Diet and Health in a Time of Transition:

Pictish and Viking Age Orkney

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Abstract

There have long been conflicting interpretations of the archaeological and written evidence for the nature of interactions between the Orcadian Pictish populations and Scandinavian migrants during the Viking Age, with theories ranging from peaceful intermarriage to violent domination of the Picts (Bäcklund 2001; Leonard 2011; Smith 2001; etc.). However, changes in diet and health from the Pre-Viking phase (PVP, 500-790) through the Viking Age (VA, 790-1050) and Late Norse phase (LNP, 1050-1200) suggest more nuanced changes, reflecting evolving subsistence practices and differences in social constructs of ethnicity, religion and status.

The results of previous archaeobotanical and zooarchaeological analysis from excavated VA and LNP sites throughout Orkney have indicated large-scale socioeconomic developments characteristic of an emerging market-based economy. From an increased specialisation and evolving hierarchical structure of site functions to an expansion of marine resource exploitation and an increased focus on agricultural production and dairying for the purpose of skat payment, these changes in subsistence practices had substantial consequences on the health and diet of the population at large.

This thesis examines diachronic changes in overall health and diet of communities in Orkney over this transitional period through osteological and isotopic (strontium, oxygen, carbon and nitrogen) analysis of human remains. The decreased prevalence of osteoarthritis among both males and

females from the PVP through the LNP throughout Orkney suggests an increased reliance on traction animals for manual labour. Additionally, the decreased prevalence of mandibular tori among males could suggest an influx of Scandinavian genes into the population. Overall, increases in $\delta^{13}C$ and $\delta^{15}N$ values among both males and females from the PVP through the LNP support previous findings and interpretations of increased marine resource consumption (Barrett et al. 2000a; 2000b; Barrett and Richards 2004; Richards et al. 2006), though no significant differences were found between sexes in any phase. Moreover, differences in mean $\delta^{13}C$ and $\delta^{15}N$ values by site and variation in the prevalence rates of nutritional deficiencies and indicators of load-bearing and occupational stress between sites suggest a growing contrast in subsistence practices between the eastern and western portions of the archipelago. Finally, while burial with Scandinavian grave goods does not appear to have been limited to those growing up in Scandinavia or to those with Scandinavian genealogy (Margaryan et al. 2020), differences in mean $\delta^{13}C$ and $\delta^{15}N$ values, prevalence rates of nutritional deficiencies and indicators of load-bearing suggest enduring perceptions of ethnic differences and identity.

Dedication

To Michael and Ryden, my inspiration and drive.

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Chapter 1. Introduction

The extent of Scandinavian influence on Pictish populations during the Viking Age (the ninth to eleventh centuries) has been debated extensively over the past fifty years (Bäcklund 2001, 33; Crawford 1987; Smith 2001; Wainwright 1962; 1980). A range of evidence supports the notion of a powerful, widespread and enduring Scandinavian culture that pervaded and eventually replaced Pictish culture, influencing ideas of identity, subsistence practices, diet and burial practices. Viking Age Scandinavian culture was not something that influenced all other cultures and peoples uniformly, as every source of available evidence seems to support a range of interpretations. What is apparent from the archaeological and written sources, however, is a deeply felt Scandinavian presence that provided a catalyst for sociocultural and economic change. As Gabor Thomas states,

> *"The final three centuries of the first millennium AD constitute a period of radical socioeconomic transformation …. While Wales, Scotland, and Ireland followed independent trajectories, they too experienced… political centralisation, increasing social stratification and the rise of new elites, intensified rural production and new forms of exchange and economic consumption" (Thomas 2011, 44).*

While it has been suggested that political unrest and violent conquest led to social and physical stress, an influx of Scandinavian settlers may have also influenced Pictish diet by affecting agriculture and animal husbandry practices, as well as culturally preferred foods (Banham 2014, 261; Barrett 2003b). While Late Iron Age (LIA) Orkney 'saw the emergence of local elites, who exerted increasing control over agricultural resources, prestige goods and traded items' (Mainland et al. 2016, 838), the Viking Age was a catalyst for large-scale socioeconomic change. Raiding and subsequent migration and settlement of Scandinavians in Orkney resulted in changes in food production, resource consumption, and the development of market trade during the latter stages of the Norse phase (Barrett 1997; 2012; Barrett et al. 2000c; 2001; Dyer 2003; Hoffmann 1996). Food, feasting and subsistence were large parts of social and cultural identity in the VA (Jarman 2012; Price 2020, 95; Roesdahl 1987, 45). It is therefore likely that changing relations between social groups (high-status versus lower-status) and between cultures (e.g., Orcadian versus Scandinavian) were recognised in part through food, the act of eating, and the processes involved in food preparation. As Catrine Jarman states, “social strata may… be actively maintained through adaptation of new cuisines or dietary patterns…. In colonial and multi-ethnic contexts foods may both actively and accidentally create and maintain boundaries and may also be used as a means for gaining control…” (*ibid.,* 21). Increased long-distance trade, urbanization, and social stratification may have resulted in significant differences in living conditions and greater variability in both diet and health between members of society, as has been exhibited in other archaeological populations (Cardoso 2007, 227). Another primary instigator of change in Viking Age Orkney was its Christianisation in the eleventh century (Barrett 2005, 207). Although there is evidence for Pictish churches on some of the islands like Papa Stour and Papa Westray prior to Norse arrival (Lamb 1995; Smith 2003), the Scandinavians brought with them distinctively pre-Christian burial customs. The extent to which pre-Viking Orkney was Christian in the eighth century is still unknown; however, the Norse officially Christianized and installed a bishop in Orkney in AD 1048 (Barrett 2005, 207; Crawford 1987, 80; Gibbon 2007; Lamb 1995). The effect Christianity had on everyday activities, diet, and burial customs both in Scandinavia and throughout the North Atlantic has been debated extensively (Barrett et al. 2000a; Barrett et al. 2004a; 2004b; Crawford 1987, 162; Gibbon 2007; Jarman 2012; Lerwick 2014; Nordeide 2011; etc.). Finally, one must consider changes in climate when interpreting changes in subsistence over time. Between approximately AD 950 and 1250 (the VA and LNP) was the medieval warm period (MWP), a time of climatic warming that likely benefitted agriculture and coincided with increased marine resource exploitation (Barrett et al. 2004, 628; Hunt 2006). This study investigates how such extensive socioeconomic, cultural, religious and environmental changes impacted diet and health of VA and LNP individuals throughout Orkney. Osteological analysis of the human remains assemblage allows for the comparison of prevalence rates of dental and skeletal pathologies (indicators of health and diet) from the PVP through the LNP. In addition to osteological analysis, strategic sampling of bone and teeth for carbon and nitrogen stable isotopes allows for a limited dietary reconstruction (particularly in providing an estimation of the proportions of terrestrial and marine protein consumed) and constitutes the primary methods of investigation for this study. While bone collagen carbon and nitrogen provide an average of dietary intake over the last several years before death, tooth dentine micro-samples provide a higher-resolution chronology of diet throughout tooth development. In conjunction, both osteological indicators of health and stable isotope indicators of diet can then be compared between individuals from different phases, geographic origins (as interpreted from strontium and oxygen isotope analysis), religious, and ethnic backgrounds (as interpreted from grave goods).

1.1. Changes in Culture: Evidence for Pictish and Scandinavian interactions in Orkney

This section reviews written and archaeological evidence for widespread cultural change in Orkney from the pre-Viking Phase (PVP, AD 500-750) through the Viking Age (VA, AD 750-1100) and the following Late Norse Phase (LNP, AD 1100-1299). The extant evidence for Pictish and Scandinavian interaction is limited and sometimes seemingly contradictory. This section sets forth the written and archaeological evidence for Pictish and Scandinavian interaction in Orkney and explains how such interactions may have had long-term effects on the diet and health of the population. In the case of the Picts, all written records date to a later period and all our information about their culture and way of life has been based on surprisingly scant archaeological evidence (Wainwright 1962; Graham-Campbell and Batey 1998). What we do have primarily consists of 'Pictish' cell or clover-shaped buildings like those at Buckquoy (described further below; Ritchie 1977), distinctively pre-Viking jewellery and combs and engraved symbol stones. Such symbol stones, carved with Pictish symbols or sometimes with crosses and other Christian iconography have been found in the Orkney Isles (such as at Birsay Bay and Newark Bay), as well as in Shetland and mainland Scotland (Graham-Campbell and Batey 1998, 7; Heald and Barber 2015, 30).

A note on chronological terminology is needed: the phase immediately pre-dating the Viking incursions is referred to as the PVP throughout this study, which is synonymous with the Late Iron Age (LIA) in Scotland. While the LIA in Orkney extends from AD 300 to 800 (Downes and Ritchie 2003), the PVP refers more specifically to AD 400-750.

