-22.4	8.8	3.4	MH35	Jones 2013
The Cairns	Orkney	Iron Age	Sheep	Radius	Fused	-19.1	7.3	3.2	TC01	Jones 2013
The Cairns	Orkney	Iron Age	Sheep	Tibia		-21.4	6.0	3.2	TC02	Jones 2013
The Cairns	Orkney	Iron Age	Cattle	Humerus	Fused	-21.5	7.6	3.2	TC03	Jones 2013
The Cairns	Orkney	Iron Age	Pig	Radius	Fused	-19.6	9.7	3.3	TC05	Jones 2013
The Cairns	Orkney	Iron Age	Cattle	Femur	Fused	-21.9	6.5	3.3	TC07	Jones 2013
The Cairns	Orkney	Iron Age	Cattle	Phal 1	Fused	-22.6	5.3	3.7	TC08	Jones 2013
The Cairns	Orkney	Iron Age	Cattle	Metacarpal	Fused	-22.3	5.4	3.5	TC09	Jones 2013
The Cairns	Orkney	Iron Age	Pig	Ulna	Fused	-21.2	9.2	3.4	TC10	Jones 2013
The Cairns	Orkney	Iron Age	Sheep	Tibia	Fused	-22.2	7.8	3.5	TC11	Jones 2013
The Cairns	Orkney	Iron Age	Cattle	Scapula	Fused	-22.0	5.9	3.4	TC12	Jones 2013
The Cairns	Orkney	Iron Age	Cattle	Humerus	Fused	-22.0	6.1	3.4	TC13	Jones 2013
St Ninain's Isle	Shetland	Iron Age	Sheep	Tibia	Fused	-21.1	8.0	3.4	SNI01	Jones 2013
St Ninain's Isle	Shetland	Iron Age	Sheep	Tibia	Fused	-21.8	5.8	3.3	SNI02	Jones 2013
St Ninain's Isle	Shetland	Iron Age	Pig	Metacarpal	Fused	-20.9	7.7	3.3	SNI03	Jones 2013
St Ninain's Isle	Shetland	Iron Age	Cattle	Zygomatic		-21.9	4.4	3.4	SNI04	Jones 2013
Knowe o' Skea	Orkney	Iron Age	Red Deer	Metatarsal	Fused	-21.2	6.8	3.2	BN01	Jones 2013
Knowe o' Skea	Orkney	Iron Age	Pig	Maxilla		-21.2	5.9	3.2	BN03	Jones 2013
Knowe o' Skea	Orkney	Iron Age	Sheep	Metatarsal	Fused	-20.9	6.4	3.3	BN04	Jones 2013
Knowe o' Skea	Orkney	Iron Age	Sheep	Humerus	Fused	-21.3	5.7	3.2	BN05	Jones 2013
Knowe o' Skea	Orkney	Iron Age	Sheep	Metacarpal	Fused	-21.4	5.6	3.2	BN06	Jones 2013
Knowe o' Skea	Orkney	Iron Age	Sheep	Radius	Fused	-20.7	4.3	3.2	BN07	Jones 2013
Knowe o' Skea	Orkney	Iron Age	Sheep	Humerus	Fused	-21.2	6.2	3.2	BN08	Jones 2013
Knowe o' Skea	Orkney	Iron Age	Cattle	Metacarpal	Fused	-21.7	5.3	3.3	BN09	Jones 2013
Knowe o' Skea	Orkney	Iron Age	Cattle	Metacarpal	Fused	-21.5	5.4	3.2	BN10	Jones 2013
Knowe o' Skea	Orkney	Iron Age	Cattle	Metacarpal	Fused	-21.8	5.3	3.5	BN11	Jones 2013
Knowe o' Skea	Orkney	Iron Age	Cattle	Tibia	Fused	-22.2	5.6	3.4	BN12	Jones 2013
Knowe o' Skea	Orkney	Iron Age	Cattle	Radius	Fused	-21.6	4.9	3.2	BN13	Jones 2013

Site	Island	Period	Species	Element	Fusion	δ^{13}C	δ^{15}N	C:N	Sample no	Reference
Knowe o' Skea	Orkney	Iron Age	Dog	Rib		-20.2	5.6	3.3	BN15	Jones 2013
Knowe o' Skea	Orkney	Iron Age	Dog	Mandible		-21.0	7.8	3.4	BN17	Jones 2013
Knowe o' Skea	Orkney	Iron Age	Pig	Mandible		-21.5	6.8	3.3	BN18	Jones 2013
Knowe o' Skea	Orkney	Iron Age	Ballan Wrasse	Premaxilla		-13.6	14.2	3.2	BN19	Jones 2013
Knowe o' Skea	Orkney	Iron Age	Cod	Cleithrum		-13.0	15.6	3.3	BN20	Jones 2013
Knowe o' Skea	Orkney	Iron Age	Cod	Dentary		-13.5	13.9	3.7	BN21	Jones 2013
Pool	Orkney	Iron Age	Red Deer	Humerus	Fused	-22.4	6.8	3.3	PO01	Jones 2013
Pool	Orkney	Iron Age	Red Deer	Humerus	Fused	-21.9	6.7	3.3	PO02	Jones 2013
Pool	Orkney	Iron Age	Sheep	Tibia	Fused	-20.3	7.5	3.3	PO03	Jones 2013
Pool	Orkney	Iron Age	Sheep	Humerus	Fused	-21.9	6.9	3.4	PO04	Jones 2013
Pool	Orkney	Iron Age	Pig	Humerus	Fused	-20.2	8.4	3.3	PO05	Jones 2013
Pool	Orkney	Iron Age	Sheep	Metacarpal	Fused	-20.6	5.8	3.2	PO06	Jones 2013
Pool	Orkney	Iron Age	Cattle	Humerus	Fused	-21.9	5.4	3.3	PO07	Jones 2013
Pool	Orkney	Iron Age	Horse	Metacarpal	Fused	-22.5	6.6	3.3	PO08	Jones 2013
Pool	Orkney	Iron Age	Sheep	Humerus	Fused	-21.1	6.7	3.3	PO09	Jones 2013
Pool	Orkney	Iron Age	Cattle	Metacarpal	Fused	-21.7	5.4	3.2	PO10	Jones 2013
Pool	Orkney	Iron Age	Pig	Humerus		-21.3	4.7	3.3	PO11	Jones 2013
Pool	Orkney	Iron Age	Sheep	Humerus		-21.8	6.6	3.2	PO12	Jones 2013
Pool	Orkney	Iron Age	Cod	Dentary		-13.0	14.1	3.3	PO13	Jones 2013
Pool	Orkney	Iron Age	Pig	Metapodial	Fused	-19.7	9.1	3.4	PO14	Jones 2013
Pool	Orkney	Iron Age	Pig	Maxilla		-19.1	10.4	3.3	PO15	Jones 2013
Pool	Orkney	Iron Age	Pig	Mandible		-18.4	9.8	3.3	PO17	Jones 2013
Pool	Orkney	Iron Age	Cattle	Metacarpal	Fused	-22.0	6.1	3.3	PO18	Jones 2013
Pool	Orkney	Iron Age	Cattle	Metacarpal	Fused	-21.9	5.7	3.4	PO19	Jones 2013
Pool	Orkney	Iron Age	Sheep	Radius	Fused	-20.2	6.7	3.2	PO20	Jones 2013
Pool	Orkney	Iron Age	Cattle	Radius	Fused	-22.2	5.3	3.4	PO21	Jones 2013
Pool	Orkney	Iron Age	Pig	Humerus	Fused	-21.3	9.1	3.4	PO22	Jones 2013
Pool	Orkney	Iron Age	Pig	Femur	Fused	-21.9	9.0	3.3	PO25	Jones 2013
Pool	Orkney	Iron Age	Horse	Metapodial		-22.9	5.9	3.3	PO26	Jones 2013
Tofts Ness	Orkney	Iron Age	Cattle	Metatarsal	Fused	-22.1	5.0	3.5	TN39	Jones 2013
Tofts Ness	Orkney	Iron Age	Cattle	Metacarpal	Fused	-21.9	5.5	3.4	TN41	Jones 2013
Tofts Ness	Orkney	Iron Age	Sheep	Humerus		-21.7	6.7	3.4	TN42	Jones 2013
Tofts Ness	Orkney	Iron Age	Sheep	Humerus	Fused	-21.4	5.9	3.5	TN43	Jones 2013
Tofts Ness	Orkney	Iron Age	Sheep	Tibia		-21.2	7.1	3.3	TN45	Jones 2013
Tofts Ness	Orkney	Iron Age	Sheep	Tibia		-21.5	7.8	3.3	TN46	Jones 2013
Tofts Ness	Orkney	Iron Age	Sheep	Humerus	Fused	-20.9	6.5	3.4	TN48	Jones 2013
Tofts Ness	Orkney	Iron Age	Cattle	Tibia		-21.5	5.8	3.4	TN50	Jones 2013

Site	Island	Period	Species	Element	Fusion	δ^{13}C	δ^{15}N	C:N	Sample no	Reference
Tofts Ness	Orkney	Iron Age	Cattle	Metacarpal		-21.8	5.7	3.3	TN51	Jones 2013
Bornish M2W	Uist	Late Iron Age	Red Deer	metatarsal		-21.7	4.9		JJ11	Jones 2013
Bornish M2W	Uist	Late Iron Age	Red Deer	Scapula	Fused	-21.5	5.3		JJ12	Jones 2013
Bornish M2W	Uist	Late Iron Age	Red Deer	Scapula	Fused	-21.9	4.4		JJ13	Jones 2013
Bornish M2W	Uist	Late Iron Age	Red Deer	Tibia	Fused	-22.2	4.6		JJ14	Jones 2013
Bornish M2W	Uist	Late Iron Age	Red Deer	Phal 1	Fused	-21.5	4.8		JJ15	Jones 2013
Bornish M2W	Uist	Late Iron Age	Red Deer	metatarsal		-21.7	4.9		JJ16	Jones 2013
Bornish M2W	Uist	Late Iron Age	Sheep	metatarsal		-21.5	5.0		JJ17	Jones 2013
Bornish M2W	Uist	Late Iron Age	Sheep	Radius		-21.0	6.1		JJ18	Jones 2013
Bornais M1	Uist	Late Iron Age	Cattle	Metacarpal	Fused	-21.1	4.2	3.2	JQ33	Mulville *et al.* 2009
Bornais M1	Uist	Late Iron Age	Cattle	Radius	Unfused	-20.9	3.6	3.3	JQ36	Mulville *et al.* 2009
Bornais M1	Uist	Late Iron Age	Cattle	Radius	Unfused	-21.4	4.3	3.3	JQ37	Mulville *et al.* 2009
Bornish M1	Uist	Late Iron Age	Cattle	Metacarpal	Unfused	-21.2	4.8	3.2	JQ38	Mulville *et al.* 2009
Bornish M1	Uist	Late Iron Age	Cattle	Metacarpal	Fused	-21.3	4.1	3.2	JQ31	Mulville *et al.* 2009
Bornish M1	Uist	Late Iron Age	Cattle	Metacarpal	Fused	-21.3	5.0	3.2	JQ35	Mulville *et al.* 2009
Bornish M1	Uist	Late Iron Age	Cattle	Metacarpal	Fused	-21.6	4.5	3.3	JQ34	Mulville *et al.* 2009
Bornish M1	Uist	Late Iron Age	Cattle	Radius	Unfused	-21.0	4.2	3.2	JQ39	Mulville *et al.* 2009
Bornish M1	Uist	Late Iron Age	Cattle	Metacarpal	Fused	-21.4	3.5	3.3	JQ40	Mulville *et al.* 2009
Bornish M1	Uist	Late Iron Age	Cattle	Radius	Fused	-21.6	4.3	3.2	JQ32	Mulville *et al.* 2009
Bornish M1	Uist	Late Iron Age	Cattle	Phal		-21.3	4.1	3.4	13360	Jones 2013
Bornish M1	Uist	Late Iron Age	Cattle	Metacarpal		-21.6	3.7	3.6	13351	Jones 2013
Bornish M1	Uist	Late Iron Age	Cattle			-20.4	4.3	3.3	2035	Jones 2013
Bornish M1	Uist	Late Iron Age	Cattle			-20.5	4.8	3.3	8565	Jones 2013
Bornish M1	Uist	Late Iron Age	Cattle			-20.5	4.7	3.3	9170	Jones 2013
Bornish M1	Uist	Late Iron Age	Red Deer	Radius		-21.7	2.9	3.6	13357	Jones 2013
Bornish M1	Uist	Late Iron Age	Red Deer	Astragalus		-21.7	4.8	3.4	13356	Jones 2013
Bornish M1	Uist	Late Iron Age	Red Deer	Astragalus		-22.0	3.7	3.6	13353	Jones 2013
Bornish M1	Uist	Late Iron Age	Red Deer	Astragalus		-21.7	5.0	3.4	13352	Jones 2013
Bornish M1	Uist	Late Iron Age	Red Deer	Tibia	Fused	-21.4	4.3	3.2	JQ30	Mulville *et al.* 2009
Bornish M1	Uist	Late Iron Age	Red Deer	Tibia	Unfused	-21.6	4.3	3.3	JQ26	Mulville *et al.* 2009
Bornish M1	Uist	Late Iron Age	Red Deer	Tibia	Fused	-21.6	4.9	3.2	JQ28	Mulville *et al.* 2009
Bornish M1	Uist	Late Iron Age	Red Deer	Tibia	Fused	-21.7	4.7	3.2	JQ29	Mulville et al. 2009
Bornish M1	Uist	Late Iron Age	Red Deer	Tibia	Fused	-22.1	3.8	3.3	JQ25	Mulville et al. 2009
Bornish M1	Uist	Late Iron Age	Red Deer	Femur	Unfused	-22.2	3.7	3.2	JQ27	Mulville et al. 2009
Bornish M1	Uist	Late Iron Age	Red Deer	Radius	Fused	-22.5	4.0	3.3	JQ22	Mulville et al. 2009
Bornish M1	Uist	Late Iron Age	Red Deer	Radius	Fused	-21.7	3.6	3.2	JQ21	Mulville et al. 2009
Bornish M1	Uist	Late Iron Age	Red Deer	Tibia	Fused	-21.4	5.1	3.3	JQ23	Mulville et al. 2009