1.1.1. Written evidence

Written evidence of VA and LNP Orkney consists chiefly of place-name evidence, ecclesiastical annals and Icelandic sagas. Several written texts refer to political events in Viking Age Orkney, including the *Orkneyinga Saga*, the *Life of St. Findan*, *the Saga of St. Olaf, Harald Hardrádi's Saga* and *the Fornmanna Sögur* (Anderson 1985). The most contemporary, detailed written account of Viking Age Orkney is provided in the *Orkneyinga saga*. The saga, compiled by several Icelandic sources between AD 1192 and 1206, gives an entertaining account of political and personal intrigue and conflict during Orkney's history as a Norse earldom (Towrie 2020; Pálsson and Edwards 1981). Not only do we get a picture of the political atmosphere and a sense of the cultural climate, but it may be possible to gain insight into agricultural and socioeconomic practices of the time. According to Julie Bond, "the importance of arable production in Orkney is perhaps unconsciously reflected in the *Orkneyinga Saga*," which describes Svein Asleifarson's farming activities before plundering the Hebrides and Ireland (Bond 1998, 88). The sagas also provide a picture of how Orkney functioned as an earldom and as part of the western Norse kingdom. Taking into account mythical elements that were incorporated into the sagas and the fact that they were written a couple of centuries after the events described the written sources can nevertheless provide insight into the physical activities, social workings and economic structure behind potential changes in health and diet from the PVP (Rowe 2009; Towrie 2020). They serve as written corroboration for interpretations of socioeconomic dynamics based on the archaeological evidence for changes in subsistence practices.

1.1.2. Place-name evidence

Some debate has arisen as to what can be inferred from place-name evidence in Britain. Some, like F.T. Wainwright, Frank Stenton and Kenneth Cameron were some of the first and strongest advocates for exploring place-name evidence (Wainwright 1962; Cameron 1971), while some have been more cautious in their interpretations (Abrams and Parsons 2004). Hugh Marwick's 'Orkney Farm Names' (1952) laid the framework for interpretations of Norse place-names throughout the Orkney Isles, as further discussed in section 2.1.4.1. While England contains a mixture of Anglo-Saxon and Scandinavian place-names (i.e., places ending with -ham, -stead, etc.), there is a noticeable dearth of Pictish or pre-Scandinavian place-names throughout Orkney (Graham-Campbell and Batey 1998, 38). The apparent Scandinavian replacement of Orcadian place-names in the VA suggests, if taken at face value, a replacement of traditional Pictish nomenclature and culture (*ibid.*, 39); place-name evidence has also been used to infer patterns of settlement, as well as the diversification and changing organization of sites. Although the replacement of Pictish place-names has been used as evidence of the removal and replacement of Pictish culture, Graham-Campbell points out that the use of some pre-Viking sites as Christian churches seems to be preserved by the Norse word for priest, *papa* (*ibid.*, 39; Gammeltoft 2004; Smith 2003). Papa Stour, Papa Westray, Papa Stronsay serve as just a few examples. Interestingly no Norse graves have yet been found at any such *papa* site (*ibid.,* 39). The Norse place-name commemorating Christian religious sites may argue for a continuation of Pictish culture (cf. Smith 2003). The same level of place-name replacement was not seen in other parts of Scotland, where a mixture of Norse, Gaelic and Anglo-Saxon place-names imply a more bilingual cultural hybridization (*ibid.,* 41). Based on the impression of population replacement suggested by place-name evidence in Orkney, one might expect osteological evidence for inter-personal conflict and violent trauma. This study will provide an osteological account of cultural interactions between Picts and Scandinavians.

1.1.3. aDNA evidence

Recent ancient DNA research in Orkney has contributed greatly to our understanding of Scandinavian migration and ethnicity in VA Orkney. A study by Sara Goodacre and colleagues (2005) investigated the proportion of individuals with Scandinavian mitochondrial DNA (inherited matrilineally) compared with Scandinavian Y-chromosomal DNA (inherited patrilineally) to investigate the genetic contributions of Scandinavian males versus females. They found that while areas close to Norway like Orkney and Shetland were likely settled by both males and females in familial groups, areas farther from Norway were settled primarily by Scandinavian males who then likely took native wives (Goodacre 2005, 129). A study published in 2020 by Ashot Margaryan and colleagues found that two of the sampled individuals from Orkney likely contained an admixture of native and Scandinavian genes (2020, 393). The study called into question the assumed relationship between inferred Scandinavian ethnicity based on grave goods and genetic ancestry. Margaryan and colleagues found very limited evidence of actual Scandinavian ancestry among VA Orcadians buried with Scandinavian grave goods (Margaryan et al. 2020, 392). Only two of the six individuals with artefactual evidence of "Scandinavian links" actually exhibited Scandinavian ancestry (*ibid*).

1.1.4. Settlement and material culture

Settlement in Iron Age Orkney is perhaps best known for the construction and long-term occupation of brochs. The form and structure of brochs provide insight into Iron Age social structure and, later, serve as a monument in the landscape and symbol of Scandinavian "legitimation through association" (McLeod 2015, 1). Though construction of brochs began around 500 BC, some bear evidence of occupation over the span of a millennium, with periodic occupation in Late Iron Age and Norse times (Armit 1997; Dockrill and Batt 2004; Lamb 1995). It appears that as the initial function of the broch as a defensive structure became unnecessary and its use as a marker of social status faded in the Iron Age, the brochs themselves fell out of use with inhabitants later occupying the surrounding areas (Fojut 1993, 17). With the end of broch building came roundhouses, "elite residences, in which architecture and spatial organization both reflected and reinforced the emergent social order" (Armit 1997, 251). The transition from brochs to roundhouses may have marked a movement from a patron/client relationship, demonstrated by the broch and its surrounding settlements, to a more complex social structure (Foster 1989; Lamb 1995, 262). According to Ian Armit, there was little evidence of domestic or internal trade between self-sufficient communities in this period (Armit 2012, 92). The primary reason for movement of people between communities would have been marriage, as alliances and gift-giving were an essential part of society (ibid, 92). Pictish or Late Iron Age settlements tended to be situated around brochs, with the houses themselves lobular or cellular in shape (Armit 1997, 252). Such structures can be seen not only in Orkney, but throughout the Western Isles and Shetland (*ibid*). This largely transitions to structures more square or rectangular in the VA. Examples of this can be seen at Buckquoy, where the cellular Pictish structures were altered and subsequent rectilinear structures were built on top (Brundle et al. 2003, 95-96; Ritchie 1977, 189).

According to Armit (1997, 252), personal ornaments became more popular in the LIA, suggesting trends toward more prominent visual displays of familial social status. While these items were rarely included in grave contexts, it is possible that differences in health and diet may be observable between individuals of different social status in the LIA or PVP. Pre-Viking style pins and brooches have been recovered from domestic contexts as well as hoards like the one from St. Ninian's Isle. Although located in Shetland, at least some of the contents were likely of Orcadian manufacture (Graham-Campbell and Batey 1998, 9). The continuity of a thriving PVP bronze manufacture at the Brough of Birsay and Buckquoy supports the idea of a survival of Pictish culture at least through the eighth century (Curle 1982, 95). Artefacts recovered from Buckquoy are considered predominantly Pictish in nature, though a pin of a kind found only in Norse or later contexts was recovered as well (Brundle et al. 2003, 96). While there is evidence of PVP houses and structures being re-inhabited by Norse settlers, as at Buckquoy, there is little evidence to determine whether these Pictish structures were abandoned prior to the arrival of the Norse or whether they were commandeered by Scandinavian settlers (Brundle et al. 2003). The inability to make this distinction, unfortunately, leaves open the question of replacement vs. cultural hybridization of the two peoples. While the long-term occupation of many Iron Age settlements in Orkney could be used to suggest socioeconomic stability and sedentism, occupation of the same or similar sites (Buckquoy, for example) tended to be more short-term and intermittent in the VA (Armit 1997, 252; Cowley 2003, 80). The periodic reuse of Pictish buildings and IA sites in the VA (such as at Gurness and Howe) suggests a Scandinavian desire to legitimize their rule over Orkney through association with Pictish history (McLeod 2015). A similar phenomenon can be seen in graffiti in the form of runic inscriptions at Neolithic sites like Maes Howe, Brough of Birsay and Skara Brae (Barnes 1994, 42; Graham-Campbell and Batey 1998).

While perhaps underappreciated, the structure of settlements and their reflection of Norse culture should not be overlooked as tangibly demonstrating a distinct Norse culture, helping us understand the everyday effect Scandinavian influence would have had on the lives of the people of Orkney. Jane Harrison's study of Norse settlement mounds in Orkney and Scandinavia provided a much-needed analysis of the influence the Norse had on settlements in Orkney. The use of mounds and the building of longhouses "were a particularly powerful combination… mounds and mound-related buildings were frequently focal places, where power and authority were negotiated and as such were structuring elements in the creation of effective patterns of social organization" (Harrison 2015, 49). The powerful effects that Norse-influenced socioeconomic and settlement would have had on the population of Orkney lead one to expect that significant differences in health, diet, or nutrition would be perceptible in these populations. It is possible that the distinction of a Norse ruling class set apart from the rest of society may have created a greater disparity in nutrition between the wealthy and others. This presence of a Norse ruling elite is also suggested by richly furnished Scandinavian burials in the VA (discussed further in Chapter 2).

1.2. Research aims and objectives

This study evaluates the extent to which culturally stimulated or economically-driven subsistence changes can be discerned from osteological and isotopic analysis of the human remains from PVP through LNP Orkney. For the purposes of this study, PVP Orkney is defined as AD 500-750, while the VA in Orkney refers to AD 750-1100 and the LNP refers to AD 1100-1300. The archaeobotanical, zooarchaeological and ichthyological evidence recovered from VA and LNP sites throughout Orkney has demonstrated an expansion in marine resource exploitation, diversification of crop cultivation, an expansion of and improvements in agriculture and altered animal husbandry practices. This evidence has been used to argue for increased site specialisation in the VA and LNP, the result of a more defined and increasingly centralized power structure (Barrett et al. 2000b). This newly centralized Norse political power was in part established through the control of production and distribution of goods, as well as the exacting of *skat* (taxation) in the form of staple goods (*ibid.*, Crawford 1987; Earle 1997; 70), leading to a growing demand for moveable wealth in the form of staple goods such as butter, cereal and dried fish, rather than prestige items. The resulting increase in focus on dairying and fish drying, as well as a growing export of cereals from Orkney (for which there is later written evidence, further discussed in Chapter 2), catalysed agricultural improvement and surplus production. Such substantial changes in subsistence practices, resource management and economic evolution would have had significant consequences for the health, nutrition, and diet of the Orcadian populations. Thus, the principal research questions of this study are as follows:

- How do different osteological indicators of overall health and nutrition of the Orcadian population vary from the PVP through the VA and LNP, given the large-scale economic and sociocultural changes evidenced by the archaeological record? In particular, did the movement towards a market-based economy necessitating increased agricultural production worsen skeletal and dental health?

- Are there changes in the osteological evidence for health and nutrition and how may they correlate with any stable isotope evidence for an increasingly marine-based diet?
- To what extent can osteological evidence of developmental stress be used in conjunction with high-resolution sequential dentine micro-sampling of molars be used to identify differences in health and diet through adolescence as potential indicators of cultural expectations of adulthood and gender?
- What is the relationship between ethnicity and geographic origin in VA Orkney? Is there osteological and/ or dietary stable isotope evidence for differential health and diet between native Orcadians and a supposed ruling Scandinavian class? Were individuals buried with Scandinavian grave goods themselves immigrants or was Scandinavian ethnicity afforded to second or third-generation immigrants, spouses, or possibly Pictish individuals?
- What socioeconomic, religious, and geographic factors may have contributed to differential disease prevalence rates and diets between contemporaneous sites throughout Orkney?

1.2.1. Assessing health through the Pictish/Norse transition using osteology

The study of osteology is itself a paradox, as we study the remains of the dead to discern patterns of living. We view those with more pathological lesions as less healthy than those who died before acquiring such lesions (Siek 2013; Wood et al. 1992). Yet many pathologies result in death before leaving any trace on the human skeleton and those individuals with osteological evidence of pathology are only those who were strong enough to have lived with that condition long enough to develop skeletal reactions. Regardless, the fact remains that human skeletal remains provide the best archaeological evidence for health in prehistoric populations. This study brings together the human osteological evidence for the changes in VA sociocultural, economic and subsistence practices that have been attested by other forms of archaeological and written evidence (as further discussed in Chapter 2). This study incorporated the osteological analysis of a total of 498 individuals from the following sites: Newark Bay, Skaill Cist, Skaill House, Bu of Cairston, Buckquoy, Deerness, Skara Brae, Scar, Pierowall, Brough Road, Broch of Gurness and Westness. A brief background on each of the sites is provided in Chapter 4.

1.2.1.1. Osteological evidence of immigration, population change and inter-personal violence

1.2.1.1.1. Demographic patterns

Through estimation of age and sex (using established osteological methods involving cranial and pelvic morphology), changes in demography were traced from the PVP through the VA and LNP. These demographic data were used to create a profile of mortality, life expectancy and fertility, which contribute to a large-scale view of the structure of the population through time. Changes in population structure could be indicative of large-scale immigration, disease or substantial socioeconomic growth (Chamberlain 2006). As Andrew Chamberlain explains in *Demography in Archaeology*, the upper limit of population size as determined by environment and resource availability is increased with "sociocultural innovations, including change in land use, novel patterns of exploitation of resources, technological advance, specialisation, increased economic exchange and so on…" (Chamberlain 2006, 5). The archaeological evidence for all these developments beginning in the PVP and VA will be discussed further in Chapter 2. If a change in population structure were due to a growing immigrant population, one might expect the bulk of this population to consist of young and middle adult individuals (ages 18 to 45 years old) beginning in the VA or LNP (*ibid.*, 39). Furthermore, variation in Y-chromosome haplotypes has also suggested a larger proportion of male Scandinavian immigrants than females in Orkney (Barrett 2003b, 91; Wilson et al. 2001, 5079-5080). For that reason, one might expect an increased proportion of males, particularly young and middle adults, in the VA and/or LNP.

1.2.1.1.2. Stature

Stature estimation by measuring long bone length provides another means by which health, nutrition and the genetic pool can be compared through time (Ruff et al. 2017). With agricultural improvements and specialisation typically come increases in population and heightened demand for resources (Chamberlain 2006, 5; Larsen 1995, 197; Roberts and Cox 2003, 212). While a decline in resource availability due to population growth may have caused an overall decline in health (and thus stature), a large-scale migration of Scandinavians with a genetic predisposition for greater stature may have raised the overall stature means of the Orcadian (particularly male) population (Ruff et al. 2012; 2017). However, the complicated relationship between stature, health and genetics may make interpretations difficult.

1.2.1.1.3. Palaeopathology and violent trauma

Palaeopathology, the analysis of pathological lesions on the skeleton and teeth including cribra orbitalia (CO), porotic hyperostosis (PH), periostitis, linear enamel hypoplasias (LEHs), calculus, caries and periodontal disease can together provide clues as to the exact nature of the pathological condition and perhaps offer a glimpse of diet and dental hygiene. CO and PH are indicative of nutritional deficiency, while periostitis and osteitis are general indicators of infection (Brickley 2018; Hill 2001; Oxenham and Cavill 2010; Stuart-Macadam 1989; 1992; Walker et al. 2009). LEHs and Harris lines are indicative of periods of arrested metabolic processes due to stress (Alfonso et al. 2005; Alfonso-Durruty 2011; Amoroso et al. 2014; Goodman et al.1980; King et al. 2005, etc.). All these indicators have somewhat complex aetiologies and many times exact diagnoses are not possible. Some specific infections are discernible from pathognomic features such as maxillofacial degeneration and atrophy of extremities with lepromatous leprosy or the visceral vertebral lytic lesions observed with tuberculosis (Aufderheide et al. 2005; Mays et al. 2001; Molleson 2005; Ortner and Putschar 1985; Roberts 2018). However, in many cases, the diagnosis of a disease is based solely on the distribution of lytic or phytic lesions. Through the systematic recording of pathological lesions, it is possible to discern patterns in the frequency and prevalence of disease and general trends in the health of individuals and to an increase in the spread of specific and non-specific pathological lesions. Increases in population density (as discussed in Chapter 2), would likely have led to an increased prevalence of specific and non-specific infections (Roberts and Cox 2003, 177). Additionally, the identification of ante- and peri-mortem traumatic lesions provides a narrative of the types of activities these individuals were taking part in habitually. Through analysis of trauma resulting from interpersonal violence, it may be possible to determine whether we are correct in assuming a certain prevalence of interpersonal violence from the period of inter-cultural conflict that was the VA. On the other hand, the prevalence of accidental trauma and indicators of load-bearing and occupational stress including stress and crush fractures, osteochondritis dissecans, osteoarthritis (OA), platymeria and platycnemia serve as indicators of changing trends in manual labour and occupational activities potentially related to subsistence strategies (see Chapter 3 for more detail). This set of traumatic and pathological indicators were separated into a category called "evidence of load-bearing and occupational stress" specifically designed to trace changes in physical labour potentially related to subsistence changes, as further discussed in the following section.

1.2.1.2. Osteological evidence of changes in subsistence

Although agriculture was not a new development in VA Orkney, this period has been credited with improvements in agricultural practices, expansion of cultivated lands and increases in productivity geared toward an increasingly market-based economy (Barrett 2012c; Barrett et al. 2004; Mainland et al. 2016). As changes in subsistence are some of the primary features of socioeconomic change in this period, it is necessary to address how osteology has and will be used to corroborate or refute other archaeological evidence for changes in subsistence, mainly agriculture and increased marine resource consumption.