Site	Island	Period	Species	Element	Fusion	δ^{13}C	δ^{15}N	C:N	Sample no	Reference
Bornish M1	Uist	Late Iron Age	Red Deer	Tibia	Unfused	-21.8	3.6	3.3	JQ20	Mulville et al. 2009
Bornish M1	Uist	Late Iron Age	Red Deer	Phal 2	Unfused	-22.1	4.2	3.2	JQ24	Mulville et al. 2009
Bornish M1	Uist	Late Iron Age	Red Deer			-20.8	5.4	3.2	9105	Jones 2013
Bornish M1	Uist	Late Iron Age	Red Deer			-20.8	5.1	3.3	9105	Jones 2013
Bornish M1	Uist	Late Iron Age	Red Deer			-21.8	5.3	3.2	9169	Jones 2013
Bornish M1	Uist	Late Iron Age	Red Deer	Metatarsal		-21.4	4.7	3.5	16527	Jones 2013
Bornish M1	Uist	Late Iron Age	Pig	Calcaneous	Unfused	-20.6	7.4	3.3	JQ14	Mulville *et al.* 2009
Bornish M1	Uist	Late Iron Age	Pig	Tibia	Unfused	-21.1	5.5	3.3	JQ19	Mulville *et al.* 2009
Bornish M1	Uist	Late Iron Age	Pig	Metatarsal	Unfused	-20.0	8.1	3.2	JQ15	Mulville *et al.* 2009
Bornish M1	Uist	Late Iron Age	Pig	Metatarsal	Unfused	-20.7	7.2	3.2	JQ17	Mulville *et al.* 2009
Bornish M1	Uist	Late Iron Age	Pig	Phal 1	Unfused	-20.8	6.8	3.2	JQ18	Mulville *et al.* 2009
Bornish M1	Uist	Late Iron Age	Pig	Scap	Unfused	-20.6	6.3	3.3	JQ16	Mulville *et al.* 2009
Bornish M1	Uist	Late Iron Age	Pig	Tibia	Fused	-19.9	7.5	3.2	JQ13	Mulville *et al.* 2009
Bornish M1	Uist	Late Iron Age	Pig	Metatarsal	Fused	-20.9	7.1	3.2	JQ12	Mulville *et al.* 2009
Bornish M1	Uist	Late Iron Age	Pig	Astrag and calc.		-20.8	6.5	3.5	13355	Jones 2013
Bornish M1	Uist	Late Iron Age	Sheep	Tibia	Fused	-20.9	4.6	3.2	JQ11	Mulville *et al.* 2009
Bornish M1	Uist	Late Iron Age	Sheep	Tibia	Fused	-21.7	5.2	3.2	JQ6	Mulville *et al.* 2009
Bornish M1	Uist	Late Iron Age	Sheep	Radius	Fused	-21.1	4.4	3.2	JQ5	Mulville *et al.* 2009
Bornish M1	Uist	Late Iron Age	Sheep	Tibia	Fused	-21.1	3.7	3.2	JQ7	Mulville *et al.* 2009
Bornish M1	Uist	Late Iron Age	Sheep	Tibia	Fused	-21.1	4.0	3.2	JQ9	Mulville *et al.* 2009
Bornish M1	Uist	Late Iron Age	Sheep	Tibia	Fused	-21.3	3.7	3.2	JQ8	Mulville *et al.* 2009
Bornish M1	Uist	Late Iron Age	Sheep	Tibia	Unfused	-21.8	5.1	3.3	JQ10	Mulville *et al.* 2009
Bornish M1	Uist	Late Iron Age	Sheep	Radius	Unfused	-21.2	3.7	3.3	JQ2	Mulville *et al.* 2009
Bornish M1	Uist	Late Iron Age	Sheep	Tibia	Fused	-21.6	4.4	3.3	JQ1	Mulville *et al.* 2009
Bornish M1	Uist	Late Iron Age	Sheep	Tibia	Fused	-21.3	5.3	3.3	JQ3	Mulville *et al.* 2009
Bornish M1	Uist	Late Iron Age	Sheep	Radius	Fused	-21.3	4.2	3.2	JQ4	Mulville *et al.* 2009
Bornish M1	Uist	Late Iron Age	Sheep	Radius		-21.4	4.4	3.5	13354	Jones 2013
Bornais	Uist	Late Iron Age	Cattle	Phal 2		-21.3	4.5	3.5	11947	Jones 2013
Bornais	Uist	Late Iron Age	Red Deer	Femur		-19.0	4.1	3.7	11946	Jones 2013
Dun Vulan	Uist	Late Iron Age	Seal			-13.5	15.5			Jones 2013
Bornish M2W	Uist	Late Iron Age	Sheep	3rd Phalanx	Fused	-21.3	5.1		JJ19	Jones 2013
Bornish M2W	Uist	Late Iron Age	Pig	metacarpal		-18.6	10.0		JJ20	Jones 2013
Bornish M2W	Uist	Late Iron Age	Pig	metatarsal	Fused	-19.8	8.5		JJ21	Jones 2013
Bornish M2W	Uist	Late Iron Age	Cattle	Phal 1	Fused	-21.1	5.2		JJ22	Jones 2013
Bornish M2W	Uist	Late Iron Age	Cattle	Femur	Fused	-21.2	4.9		JJ23	Jones 2013
Bornish M2W	Uist	Late Iron Age	Cattle	Radius	Fused	-21.2	5.5		JJ24	Jones 2013
Bornish M2W	Uist	Late Iron Age	Cattle	Phal 1	Fused	-21.3	4.8		JJ25	Jones 2013

Site	Island	Period	Species	Element	Fusion	$\delta^{13}C$	$\delta^{15}N$	C:N	Sample no	Reference
Bornish M2W	Uist	Late Iron Age	Cattle	metacarpal		-21.0	4.6		JJ26	Jones 2013
Northton	Lewis/Harris	Late Iron Age	Red Deer	Scapula	Fused	-21.8	3.5	3.3	NT53	Jones 2013
Northton	Lewis/Harris	Late Iron Age	Red Deer	Scapula	Fused	-21.6	4.7	3.3	NT54	Jones 2013
Northton	Lewis/Harris	Late Iron Age	Red Deer	Scapula	Fused	-22.2	4.8	3.4	NT55	Jones 2013
Northton	Lewis/Harris	Late Iron Age	Red Deer	Scapula	Fused	-21.7	5.4	3.4	NT56	Jones 2013
Northton	Lewis/Harris	Late Iron Age	Red Deer	Scapula		-21.7	4.3	3.3	NT57	Jones 2013
Northton	Lewis/Harris	Late Iron Age	Cattle	Radius/Ulna	Fused	-21.5	4.9	3.5	NT64	Jones 2013
Northton	Lewis/Harris	Late Iron Age	Sheep	Metacarpal		-21.6	4.6	3.3	NT65	Jones 2013
Northton	Lewis/Harris	Late Iron Age	Sheep	Metacarpal		-22.3	4.3	3.4	NT66	Jones 2013
Northton	Lews/Harris	Late Iron Age	Seal	Fibula	Fused	-11.9	17.9	3.3	NT96	Jones 2013
Dun Vulan	Uist	Middle Iron Age	Cattle	Humerus	Fused	-21.4	5.7	3.5	DV01	Jones 2013
Dun Vulan	Uist	Middle Iron Age	Sheep	Humerus	Fused	-20.5	4.8	3.3	DV02	Jones 2013
Dun Vulan	Uist	Middle Iron Age	Pig	Tibia	Fused	-21.5	4.6	3.5	DV03	Jones 2013
Dun Vulan	Uist	Middle Iron Age	Sheep	Metacarpal	Fused	-21.1	7.5	3.3	DV04	Jones 2013
Dun Vulan	Uist	Middle Iron Age	Pig	Humerus		-21.2	8.2	3.5	DV05	Jones 2013
Dun Vulan	Uist	Middle Iron Age	Sheep	Ulna		-20.8	5.7	3.3	DV06	Jones 2013
Dun Vulan	Uist	Middle Iron Age	Cattle	Metatarsal	Fused	-20.9	5.3	3.2	DV07	Jones 2013
Dun Vulan	Uist	Middle Iron Age	Pig	Metacarpal	Fused	-21.6	8.1	3.4	DV09	Jones 2013
Dun Vulan	Uist	Middle Iron Age	Cattle	Ulna	Fused	-21.0	4.7	3.5	DV10	Jones 2013
Dun Vulan	Uist	Middle Iron Age	Cattle	Metatarsal	Fused	-21.3	6.4	3.5	DV11	Jones 2013
Dun Vulan	Uist	Middle Iron Age	Red Deer?	Radius	Fused	-21.2	5.1	3.5	DV12	Jones 2013
Dun Vulan	Uist	Middle Iron Age	Sheep	Tibia		-19.8	10.0	3.3	DV13	Jones 2013
Dun Vulan	Uist	Middle Iron Age	Pig	Ulna		-18.4	11.2	3.2	DV14	Jones 2013
Dun Vulan	Uist	Middle Iron Age	Sheep	Tibia	Fused	-20.4	4.0	3.4	DV15	Jones 2013
Dun Vulan	Uist	Middle Iron Age	Sheep	Metatarsal	Fused	-21.2	5.5	3.4	DV16	Jones 2013
Dun Vulan	Uist	Middle Iron Age	Cattle	Metacarpal	Fused	-21.1	4.5	3.2	DV17	Jones 2013
Dun Vulan	Uist	Middle Iron Age	Pig	Tibia	Unfused	-21.2	8.5	3.3	DV18	Jones 2013
Dun Vulan	Uist	Middle Iron Age	Pig	Radius	Fused	-18.4	10.8	3.3	DV19	Jones 2013
Dun Vulan	Uist	Middle Iron Age	Cattle	Radius	Fused	-21.1	5.1	3.4	DV20	Jones 2013
Dun Vulan	Uist	Middle Iron Age	Sheep	Ulna	Fused	-20.8	6.1	3.2	DV21	Jones 2013
Dun Vulan	Uist	Middle Iron Age	Roe Deer	Calcaneum	Fused	-20.8	6.6	3.2	DV22	Jones 2013
Dun Vulan	Uist	Middle Iron Age	Pig	Humerus		-16.8	12.1	3.3	DV23	Jones 2013
Dun Vulan	Uist	Middle Iron Age	Pig	Humerus	Fused	-17.4	11.2	3.3	DV24	Jones 2013
Dun Vulan	Uist	Middle Iron Age	Cattle	Tibia		-20.6	5.0	3.2	DV25	Jones 2013
Sligenach	Uist	Middle Iron Age	Sheep	Radius		-21.3	4.5	3.5	SL03	Jones 2013
Scalloway	Shetland	Middle Iron Age	Sheep	Metacarpal	Fused	-21.3	5.5	3.3	SC01	Jones 2013
Scalloway	Shetland	Middle Iron Age	Sheep	Metacarpal	Fused	-21.3	5.2	3.3	SC02	Jones 2013

Site	Island	Period	Species	Element	Fusion	δ^{13}C	δ^{15}N	C:N	Sample no	Reference
Scalloway	Shetland	Middle Iron Age	Sheep	Humerus	Fused	-21.3	5.6	3.3	SC03	Jones 2013
Scalloway	Shetland	Middle Iron Age	Sheep	Metacarpal	Fused	-21.6	5.1	3.3	SC04	Jones 2013
Scalloway	Shetland	Middle Iron Age	Sheep	Tibia	Fused	-21.6	5.4	3.3	SC05	Jones 2013
Scalloway	Shetland	Middle Iron Age	Sheep	Humerus	Fused	-21.5	6.7	3.3	SC06	Jones 2013
Scalloway	Shetland	Middle Iron Age	Sheep	Metacarpal	Fused	-21.0	4.9	3.3	SC07	Jones 2013
Scalloway	Shetland	Middle Iron Age	Pig	Metacarpal	Fused	-21.9	7.3	3.3	SC08	Jones 2013
Scalloway	Shetland	Middle Iron Age	Pig	Tibia	Fused	-22.0	5.8	3.3	SC09	Jones 2013
Scalloway	Shetland	Middle Iron Age	Pig	Pelvis	Fused	-21.6	5.7	3.4	SC10	Jones 2013
Scalloway	Shetland	Middle Iron Age	Cattle	Humerus	Fused	-21.6	5.8	3.4	SC11	Jones 2013
Scalloway	Shetland	Middle Iron Age	Cattle	Humerus	Fused	-22.3	8.6	3.3	SC12	Jones 2013
Scalloway	Shetland	Middle Iron Age	Cattle	Humerus	Fused	-21.7	6.0	3.4	SC13	Jones 2013
Scalloway	Shetland	Middle Iron Age	Cattle	Femur	Fused	-21.8	6.4	3.3	SC14	Jones 2013
Scalloway	Shetland	Middle Iron Age	Cattle	Metatarsal	Fused	-21.4	5.4	3.3	SC15	Jones 2013
Scalloway	Shetland	Middle Iron Age	Cattle	Femur		-21.0	4.8	3.4	SC16	Jones 2013
Scalloway	Shetland	Middle Iron Age	Cattle	Scapula	Fused	-22.0	6.3	3.3	SC17	Jones 2013
Scalloway	Shetland	Middle Iron Age	Pig	Pelvis		-20.7	4.6	3.3	SC18	Jones 2013
Scalloway	Shetland	Middle Iron Age	Sheep	Metacarpal	Fused	-21.6	5.1	3.3	SC19	Jones 2013
Scalloway	Shetland	Middle Iron Age	Cattle	Metatarsal		-21.6	6.0	3.3	SC20	Jones 2013
Scalloway	Shetland	Middle Iron Age	Pig	Radius	Fused	-22.3	5.1	3.4	SC21	Jones 2013
Scalloway	Shetland	Middle Iron Age	Pig	Radius	Fused	-22.0	7.6	3.3	SC22	Jones 2013
Scalloway	Shetland	Middle Iron Age	Pig	Ulna		-22.0	5.3	3.3	SC23	Jones 2013
Scalloway	Shetland	Middle Iron Age	Cod	Parasphenoid		-12.4	13.2	3.3	SC24	Jones 2013
Scalloway	Shetland	Middle Iron Age	Haddock	dentary		-13.3	13.3	3.3	SC26	Jones 2013
Scalloway	Shetland	Middle Iron Age	Cod	Post-Temp.		-12.8	13.6	3.3	SC27	Jones 2013
Scalloway	Shetland	Middle Iron Age	Cod	Premaxilla		-12.9	14.9	3.6	SC28	Jones 2013
Scalloway	Shetland	Middle Iron Age	Cod	dentary		-12.4	13.4	3.3	SC29	Jones 2013
Scalloway	Shetland	Middle Iron Age	Cod	Parasphenoid		-12.2	12.6	3.3	SC30	Jones 2013
Scalloway	Shetland	Middle Iron Age	Haddock	dentary		-13.7	12.4	3.3	SC31	Jones 2013
Scalloway	Shetland	Middle Iron Age	Cod	Premaxilla		-13.7	14.3	3.4	SC32	Jones 2013
Scalloway	Shetland	Middle Iron Age	Haddock	Maxilla		-14.1	13.9	3.5	SC34	Jones 2013
Northton	Lewis/Harris	Middle Iron Age	Sheep	Scapula	Fused	-21.7	5.1	3.5	NT71	Jones 2013
Northton	Lewis/Harris	Middle Iron Age	Sheep	Humerus	Fused	-22.5	7.2	3.4	NT73	Jones 2013
Northton	Lewis/Harris	Middle Iron Age	Cattle	Metatarsal	Fused	-21.7	6.2	3.5	NT74	Jones 2013
Northton	Lewis/Harris	Middle Iron Age	Cattle	Metatarsal	Fused	-21.8	6.7	3.5	NT75	Jones 2013
Northton	Lewis/Harris	Middle Iron Age	Cattle	Metatarsal	Fused	-21.4	5.8	3.3	NT76	Jones 2013
Northton	Lewis/Harris	Middle Iron Age	Seal	Humerus	Fused	-10.1	16.0	3.3	NT80	Jones 2013
Northton	Lews/Harris	Middle Iron Age	Guillemot	Radius		-15.3	14.3	3.4	NT83	Jones 2013