While extensive research has been done on how the transition from hunter-gatherer to agricultural subsistence impacted osteological indicators of health, studies on the osteological effects of agricultural expansion in an already agricultural society are much more limited. Clark Spencer Larsen has been at the forefront of research concerning the osteological effects of agriculture and agricultural intensification, primarily relating to North America. His research and hypotheses form the basis of some of the osteological research questions in this study. Studies by Larsen and many others (Cohen and Armelagos 1984; Jackes et al. 1997; Meinzer et al. 2019; Roberts and Cox 2007, 160; Steckel et al. 2019) have reported significant changes in overall health with an intensification of agriculture. While the transition from a hunter-gatherer to agriculturalist regime resulted in overall decline in stature, life expectancy and an increase in infant mortality (Goodman and Armelagos 1989; Macintosh et al. 2016; Meinzer et al. 2019; Mummert et al. 2011; Ruff et al. 2017; 2018), dental health has been shown to suffer greatly with agricultural intensification and the consumption of more carbohydrate-rich diets reliant on cereals and grains (Larsen 1995, 187; Witwer-Backofen and Engel 2019). Dental caries (or cavities; further described in Chapter 3) have been shown to affect significantly more teeth in societies undergoing agricultural intensification, particularly among females (*ibid.*, 188; Lukacs 2007, 906). Larsen (1983) and Lukacs (2007) have found that in many regions females were more affected by dental caries than men, which could be used to suggest a sex-based division of labour or could simply be due to changes in nutrition during pregnancy (Larsen 1983; 1995, 189; Larsen et al. 1991; Lukacs 2007; Walker 1990; Willis and Oxenham 2013; Witwer-Backofen and Engel 2019, 85). In addition to caries, periodontal disease, and ante-mortem tooth loss (AMTL) have also been found to have worsened in populations undergoing agricultural intensification (Larsen 1995; Willis and Oxenham 2013; Witwer-Backofen and Engel 2019). Although agriculture was not new to Orkney (having begun in the Neolithic), it is possible that heavier reliance on agricultural products may have worsened these conditions. Aside from dental pathologies, several studies have shown a significant difference in the prevalence of osteoarthritis, particularly of load-bearing joints (i.e., knees, hips, vertebrae) with the introduction or expansion of agriculture (Larsen 1995; Roberts and Cox 2003, 195; 2007, 162; cf. Bridges 1992; Hodges 1987). While increased agricultural production and expansion of arable land would likely have required more manual labour, the brunt of this was likely felt mostly by the draft animals used for traction, rather than the humans. This is evidenced by recent studies on Early Medieval British populations that exhibited a decline in degenerative joint disease and load-bearing indicators with the evolution of agriculturalist strategies (Roberts and Cox 2007, 162). A potential decline in osteological indicators of load-bearing and physical stress (further discussed in Chapter 3) among populations undergoing agricultural intensification or expansion will be tested among the PVP, VA and LNP Orcadian populations.

In addition to agricultural expansion and increased production, the VA (especially from ca. AD 1000, onward) saw an increase in marine resource exploitation and consumption (explained in Chapter 2). Consumption of marine resources (in particular, fatty fishes) has been clinically shown to have numerous health benefits (American Heart Association 2016). Omega-3 fatty acids act as an anti-inflammatory, slowing progression and improving functionality in joints with osteoarthritis and degenerative joint disease (Akbar et al. 2017; Felson and Bischoff-Ferrari 2015; Rajaei et al. 2015). In addition to benefitting individuals with arthritis, Omega-3 fatty acids have been shown to lower the risk of cardiovascular diseases and even reduce periodontal disease (Deore et al. 2014; Maskrey et al. 2013; Naqvi et al. 2010). Additionally, fatty fish like herring provide vitamin D, lowering the risk of rickets or osteomalacia during winter months with limited sunlight (Lu et al. 2007). A substantial increase in the consumption of fatty fishes could therefore have led to a decrease in the prevalence of arthritis, periodontal disease, rickets and other inflammatory conditions in the VA and LNP.

1.2.1.3. Osteology objectives

While a more varied diet could have improved overall nutrition, an increase in agricultural productivity and increased long-distance trade and commerce may have had some negative consequences for general health. Increased interaction between Orcadians and Scandinavian merchants and sailors trading in the North Atlantic (as recorded by the *Orkneyinga Saga*) would have facilitated the spread of contagious diseases (Roberts and Cox 2007). In addition, if the human population (rather than draft animals) were charged with the hard labour associated with increased agricultural activity, there would have likely been an increased frequency of degenerative diseases like osteoarthritis (Kirkhorn et al. 2003). As discussed above, a diet focused on agricultural produce has also been associated with a decline in dental health in other archaeological populations; with an increase in dental caries and increased occlusal wear (Lukacs 2007; Watson 2008). The primary objectives of the osteological analysis are as follows:

- Population structure is compared by phase to determine whether there was a greater proportion of males (potential Norse immigrants) in the VA, and whether there may have been an influx of young adults that could potentially signal settlement in the LNP.
- Stature means (based on long bone metrics) are compared between phases as a measure of overall nutrition and health. If stature varied by phase, does this correspond to the prevalence of nutritional deficiency indicators (cribra orbitalia, porotic hyperostosis, and cribra femora) and markers of developmental stress (e.g., LEHs)? Alternatively, an increase in stature could be the result of a VA admixture of Scandinavian genes.
- The prevalence of occupational stress markers and indicators of physical load-bearing are compared between phases and compared against archaeological evidence of subsistence patterns to determine if osteological changes could be reflective of subsistence-related activities (i.e., physical activities involved with agriculture or husbandry). If the rates of occupational stress markers differ by site subsistence that may support the hypothesis of increased site specialisation in the VA and LNP.
- The prevalence of nutritional deficiencies and occupational stress markers are compared between individuals buried with and without Scandinavian style grave goods to assess whether those who identified as Scandinavian may have held a higher social status or different roles in society.
- The prevalence of nutritional deficiencies, specific and non-specific infections are compared between sites with different population sizes and different geographic locations

across Orkney to determine if they could be attributable to an increasingly urbanized Orkney or an influx of immigrants bringing new diseases.

1.2.2. Diet through carbon and nitrogen stable isotopes

Analysis of stable isotopes indicative of diet (carbon and nitrogen) provides a complementary perspective to osteological evidence of health. Bone collagen dietary stable isotopes provide information on the proportions of marine resources that are being consumed by different sexes and age groups. As discussed further in Chapter 2, previous studies on PVP, VA and LNP carbon and nitrogen stable isotopes in Orkney and throughout the North Atlantic have found a substantial increase in $\delta^{13}C$ and $\delta^{15}N$ values around the end of the first millennium AD, interpreted as a shift towards greater marine resource exploitation and consumption. This period has been coined the "fish event horizon" (FEH) in studies by James Barrett and Mike Richards (2000; 2004). Archaeo-ichthyological analysis of sites like Quogrew and Pool has indicated an increased fishing of gadid (cod family) species, "known to have been of paramount importance in Iron Age, Viking Age, and Medieval Norway" (Barrett et al. 2001, 146; Perdikaris 1999). The type and size of fish as well as the timing of the stable isotope shift in humans led Barrett and colleagues to interpret the increase in deep-sea fishing as potentially being of Scandinavian influence (Barrett 2001; Barrett et al. 2004; Jones and Mulville 2016). Barrett and colleagues have also suggested that the increase in fish consumption was perhaps related to the introduction of Christian fasting practices, where fish were regularly substituted for red meat (discussed further in Chapter 2).

While Barrett and Richards (2004) found no significant difference in dietary isotopes between males and females in the PVP, males in the VA had significantly higher $\delta^{13}C$ and $\delta^{15}N$ when compared with VA females (Barrett and Richards 2004). The discrepancy in diet between sexes in the VA has been used to argue for a sex-based division of labour in which (mainly) males were tasked with fishing and thus consuming higher quantities of marine resources, while females were chiefly concerned with agricultural activities (*ibid.*, 64). It is also possible that native Pictish females were more likely to retain the more terrestrial diets of their forbearers. Whether or not the prevalence of osteological indicators of load-bearing correlate with differences in labour between sexes is tested in this study. In addition to bone collagen $\delta^{13}C$ and $\delta^{15}N$ analysis, tooth dentine from a series of third molars has been sequentially micro-sampled for $\delta^{13}C$ and $\delta^{15}N$ analysis. While adult bone collagen provides average $\delta^{13}C$ and $\delta^{15}N$ values over the last 10-15 years of an adult's life (Hedges et al. 2007), dentine micro-sampling can provide a high-resolution profile of diet throughout tooth development (in the case of third molars, corresponding to between approximately nine to 21 years of age). Comparing bone and sequential dentine collagen values may reveal short-term yet significant dietary changes that otherwise would be masked by analysing bone collagen alone (cf. Montgomery et al. 2013, 1067). Sequential dentine samples also provide information as to when in life diets between sexes began to diverge and whether it may have been the result of sex-based division of labour or cultural ideas of gender. The primary objectives of the carbon and nitrogen stable isotope analysis are as follows:

- Using carbon and nitrogen stable isotopes as indicators of terrestrial or marine protein consumption, this study addresses whether the 'fish event horizon' began in the VA or LNP and whether (as discussed further in Chapter 3) there were dietary differences between males and females in the VA which may suggest a sex-based or cultural gendered division of labour.
- Carbon and nitrogen stable isotopes are compared with evidence of nutritional deficiencies and dental pathologies to determine whether an increase in marine protein consumption (a vital source of Omega-3 fatty acids) at the end of the first millennium may have reduced the prevalence of periodontal disease and osteoarthritis.
- Carbon and nitrogen stable isotopes are compared between individuals with and without Scandinavian style grave goods, addressing the question of whether the intensification of marine exploitation may have been culturally driven.

- Carbon and nitrogen stable isotopes are also compared between individuals buried in churchyard and non-churchyard sites to test whether Christianity may have played a role in the adoption of fish consumption.
- Sequential dentine micro-sample chronologies of diet were reconstructed to determine whether patterns in diet differed significantly in males and females through adolescence and whether the timing of dietary changes could be suggestive of cultural notions of gender and maturity.