Site	Island	Period	Species	Element	Fusion	$\delta^{13}C$	$\delta^{15}N$	C:N	Sample no	Reference
Scalloway	Shetland	Middle Iron Age	Ling	Dentary		-12.4	14.8	3.3	SC33	Jones 2013
Bornish Mound 2a	Uist	Early Norse	Pig	Humerus	Fused	-20.0	10.1		JJ01	Jones 2013
Bornish Mound 2a	Uist	Early Norse	Pig	Humerus	Fused	-17.6	11.4		JJ02	Jones 2013
Bornish Mound 2a	Uist	Early Norse	Pig	Humerus	Fused	-19.1	9.9		JJ03	Jones 2013
Bornish Mound 2a	Uist	Early Norse	Pig	Humerus	Fused	-21.5	6.1		JJ04	Jones 2013
Bornish Mound 2a	Uist	Early Norse	Pig	Humerus	Fused	-19.1	8.9		JJ05	Jones 2013
Bornish Mound 2a	Uist	Early Norse	Red Deer	Radius	Fused	-21.3	5.3		JJ06	Jones 2013
Bornish Mound 2a	Uist	Early Norse	Red Deer	Radius	Fused	-21.6	4.4		JJ07	Jones 2013
Bornish Mound 2a	Uist	Early Norse	Red Deer	Radius	Fused	-21.5	4.6		JJ08	Jones 2013
Bornish Mound 2a	Uist	Early Norse	Sheep	Humerus	Fused	-21.1	6.1		JJ09	Jones 2013
Bornish Mound 2a	Uist	Early Norse	Sheep	Humerus		-21.3	4.9		JJ10	Jones 2013
Bornais Mound 2	Uist	Early Norse	Herring Gull / Lesser Black Back	Humerus	Fused	-12.3	15.4		JJ95	Jones 2013
Bornais Mound 2	Uist	Early Norse	Large Goose	Humerus	Fused	-22.0	7.7		JJ97	Jones 2013
Earl's Bu	Orkney	Early Norse	Sheep	Metacarpal	Fused	-21.7	5.3	3.3	EB25	Jones 2013
Earl's Bu	Orkney	Early Norse	Sheep	Metacarpal	Fused	-22.0	6.8	3.4	EB26	Jones 2013
Earl's Bu	Orkney	Early Norse	Sheep	Mandible		-21.9	6.2	3.5	EB27	Jones 2013
Earl's Bu	Orkney	Early Norse	Sheep	Metacarpal		-21.9	6.2	3.4	EB28	Jones 2013
Earl's Bu	Orkney	Early Norse	Sheep	Metacarpal		-22.0	5.6	3.4	EB29	Jones 2013
Earl's Bu	Orkney	Early Norse	Sheep	Femur	Fused	-21.7	5.9	3.4	EB30	Jones 2013
Earl's Bu	Orkney	Early Norse	Sheep	Scapula	Fused	-21.6	4.8	3.4	EB31	Jones 2013
Earl's Bu	Orkney	Early Norse	Pig	Radius	Fused	-21.1	9.0	3.4	EB32	Jones 2013
Earl's Bu	Orkney	Early Norse	Pig	Scapula	Fused	-21.3	9.1	3.3	EB33	Jones 2013
Earl's Bu	Orkney	Early Norse	Pig	Maxilla		-20.7	9.2	3.4	EB34	Jones 2013
Earl's Bu	Orkney	Early Norse	Pig	Femur		-21.3	8.3	3.3	EB35	Jones 2013
Earl's Bu	Orkney	Early Norse	Cattle	Ulna	Fused	-21.6	5.5	3.3	EB36	Jones 2013
Earl's Bu	Orkney	Early Norse	Cattle	Calcaneus	Fused	-22.2	5.1	3.3	EB37	Jones 2013
Earl's Bu	Orkney	Early Norse	Sheep	Metacarpal		-22.0	6.3	3.3	EB38	Jones 2013
Earl's Bu	Orkney	Early Norse	Pig	Pelvis		-19.8	8.5	3.3	EB39	Jones 2013
Earl's Bu	Orkney	Early Norse	Cattle	Scapula	Fused	-21.7	5.7	3.3	EB40	Jones 2013
Earl's Bu	Orkney	Early Norse	Cattle	Scapula		-22.2	6.2	3.5	EB41	Jones 2013
Earl's Bu	Orkney	Early Norse	Cattle	Calcaneus	Fused	-21.6	5.4	3.2	EB42	Jones 2013
Earl's Bu	Orkney	Early Norse	Cattle	Metacarpal		-21.9	6.2	3.3	EB44	Jones 2013
Earl's Bu	Orkney	Early Norse	Red Deer?	Radius		-22.0	5.6	3.3	EB45	Jones 2013
Bornish M2W	Uist	Middle Norse	Cattle	Humerus	Fused	-21.8	5.0		JJ34	Jones 2013
Bornish Mound 2	Uist	Middle Norse	Cattle	Humerus	Fused	-21.7	4.9		JJ35	Jones 2013
Bornish Mound 2a	Uist	Middle Norse	Cattle	Radius	Fused	-21.3	5.0		JJ36	Jones 2013
Bornish Mound 2a	Uist	Middle Norse	Cattle	Humerus	Fused	-21.5	4.9		JJ37	Jones 2013

Site	Island	Period	Species	Element	Fusion	$\delta^{13}C$	$\delta^{15}N$	C:N	Sample no	Reference
Bornish Mound 2	Uist	Middle Norse	Pig	Humerus		-20.4	7.8		JJ38	Jones 2013
Bornish Mound 2a	Uist	Middle Norse	Sheep	Radius	Fused	-21.4	5.9		JJ39	Jones 2013
Bornish Mound 2	Uist	Middle Norse	Sheep	Radius	Fused	-21.8	4.4		JJ40	Jones 2013
Bornish Mound 2	Uist	Middle Norse	Red Deer	metacarpal		-21.8	5.9		JJ41	Jones 2013
Bornish Mound 2a	Uist	Middle Norse	Red Deer	metacarpal	Fused	-21.7	5.2		JJ42	Jones 2013
Bornais Mound 2	Uist	Middle Norse	Gannet	Ulna		-13.9	13.6		JJ92	Jones 2013
Bornais Mound 2	Uist	Middle Norse	Gannet	Ulna	Fused	-13.0	14.3		JJ93	Jones 2013
Bornais Mound 2	Uist	Middle Norse	Herring Gull / Lesser Black Back	Humerus		-13.5	13.2		JJ94	Jones 2013
Bornish Mound 2a	Uist	Late Norse	Cattle	Tibia		-22.0	5.7		JJ27	Jones 2013
Bornish Mound 2a	Uist	Late Norse	Cattle	Tibia	Fused	-21.6	4.2		JJ28	Jones 2013
Bornish Mound 2a	Uist	Late Norse	Red Deer	Radius	Fused	-21.6	4.8		JJ29	Jones 2013
Bornish Mound 2a	Uist	Late Norse	Sheep	metatarsal		-21.6	5.3		JJ30	Jones 2013
Bornish Mound 2a	Uist	Late Norse	Sheep	metatarsal		-21.3	4.4		JJ31	Jones 2013
Bornish Mound 2a	Uist	Late Norse	Pig	Tibia		-21.5	7.1		JJ32	Jones 2013
Bornish Mound 2a	Uist	Late Norse	Pig	Tibia		-20.7	7.3		JJ33	Jones 2013
Bornish Mound 2a	Uist	Late Norse	Cattle	Tibia		-21.4	4.5		JJ43	Jones 2013
Bornish Mound 2a	Uist	Late Norse	Cattle	Tibia		-21.5	5.8		JJ44	Jones 2013
Bornish Mound 2a	Uist	Late Norse	Cattle	Tibia		-21.1	4.5		JJ45	Jones 2013
Bornish Mound 2a	Uist	Late Norse	Sheep	metatarsal	Fused	-21.4	5.0		JJ46	Jones 2013
Bornish Mound 2a	Uist	Late Norse	Sheep	metatarsal		-21.6	4.8		JJ47	Jones 2013
Bornish Mound 2a	Uist	Late Norse	Sheep	metatarsal		-21.4	4.2		JJ48	Jones 2013
Bornish Mound 2a	Uist	Late Norse	Red Deer	Radius		-21.8	5.2		JJ49	Jones 2013
Bornish Mound 2a	Uist	Late Norse	Red Deer	metacarpal	Fused	-21.5	5.4		JJ50	Jones 2013
Bornish Mound 2a	Uist	Late Norse	Pig	metacarpal	Fused	-21.1	7.3		JJ51	Jones 2013
Bornish Mound 2a	Uist	Late Norse	Pig	Radius	Fused	-20.0	8.1		JJ52	Jones 2013
Bornish Mound 2a	Uist	Late Norse	dog	Phal 1	Fused	-12.3	15.6		JJ53	Jones 2013
Bornais Mound 2a	Uist	Late Norse	Swan	Tibio-Tarsus		-12.2	7.5		JJ90	Jones 2013
Bornais Mound 2	Uist	Late Norse	Swan	Tibio-Tarsus		-12.8	14.6		JJ91	Jones 2013
Bornais Mound 2	Uist	Late Norse	Large Goose	Humerus		-22.3	4.7		JJ96	Jones 2013
Earl's Bu	Orkney	Late Norse	Cattle	Humerus	Fused	-21.4	5.4	3.3	EB01	Jones 2013
Earl's Bu	Orkney	Late Norse	Cattle	Calcaneus	Fused	-22.0	5.7	3.3	EB02	Jones 2013
Earl's Bu	Orkney	Late Norse	Cattle	Tibia	Fused	-21.4	5.4	3.3	EB03	Jones 2013
Earl's Bu	Orkney	Late Norse	Cattle	Radius		-21.7	6.1	3.4	EB04	Jones 2013
Earl's Bu	Orkney	Late Norse	Cattle	Metatarsal		-21.4	5.8	3.3	EB05	Jones 2013
Earl's Bu	Orkney	Late Norse	Cattle	Scapula		-21.3	6.4	3.3	EB06	Jones 2013
Earl's Bu	Orkney	Late Norse	Cattle	Femur		-21.3	5.3	3.3	EB07	Jones 2013

Site	Island	Period	Species	Element	Fusion	δ^{13}C	δ^{15}N	C:N	Sample no	Reference
Earl's Bu	Orkney	Late Norse	Cattle	Zygomatic		-21.9	5.3	3.3	EB08	Jones 2013
Earl's Bu	Orkney	Late Norse	Sheep	Astragalus	Fused	-21.6	5.6	3.5	EB09	Jones 2013
Earl's Bu	Orkney	Late Norse	Pig	Tibia	Fused	-21.3	11.3	3.3	EB10	Jones 2013
Earl's Bu	Orkney	Late Norse	Pig	Astragalus	Fused	-22.0	8.3	3.4	EB11	Jones 2013
Earl's Bu	Orkney	Late Norse	Pig	Astragalus	Fused	-22.1	8.4	3.4	EB12	Jones 2013
Earl's Bu	Orkney	Late Norse	Pig	Femur	Unfused	-21.7	8.9	3.3	EB13	Jones 2013
Earl's Bu	Orkney	Late Norse	Pig	Ulna	Fused	-21.4	7.8	3.3	EB14	Jones 2013
Earl's Bu	Orkney	Late Norse	Pig	Radius	Fused	-21.6	9.7	3.3	EB15	Jones 2013
Earl's Bu	Orkney	Late Norse	Pig	Humerus	Fused	-21.9	8.6	3.3	EB16	Jones 2013
Earl's Bu	Orkney	Late Norse	Sheep	Radius	Fused	-21.7	5.9	3.3	EB17	Jones 2013
Earl's Bu	Orkney	Late Norse	Sheep	Femur		-21.9	6.3	3.4	EB18	Jones 2013
Earl's Bu	Orkney	Late Norse	Sheep	Mandible		-21.3	5.8	3.3	EB19	Jones 2013
Earl's Bu	Orkney	Late Norse	Sheep	Patella		-21.3	7.5	3.2	EB20	Jones 2013
Earl's Bu	Orkney	Late Norse	Sheep	Zygomatic		-21.5	4.9	3.3	EB21	Jones 2013
Earl's Bu	Orkney	Late Norse	Sheep	Phal 1	Fused	-22.0	6.1	3.3	EB22	Jones 2013
Earl's Bu	Orkney	Late Norse	Dog	Radius	Fused	-20.0	10.5	3.3	EB23	Jones 2013
Earl's Bu	Orkney	Late Norse	Dog	Pelvis		-18.8	11.7	3.4	EB24	Jones 2013
Earl's Bu	Orkney	Late Norse	Large Grey Goose	Carpometacarp.	Fused	-20.5	5.2	3.3	EB46	Jones 2013
Earl's Bu	Orkney	Late Norse	Carion Crow/Rook	Ulna	Fused	-11.4	14.2	3.3	EB47	Jones 2013
Earl's Bu	Orkney	Late Norse	Raven	Ulna	Fused	-17.6	12.6	3.5	EB48	Jones 2013
Earl's Bu	Orkney	Late Norse	Shag	Coracoid	Fused	-13.4	14.7	3.3	EB49	Jones 2013
Bornish M2A	Uist	Norse	Red Deer	Metacarpal		-22.0	4.6	3.4	BOM2A 02	Jones 2013
Bornish M2A	Uist	Norse	Red Deer	Metacarpal		-21.2	5.5	3.2	BOM2A 03	Jones 2013
Bornish M2A	Uist	Norse	Red Deer	Radius		-21.7	4.3	3.2	BOM2A 04	Jones 2013
Bornish M2A	Uist	Norse	Red Deer	Metacarpal		-21.6	6.0	3.2	BOM2A 05	Jones 2013
Bornish M2A	Uist	Norse	Red Deer	Radius		-21.6	4.9	3.2	BOM2A 06	Jones 2013
Bornish M2A	Uist	Norse	Red Deer	Radius		-21.6	6.1	3.2	BOM2A 07	Jones 2013
Bornish M2A	Uist	Norse	Red Deer	Radius		-21.9	5.2	3.2	BOM2A 08	Jones 2013
Bornais (M1)	Uist	Norse	Cattle	Phal 1		-21.4	4.8	3.3	13359	Jones 2013
Bornais (M1)	Uist	Norse	Cattle	Lumbar Vert		-20.9	4.5	3.5	13358	Jones 2013
Bornais	Uist	Norse	Cattle	Metacarpal		-21.7	5.3	3.8	11948	Jones 2013
Bornais	Uist	Norse	Cattle	Metacarpal		-21.0	5.3	3.1	11945	Jones 2013
Bornais	Uist	Norse	Cattle	Thoracic Vert		-21.7	4.2	3.3	11943	Jones 2013
Bornais	Uist	Norse	Cattle	Lumbar Vert		-22.1	3.7	3.6	11942	Jones 2013
Bornais	Uist	Norse	Cattle	Rib		-21.6	4.6	3.5	11941	Jones 2013
Bornais	Uist	Norse	Cattle	Metatarsal		-21.1	4.8	3.4	11940	Jones 2013
Bornais	Uist	Norse	Cattle	Radius & Ulna		-21.4	4.3	3.6	11939	Jones 2013

Site	Island	Period	Species	Element	Fusion	$\delta^{13}C$	$\delta^{15}N$	C:N	Sample no	Reference
Bornais	Uist	Norse	Cattle	Metatarsal		-21.2	5.1	3.2	11938	Jones 2013
Bornais	Uist	Norse	Cattle	Nav-cub & tars		-21.3	4.4	3.3	11936	Jones 2013
Bornish	Uist	Norse	Cattle			-20.8	6.2	3.3	8157	Jones 2013
Bornish	Uist	Norse	Cattle			-21.7	8.6	3.3	5896	Jones 2013
Bornish	Uist	Norse	Cattle			-22.7	4.2	3.3	8707	Jones 2013
Bornish	Uist	Norse	Cattle			-21.0	9.6	3.3	8155	Jones 2013
Bornais (M1)	Uist	Norse	Red Deer			-21.6	4.9		16528	Jones 2013
Bornais (M1)	Uist	Norse	Red Deer			-21.4	6.6	3.4	16526	Jones 2013
Bornais	Uist	Norse	PIG	Metatarsal		-19.3	8.7	3.1	11944	Jones 2013
Bornais	Uist	Norse	Sheep	Lumbar Vert		-21.6	4.8	3.6	11937	Jones 2013
Bornish	Uist	Norse	Sheep			-21.4	5.7	3.3	5854	Mulville *et al.* 2009
Bornish	Uist	Norse	Sheep			-20.5	3.4	3.3	8152	Mulville *et al.* 2009
Bostadh	Uist	Norse	Sheep	Radius	Fused	-20.9	4.4	3.2	BOST01	Jones 2013
Bostadh	Uist	Norse	Red Deer	Radius	Fused	-21.7	5.8	3.4	BOST02	Jones 2013
Bostadh	Uist	Norse	Cattle	Tibia	Fused	-20.8	5.9	3.3	BOST03	Jones 2013
Bostadh	Uist	Norse	Cattle	Metatarsal	Fused	-21.1	5.4	3.3	BOST04	Jones 2013
Jarlshof	Shetland	Norse	Grey Seal	Humerus	Fused	-12.4	14.8	3.3	JA02	Jones 2013
Jarlshof	Shetland	Norse	Grey Seal	Humerus	Fused	-13.7	15.9	3.7	JA03	Jones 2013
Jarlshof	Shetland	Norse	Cattle	Metacarpal	Fused	-21.7	5.2	3.3	JA04	Jones 2013
Jarlshof	Shetland	Norse	Cattle	Metacarpal	Fused	-21.0	4.7	3.2	JA05	Jones 2013
Jarlshof	Shetland	Norse	Cattle	Metacarpal	Fused	-21.5	5.6	3.2	JA06	Jones 2013
Jarlshof	Shetland	Norse	Cattle	Metacarpal	Fused	-21.7	5.5	3.3	JA07	Jones 2013
Jarlshof	Shetland	Norse	Cattle	Atlas		-21.1	5.5	3.3	JA08	Jones 2013
Jarlshof	Shetland	Norse	Cattle	Atlas		-19.7	6.3	3.3	JA09	Jones 2013
Jarlshof	Shetland	Norse	Cattle	Atlas		-19.8	7.3	3.4	JA10	Jones 2013
Jarlshof	Shetland	Norse	Dog	Mandible		-12.9	14.6	3.4	JA11	Jones 2013
Jarlshof	Shetland	Norse	Dog	Mandible		-13.4	16.2	3.3	JA12	Jones 2013
Jarlshof	Shetland	Norse	Sheep	Metacarpal	Fused	-21.3	3.7	3.4	JA13	Jones 2013
Jarlshof	Shetland	Norse	Sheep	Metacarpal	Fused	-21.7	6.5	3.3	JA14	Jones 2013
Jarlshof	Shetland	Norse	Sheep	Metacarpal	Fused	-21.7	6.3	3.3	JA15	Jones 2013
Jarlshof	Shetland	Norse	Sheep	Metacarpal	Fused	-21.6	4.5	3.3	JA16	Jones 2013
Jarlshof	Shetland	Norse	Sheep	Radius	Fused	-21.1	5.6	3.4	JA17	Jones 2013
Jarlshof	Shetland	Norse	Sheep	Radius	Fused	-21.4	6.4	3.5	JA18	Jones 2013
Jarlshof	Shetland	Norse	Sheep	Tibia	Fused	-21.7	4.9	3.3	JA19	Jones 2013
Cille Pheadair	Uist	Norse	Cattle	Mandible		-21.3	4.1	3.4	KIL01	Jones 2013
Cille Pheadair	Uist	Norse	Cattle	Mandible		-21.6	4.5	3.6	KIL02	Jones 2013
Cille Pheadair	Uist	Norse	Cattle	Mandible		-21.2	5.8	3.4	KIL03	Jones 2013

Site	Island	Period	Species	Element	Fusion	$\delta^{13}C$	$\delta^{15}N$	C:N	Sample no	Reference
Cille Pheadair	Uist	Norse	Cattle	Mandible		-22.0	5.2	3.7	KIL05	Jones 2013
Cille Pheadair	Uist	Norse	Cattle	Mandible		-21.5	3.7	3.5	KIL06	Jones 2013
Cille Pheadair	Uist	Norse	Sheep	Mandible		-21.5	5.7	3.6	KIL07	Jones 2013
Cille Pheadair	Uist	Norse	Sheep	Mandible		-21.6	3.8	3.7	KIL08	Jones 2013
Cille Pheadair	Uist	Norse	Sheep	Mandible		-21.1	5.2	3.3	KIL09	Jones 2013
Cille Pheadair	Uist	Norse	Pig	Maxilla		-17.8	11.3	3.7	KIL10	Jones 2013
Cille Pheadair	Uist	Norse	Red Deer	Radius	Fused	-21.9	5.7	3.5	KIL11	Jones 2013
Cille Pheadair	Uist	Norse	Red Deer	Radius	Fused	-22.1	4.0	3.6	KIL12	Jones 2013
Cille Pheadair	Uist	Norse	Seal	Radius	Fused	-12.3	18.1	3.5	KIL13	Jones 2013
Cille Pheadair	Uist	Norse	Sheep	Radius	Fused	-21.8	6.0	3.5	KIL14	Jones 2013
Cille Pheadair	Uist	Norse	Sheep	Radius	Fused	-21.3	4.6	3.5	KIL15	Jones 2013
Cille Pheadair	Uist	Norse	Pig	Ulna	Fused	-20.4	7.3	3.6	KIL16	Jones 2013
Cille Pheadair	Uist	Norse	Sheep	Radius	Fused	-21.7	5.7	3.4	KIL18	Jones 2013
Cille Pheadair	Uist	Norse	Pig	Metatarsal	Fused	-21.0	7.9	3.5	KL19	Jones 2013
Cille Pheadair	Uist	Norse	Red Deer	Tibia	Fused	-21.9	6.9	3.4	KIL20	Jones 2013
Cille Pheadair	Uist	Norse	Pig	Zygomatic		-20.6	7.4	3.4	KIL21	Jones 2013
Cille Pheadair	Uist	Norse	Sheep	Tibia	Fused	-21.4	6.2	3.3	KIL22	Jones 2013
Cille Pheadair	Uist	Norse	Red Deer	Metatarsal		-22.0	4.4	3.5	KIL23	Jones 2013
Cille Pheadair	Uist	Norse	Pig	Ulna	Fused	-21.7	4.8	3.4	KIL24	Jones 2013
Cille Pheadair	Uist	Norse	Pig	Ulna	Unfused	-18.8	9.8	3.4	KIL25	Jones 2013
Cille Pheadair	Uist	Norse	Seal	Pelvis	Fused	-12.6	16.1	3.4	KL26	Jones 2013
Cille Pheadair	Uist	Norse	Red Deer	Phal II	Fused	-21.8	5.5	3.5	KIL28	Jones 2013
Cille Pheadair	Uist	Norse	Red Deer	Femur	Fused	-21.6	6.0	3.4	KIL30	Jones 2013
Cille Pheadair	Uist	Norse	Pig	Humerus	Fused	-19.1	8.7	3.5	KIL31	Jones 2013
Cille Pheadair	Uist	Norse	Pig	Humerus	Fused	-21.9	6.9	3.5	KIL32	Jones 2013
Cille Pheadair	Uist	Norse	Gannet	Humerus	Fused	-14.8	14.1	3.4	KIL33	Jones 2013
Cille Pheadair	Uist	Norse	Gannet	Humerus	Fused	-14.2	12.8	3.4	KIL34	Jones 2013
Cille Pheadair	Uist	Norse	Gannet	Humerus	Fused	-14.0	15.0	3.3	KIL35	Jones 2013
Cille Pheadair	Uist	Norse	Fulmar	Carpometacarp.	Fused	-16.0	16.2	3.3	KIL36	Jones 2013
Cille Pheadair	Uist	Norse	Cormorant	Tibiotarsus	Fused	-12.2	15.1	3.2	KIL38	Jones 2013
Cille Pheadair	Uist	Norse	Cormorant	Tibiotarsus		-12.9	15.8	3.2	KIL39	Jones 2013
Cille Pheadair	Uist	Norse	Great Black-Backed Gull	Humerus	Fused	-14.0	14.8	3.3	KIL40	Jones 2013
Cille Pheadair	Uist	Norse	Great Black-Backed Gull	Humerus	Fused	-14.9	15.8	3.3	KIL41	Jones 2013
Cille Pheadair	Uist	Norse	Guillemot	Femur	Fused	-15.1	15.5	3.3	KIL42	Jones 2013
Cille Pheadair	Uist	Norse	Guillemot	Femur	Fused	-15.3	15.0	3.3	KIL43	Jones 2013
Cille Pheadair	Uist	Norse	Shag	Tarsometat.	Fused	-14.2	15.8	3.3	KIL44	Jones 2013
Cille Pheadair	Uist	Norse	Shag	Tarsometat.		-15.0	16.3	3.3	KIL45	Jones 2013
Cille Pheadair	Uist	Norse	Large Grey Goose	Humerus		-20.4	6.7	3.4	KIL46	Jones 2013
Cille Pheadair	Uist	Norse	Large Grey Goose	Humerus		-22.9	9.5	3.4	KIL47	Jones 2013
Cille Pheadair	Uist	Norse	Large Grey Goose	Humerus	Fused	-22.2	9.6	3.3	KIL48	Jones 2013

Appendix 2: Inter Species dietary comparisons in each Island group Mann-Whitney U test results

Statistically significant values are highlighted in bold.

Neolithic Orkney species comparisons

Mann Whitney U test results comparing C and N values of Neolithic Cattle and Sheep in Orkney

Ranks

	Species	N	Mean Rank	Sum of Ranks
C13	Cattle	92	48.24	4438.00
	Sheep	19	93.58	1778.00
	Total	111		
N15	Cattle	92	51.97	4781.00
	Sheep	19	75.53	1435.00
	Total	111		

Test Statistics[a]

	C13	N15
Mann-Whitney U	160.000	503.000
Wilcoxon W	4438.000	4781.000
Z	-5.598	-2.905
Asymp. Sig. (2-tailed)	**.000**	**.004**

a. Grouping Variable: Species

Mann Whitney U test results comparing C and N values of Neolithic Cattle and Red Deer in Orkney

Ranks

	Species	N	Mean Rank	Sum of Ranks
C13	Cattle	92	54.58	5021.00
	Red Deer	12	36.58	439.00
	Total	104		
N15	Cattle	92	52.41	4822.00
	Red Deer	12	53.17	638.00
	Total	104		

Test Statistics[a]

	C13	N15
Mann-Whitney U	361.000	544.000
Wilcoxon W	439.000	4822.000
Z	-1.947	-.081
Asymp. Sig. (2-tailed)	.052	.935

a. Grouping Variable: Species

Mann Whitney U test results comparing C and N values of Neolithic Sheep and Red Deer in Orkney

Ranks

	Species	N	Mean Rank	Sum of Ranks
C13	Sheep	19	21.63	411.00
	Red Deer	12	7.08	85.00
	Total	31		
N15	Sheep	19	18.21	346.00
	Red Deer	12	12.50	150.00
	Total	31		

Test Statistics[b]

	C13	N15
Mann-Whitney U	7.000	72.000
Wilcoxon W	85.000	150.000
Z	-4.339	-1.703
Asymp. Sig. (2-tailed)	.000	.089
Exact Sig. [2*(1-tailed Sig.)]	**.000**	.093[a]

Mann Whitney U test results comparing C and N values of Neolithic Sheep and Pig in Orkney

Ranks

	Species	N	Mean Rank	Sum of Ranks
C13	Sheep	19	20.16	383.00
	Pig	11	7.45	82.00
	Total	30		
N15	Sheep	19	10.11	192.00
	Pig	11	24.82	273.00
	Total	30		

Test Statistics[b]

	C13	N15
Mann-Whitney U	16.000	2.000
Wilcoxon W	82.000	192.000
Z	-3.809	-4.411
Asymp. Sig. (2-tailed)	.000	.000
Exact Sig. [2*(1-tailed Sig.)]	**.000a**	**.000a**

a. Not corrected for ties.

b. Grouping Variable: Species

Mann Whitney U test results comparing C and N values of Neolithic Cattle and Pig in Orkney

Ranks

	Species	N	Mean Rank	Sum of Ranks
C13	Cattle	92	53.21	4895.00
	Pig	11	41.91	461.00
	Total	103		
N15	Cattle	92	46.53	4281.00
	Pig	11	97.73	1075.00
	Total	103		

Test Statistics[a]

	C13	N15
Mann-Whitney U	395.000	3.000
Wilcoxon W	461.000	4281.000
Z	-1.187	-5.371
Asymp. Sig. (2-tailed)	.235	**.000**

a. Grouping Variable: Species

Mann Whitney U test results comparing C and N values of Neolithic pig and Red Deer in Orkney

Ranks

	Species	N	Mean Rank	Sum of Ranks
C13	Pig	11	12.55	138.00
	Red Deer	12	11.50	138.00
	Total	23		
N15	Pig	11	18.00	198.00
	Red Deer	12	6.50	78.00
	Total	23		

Test Statistics[b]

	C13	N15
Mann-Whitney U	60.000	.000
Wilcoxon W	138.000	78.000
Z	-.369	-4.062
Asymp. Sig. (2-tailed)	.712	.000
Exact Sig. [2*(1-tailed Sig.)]	.740[a]	**.000a**

a. Not corrected for ties.

b. Grouping Variable: Species

Neolithic Orkney species comparisons

Mann Whitney U test results comparing C and N values of Neolithic Cattle and Sheep in the Western Isles

Ranks

	Species	N	Mean Rank	Sum of Ranks
C13	Cattle	7	11.57	81.00
	Sheep	11	8.18	90.00
	Total	18		
N15	Cattle	7	6.14	43.00
	Sheep	11	11.64	128.00
	Total	18		

Test Statistics[b]

	C13	N15
Mann-Whitney U	24.000	15.000
Wilcoxon W	90.000	43.000
Z	-1.313	-2.128
Asymp. Sig. (2-tailed)	.189	.033
Exact Sig. [2*(1-tailed Sig.)]	.211[a]	**.035a**

a. Not corrected for ties.

b. Grouping Variable: Species

Mann Whitney U test results comparing C and N values of Neolithic Cattle and Red Deer in the Western Isles

Ranks

	Species	N	Mean Rank	Sum of Ranks
C13	Cattle	7	9.29	65.00
	Red Deer	7	5.71	40.00
	Total	14		
N15	Cattle	7	9.71	68.00
	Red Deer	7	5.29	37.00
	Total	14		

Test Statistics[b]

	C13	N15
Mann-Whitney U	12.000	9.000
Wilcoxon W	40.000	37.000
Z	-1.597	-1.981
Asymp. Sig. (2-tailed)	.110	.048
Exact Sig. [2*(1-tailed Sig.)]	.128[a]	**.053a**

a. Not corrected for ties.

b. Grouping Variable: Species

Mann Whitney U test results comparing C and N values of Neolithic Sheep and Red Deer in the Western Isles

Ranks

	Species	N	Mean Rank	Sum of Ranks
C13	Sheep	11	9.36	103.00
	Red Deer	7	9.71	68.00
	Total	18		
N15	Sheep	11	12.09	133.00
	Red Deer	7	5.43	38.00
	Total	18		

Test Statistics[b]

	C13	N15
Mann-Whitney U	37.000	10.000
Wilcoxon W	103.000	38.000
Z	-.136	-2.581
Asymp. Sig. (2-tailed)	.892	.010
Exact Sig. [2*(1-tailed Sig.)]	.930[a]	**.008a**

a. Not corrected for ties.

b. Grouping Variable: Species

Beaker Period: Western Isles

Mann Whitney U test results comparing C and N values of Beaker Cattle and Sheep in the Western Isles

Ranks

	Species	N	Mean Rank	Sum of Ranks
C13	Cattle	8	8.00	64.00
	Sheep	11	11.45	126.00
	Total	19		
N15	Cattle	8	12.56	100.50
	Sheep	11	8.14	89.50
	Total	19		

Test Statistics[b]

	C13	N15
Mann-Whitney U	28.000	23.500
Wilcoxon W	64.000	89.500
Z	-1.346	-1.695
Asymp. Sig. (2-tailed)	.178	.090
Exact Sig. [2*(1-tailed Sig.)]	.206[a]	.091[a]

a. Not corrected for ties.

b. Grouping Variable: Species

Mann Whitney U test results comparing C and N values of Beaker Sheep and Red Deer in the Western Isles

Ranks

	Species	N	Mean Rank	Sum of Ranks
C13	Sheep	11	11.00	121.00
	Red Deer	5	3.00	15.00
	Total	16		
N15	Sheep	11	8.59	94.50
	Red Deer	5	8.30	41.50
	Total	16		

Test Statistics[b]

	C13	N15
Mann-Whitney U	.000	26.500
Wilcoxon W	15.000	41.500
Z	-3.129	-.114
Asymp. Sig. (2-tailed)	.002	.910
Exact Sig. [2*(1-tailed Sig.)]	**.000a**	.913[a]

a. Not corrected for ties.

b. Grouping Variable: Species

Mann Whitney U test results comparing C and N values of Beaker Cattle and Red Deer in the Western Isles

Ranks

	Species	N	Mean Rank	Sum of Ranks
C13	Cattle	8	8.88	71.00
	Red Deer	5	4.00	20.00
	Total	13		
N15	Cattle	8	8.94	71.50
	Red Deer	5	3.90	19.50
	Total	13		

Test Statistics[b]

	C13	N15
Mann-Whitney U	5.000	4.500
Wilcoxon W	20.000	19.500
Z	-2.230	-2.278
Asymp. Sig. (2-tailed)	.026	.023
Exact Sig. [2*(1-tailed Sig.)]	**.030a**	**.019a**

a. Not corrected for ties.

b. Grouping Variable: Species

Bronze Age: Western Isles

Mann Whitney U test results comparing C and N values of Bronze Cattle and Sheep in the Western Isles

Ranks

	Species	N	Mean Rank	Sum of Ranks
C13	Cattle	19	13.55	257.50
	Sheep	16	23.28	372.50
	Total	35		
N15	Cattle	19	13.87	263.50
	Sheep	16	22.91	366.50
	Total	35		

Test Statistics[b]