1.2.3. Ancestry versus ethnicity using strontium and oxygen isotopes

1.2.3.1. Ancestry and ethnicity: the archaeological conundrum

While ancestry and ethnicity are central to this thesis, both concepts are deceptively complex. The implications and connotations of ancestry and ethnicity are sometimes blurred or mis-interpreted, though each is a distinctive topic with its own complications (Graves-Brown et al. 1996; Wolf et al. 1994). It is important to remember that as archaeologists we are limited in our ability to interpret emic concepts of ethnicity and identity. To some extent we scientifically derive a concept of geographic origin or ancestry from isotopic and ancient DNA analyses. In this sense, the tree from which a branch of a people is derived is rooted in geographical terms and defined by the landscape. Based on strontium and oxygen isotopes or ancient DNA, we can identify potential regions as a "homeland" for an individual or group of people. However, this sometimes has little or nothing to do with the ethnic identity of that group of people. Ethnicity relates to the culture (set of practices, beliefs, political and social structure, etc.) that an individual identifies with. One need not be from Scandinavia to ascribe to "Viking" or Scandinavian culture or self-identify as such. An aDNA study conducted by Ashot Margaryan and colleagues (2020) has indicated as much, with only two of the six Orcadian individuals with "archaeological evidence for Scandinavian cultural links" exhibiting approximately 50% Norwegian ancestry (Margaryan et al. 2020, 392) (see Chapter 8). It should be noted that the term Viking refers to the raiders and pillagers (those who went *víking*) and not

Scandinavian culture (see Barrett and Richards 2004, 250; Graham-Campbell and Batey 1998). Although the period between AD 750 and 1100 is referred to as the 'Viking Age', there was a distinction between Scandinavian culture and the Vikings as a subset thereof (discussed further below; Graham-Campbell and Batey 1998).

In attempting to discern diet and health patterns between 'native' Orcadian and Scandinavian, one must address the complications inherent in distinguishing between Picts and Scandinavians. This has been a topic of much debate over the past several decades and guidelines for distinguishing "Pictish" from "Scandinavian" burials largely remain as ambiguous as it did at the start (Crawford 1987; Wainwright 1980). To distinguish between 'native' Pictish and Viking individuals, it is necessary to tease out tangible markers of identity and ethnicity. Regarding ancestry or geographical origin, identifiers (for the purpose of this study) are fairly straightforward. Strontium and oxygen isotopes (in conjunction with previous strategic radiocarbon dating) were used to attempt to distinguish locals from non-locals (see Chapter 3). Regarding ethnicity, there are a few aspects of burial that aid in differentiating those who may have identified strongly as 'Scandinavian' or 'Viking'. On one end of the spectrum would fall boat burials (typically ornate and lavished with grave goods), the precedents for which are encountered at sites throughout Scandinavia, including those found at the Borre mound cemetery, Hedeby, Uppsala, and Trondheim (Unterweger and Smith 2014). As is also the case in Scandinavia, some boat graves on Orkney produce evidence of an actual boat (such as at Scar), while some are graves in the shape of a boat the outline of which was formed with stone, or with a few remnants of iron rivets (which presumably had been originally attached to planks) that may have been symbolic of a boat burial (examples at Pierowall and Westness).

While the inclusion of Scandinavian artefacts and differences in burial settings have driven the argument for a distinction between "native" Pictish and Scandinavian, there is still the long-standing debate as to the homogeneity of "Vikings" themselves as a cultural group and whether artefactual evidence can be used to support the idea of a cohesive "Viking" identity. In this regard, strontium and oxygen stable isotopes, as well as aDNA, can and have been used to contribute to this discussion by addressing the geographic origin of individuals with a "Viking" identity (Jarman 2012; Margaryan et al. 2020). Previous findings are discussed in relation to the results of this study in Chapter 8. Were the 'Vikings' groups of Scandinavians or relatively homogeneous geographical origin with pride for their homeland and a dominant, identifiable culture that inundated the foundation of Pictish culture? To what extent was the "Viking" goal a cohesive, amalgamated mission of pillaging wealth, transferring ethnicity and conquering land and people? Or did "Viking" simply refer to a heterogeneous group of mercenaries, mostly from Scandinavia (almost coincidentally), with no tangible unified identity, but with only a goal of self-aggrandizement in mind? Possibly both. Initial Viking raids in the late eighth century were (according to annals) violent hit-and-run attacks aimed at acquiring wealth by any means necessary (Barrett 2012b, 17; Crawford 1987, 49; Graham-Campbell 2017; Towrie 2020). A second and third surge of Scandinavian migration in the ninth and eleventh/twelfth centuries appeared to be a more coordinated, long-term approach aimed at acquiring land and power and exacting tariffs from different communities in the North Atlantic (Barrett and Richards 2004; Crawford 1987). As Norse elite became the ruling nobility of Orkney, association with Scandinavian ethnicity (i.e., through the inclusion of Scandinavian grave goods) may have become a symbol of status rather than indicative of genetic ancestry. Regarding this issue, it will be useful to compare material indicators for "Viking" identity with isotopic and ancient DNA evidence for origin/ethnicity. Were those strongly identified as Vikings (per grave goods) non-locals, potentially from Scandinavia, or were they possibly second or third-generation immigrants? The *Orkneyinga Saga* suggests a long period of trans-North Sea travel, with earls (seemingly from both sides of the sea) being appointed or removed from office by their Norwegian king. This suggests high-status Norse may show Scandinavian isotope values. The assignment of Orcadian earls by Norwegian kings could also have contributed to the replacement of Pictish/Gaelic place-names with Norse names.

If differences in diet between sexes were related to Scandinavian ideas of gender, we might expect to see them first reflected in the dentine of individuals with strontium and oxygen signals compatible with Scandinavian origin. However, investigating mobility through isotopes comes with its limitations. Only individuals born and/or raised in Scandinavia will show strontium and oxygen signals compatible with Scandinavian origin. This means the children of first-generation immigrants who may consider themselves ethnically or ancestrally Scandinavian will fail to show isotopic evidence of Scandinavian origin. The primary objectives of the strontium and oxygen stable isotope data are as follows:

- Investigate the relationship between Scandinavian ethnicity and identity by using strontium and oxygen stable isotopes to differentiate locals from non-locals (potentially Scandinavians), in relation to burial practice (i.e., boat or furnished burials).
- Use carbon and nitrogen dietary isotopes in conjunction with strontium and oxygen as indicators of mobility to compare the diets of local and non-local individuals.

While both osteological and stable isotopic methods have their limitations (discussed further in Chapter 8), they provide the best methods available for discerning trends in the health and diet of the Orcadian population from the PVP through the VA and LNP. Osteological examination, in conjunction with isotopic data, has been used to assess whether dietary trends were adopted similarly at sites across Orkney, as well as between different sexes and age groups. As detailed below, varying levels of Viking interaction and environmental conditions at the different sites across Orkney and could have resulted in different osteological and isotopic manifestations of any Scandinavian-influenced diet and/or health trends. Additionally, this evidence will be used to determine whether there were differences in occupational stress markers between locals and non-locals, males or females, that could be reflective of differences in social status or habitual physical activity during this phase of cultural hybridization and economic change.

The distribution of diet and health trends across different sites, as well as across site demographics provide insight as to possible underlying socio-cultural causes, as well as culturally-defined notions of gender, adolescence, and maturity. Through comparing differences in agriculture and husbandry in pre-Viking and VA Orkney, differences in adaptation and cultural hybridisation of Scandinavian and Orcadian populations can be interpreted. If changes in diet were the result of environmental factors (e.g., famine or an increasingly warm climate), one would expect to find a temporary or seasonal regional shift in diet, uniform between nearby sites, and possibly correlating with a period of significantly different overall health. Such temporary or seasonal shifts in resources may be apparent through high-resolution sequential dentine analysis, while long-term differences can be analysed through isotopic variances in bone collagen between individuals of varying dates.

1.3. Chapter Structure

The next chapter, Chapter 2: A Review of Previous Work, addresses the archaeological and written evidence for economic and subsistence shifts in the VA throughout Orkney and the limitations inherent in this line of research. Chapter 3: Methodology discusses the osteological methodology employed in age and sex estimations as well as methods of recording of the pathological and traumatic lesions observable on the human skeletal remains. Chapter 3 also provides the methodology and laboratory protocol for carbon, nitrogen, strontium, and oxygen stable isotope measurement. The chapter concludes by discussing the implications of the osteological and stable isotope methods in this study and describes how they contribute to a larger picture of patterns in diet and health and a larger-still picture of changing subsistence and economic functions in Orkney from the PVP to the VA and LNP. Chapter 4: Skeletal Collections and Site Backgrounds provides an overview of each site included in the study, with a brief history of archaeological research along with information on subsistence, based on faunal and archaeobotanical remains from nearby farmsteads as well as site type classifications based on name categories, site location and burial settings. Chapter 5: Osteological Results details the results of the osteological analysis, reflecting demographic patterns as well as prevalence rates for nutritional deficiencies, developmental stress indicators, occupational stress and load-bearing, specific and non-specific infections, and trauma.

Chapter 6: Dietary Isotope Results provides the results of carbon and nitrogen stable isotope measurements, supplementing quantitative evidence for sourcing of terrestrial and marine protein for consumption. This includes measurements from bone collagen, as well as sequential dentine micro-sampling which provides a life history of diet through childhood and adolescence. Chapter 7: Mobility Isotope Results details the results of strontium and oxygen measurements, which were taken from tooth enamel and used as a proxy for mobility, specifically non-local origin. Chapter 8: Discussion and Interpretations provides a contextualization of the osteological and stable isotope results in light of the archaeological evidence and tests the established theories on VA and LNP health, subsistence and diet in Orkney with the new evidence presented in this study. Finally, Chapter 9 draws together the main conclusions reached and suggests potential future research questions and lines of investigation.

Chapter 2. A Review of Previous Work: Evidence for Viking Age Changes in Orkney's Economy and Implications for Diet and Health

Whether a time of peaceful cultural hybridization or violent conquest, the Viking Age (VA) in Orkney has been credited as the launch for state formation, economic growth and long-distance trade, resulting in the development of a market-based economy in the ninth to thirteenth centuries (Barrett et al. 2000b; 2004, 618). Written and archaeological evidence (as detailed below) have been used to depict the Viking Age as a period of substantial transition, with Orkney developing from a dispersed group of self-sustained farmsteads scattered across the landscape of an insular archipelago to a wealthy and prosperous earldom at the centre of a North Atlantic trade network (Barrett 2007, 299). Barbara Crawford's *Scandinavian Scotland* (1987) presented a condensation of archaeological and written evidence for the social and economic evolution that Orkney (and Scotland at large) experienced during the Pictish/Norse transition and beyond. She laid the groundwork for future research by defining the principal developments of the Viking Age and Late Norse Phase, investigated further by James Barrett (2000b; 2004). These include a) a transition to a market-based economy, substituting a focus on the circulation of prestige items to mercantile trade in staple goods (Barrett et al. 1997; 2004), b) an increase in population size due to Scandinavian migration, requiring larger agricultural output in addition to the production of goods for long-distance trade (Bond 1993; Barrett et al. 2000b), c) intensification of deep-sea marine resource exploitation and consumption around the turn of the millennium (*ibid)*, d) a change in infrastructure from self-sufficient farmsteads to a system of specialised sites geared to provisioning high-status centres (Griffiths 2013); and e) the introduction of a Scandinavian ruling elite and Christianisation of Orkney that influenced cultural preferences relating to diet and subsistence (Barrett et al. 2003; Lerwick 2014; Mainland et al. 2016). All these developments have direct implications for subsistence practices and in turn, the diet and health of the Orcadian population.

The timing of these developments and their effects on the subsistence, diet and health of Orcadians has remained a subject of debate despite extensive archaeobotanical, zooarchaeological, architectural and onomastic investigations. This chapter discusses the archaeological evidence for these developments and the evolution in diet and subsistence that are cited as the result of these changes. Furthermore, it details how osteological evidence of health and stable isotopic evidence of diet, may reflect these changes and how these methods have already contributed and continue to contribute, to our understanding of the Viking Age as a period of socioeconomic change in Orkney. In addition to the large-scale economic transition, the cultural and religious components of lifestyle changes in the VA and LNP muddy the waters when trying to understand changes in subsistence. The second part of this chapter will discuss the archaeological evidence for the influence of Scandinavian culture and the Christianisation of Orkney on diet in VA and LNP.

2.1. The development of a market-based economy

The shift towards a market-based economy geared toward supporting long-distance trade, coupled with an increased population size due to immigrating Scandinavians, has been cited as the primary stimulus for dramatic changes in economic and subsistence practices during the PVP and VA in Orkney (Barrett 2000b; 2004; Bond 1998; Simpson et al. 2005). While land in Orkney was used mainly for agriculture or mixed farming throughout the VA (Kaland 1982, 88), it has been argued that the influx of Scandinavian settlers and the transition to a market-based economy created a need for increased agricultural output, as well as a focus on staple goods as moveable wealth (Barrett 2012a; Bond 2003; Critch et al. 2019; Harland 2006; Jones and Mulville 2018). As Simpson and colleagues reported in their study of VA and medieval anthropogenic soil analysis, with the onset of Scandinavian state formation and the incorporation of "peripheral" North Atlantic polities "came the acceleration of long-range market trade of utilitarian products, including dried fish and grain and the associated intensification of marine-resource exploitation and agricultural production" (Simpson et al. 2005, 356). This section discusses the archaeological evidence for an emerging market-based economy in VA Orkney and subsequent adaptations in subsistence that may have impacted osteological indicators of nutrition and load-bearing.

2.1.1. Staple goods as portable wealth

The principal claims of a fundamental shift in Orkney's economy have been based on the archaeological evidence of increased production of items suitable for the long-distance movement of everyday items, rather than prestige goods, not only for trade but as skat payment beginning in the ninth century (Gibbon 2007, 238). Evidence for a focus on practical and adaptable wealth includes the growing predominance of hack-silver and ring-money in hoards in the early tenth century, as well as bioarchaeological evidence of an increase in the production of cereals, dried fish, cheese and butter (Critch et al. 2019). The form of taxation known as *butter skat* demonstrates the demand to produce surplus butter as a form of currency and multipurpose foodstuff in the VA and LNP (Challinor 2004; Critch et al. 2019).

According to Diane Alldritt's 2003 thesis, "a period of pastoral expansion [occurred] during the late Norse period, particularly reflected by an increased need for fodder and the necessity to produce surplus goods, such as dried fish, cereal grain and butter, for long-distance trade" (Alldritt 2003, 2). Many of these organic and perishable items have not survived archaeologically. One form of material evidence for Scandinavian impact on economic growth that has survived archaeologically is the deposition of coinage and bullion in hoards (Critch et al. 2019; Kershaw 2017). Although coinage may not seem relevant to diet and health at first glance, the growing use of coins in the VA has larger implications for economic change and the necessities of long-distance exchange throughout the North Atlantic (Barrett 2012c; Graham-Campbell and Batey 1998, 228; J. Kershaw, pers. comm., 2019). Coins have been found at several sites across Orkney, in varying archaeological contexts including hoards, burials and settlements. The VA hoards from Skaill and Burray, for example, contained coins as well as ring-money (Graham-Campbell 1984; Graham-Campbell and

Batey 1998; J. Kershaw, pers. comm., 2019; Morris et al. 1985). While the Skaill hoard (960-80) included prestige items such as penannular brooches, the Burray hoard (997-1010) consisted mainly of ingots and hack-silver (Barrett 2012a, Graham-Campbell 2019). The earlier hoard contained more complete and ornate items while the later hoard contained pieces of metal that had been cut up and exchanged by weight (hack-silver). Although close in date, the two hoards differ in their representation of trending transactional preferences (J. Kershaw, pers. comm., 2019). While the value of prestige items lies in their cultural context (aesthetic trends and symbols of status) and are only valuable intact, ring-money and hack-silver could be cut into pieces and used for a range of transactions - from large transactions to everyday purchases of food or clothes. In addition to coinage and hack-silver, there is evidence for the long-distance trade of combs and jewellery. “Fish-tail” combs like those from Burrian and Northskaill are decorated with Scandinavian symbolism and representations of economic and political activity. The combs were shown to have expressed regional culture and identity, their imagery reflecting the importance of fish exploitation (Clarke and Heald 2002; Ashby 2009).

Through archaeo-ichthyological remains from middens at sites like Earl’s Bu and Quoygrew, Barrett and colleagues have traced the tenth and eleventh centuries rise in marine resource exploitation, which they interpret as evidence of an increasingly market-based economy, as dried fish was a form of staple good used as moveable wealth suitable for long-distance trade (Barrett 1997; 2012; Barrett et al. 1999; 2004; Critch et al. 2019). In addition to the expansion of deep-sea fishing, Scandinavian settlers have also been credited with the creation of the stockfish trade (Nicholson 2004, 156). Although evidence of a shift toward moveable wealth and surplus production has been used to support the idea of a VA shift to a market-based economy (Barrett et al. 2000c, 20; Bond 1998), there is growing reason to suspect that substantial changes in agricultural practices and marine resource exploitation began prior to the VA. For example, Alldritt’s thesis on the economy of LIA and VA Orkney found that the production of butter and dried fish likely began in the PVP and continued through the LNP.

The limitations in interpreting patterns in subsistence in PVP and VA Orkney based on the faunal and archaeobotanical remains, however, need to be addressed. As Jones and Mulville have observed, "post-Neolithic, little is known about the importance of aquatic marine resources in insular prehistoric human and animal diets, with studies predominantly focusing on individual site analyses or individual periods" (Jones and Mulville 2016, 1; cf. Bond 2007; McCormick 1984; 2006; Mulville 1999; 2012; Mulville and Powell 2012; Nicholson and Davis 2007; Noddle, 1977; 1997; Sellar 1989 (in Bell and Dickson 1989); etc.). To get a comprehensive view of diet patterns in PVP Orkney, one must therefore rely on bioarchaeological reports of botanical and faunal remains from well-excavated Pictish and multi-phase farmstead and settlement sites including Pool, Buckquoy and Mine Howe. Despite the information we can glean from such recent, meticulously excavated farmstead sites, comparing archaeobotanical remains between LIA sites in Orkney remains difficult due to inconsistent sample collection. Unfortunately, many of the botanical remains that may once have been at many of these farmstead sites have not been recovered due to inconsistent employment of flotation and sieving standards (Graham-Campbell and Batey 1998, 206). In addition, the paucity of LIA farm sites limits our understanding of the extent to which these subsistence methods were used throughout the islands or only in areas of good quality soils. Archaeological evidence for the timing of changes in subsistence and their subsequent socioeconomic impact will be addressed in the following section.