	C13	N15
Mann-Whitney U	67.500	73.500
Wilcoxon W	257.500	263.500
Z	-2.804	-2.602
Asymp. Sig. (2-tailed)	.005	.009
Exact Sig. [2*(1-tailed Sig.)]	**.004a**	**.008a**

a. Not corrected for ties.

b. Grouping Variable: Species

Mann Whitney U test results comparing C and N values of Bronze Cattle and Red Deer in the Western Isles

Ranks

	Species	N	Mean Rank	Sum of Ranks
C13	Cattle	19	13.63	259.00
	Red Deer	8	14.88	119.00
	Total	27		
N15	Cattle	19	13.05	248.00
	Red Deer	8	16.25	130.00
	Total	27		

Test Statistics[b]

	C13	N15
Mann-Whitney U	69.000	58.000
Wilcoxon W	259.000	248.000
Z	-.373	-.958
Asymp. Sig. (2-tailed)	.709	.338
Exact Sig. [2*(1-tailed Sig.)]	.735[a]	.360[a]

a. Not corrected for ties.

b. Grouping Variable: Species

Mann Whitney U test results comparing C and N values of Bronze Sheep and Red Deer in the Western Isles

Ranks

	Species	N	Mean Rank	Sum of Ranks
C13	Sheep	16	14.59	233.50
	Red Deer	8	8.31	66.50
	Total	24		
N15	Sheep	16	13.47	215.50
	Red Deer	8	10.56	84.50
	Total	24		

Test Statistics[b]

	C13	N15
Mann-Whitney U	30.500	48.500
Wilcoxon W	66.500	84.500
Z	-2.062	-.951
Asymp. Sig. (2-tailed)	.039	.342
Exact Sig. [2*(1-tailed Sig.)]	**.038a**	.350[a]

a. Not corrected for ties.

b. Grouping Variable: Species

Iron Age : Western Isles

Mann Whitney U test results comparing C and N values of Iron Age Sheep and Cattle in the Western Isles

Ranks

	species	N	Mean Rank	Sum of Ranks
C13	Cattle	41	40.07	1643.00
	Sheep	38	39.92	1517.00
	Total	79		
N15	Cattle	41	37.54	1539.00
	Sheep	38	42.66	1621.00
	Total	79		

Test Statistics[a]

	C13	N15
Mann-Whitney U	776.000	678.000
Wilcoxon W	1517.000	1539.000
Z	-.030	-.992
Asymp. Sig. (2-tailed)	.976	.321

a. Grouping Variable: species

Mann Whitney U test results comparing C and N values of Iron Age Red deer and Cattle in the Western Isles

Ranks

	species	N	Mean Rank	Sum of Ranks
C13	Cattle	41	50.04	2051.50
	Red Deer	35	24.99	874.50
	Total	76		
N15	Cattle	41	42.76	1753.00
	Red Deer	35	33.51	1173.00
	Total	76		

Test Statistics[a]

	C13	N15
Mann-Whitney U	244.500	543.000
Wilcoxon W	874.500	1173.000
Z	-4.944	-1.822
Asymp. Sig. (2-tailed)	**.000**	.068

a. Grouping Variable: species

Mann Whitney U test results comparing C and N values of Iron Age Sheep and Red deer in the Western Isles

Ranks

	species	N	Mean Rank	Sum of Ranks
C13	Sheep	38	47.09	1789.50
	Red Deer	35	26.04	911.50
	Total	73		
N15	Sheep	38	43.37	1648.00
	Red Deer	35	30.09	1053.00
	Total	73		

Test Statistics[a]

	C13	N15
Mann-Whitney U	281.500	423.000
Wilcoxon W	911.500	1053.000
Z	-4.247	-2.676
Asymp. Sig. (2-tailed)	**.000**	**.007**

a. Grouping Variable: species

Mann Whitney U test results comparing C and N values of Iron Age Cattle and Pig in the Western Isles

Ranks

	species	N	Mean Rank	Sum of Ranks
C13	Cattle	41	27.06	1109.50
	Pig	24	43.15	1035.50
	Total	65		
N15	Cattle	41	22.12	907.00
	Pig	24	51.58	1238.00
	Total	65		

Test Statistics[a]

	C13	N15
Mann-Whitney U	248.500	46.000
Wilcoxon W	1109.500	907.000
Z	-3.318	-6.066
Asymp. Sig. (2-tailed)	**.001**	**.000**

a. Grouping Variable: species

Mann Whitney U test results comparing C and N values of Iron Age Pig and Red deer in the Western Isles

Ranks

	species	N	Mean Rank	Sum of Ranks
C13	Pig	24	44.54	1069.00
	Red Deer	35	20.03	701.00
	Total	59		
N15	Pig	24	46.65	1119.50
	Red Deer	35	18.59	650.50
	Total	59		

Test Statistics[a]

	C13	N15
Mann-Whitney U	71.000	20.500
Wilcoxon W	701.000	650.500
Z	-5.400	-6.169
Asymp. Sig. (2-tailed)	**.000**	**.000**

a. Grouping Variable: species

Mann Whitney U test results comparing C and N values of Iron Age sheep and Pig in the Western Isles

Ranks

	species	N	Mean Rank	Sum of Ranks
C13	Sheep	38	25.53	970.00
	Pig	24	40.96	983.00
	Total	62		
N15	Sheep	38	21.76	827.00
	Pig	24	46.92	1126.00
	Total	62		

Test Statistics[a]

	C13	N15
Mann-Whitney U	229.000	86.000
Wilcoxon W	970.000	827.000
Z	-3.287	-5.351
Asymp. Sig. (2-tailed)	**.001**	**.000**

a. Grouping Variable: species

Iron Age Comparisons Orkney

Mann Whitney U test results comparing C and N values of Iron Age Cattle and Sheep in Orkney

Ranks

	species	N	Mean Rank	Sum of Ranks
C13	Cattle	19	15.55	295.50
	Sheep	15	19.97	299.50
	Total	34		
N15	Cattle	19	13.47	256.00
	Sheep	15	22.60	339.00
	Total	34		

Test Statistics[b]

	C13	N15
Mann-Whitney U	105.500	66.000
Wilcoxon W	295.500	256.000
Z	−1.287	−2.656
Asymp. Sig. (2-tailed)	.198	.008
Exact Sig. [2*(1-tailed Sig.)]	.202[a]	**.007a**

a. Not corrected for ties.

b. Grouping Variable: species

Mann Whitney U test results comparing C and N values of Iron Age Cattle and Red Deer in Orkney

Ranks

	species	N	Mean Rank	Sum of Ranks
C13	Cattle	19	16.37	311.00
	Red Deer	13	16.69	217.00
	Total	32		
N15	Cattle	19	13.37	254.00
	Red Deer	13	21.08	274.00
	Total	32		

Test Statistics[b]

	C13	N15
Mann-Whitney U	121.000	64.000
Wilcoxon W	311.000	254.000
Z	−.097	−2.287
Asymp. Sig. (2-tailed)	.923	.022
Exact Sig. [2*(1-tailed Sig.)]	.940[a]	**.022a**

a. Not corrected for ties.

b. Grouping Variable: species

Mann Whitney U test results comparing C and N values of Iron Age Pig and Red Deer in Orkney

Ranks

	species	N	Mean Rank	Sum of Ranks
C13	Pig	11	17.59	193.50
	Red Deer	13	8.19	106.50
	Total	24		
N15	Pig	11	16.86	185.50
	Red Deer	13	8.81	114.50
	Total	24		

Test Statistics[b]

	C13	N15
Mann-Whitney U	15.500	23.500
Wilcoxon W	106.500	114.500
Z	−3.256	−2.786
Asymp. Sig. (2-tailed)	.001	.005
Exact Sig. [2*(1-tailed Sig.)]	**.001a**	**.004a**

a. Not corrected for ties.

b. Grouping Variable: species

Mann Whitney U test results comparing C and N values of Iron Age Sheep and Pig in Orkney

Ranks

	species	N	Mean Rank	Sum of Ranks
C13	Sheep	15	10.63	159.50
	Pig	11	17.41	191.50
	Total	26		
N15	Sheep	15	10.00	150.00
	Pig	11	18.27	201.00
	Total	26		

Test Statistics[b]

	C13	N15
Mann-Whitney U	39.500	30.000
Wilcoxon W	159.500	150.000
Z	-2.237	-2.726
Asymp. Sig. (2-tailed)	.025	.006
Exact Sig. [2*(1-tailed Sig.)]	**.024a**	**.005a**

a. Not corrected for ties.

b. Grouping Variable: species

Mann Whitney U test results comparing C and N values of Iron Age Sheep and Red deer in Orkney

Ranks

	species	N	Mean Rank	Sum of Ranks
C13	Sheep	15	15.70	235.50
	Red Deer	13	13.12	170.50
	Total	28		
N15	Sheep	15	15.10	226.50
	Red Deer	13	13.81	179.50
	Total	28		

Test Statistics[b]

	C13	N15
Mann-Whitney U	79.500	88.500
Wilcoxon W	170.500	179.500
Z	-.832	-.415
Asymp. Sig. (2-tailed)	.406	.678
Exact Sig. [2*(1-tailed Sig.)]	.413[a]	.683[a]

a. Not corrected for ties.

b. Grouping Variable: species

Mann Whitney U test results comparing C and N values of Iron Age Sheep and Red deer in Orkney

Ranks

	species	N	Mean Rank	Sum of Ranks
C13	Cattle	19	11.13	211.50
	Pig	11	23.05	253.50
	Total	30		
N15	Cattle	19	10.66	202.50
	Pig	11	23.86	262.50
	Total	30		

Test Statistics[b]

	C13	N15
Mann-Whitney U	21.500	12.500
Wilcoxon W	211.500	202.500
Z	-3.580	-3.967
Asymp. Sig. (2-tailed)	.000	.000
Exact Sig. [2*(1-tailed Sig.)]	**.000a**	**.000a**

a. Not corrected for ties.

b. Grouping Variable: species

Iron Age Comparisons Shetland

Mann Whitney U test results comparing C and N values of Iron Age Cattle and pig in the Shetland

Ranks

	species	N	Mean Rank	Sum of Ranks
C13	Cattle	9	9.50	85.50
	Pig	8	8.44	67.50
	Total	17		
N15	Cattle	9	9.06	81.50
	Pig	8	8.94	71.50
	Total	17		

Test Statistics[b]

	C13	N15
Mann-Whitney U	31.500	35.500
Wilcoxon W	67.500	71.500
Z	-.437	-.048
Asymp. Sig. (2-tailed)	.662	.962
Exact Sig. [2*(1-tailed Sig.)]	.673[a]	.963[a]

a. Not corrected for ties.

b. Grouping Variable: species

Mann Whitney U test results comparing C and N values of Iron Age Sheep and Pig in the Shetland

Ranks

	species	N	Mean Rank	Sum of Ranks
C13	Sheep	10	11.25	112.50
	Pig	8	7.31	58.50
	Total	18		
N15	Sheep	10	8.75	87.50
	Pig	8	10.44	83.50
	Total	18		

Test Statistics[b]

	C13	N15
Mann-Whitney U	22.500	32.500
Wilcoxon W	58.500	87.500
Z	-1.570	-.668
Asymp. Sig. (2-tailed)	.117	.504
Exact Sig. [2*(1-tailed Sig.)]	.122[a]	.515[a]

a. Not corrected for ties.

b. Grouping Variable: species

Mann Whitney U test results comparing C and N values of Iron Age Cattle and Sheep in Shetland

Ranks

	species	N	Mean Rank	Sum of Ranks
C13	Cattle	9	7.33	66.00
	Sheep	10	12.40	124.00
	Total	19		
N15	Cattle	9	11.00	99.00
	Sheep	10	9.10	91.00
	Total	19		

Test Statistics[b]

	C13	N15
Mann-Whitney U	21.000	36.000
Wilcoxon W	66.000	91.000
Z	-1.982	-.736
Asymp. Sig. (2-tailed)	.047	.462
Exact Sig. [2*(1-tailed Sig.)]	.053[a]	.497[a]

a. Not corrected for ties.

b. Grouping Variable: species

Appendix 3- Geographical comparisons of isotopic values using the Mann-Whitney U test

Neolithic Island comparisons

Mann Whitney U test comparing Neolithic Cattle in the Northern and the Western Isles

Ranks

	Island	N	Mean Rank	Sum of Ranks
C13	Orkney	94	50.51	4747.50
	Western Isles	9	67.61	608.50
	Total	103		
N15	Orkney	94	54.87	5157.50
	Western Isles	9	22.06	198.50
	Total	103		

Test Statistics[a]

	C13	N15
Mann-Whitney U	282.500	153.500
Wilcoxon W	4747.500	198.500
Z	-1.649	-3.151
Asymp. Sig. (2-tailed)	.099	**.002**

a. Grouping Variable: Island

Mann Whitney U test comparing Neolithic Sheep in the Northern and the Western Isles

Ranks

	Island	N	Mean Rank	Sum of Ranks
C13	Orkney	26	23.25	604.50
	Western Isles	11	8.95	98.50
	Total	37		
N15	Orkney	26	23.19	603.00
	Western Isles	11	9.09	100.00
	Total	37		

Test Statistics[b]

	C13	N15
Mann-Whitney U	32.500	34.000
Wilcoxon W	98.500	100.000
Z	-3.684	-3.626
Asymp. Sig. (2-tailed)	.000	.000
Exact Sig. [2*(1-tailed Sig.)]	**.000a**	**.000a**

a. Not corrected for ties.

b. Grouping Variable: Island

Mann Whitney U test comparing Neolithic Red Deer in the Northern and the Western Isles

Ranks

	Island	N	Mean Rank	Sum of Ranks
C13	Northern Isles	12	7.83	94.00
	Western Isles	7	13.71	96.00
	Total	19		
N15	Northern Isles	12	12.83	154.00
	Western Isles	7	5.14	36.00
	Total	19		

Test Statistics[b]

	C13	N15
Mann-Whitney U	16.000	8.000
Wilcoxon W	94.000	36.000
Z	-2.197	-2.874
Asymp. Sig. (2-tailed)	.028	.004
Exact Sig. [2*(1-tailed Sig.)]	**.028a**	**.003a**

a. Not corrected for ties.

b. Grouping Variable: Island

Bronze Age Island comparisons

Mann Whitney U test comparing Bronze Age Cattle in the Northern and the Western Isles

Ranks

	Island	N	Mean Rank	Sum of Ranks
C13	Orkney	5	13.30	66.50
	Western Isles	27	17.09	461.50
	Total	32		
N15	Orkney	5	29.10	145.50
	Western Isles	27	14.17	382.50
	Total	32		

Test Statistics[b]

	C13	N15
Mann-Whitney U	51.500	4.500
Wilcoxon W	66.500	382.500
Z	-.841	-3.277
Asymp. Sig. (2-tailed)	.400	.001
Exact Sig. [2*(1-tailed Sig.)]	.418[a]	**.000a**

a. Not corrected for ties.

b. Grouping Variable: Island

Mann Whitney U test comparing Bronze Age Sheep in the Northern and the Western Isles

Ranks

	Island	N	Mean Rank	Sum of Ranks
C13	Orkney	4	14.50	58.00
	Western Isles	25	15.08	377.00
	Total	29		
N15	Orkney	4	23.13	92.50
	Western Isles	25	13.70	342.50
	Total	29		

Test Statistics[b]

	C13	N15
Mann-Whitney U	48.000	17.500
Wilcoxon W	58.000	342.500
Z	-.127	-2.059
Asymp. Sig. (2-tailed)	.899	.039
Exact Sig. [2*(1-tailed Sig.)]	.927[a]	**.036a**

a. Not corrected for ties.

b. Grouping Variable: Island

Iron Age Island comparisons

Mann Whitney U test comparing Iron Age Cattle in Orkney and the Western Isles

Ranks

	island	N	Mean Rank	Sum of Ranks
C13	Orkney	19	11.87	225.50
	Western Isles	41	39.13	1604.50
	Total	60		
N15	Orkney	19	43.55	827.50
	Western Isles	41	24.45	1002.50
	Total	60		

Test Statistics[a]

	C13	N15
Mann-Whitney U	35.500	141.500
Wilcoxon W	225.500	1002.500
Z	-5.640	-3.946
Asymp. Sig. (2-tailed)	**.000**	**.000**

a. Grouping Variable: island

Mann Whitney U test comparing Iron Age Orkney Sheep in and Western Isles

Ranks

	island	N	Mean Rank	Sum of Ranks
C13	Orkney	15	19.20	288.00
	Western Isles	38	30.08	1143.00
	Total	53		
N15	Orkney	15	39.73	596.00
	Western Isles	38	21.97	835.00
	Total	53		

Test Statistics[a]

	C13	N15
Mann-Whitney U	168.000	94.000
Wilcoxon W	288.000	835.000
Z	−2.316	−3.774
Asymp. Sig. (2-tailed)	**.021**	**.000**

a. Grouping Variable: island

Mann Whitney U test comparing Iron Age Orkney Pig in the Western Isles

Ranks

	island	N	Mean Rank	Sum of Ranks
C13	Orkney	11	15.45	170.00
	Western Isles	24	19.17	460.00
	Total	35		
N15	Orkney	11	21.36	235.00
	Western Isles	24	16.46	395.00
	Total	35		

	C13	N15
Mann-Whitney U	104.000	95.000
Wilcoxon W	170.000	395.000
Z	−.998	−1.316
Asymp. Sig. (2-tailed)	.318	.188
Exact Sig. [2*(1-tailed Sig.)]	.334[a]	.198[a]

a. Not corrected for ties.

b. Grouping Variable: island

Mann Whitney U test comparing Iron Age Red Deer in Orkney and the Western Isles

Ranks

island	N	Mean Rank	Sum of Ranks
Orkney	13	19.19	249.50
Western Isles	35	26.47	926.50
Total	48		
Orkney	13	39.96	519.50
Western Isles	35	18.76	656.50
Total	48		

Test Statistics[a]

	C13	N15
Mann-Whitney U	158.500	26.500
Wilcoxon W	249.500	656.500
Z	-1.614	-4.670
Asymp. Sig. (2-tailed)	.107	**.000**

a. Grouping Variable: island

Norse Island comparisons

Mann Whitney U test comparing Norse Orkney Cattle in and the Western Isles

Ranks

	island	N	Mean Rank	Sum of Ranks
C13	Orkney	14	17.25	241.50
	Western Isles	31	25.60	793.50
	Total	45		
N15	Orkney	14	32.29	452.00
	Western Isles	31	18.81	583.00
	Total	45		

Test Statistics[a]

	C13	N15
Mann-Whitney U	136.500	87.000
Wilcoxon W	241.500	583.000
Z	-1.982	-3.193
Asymp. Sig. (2-tailed)	**.047**	**.001**

a. Grouping Variable: island

Mann Whitney U test comparing Norse Sheep in Orkney and the Western Isles

Ranks

	island	N	Mean Rank	Sum of Ranks
C13	Orkney	15	11.60	174.00
	Western Isles	20	22.80	456.00
	Total	35		
N15	Orkney	15	24.17	362.50
	Western Isles	20	13.38	267.50
	Total	35		

Test Statistics[b]

	C13	N15
Mann-Whitney U	54.000	57.500
Wilcoxon W	174.000	267.500
Z	-3.223	-3.089
Asymp. Sig. (2-tailed)	.001	.002
Exact Sig. [2*(1-tailed Sig.)]	**.001a**	**.001a**

a. Not corrected for ties.

b. Grouping Variable: island

Mann Whitney U test comparing Norse Pig in Orkney and Western Isles

Ranks

	island	N	Mean Rank	Sum of Ranks
C13	Orkney	12	10.08	121.00
	Western Isles	19	19.74	375.00
	Total	31		
N15	Orkney	12	19.04	228.50
	Western Isles	19	14.08	267.50
	Total	31		

Test Statistics[b]

	C13	N15
Mann-Whitney U	43.000	77.500
Wilcoxon W	121.000	267.500
Z	-2.884	-1.482
Asymp. Sig. (2-tailed)	.004	.138
Exact Sig. [2*(1-tailed Sig.)]	**.003a**	.141[a]

a. Not corrected for ties.

b. Grouping Variable: island

Middle Iron Age Island comparisons

Mann Whitney U test comparing Middle Iron Age Cattle in Shetland and the Western Isles

Ranks

	island	N	Mean Rank	Sum of Ranks
C13	Shetland	8	6.56	52.50
	Western Isles	14	14.32	200.50
	Total	22		
N15	Shetland	8	14.00	112.00
	Western Isles	14	10.07	141.00
	Total	22		

Test Statistics[b]

	C13	N15
Mann-Whitney U	16.500	36.000
Wilcoxon W	52.500	141.000
Z	-2.704	-1.367
Asymp. Sig. (2-tailed)	.007	.172
Exact Sig. [2*(1-tailed Sig.)]	**.005a**	.188[a]

a. Not corrected for ties.

b. Grouping Variable: island

Mann Whitney U test comparing Middle Iron Age Sheep in Shetland and the Western Isles

Ranks

	island	N	Mean Rank	Sum of Ranks
C13	Shetland	8	7.06	56.50
	Western Isles	10	11.45	114.50
	Total	18		
N15	Shetland	8	8.81	70.50
	Western Isles	10	10.05	100.50
	Total	18		

Test Statistics[b]

	C13	N15
Mann-Whitney U	20.500	34.500
Wilcoxon W	56.500	70.500
Z	-1.746	-.490
Asymp. Sig. (2-tailed)	.081	.624
Exact Sig. [2*(1-tailed Sig.)]	.083[a]	.633[a]

a. Not corrected for ties.

b. Grouping Variable: island

Mann Whitney U test comparing Middle Iron Age Pig in Shetland and the Western Isles

Ranks

	island	N	Mean Rank	Sum of Ranks
C13	Shetland	7	4.64	32.50
	Western Isles	8	10.94	87.50
	Total	15		
N15	Shetland	7	4.93	34.50
	Western Isles	8	10.69	85.50
	Total	15		

Test Statistics[b]

	C13	N15
Mann-Whitney U	4.500	6.500
Wilcoxon W	32.500	34.500
Z	-2.737	-2.493
Asymp. Sig. (2-tailed)	.006	.013
Exact Sig. [2*(1-tailed Sig.)]	**.004a**	**.009a**

a. Not corrected for ties.

b. Grouping Variable: island

Appendix 4- Temporal comparisons of species isotopic values through time using the Mann-Whitney U test

Cattle: Western Isles

Mann Whitney U test comparing Neolithic and Beaker Period cattle in the Western Isles

Ranks

	period	N	Mean Rank	Sum of Ranks
C13	Neolithic	7	8.43	59.00
	Beaker	8	7.62	61.00
	Total	15		
N15	Neolithic	7	9.29	65.00
	Beaker	8	6.88	55.00
	Total	15		

Test Statistics[b]

	C13	N15
Mann-Whitney U	25.000	19.000
Wilcoxon W	61.000	55.000
Z	-.354	-1.049
Asymp. Sig. (2-tailed)	.723	.294
Exact Sig. [2*(1-tailed Sig.)]	.779[a]	.336[a]

a. Not corrected for ties.

b. Grouping Variable: period

Mann Whitney U test comparing Beaker period and Bronze Age cattle in the Western Isles

Ranks

	period	N	Mean Rank	Sum of Ranks
C13	Beaker	8	13.50	108.00
	Bronze Age	19	14.21	270.00
	Total	27		
N15	Beaker	8	11.50	92.00
	Bronze Age	19	15.05	286.00
	Total	27		

Test Statistics[b]

	C13	N15
Mann-Whitney U	72.000	56.000
Wilcoxon W	108.000	92.000
Z	-.213	-1.067
Asymp. Sig. (2-tailed)	.831	.286
Exact Sig. [2*(1-tailed Sig.)]	.856[a]	.307[a]

a. Not corrected for ties.

b. Grouping Variable: period

Mann Whitney U test comparing Bronze Age and Iron Age cattle in the Western Isles

Ranks

	period	N	Mean Rank	Sum of Ranks
C13	Bronze Age	19	27.21	517.00
	Iron Age	41	32.02	1313.00
	Total	60		
N15	Bronze Age	19	33.74	641.00
	Iron Age	41	29.00	1189.00
	Total	60		

Test Statistics[a]

	C13	N15
Mann-Whitney U	327.000	328.000
Wilcoxon W	517.000	1189.000
Z	-.996	-.979
Asymp. Sig. (2-tailed)	.319	.328

a. Grouping Variable: period

Mann Whitney U test comparing Iron Age and Norse cattle in the Western Isles

Ranks

	period	N	Mean Rank	Sum of Ranks
C13	Iron Age	41	42.94	1760.50
	Norse	31	27.98	867.50
	Total	72		
N15	Iron Age	41	35.83	1469.00
	Norse	31	37.39	1159.00
	Total	72		

Test Statistics[a]

	C13	N15
Mann-Whitney U	371.500	608.000
Wilcoxon W	867.500	1469.000
Z	-3.014	-.313
Asymp. Sig. (2-tailed)	**.003**	.754

a. Grouping Variable: period

Sheep: Western Isles

Mann Whitney U test comparing Neolithic and Beaker sheep in the Western Isles

Ranks

	period	N	Mean Rank	Sum of Ranks
C13	Neolithic	11	7.18	79.00
	Beaker	11	15.82	174.00
	Total	22		
N15	Neolithic	11	16.55	182.00
	Beaker	11	6.45	71.00
	Total	22		

Test Statistics[b]

	C13	N15
Mann-Whitney U	13.000	5.000
Wilcoxon W	79.000	71.000
Z	-3.164	-3.649
Asymp. Sig. (2-tailed)	.002	.000
Exact Sig. [2*(1-tailed Sig.)]	**.001a**	**.000a**

a. Not corrected for ties.

b. Grouping Variable: period

Mann Whitney U test comparing Beaker and Bronze Age sheep in the Western Isles

Ranks

	period	N	Mean Rank	Sum of Ranks
C13	Beaker	11	9.05	99.50
	Bronze Age	16	17.41	278.50
	Total	27		
N15	Beaker	11	7.77	85.50
	Bronze Age	16	18.28	292.50
	Total	27		

Test Statistics[b]

	C13	N15
Mann-Whitney U	33.500	19.500
Wilcoxon W	99.500	85.500
Z	-2.698	-3.384
Asymp. Sig. (2-tailed)	.007	.001
Exact Sig. [2*(1-tailed Sig.)]	**.006a**	**.000a**

a. Not corrected for ties.

b. Grouping Variable: period

Mann Whitney U test comparing Bronze Age and Iron Age sheep in the Western Isles

Ranks

	period	N	Mean Rank	Sum of Ranks
C13	Bronze Age	16	39.84	637.50
	Iron Age	40	23.96	958.50
	Total	56		
N15	Bronze Age	16	36.62	586.00
	Iron Age	40	25.25	1010.00
	Total	56		

Test Statistics[a]

	C13	N15
Mann-Whitney U	138.500	190.000
Wilcoxon W	958.500	1010.000
Z	-3.301	-2.360
Asymp. Sig. (2-tailed)	**.001**	**.018**

a. Grouping Variable: period

Mann Whitney U test comparing Iron Age and Norse sheep in the Western Isles

Ranks

	period	N	Mean Rank	Sum of Ranks
C13	Iron Age	40	33.48	1339.00
	Norse	18	20.67	372.00
	Total	58		
N15	Iron Age	40	30.16	1206.50
	Norse	18	28.03	504.50
	Total	58		

Test Statistics[a]

	C13	N15
Mann-Whitney U	201.000	333.500
Wilcoxon W	372.000	504.500
Z	-2.685	-.446
Asymp. Sig. (2-tailed)	**.007**	.656

a. Grouping Variable: period

Mann Whitney U test comparing Iron Age and Norse Pigs in the Western Isles

Ranks

	period	N	Mean Rank	Sum of Ranks
C13	Iron Age	24	21.48	515.50
	Norse	19	22.66	430.50
	Total	43		
N15	Iron Age	24	21.23	509.50
	Norse	19	22.97	436.50
	Total	43		

Test Statistics[a]

	C13	N15
Mann-Whitney U	215.500	209.500
Wilcoxon W	515.500	509.500
Z	-.306	-.453
Asymp. Sig. (2-tailed)	.760	.651

a. Grouping Variable: period

Red Deer: Western Isles

Mann Whitney U test comparing Neolithic and Beaker Red Deer in the Western Isles

Ranks

	period	N	Mean Rank	Sum of Ranks
C13	Neolithic	7	8.50	59.50
	Beaker	5	3.70	18.50
	Total	12		
N15	Neolithic	7	6.79	47.50
	Beaker	5	6.10	30.50
	Total	12		

Test Statistics[b]

	C13	N15
Mann-Whitney U	3.500	15.500
Wilcoxon W	18.500	30.500
Z	-2.380	-.331
Asymp. Sig. (2-tailed)	.017	.740
Exact Sig. [2*(1-tailed Sig.)]	**.018a**	.755[a]

a. Not corrected for ties.

b. Grouping Variable: period

Mann Whitney U test comparing Beaker and Bronze Age Red Deer in the Western Isles

Ranks

	period	N	Mean Rank	Sum of Ranks
C13	Beaker	5	4.00	20.00
	Bronze Age	6	7.67	46.00
	Total	11		
N15	Beaker	5	4.00	20.00
	Bronze Age	6	7.67	46.00
	Total	11		

Test Statistics[b]

	C13	N15
Mann-Whitney U	5.000	5.000
Wilcoxon W	20.000	20.000
Z	-1.851	-1.830
Asymp. Sig. (2-tailed)	.064	.067
Exact Sig. [2*(1-tailed Sig.)]	.082[a]	.082[a]

a. Not corrected for ties.

b. Grouping Variable: period

Mann Whitney U test comparing Bronze Age and Iron Age Red Deer in the Western Isles

Ranks

	period	N	Mean Rank	Sum of Ranks
C13	Bronze Age	6	32.75	196.50
	Iron Age	38	20.88	793.50
	Total	44		
N15	Bronze Age	6	30.83	185.00
	Iron Age	38	21.18	805.00
	Total	44		

Test Statistics[b]

	C13	N15
Mann-Whitney U	52.500	64.000
Wilcoxon W	793.500	805.000
Z	-2.117	-1.713
Asymp. Sig. (2-tailed)	.034	.087
Exact Sig. [2*(1-tailed Sig.)]	**.033a**	.091[a]

a. Not corrected for ties.

b. Grouping Variable: period

Mann Whitney U test comparing Iron Age and Norse Red Deer in the Western Isles

Ranks

	period	N	Mean Rank	Sum of Ranks
C13	Iron Age	38	30.41	1155.50
	Norse	21	29.26	614.50
	Total	59		
N15	Iron Age	38	24.47	930.00
	Norse	21	40.00	840.00
	Total	59		

Test Statistics[a]

	C13	N15
Mann-Whitney U	383.500	189.000
Wilcoxon W	614.500	930.000
Z	-.247	-3.329
Asymp. Sig. (2-tailed)	.805	**.001**

a. Grouping Variable: period

Cattle: Orkney

Mann Whitney U test comparing Neolithic and Iron Age cattle in Orkney

Ranks

	period	N	Mean Rank	Sum of Ranks
C13	Neolithic	92	61.11	5622.00
	Iron Age	20	35.30	706.00
	Total	112		
N15	Neolithic	92	58.69	5399.50
	Iron Age	20	46.42	928.50
	Total	112		

Test Statistics[a]

	C13	N15
Mann-Whitney U	496.000	718.500
Wilcoxon W	706.000	928.500
Z	-3.237	-1.533
Asymp. Sig. (2-tailed)	**.001**	.125

a. Grouping Variable: period

Mann Whitney U test comparing Iron Age and Norse cattle in Orkney

Ranks

	period	N	Mean Rank	Sum of Ranks
C13	Iron Age	20	15.05	301.00
	Norse	14	21.00	294.00
	Total	34		
N15	Iron Age	20	17.10	342.00
	Norse	14	18.07	253.00
	Total	34		

Test Statistics[b]

	C13	N15
Mann-Whitney U	91.000	132.000
Wilcoxon W	301.000	342.000
Z	-1.723	-.281
Asymp. Sig. (2-tailed)	.085	.779
Exact Sig. [2*(1-tailed Sig.)]	.090[a]	.796[a]

a. Not corrected for ties.