2.1.2. Agricultural improvements and increased production

Settlement in PVP Orkney consisted predominantly of dispersed farmsteads practicing subsistence farming (Davidson and Jones 1985). There is archaeological and written evidence of both intensification (increased anthropogenic soil formation) and expansion of arable land in the VA and LNP, however. Agricultural intensification - the increase of input (labour and manure) and output (product) per unit of land - has been attributed to the VA, caused in part by the need to supply demand for a growing population and to pay skat. The importance of cereal as an export for Orkney is attested to by written records, such as the *Islendinga Saga* and *Bandamanna Saga* (both date to the 13th century), which reference meal, malt and grain from Orkney being bought in Iceland (Andersson 2006; Barrett et al. 2000b, 20; Gelsinger 1981; Jónsson 1936). According to Crawford, Orkney was skatted in the form of cereals and butter, while Shetland was skatted in the form of butter and cheese. The export of Orcadian cereal to Norway continued into the fifteenth century until the transfer of the Orkney Isles to Scotland in 1472 (Helle 2019, 49). The written records for skat payments, as well as the land quality and climate of Orkney, support the idea of a greater agricultural focus in Orkney than Shetland in the VA and LNP (Crawford 1987). The development of anthropogenic soils was one of the primary agricultural developments in the VA, as evidenced by increases in topsoil thickness, soil phosphate, carbon and nitrogen levels (Guttman 2005, 227; Breuning-Madsen et al. 2012, 49). There was evidently an effort to improve soil quality through raised soils and plaggen soils, in addition to the continuation of midden cultivation (the incorporation of middens into cultivated soil, which had been employed since the Late Bronze Age or Early Iron Age in Orkney) (Guttman 2005). Improvements in agriculture not only provided an increased production of cereal to be used as an alternate form of moveable wealth to be traded over long distances, but they also helped support a growing population by providing fodder for animals over winter. In addition to efforts to improve soil quality, there was likely an expansion in the amount of land that was cultivated, diversification of crops and the introduction of the horizontal mill (Batey 1992; 1993; Bond 2003). These developments in agricultural practices not only help explain the evolution of subsistence in the VA but also have implications for changes in the community and social organization at large. As Ian Simpson and colleagues have explained, "The development of … [raised] soils … requires careful integration of animal and arable husbandry and indicates a well-organized agricultural community with well-defined land-use structures" which would have allowed for increased production (Simpson 1993, 4). The increasing need for agricultural surplus would have urged forward a system of more specialised and interworking farmsteads, as will be discussed in section 2.1.4.

Although the first instance of cultivated oats in the Northern Isles comes from Pool and dates to the third to fourth centuries, there were substantial increases in the number of samples from the PVP through the VA contexts *(*Bond 1998*,* 107). According to Bond, the hardiness of oats and their ability to grow in poorer-quality soil meant more availability of fodder for horses, cows and pigs and the expansion of arable land to areas with less fertile soil. The presence of oats in botanical samples increased steadily from the PVP through the VA and LNP (*ibid)*. In addition to the presence of oats, a more prevalent nitrogen-loving weed species assemblage suggests well-manured soils and more "vigorous cultivation practices" than in the Bronze Age, likely using an ard and an infield-outfield system (*ibid*). It is possible that implementation of the infield-outfield system would have diversified plant $\delta^{13}C$ and $\delta^{15}N$ values within each farmstead, as infield crops may have been more intensely manured than outfield crops (Bogaard et al. 2007; 2013; Styring et al. 2014; Vaiglova et al. 2014). This variability may in turn have been visible among the human populations from these farmsteads.

The expansion in oat cultivation in the VA may have made overwintering livestock more feasible, increasing the need for stables and shelters for livestock (Bond 2003). Structural changes to buildings in these farmsteads suggest such a shift in economic focus. At Beachview, Sandwick and Freswick (as at Jarlshof in Shetland), byres and barns are found from the VA, indicating a need to house livestock over the winter (Graham-Campbell and Batey 1998, 209). Excavations at farmstead sites like Skaill and Quoygrew have also uncovered evidence of increased barley and flax production (Bond 2003, 105; Barrett 2012c, 15). While it was previously thought that flax/linseed was not grown on Orkney until the 18th century, carbonized plant remains from Pool have indicated a rise in flax-growing starting in the VA (Bond and Hunter 1987, 175). According to Bond and Hunter (1987, 176), the growing of hulled barley and cultivated oats "…are now well attested in the Norse archaeological record for north Scotland including Pool… and can demonstrate a necessary level of husbandry from which the cultivation of flax, traditionally a difficult crop, might have evolved". They view the introduction of flax as a major crop as marking a significant and cultural change in farming: “interestingly, this development occurs in the ‘Pictish’/Norse interface phase of occupation at Pool and coincides with cultural changes interpreted from both structural and artefactual remains” (Bond and Hunter 1987, 181). In addition to the introduction of new crops, Norse settlers also brought with them the horizontal mill (or ‘Norse Mill’) such as that found at Orphir. Similar mills have been found from the VA at Omgård in Denmark (Jessen 2017). It is believed that Scandinavians brought this technology to Orkney, as well as Caithness/Sutherland, the Outer Hebrides, Isle of Man, Shetland and Faroe, though Ireland has provided evidence of a pre-Norse horizontal mill (Batey 1993, 23).

While some of the North Atlantic Islands including Shetland and Iceland have exhibited palynological evidence for deforestation in the VA, the forests and larger groups of trees (including birch, pine and hazel) largely disappeared from Orkney in the Neolithic (Keatinge and Dickson 1979). Norse land-use practices in Orkney instead focused on turf-cutting of outfield lands to be used to enrich infield productivity, which may have contributed significantly to soil erosion and decreased soil productivity of outfield land (Fenton 1978; McGovern 1988, 231). It is possible changes in manual labour involved in cultivating and processing new crops (especially flax) as well as the implementation of the horizontal watermill and increased turf cutting would have resulted in osteological indicators of occupational stress or load-bearing.

There is evidence for agricultural trends and manuring practices for earlier periods in Orkney, such as soil micromorphology, magnetism and phosphate analysis, which have shown variation in manuring practices from the Bronze to Iron Age (Guttman 2005, 232). Excavations from Pool, for example, have uncovered evidence for improved agricultural practices in the Northern Isles beginning in the mid to late Iron Age (Bond et al. 2003, 138). Alldritt’s 2003 thesis on the environment and economy of Northern Scotland and the Northern Isles in the first millennium AD found that while agricultural intensification likely began in the PVP, it continued and perhaps accelerated with Norse settlement and increased connections throughout the North Sea. While the raising of soil beds in Orkney may have begun in the pre-Viking period, Simpson's 1993 study on anthropogenic soil formation found that the vast majority of raised soils were associated with Scandinavian place-names and dated to the mid-late VA (Simpson 1993, 9; 2005). The addition of using plaggen soils in the VA, however, supports the idea of increasing labour and manuring. A detailed excavation at Quoygrew provided evidence of substantial VA improvements in agricultural productivity, although improvements in land management (primarily drainage) may not have started until the thirteenth century (Simpson et al. 2005, 374). As Amorosi et al. observed,

> *"[w]here [faunal] species representation… indicate a change in the economics of animal husbandry towards systems which require a high-quality diet, or the increased use of cattle for traction evident during the Pictish-Norse interface and Norse phases at Pool in Orkney (Hunter 1997), it can be argued that an improvement in fodder production must also have occurred, perhaps through intensification of arable production or the adoption of hitherto under-utilised land for fodder/grazing" (1996, 47).*

So how might agricultural intensification (increased labour and manuring for increased output) manifest as osteological indicators of health or stable isotope evidence of diet? An expansion in cultivated land would have meant more manual labour required to harvest it (Larsen 1995; Roberts and Cox 2007, 162), with either a larger workforce or more strenuous labour for those involved. Osteological markers of physical labour associated with agriculture include osteoarthritis and other indicators of load-bearing (see Chapter 3.1.6. for more detail). Increasing demand for manufactured items such as jewellery and combs as well as cereal products and perishables in the VA likely led to growing site specialisation and the division of labour (Barrett 2001), which would have likely meant that individuals from sites focused on agriculture were charged with the production of increased surplus. Thus, instead of a greater proportion of the population exhibiting signs of agricultural activities, it is more likely that those in charge of agricultural practices in the VA and LNP would have exhibited more severe osteological stress markers and indicators of load-bearing due to increased workload. A greater difference in the prevalence of osteological stress markers between individuals from different sites may therefore be expected. Furthermore, if there was a gradual increase in labour beginning before the PVP, there may not be an observable difference in osteological stress markers between the PVP and VA. On the other hand, if the greatest differences in agricultural practices began in the LNP one might expect to see significant differences in the prevalence rates of osteological stress markers between the VA and LNP. Stable isotope evidence of diet may prove more complicated. Although soil nitrogen and carbon isotopes increase with manuring - something we may expect to see in the VA - nitrogen isotope values are more obviously affected by increases in marine resource consumption, as discussed below.

The importance of agriculture in VA society can perhaps be supported by the inclusion of sickles in both male and female graves at Pierowall and Westness. An ard was also recovered from one of the Viking boat graves at Westness (Graham-Campbell and Batey 1998, 209). The comparison of osteological indicators of health and stable isotope indicators of diet between individuals buried with and without these agricultural implements may shed light on how their perceived status or role in society is reflected by physical evidence of their everyday activities and the foods they ate.