b. Grouping Variable: period

Sheep: Orkney

Mann Whitney U test comparing Neolithic and Iron Age Sheep in Orkney

Ranks

	period	N	Mean Rank	Sum of Ranks
C13	Neolithic	19	22.21	422.00
	Iron Age	15	11.53	173.00
	Total	34		
N15	Neolithic	19	16.76	318.50
	Iron Age	15	18.43	276.50
	Total	34		

Test Statistics[b]

	C13	N15
Mann-Whitney U	53.000	128.500
Wilcoxon W	173.000	318.500
Z	-3.109	-.487
Asymp. Sig. (2-tailed)	.002	.626
Exact Sig. [2*(1-tailed Sig.)]	**.001a**	.632a

a. Not corrected for ties.

b. Grouping Variable: period

Mann Whitney U test comparing Iron Age and Norse sheep in Orkney

Ranks

	period	N	Mean Rank	Sum of Ranks
C13	Iron Age	15	16.00	240.00
	Norse	15	15.00	225.00
	Total	30		
N15	Iron Age	15	18.87	283.00
	Norse	15	12.13	182.00
	Total	30		

Test Statistics[b]

	C13	N15
Mann-Whitney U	105.000	62.000
Wilcoxon W	225.000	182.000
Z	-.312	-2.097
Asymp. Sig. (2-tailed)	.755	.036
Exact Sig. [2*(1-tailed Sig.)]	.775[a]	.037[a]

a. Not corrected for ties.

b. Grouping Variable: period

Red Deer: Orkney

Mann Whitney U test comparing Neolithic and Iron Age Red Deer in Orkney

Ranks

	period	N	Mean Rank	Sum of Ranks
C13	Neolithic	12	14.17	170.00
	Iron Age	13	11.92	155.00
	Total	25		
N15	Neolithic	12	11.17	134.00
	Iron Age	13	14.69	191.00
	Total	25		

Test Statistics[b]

	C13	N15
Mann-Whitney U	64.000	56.000
Wilcoxon W	155.000	134.000
Z	-.767	-1.198
Asymp. Sig. (2-tailed)	.443	.231
Exact Sig. [2*(1-tailed Sig.)]	.470[a]	.247[a]

a. Not corrected for ties.

b. Grouping Variable: period

Mann Whitney U test comparing Iron Age and Norse Pig in Orkney

Ranks

	period	N	Mean Rank	Sum of Ranks
C13	Iron Age	11	14.68	161.50
	Norse	12	9.54	114.50
	Total	23		
N15	Iron Age	11	12.41	136.50
	Norse	12	11.62	139.50
	Total	23		

Test Statistics[b]

	C13	N15
Mann-Whitney U	36.500	61.500
Wilcoxon W	114.500	139.500
Z	-1.819	-.277
Asymp. Sig. (2-tailed)	.069	.782
Exact Sig. [2*(1-tailed Sig.)]	.069[a]	.786[a]

a. Not corrected for ties.

b. Grouping Variable: period

Shetland Species comparisons

Mann Whitney U test comparing Iron Age and Norse cattle in Shetland

Ranks

	period	N	Mean Rank	Sum of Ranks
C13	Iron Age	9	6.39	57.50
	Norse	7	11.21	78.50
	Total	16		
N15	Iron Age	9	9.06	81.50
	Norse	7	7.79	54.50
	Total	16		

Test Statistics[b]

	C13	N15
Mann-Whitney U	12.500	26.500
Wilcoxon W	57.500	54.500
Z	-2.020	-.530
Asymp. Sig. (2-tailed)	.043	.596
Exact Sig. [2*(1-tailed Sig.)]	.042[a]	.606[a]

a. Not corrected for ties.

b. Grouping Variable: period

Mann Whitney U test comparing Iron Age and Norse Sheep in Shetland

Ranks

	period	N	Mean Rank	Sum of Ranks
C13	Iron Age	10	9.95	99.50
	Norse	7	7.64	53.50
	Total	17		
N15	Iron Age	10	9.40	94.00
	Norse	7	8.43	59.00
	Total	17		

Test Statistics[b]

	C13	N15
Mann-Whitney U	25.500	31.000
Wilcoxon W	53.500	59.000
Z	-.942	-.391
Asymp. Sig. (2-tailed)	.346	.696
Exact Sig. [2*(1-tailed Sig.)]	.364[a]	.740[a]

a. Not corrected for ties.

b. Grouping Variable: period

Mann Whitney U test comparing Iron Age and Norse Red Deer in the Shetland

Ranks

	period	N	Mean Rank	Sum of Ranks
C13	Iron Age	10	9.95	99.50
	Norse	7	7.64	53.50
	Total	17		
N15	Iron Age	10	9.40	94.00
	Norse	7	8.43	59.00
	Total	17		

Test Statistics[b]

	C13	N15
Mann-Whitney U	25.500	31.000
Wilcoxon W	53.500	59.000
Z	-.942	-.391
Asymp. Sig. (2-tailed)	.346	.696
Exact Sig. [2*(1-tailed Sig.)]	.364[a]	.740[a]

a. Not corrected for ties.

b. Grouping Variable: period

Appendix 5-Human Isotopic Values

Site	Island	Period	Species	Sex	Age	Element	$\delta^{13}C$	$\delta^{15}N$	C:N	References
Cnoc Coig	Inner Hebrides	Mesolithic	Human	Female?		Clavicle	-13.2	14.5	3.1	Richards and Mellars 1998
Cnoc Coig	Inner Hebrides	Mesolithic	Human	Male?		Clavicle	-12.3	16.0	3.1	Richards and Mellars 1998
Cnoc Coig	Inner Hebrides	Mesolithic	Human			Metacarpal	-12.0	14.7	2.9	Richards and Mellars 1998
Cnoc Coig	Inner Hebrides	Mesolithic	Human			Metacarpal	-12.0	17.0	3.1	Richards and Mellars 1998
Cnoc Coig	Inner Hebrides	Mesolithic	Human			Frontal	-13.6	15.2	3.1	Richards and Mellars 1998
Casteal nan Gillean II	Inner Hebrides	Mesolithic	Human			Metatarsal	-15.8	14.6	3.1	Richards and Mellars 1998
Carding Mill Bay	Mainland	Neolithic	Human		Adult	Humerus	-21.3	8.8	3.2	Schulting and Richards 2002a
Carding Mill Bay	Mainland	Neolithic	Human		Adult?	Phalanx	-21.5	10.0	3.1	Schulting and Richards 2002a
Carding Mill Bay	Mainland	Neolithic	Human		Adult	Femur	-21.3	8.9	3.2	Schulting and Richards 2002a
Carding Mill Bay	Mainland	Neolithic	Human		Adult?	Metatarsal	-21.3	9.1	3.2	Schulting and Richards 2002a
Carding Mill Bay	Mainland	Neolithic	Human		Adult?	Parietal	-21.5	9.6	3.2	Schulting and Richards 2002a
Carding Mill Bay	Mainland	Neolithic	Human		Subadult	Scapula	-21.3	9.5	3.1	Schulting and Richards 2002a
Carding Mill Bay	Mainland	Neolithic	Human		Adult?	Phalanx	-21.5	9.0	3.2	Schulting and Richards 2002a
Carding Mill Bay	Mainland	Neolithic	Human		Adult?	MC	-21.0	8.9	3.1	Schulting and Richards 2002a
Carding Mill Bay	Mainland	Neolithic	Human		Adult?	Phalanx	-21.5	9.9	3.1	Schulting and Richards 2002a
Carding Mill Bay	Mainland	Neolithic	Human		Adult?	MT	-21.4	9.8	3.1	Schulting and Richards 2002a
Crarae	Mainland	Neolithic	Human		Adult	Pelvis	-21.8	9.0	3.3	Schulting and Richards 2002a
Crarae	Mainland	Neolithic	Human		Adult	Phalanx	-21.3	9.5	3.3	Schulting and Richards 2002a
Crarae	Mainland	Neolithic	Human		Adult?	Patella	-21.7	9.1	3.5	Schulting and Richards 2002a
Holm of Papa Westray	Orkney	Neolithic	Human		Sub Adult	Phalanx	-19.6	11.3	3.2	Schulting and Richards 2009
Holm of Papa Westray	Orkney	Neolithic	Human		Adult	Femur	-19.9	10.4	3.0	Schulting and Richards 2009
Holm of Papa Westray	Orkney	Neolithic	Human		Adult	Femur	-20.8	10.0	2.9	Schulting and Richards 2009
Quanterness	Orkney	Neolithic	Human		Adult		-20.3	9.7		Schulting *et al.* 2010
Quanterness	Orkney	Neolithic	Human		Adult		-20.6	10.3		Schulting *et al.* 2010
Quanterness	Orkney	Neolithic	Human		Adult		-20.6	10.4		Schulting *et al.* 2010
Quanterness	Orkney	Neolithic	Human		Adult		-20.5	10.6		Schulting *et al.* 2010
Quanterness	Orkney	Neolithic	Human		Adult		-20.5	10.7		Schulting *et al.* 2010
Quanterness	Orkney	Neolithic	Human		Adult		-20.2	10.9		Schulting *et al.* 2010
Quanterness	Orkney	Neolithic	Human		Adult		-20.1	11.0		Schulting *et al.* 2010
Quanterness	Orkney	Neolithic	Human		Adult		-20.1	11.3		Schulting *et al.* 2010
Quanterness	Orkney	Neolithic	Human		Adult		-20.5	11.2		Schulting *et al.* 2010

Site	Island	Period	Species	Sex	Age	Element	$\delta^{13}C$	$\delta^{15}N$	C:N	References
Quanterness	Orkney	Neolithic	Human		Adult		-20.8	11.3		Schulting *et al.* 2010
Quanterness	Orkney	Neolithic	Human		Adult		-21.3	11.4		Schulting *et al.* 2010
Quanterness	Orkney	Neolithic	Human		Adult		-20.4	11.4		Schulting *et al.* 2010
Quanterness	Orkney	Neolithic	Human		Adult		-20.2	11.5		Schulting *et al.* 2010
Quanterness	Orkney	Neolithic	Human		Adult		-20.3	11.5		Schulting *et al.* 2010
Quanterness	Orkney	Neolithic	Human		Adult		-20.2	12.1		Schulting *et al.* 2010
Quanterness	Orkney	Neolithic	Human		Adult		-21.3	12.4		Schulting *et al.* 2010
Quanterness	Orkney	Neolithic	Human		Sub Adult		-21.5	10.5		Schulting *et al.* 2010
Quanterness	Orkney	Neolithic	Human		Sub Adult		-21.0	11.4		Schulting *et al.* 2010
Quanterness	Orkney	Neolithic	Human		Sub Adult		-20.7	10.9		Schulting *et al.* 2010
Quanterness	Orkney	Neolithic	Human		Sub Adult		-19.8	10.7		Schulting *et al.* 2010
Cladh Hallan	Uist	Bronze Age	Human		Juvenile	Femur	-22.2	10.6		Parker Pearson *et al.* 2005
Cladh Hallan	Uist	Bronze Age	Human		Adult	Scapula	-19.1	5.9		Parker Pearson *et al.* 2005
Cladh Hallan	Uist	Bronze Age	Human	Male	Adult	Skull	-20.0	10.8	3.4	Parker Pearson *et al.* 2005
Cladh Hallan	Uist	Bronze Age	Human	Male	Adult	Mandible	-19.9	10.8	3.3	Parker Pearson *et al.* 2005
Cladh Hallan	Uist	Bronze Age	Human	Male	Adult	Tibia	-19.9	9.9		Parker Pearson *et al.* 2005
Cladh Hallan	Uist	Bronze Age	Human	Female	Adult	Femur	-19.5	11.4	2.4	Parker Pearson *et al.* 2005
Cladh Hallan	Uist	Bronze Age	Human		3 Years	Femur	-18.8	8.6		Parker Pearson *et al.* 2005
Northton	Lewis/Harris	Bronze Age	Human	Female	45+		-19.7	9.5	3.2	Mandy Jay Pers. Comm. 2012
Northton	Lewis/Harris	Bronze Age	Human	Male	35-45		-19.1	11.3	3.3	Mandy Jay Pers. Comm. 2012
Baleshare	Uist	Iron Age	Human			Mandible	-19.8	10.1	3.3	Radiocarbon certificate
Northton	Lewis/Harris	Iron Age	Human				-20.1	10.9	3.1	Armit and Tucker pers. Comm.
Whitegate	Mainland	Iron Age	Human				-18.1	12.4	3.4	Armit and Tucker pers. Comm.
Balevullin	Tiree	Iron Age	Human				-20.6	11.5	3.2	Armit and Tucker pers. Comm.
Hillhead	Shetland	Iron Age	Human			Skull	-20.0	11.2	3.2	Armit and Tucker pers. Comm.
Cnip	Lewis/Harris	Iron Age	Human			Skull	-18.2	12.3	3.4	Armit and Tucker pers. Comm.
Sloc Sadhaidh	Uist	Iron Age	Human			Mandible	-19.8	10.1	3.3	Armit and Tucker pers. Comm.
Icegarth	Orkney	Iron Age	Human				-21.7	7.1	3.4	Armit and Tucker pers. Comm.
Lingro	Orkney	Iron Age	Human				-19.4	14.9	3.2	Armit and Tucker pers. Comm.
Crosskirk	Mainland	Iron Age	Human				-20.5	12.6	3.2	Armit and Tucker pers. Comm.
Crosskirk	Mainland	Iron Age	Human				-20.5	6.9	3.2	Armit and Tucker pers. Comm.
Dun Mor Vaul	Tiree	Iron Age	Human				-21.3	11.8	3.2	Armit and Tucker pers. Comm.

Site	Island	Period	Species	Sex	Age	Element	$\delta^{13}C$	$\delta^{15}N$	C:N	References
Kintradwell	Mainland	Iron Age	Human				-20.4	12.7	3.2	Armit and Tucker pers. Comm.
Kintradwell	Mainland	Iron Age	Human				-19.5	10.6	3.2	Armit and Tucker pers. Comm.
Balevullin	Tiree	Iron Age	Human				-20.6	11.5	3.2	Armit and Tucker pers. Comm.
Dun Mor Vaul	Tiree	Iron Age	Human				-21.3	11.8	3.2	Armit and Tucker pers. Comm.
Kintradwell	Mainland	Iron Age	Human				-20.4	12.7	3.2	Armit and Tucker pers. Comm.
Kintradwell	Mainland	Iron Age	Human				-19.5	10.6	3.2	Armit and Tucker pers. Comm.
Broch of Gurness	Orkney	Iron Age	Human			Mandible	-19.4	14.2	3.3	Jones 2013
Jarlshof	Shetland	Iron Age	Human				-20.7	11.0	3.6	Armit and Tucker pers.Comm.
Dun Vulan	Uist	Middle Iron Age	Human			Mandible	-19.1	11.4	3.2	Pete Marshall Pers comm.
Dun Vulan	Uist	Middle Iron Age	Human				-18.9	9.1	3.1	Pete Marshall Pers comm.
Dun Vulan	Uist	Middle Iron Age	Human			Parietal	-18.8	11.4	3.1	Pete Marshall Pers. Comm.
Dun Vulan	Uist	Middle Iron Age	Human				-19.1	10.7	3.1	Pete Marshall Pers. Comm.
Kildonan	Uist	Late Iron Age	Human				-20.3	11.2	3.4	Pete Marshall Pers comm.
Bornais (M1)	Uist	Late Iron Age	Human			Skull	-21.3	11.6	3.9	Marshall Pers. Comm.
Newark Bay	Orkney	Late Iron Age	Human	Female	Older Adult		-17.9	12.1	3.3	Richards *et al.* (2006)
Dun Vulan	Uist	Late Iron Age	Human			Humerus	-21.2	6.3	3.4	Pete Marshall Pers. Comm.
Kilphedair	Uist	Late Iron Age	Human			Rib	-21.8	10.7	3.4	Pete Marshall Pers. Comm.
Northton	Lewis/Harris	Late Iron Age	Human				-20.1	10.5	3.3	Mandy Jay Pers. Comm. 2012
Northton	Lewis/Harris	Late Iron Age	Human		14-16		-20.3	10.3	3.3	Mandy Jay Pers. Comm. 2012
Broch of Gurness	Orkney	Early Norse	Human		Human	Humerus	-20.3	11.4	3.4	Jones 2013
Westness	Orkney	Norse	Human	Female	Adult		-21.0	11.0	3.3	Barrett and Richards 2004
Westness	Orkney	Norse	Human		Juvenile		-21.0	10.4	3.5	Barrett and Richards 2004
Westness	Orkney	Norse	Human	Female	Adult		-21.0	11.3	3.5	Barrett and Richards 2004
Westness	Orkney	Norse	Human	Male	Adult		-20.9	11.5	3.3	Barrett and Richards 2004
Westness	Orkney	Norse	Human	Female	Adult		-20.8	11.0	3.3	Barrett and Richards 2004
Westness	Orkney	Norse	Human	Male	Adult		-20.8	10.4	3.5	Barrett and Richards 2004
Westness	Orkney	Norse	Human	Female	Adult		-20.7	11.8	3.4	Barrett and Richards 2004
Westness	Orkney	Norse	Human	Female	Adult		-20.6	11.7	3.6	Barrett and Richards 2004
Westness	Orkney	Norse	Human	Female	Adult		-20.6	10.9	3.2	Barrett and Richards 2004
Westness	Orkney	Norse	Human	Male	Adult		-20.5	11.0	3.3	Barrett and Richards 2004
Westness	Orkney	Norse	Human	Male	Adult		-18.4	14.4	3.3	Barrett and Richards 2004
Westness	Orkney	Norse	Human	Male	Adult		-18.2	14.8	3.4	Barrett and Richards 2004
Westness	Orkney	Norse	Human	Male	Adult		-18.1	13.7	3.3	Barrett and Richards 2004
Newark Bay	Orkney	Norse	Human	Female	Young Adult		-19.7	10.9	3.4	Richards *et al*. 2006
Westness	Orkney	Norse	Human	Female	Adult		-21.1	10.8	3.4	Barrett and Richards 2004

Site	Island	Period	Species	Sex	Age	Element	$\delta^{13}C$	$\delta^{15}N$	C:N	References
Newark Bay	Orkney	Norse	Human	Male	Young Adult		-16.9	14.4	3.3	Richards *et al.* 2006
Newark Bay	Orkney	Norse	Human	Female	Young Adult		-20.3	8.6	3.3	Richards *et al.* 2006
Newark Bay	Orkney	Norse	Human	Female	Adult		-19.6	9.9	3.3	Richards *et al.* 2006
Newark Bay	Orkney	Norse	Human	Male	Adult		-15.4	15.6	3.2	Richards *et al.* 2006
Newark Bay	Orkney	Norse	Human	Female	Adult		-19.6	10.4	3.3	Richards *et al.* 2006
Newark Bay	Orkney	Norse	Human	Female	Adult		-18.5	12.0	3.2	Richards *et al.* 2006
Newark Bay	Orkney	Norse	Human	Male	Adult		-17.5	13.7	3.3	Richards *et al.* 2006
Newark Bay	Orkney	Norse	Human	Female	Adult		-17.1	14.6	3.3	Richards *et al.* 2006
Newark Bay	Orkney	Norse	Human	Male	Adult		-17.5	13.8	3.3	Richards *et al.* 2006
Newark Bay	Orkney	Norse	Human	Female	Adult		-19.6	10.8	3.3	Richards *et al.* 2006
Newark Bay	Orkney	Norse	Human	Male	Adult		-17.3	14.4	3.3	Richards *et al.* 2006
Newark Bay	Orkney	Norse	Human	Male	Adult		-17.7	13.8	3.3	Richards *et al.* 2006
Newark Bay	Orkney	Norse	Human	Female	Adult		-19.4	11.0	3.3	Richards *et al.* 2006
Newark Bay	Orkney	Norse	Human	Female	Adult		-16.3	15.6	3.3	Richards *et al.* 2006
Newark Bay	Orkney	Norse	Human	Male	Older Adult		-20.0	10.9	3.4	Richards *et al.* 2006
Newark Bay	Orkney	Norse	Human	Male	Older Adult		-17.7	13.7	3.3	Richards *et al.* 2006
Newark Bay	Orkney	Norse	Human	Female	Older Adult		-19.1	10.4	3.3	Richards *et al.* 2006
Newark Bay	Orkney	Norse	Human	Female	Older Adult		-17.5	14.4	3.3	Richards *et al.* 2006

Appendix 6: Northern Isles Faunal NISP

		NISP					
Site Name	**Period**	**Terrestrial Mammal**	**Sea Mammal**	**Fish**	**Shellfish**	**Birds**	**Zooarchaeological References**
Tofts Ness	Neolithic	12100	175	84	3	214	Nicholson and Davis (2007)
Quanterness cairn	Neolithic	390	0	2	0	131	Clutton-Brock (1979)
Howe	Neolithic	14	0	0	0	1	Smith (1994); Locker (1994)
Point of Cott Westray	Neolithic	521	0	0	0	128	Noddle (1983)
Knap of Howar	Neolithic	4814	13	10	0	254	Noddle (1983)
Pierowall Quarry	Neolithic	385	0	3	869	24	McCormick (1984)
Isbister	Neolithic	5460	27	304	88	0	Barker (1983)
Links of Noltland	Neolithic	8684	0	0	0	0	Armour-Chelu (1992)
Pool	Neolithic	2120	7	2	0	10	Bond (2007)
Bay of Moaness	Bronze Age	112	0	0		0	Buckland *et al*. (1997)
Tofts Ness	Bronze Age	1323	27	74	91	262	Nicholson and Davis (2007)
Skaill, Deerness	Bronze Age	1232	11	0	0	0	Noddle (1997)
Point of Buckquoy	Bronze Age	517	3	239	6400	70	Bramwell (1976-77; Evans and Spencer 1976-77; Noddle (1976-77)
Mine Howe	Iron Age	10885	32	862	0	7	Mainland and Ewens 2004; Mainland *et al.* 2003)
Warebeth Broch	Iron Age	2106	0	48	7	0	Sellar (1989)
Tofts Ness	Iron Age	5069	43	66	1325	88	Nicholson and Davis (2007)
Skaill, Deerness	Iron Age	12872	120	18	93	0	Noddle (1997)
Scatness	Iron Age	643	0	0	0	53	Cussans and Bond (2010)

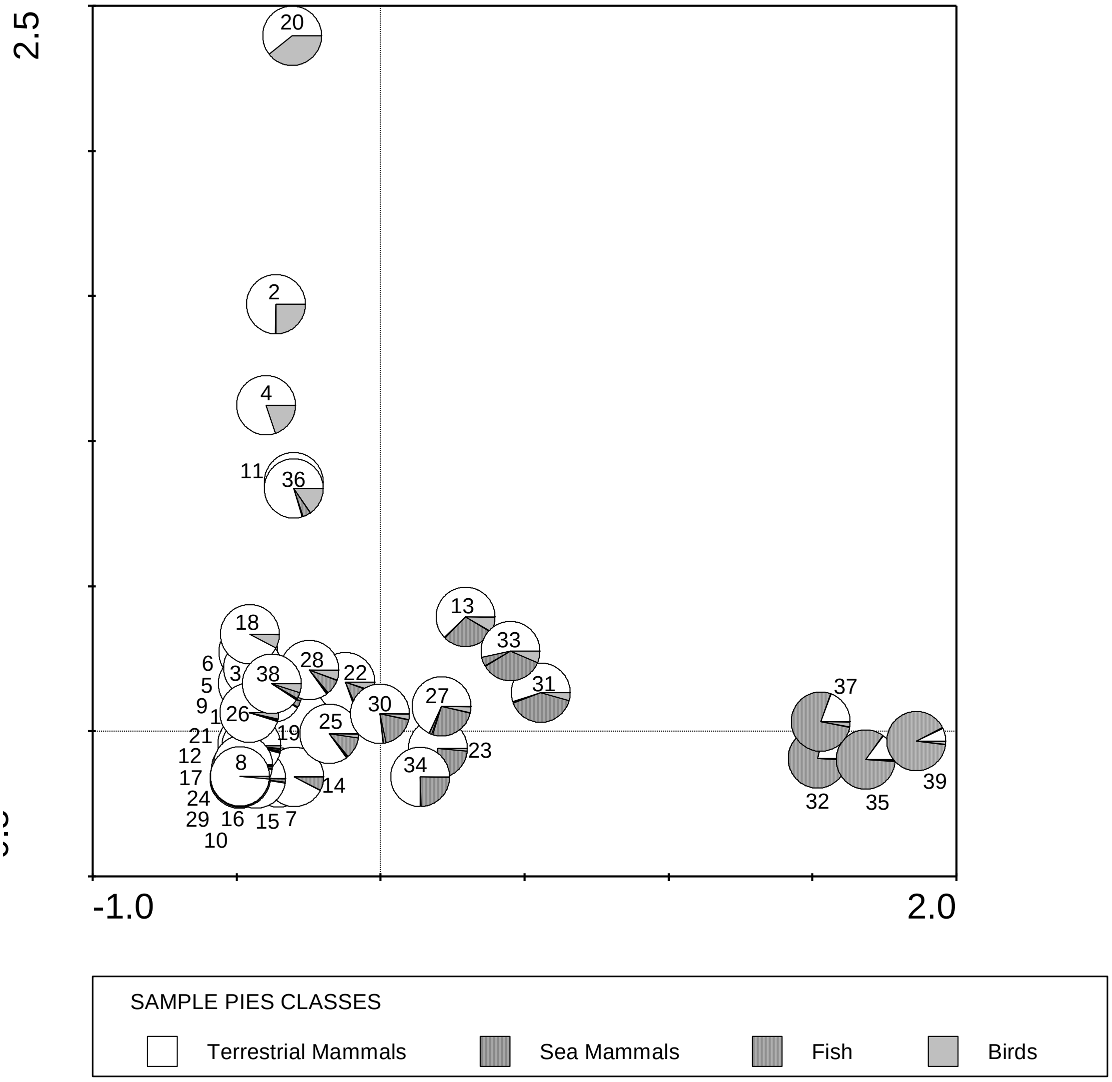
		NISP					
Site Name	**Period**	**Terrestrial Mammal**	**Sea Mammal**	**Fish**	**Shellfish**	**Birds**	**Zooarchaeological References**
Scalloway	Iron Age	4307	20	168	96	211	Sullivan (1998)
Pool	Iron Age	19109	194	3810	0	109	Bond (2007)
Howe	Iron Age	23619	253	1486	14820	731	Smith (1994); Locker (1994)
Pierowall Quarry	Iron Age	144	0	0	0	93	McCormick (1984)
Room 5 clifftop settlement	Iron Age	148	2	0	0	0	Sellar (1982)
Buckquoy	Iron Age	2206	15	15	10710	79	Noddle (1997)
Old Scatness	Iron Age	916	25	355	333	49	Cussans and Bond (2010)
Room 5 clifftop settlement	Norse	272	4	0	0	0	Sellar (1982)
Skaill, Deerness	Norse	5877	111	1391	0	251	Noddle (1997)
Brough Road (areas 1 and 2)	Norse	2497	30	1792	23891	199	Rackham (1989)
Quoygrew	Norse	8374	141	3183	23891	251	Colley 1983a; Harland (2006)
Old Scatness	Norse	686	51	2173	6935	99	Cussans and Bond (2010)
Earl's Bu	Norse	5189	19	8292	0	71	Mainland (1995)
Brough of Deerness	Norse	319	1	18	93	61	Rackham (1989)
Buckquoy	Norse	2777	22	104	10710	151	Noddle (1997)

Appendix 7: Western Isles Faunal NISPs

		NISPs					
Site Name	Period	Terrestrial Mammal	Sea Mammal	Fish	Shellfish	Birds	Zooarchaeological Refs.
Udal North	Neolithic	403	0	6	0	2	Serjeantson n.d.
Northton	Neolithic	608	8	1	0	19	Finlay (1984)
Udal North	Beaker	98	0	2	0	2	Serjeantson n.d.
Rosinish	Beaker	13	0	0	0	3	Serjeantson (1984)
Northon	Beaker	729	24	13	0	35	Finlay (1984)
Udal North	Bronze Age	481	6	112	0	4	Serjeantson n.d.
Baleshare	Bronze Age	2040	6	0	0	0	Halstead (2003)
Cladh Hallan	Bronze Age	15663	179	5035	0	323	Mulville and Powell Forthcominga; Ingrem forthcoming a; Best and Powell forthcoming)
A'Cheardach Mhor	Iron Age	300	4	2	0	0	Clarke (1960)
Sollas wheelhouse A	Iron Age	730	0	0	0	5	Finlay (1984)
Bruach Ban	Iron Age	50	3	0	0	1	Finlay (1984)
Sollas wheel house B	Iron Age	354	0	15	0	31	Finlay (1984)
Sligenach	Iron Age	80	1	0	0	0	Mulville and Powell (forthcoming)
Sollas	Iron Age	259	0	17	0	0	Finlay (1984)
Sheader (Search SY14)	Iron Age	145	4	143	0	0	Mulville (2000)
Mingulay MY384	Iron Age	415	6	63	0	26	Mulville (2000)
Hornish Point	Iron Age	440	0	0	0	12	Halstead (2003)
Cnip	Iron Age	1505	88	2545	158	0	McCormick (2006)
A'Cheardach Bheag	Iron Age	159	19	0	0	0	Fairhurst (1971)
Bruthach a Tuath	Iron Age	93	1	0	0	1	Finlay (1984)

		NISPs					
Site Name	Period	Terrestrial Mammal	Sea Mammal	Fish	Shellfish	Birds	Zooarchaeological Refs.
Berigh		1880	8	0	0	14	Thoms (2004)
Northton	Iron Age	399	10	5	0	2	Finlay (1984)
Udal North	Iron Age	3306	35	161	0	0	Serjeantson n.d.
Cladh Hallan	Iron Age	3138	29	332	32	0	Mulville and Powell Forthcoming
Bornish	Iron Age	3299	10	460	0	314	Mulville and Powell (2012) Ingrem (2012)
Bostadh	Iron Age	254	1	14032	34608	61	Thoms (2004)
A'Cheardach Mhor	Norse	191	1	0	0	1	Clarke (1960)
Cille Pheadair	Norse	6627	13	0	0	645	Mulville and Powell forthcoming; Best and Powell forthcoming; Ingrem forthcoming)_
Bostadh	Norse	1588	10	1871	799	8	Thoms (2004); Cerón-Carrasco 2005
Bornais	Norse	15490	183	15175	0	1122	Mulville and Powell (2012; forthcoming;) Ingrem 2005; Mulville 2005a; Best and Powell forthcomign)
Udal North	Norse	199	0	0	0	0	Serjeantson n.d.

Appendix 8: Correspondence analysis with shellfish removed



Key
60) Neolithic Tofts Ness
61) Neolithic Quanterness cairn
62) Neolithic Howe
63) Neolithic Point of Cott Westray
64) Neolithic Knap of Howar
65) Neolithic Pierowall Quarry
66) Neolithic Isbister
67) Neolithic Links of Noltland
68) Neolithic Pool
69) Bronze Age Bay of Moaness
70) Bronze Age Tofts Ness
71) Bronze Age Skaill, Deerness
72) Bronze Age Point of Buckquoy
73) Iron Age Mine Howe
74) Iron Age Warebeth Broch
75) Iron Age Tofts Ness
76) Iron Age Skaill, Deerness
77) Iron Age Scatness
78) Iron Age Scalloway

40) Early Iron Age Pierowall Quarry
41) Early Iron Age Howe
42) Middle Iron Age Howe
43) Late Iron Age Pool
44) Late Iron Age Room 5 clifftop settlement
45) Late Iron Age Pool
46) Late Iron Age Buckquoy
47) Late Iron Age Old Scatness
48) Late Iron Age Howe
49) Norse Room 5 clifftop settlement
50) Norse Skaill, Deerness
51) Norse Brough Road (areas 1 and 2)
52) Early Norse Quoygrew
53) Early Norse Old Scatness
54) Middle Norse Earl's Bu
55) Late Norse Earl's Bu
56) Late Norse Brough of Deerness
57) Late Norse Quoygrew
58) Late Norse Buckquoy
59) Late Norse Old Scatness