2.1.3. Marine resource exploitation

Arguably one of the largest shifts in subsistence in VA Orkney involves a move towards deep-sea marine resource exploitation at the end of the first millennium AD, called the “fish event horizon” by James Barrett and colleagues (Barrett et al. 1997; 2004). The excavation of middens from sites like Pool and Sanday have uncovered a growing emphasis on larger, deep-sea fishes such as gadids (primarily cod, ling and haddock) and salmon in the VA. Although the case has been made for a large-scale movement toward marine resource consumption in the VA (Barrett 1999; Nicholson 2004; see section on VA diet, below), the remains of small, inshore marine species such as limpets, mussels and saithe have been recovered from PVP contexts at sites like Birsay Bay (Morris 1989; Nicholson 2004, 156).

With the advent of agriculture in the Northern Isles in the Neolithic period, a decline in the consumption of fish has been previously reported (Schulting et al. 2010, 2011). It seems that fish continued to be of low importance until the VA. Studies of fish remains from multiple sites throughout Orkney have found an increase in the quantity, diversity and overall size of bones in VA contexts (Barrett 1999; 2001; Nicholson 2004). This includes a study by Simpson and colleagues at the site of Quoygrew which found stratified layers of soil containing fishbone- suggesting a significant increase in marine resource exploitation beginning around AD 966 and continuing through the thirteenth century (Simpson et al. 2005, 357). Similar increases in marine resource consumption have been found in the form of archaeological fish remains at Skaill (Deerness), Pool and Saevar Howe in comparison to Iron Age sites like St. Boniface and Howe (Barrett et al. 1999, 356; Kaland 1982, 91). The tenth and eleventh centuries in Orkney brought significant increases in marine resource dependence, potentially caused by Scandinavian-influenced increases in fishing (Barrett 2001; Barrett et al. 2004; Jones and Mulville 2015). Although Norse introduction of fishing technology has been suggested as one of the reasons for an expansion in deep-sea fishing in the VA (Nicholson 2004, 156), it may be important to note that both inshore and offshore species of fish have been found at the Neolithic site of Knap of Howar - including cod, large saithe and ling - indicating the existence of deep-sea fishing millennia prior to Norse settlement (Ritchie 1985, 47). Fishbone evidence from Buckquoy suggests that "although line-fishing from boats must have occurred in the Pictish period, deep-water line-fishing was far more frequent" during the VA (Ritchie 1977, 191). Fishbone analysis suggests increased fishing of gadid (cod family) species, "known to have been of paramount importance in Iron Age, Viking Age and Medieval Norway" (Barrett et al. 2001, 146; see also Perdikaris 1999). Pálsson (1988) has argued that the development of fishing can be seen as reflective of social complexity and stability, though this is could be equally reflective of the increasing social organization and rise of chiefdoms in LIA Orkney rather than Norse influence (Dockrill and Batt 2004; Nicholson 2004).

The curing or drying of fish allowed for their trade across long distances and storage over longer periods of time, just as increased dairying focused on the production of cheese and butter to be traded across long distances or stored for longer periods of time. Barrett and colleagues found that demand for fish throughout Britain in the LNP became so high that fish were increasingly being imported from Arctic Norway and the Baltic (Barrett et al. 2011, 1521). Despite the argument for growing production of dried fish for long-distance exportation, only the largest well-excavated VA and LNP sites in Orkney (Quoygrew) provided evidence of specialized large-scale production suitable for commercial long-distance trade or export (Barrett 1997; Nicholson 1998; 2012). The scale of most fish processing indicates a local distribution for local consumption. Was fishing geared toward local consumption or were marine resources being distributed at least throughout Orkney? It is possible regional differences in $\delta^{13}C$ and $\delta^{15}N$ isotopes could provide some clarification. Interestingly, fish remains from Freswick Links, Caithness (also part of the Norse earldom of Orkney) revealed line fishing of large (predominantly over 1 meter long) fish like cod in the Pictish period, continuing through Norse arrival (Batey 1982, 58; Jones 1991). Fish middens from Robertshaven also attest to Norse involvement in the stockfish fishing industry at specialised sites in Caithness (Barrett 1997, 619; Laing et al. 2013, 272). Historically, though, the fishing industry in Caithness has been born of necessity, as the land quality is too poor to support a subsistence economy. Colleen Batey suggested that sites throughout Caithness (such as at Wick and Staxigoe) ended in abandonment due to a decline in fish populations (Batey 1987, 7). The impact the transitioning Pictish/Norse cultural and social structure would have had on fish consumption will be further discussed in 2.2.1. Unfortunately, the collection of fishbone from archaeological assemblages has suffered from a lack of consistency prior to the late 1990s. Mesh size and collection methods have improved in recent decades. Unfortunately, there is no way to recover fish remains that may have been lost during previous excavations.

2.1.4. Site specialisation

The shift in resource demands for a growing population and an increased need for surplus meant that different sites in Orkney responded with a range in dietary adaptations and trends throughout the VA and LNP, including site specialisation. Site specialisation is a common response in a rising market-based economy and several lines of evidence have suggested the same was the case in VA and LNP Orkney. This section explains the different types of evidence for site specialisation and the ways human osteology and stable isotope evidence of diet could clarify the chronology of this process.

2.1.4.1. Place-name evidence

The onomastic line of evidence was first proposed by Hugh Marwick (1952) and later supported by William Thomson (1995), Graham-Campbell (1998) and Nicolaisen (1982), who considered place-names as evidence for interpreting the chronology and economic function of VA sites in Orkney. Marwick's analysis of place-names in Orkney argued the chronological and practical sequence of farmstead organization (Marwick 1952). His map (Figure 2.1, below) demonstrates the relationship between primary (later referred to as "consumer") sites such as those with names ending in skaill or *-skali* and the peripheral (or producer) *-kui* or *-quoy* sites (Thomson 1995, 44).

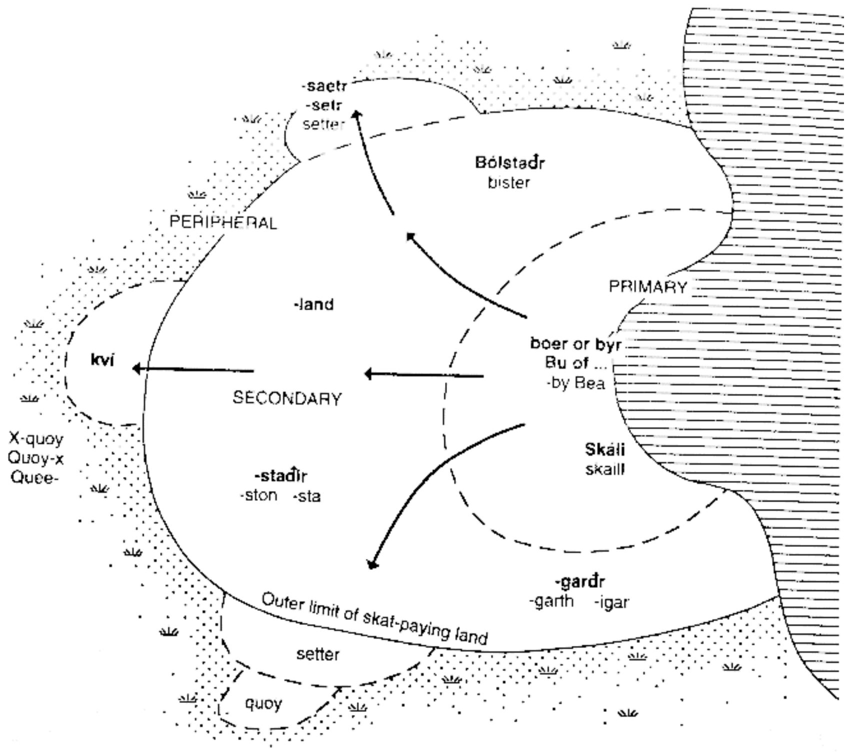

Figure 2.1. Farmstead organization scheme by Hugh Marwick, relating site names to chronology and function (Thomson 1995, 44 after Marwick 1952; reproduced with permission of The Licensor through PLSclear).

Marwick and Thomson differentiate between names implying habitation (i.e., *-stadir* sites, meaning farm) and topographical names - those referring to the landscape (i.e., *-ness* sites, meaning headland). While these landmark site names are less indicative of subsistence activities at the site, Barbara Crawford suggested that sites named for land features were fundamental for Scandinavian navigation and were of key strategic importance in operating the trade network from Norway and Shetland through the western isles and mainland Scotland (1987, 46). It is possible that due to their prominence in the landscape (and possible associations of perceived power), they were among the first sites settled by Scandinavian newcomers.

Although the nature of place-names may be misleading when attempting to interpret the original site size or population, it can be useful in interpreting the original function or purpose of the site. For example, *Skáli* (or skaill) sites are prevalent in Orkney. While the word *skáli* was originally used to mean a hut or hovel, the use of this name throughout Orkney referred chiefly to high-status sites and halls (*ibid.*, 39). Examples include Skaill, Deerness and the Bay of Skaill. Another example of place-name evidence suggesting site use is in *-quoy* names (as in Quoygrew or Buckquoy). These are indicative of cattle farms, as *-quoy* means "cattle-fold." As James Graham-Campbell and Colleen Batey explained, "the grazing of sheep is suggested by the island name Soay and Haversay, mean[ing] 'he-goat-island…the presence of horses is also indicated by the names Rossal ('horse-field') and Hestaval ('horse-hill')" (Graham-Campbell and Batey 1998, 208).

If Scandinavian place-names were (at least in part) derived from site function, it may be that differences in habitual activities between sites resulted in differences in osteological indicators of occupational stress or stable isotope indicators of diet. For example, if *skaill* sites were high-status consumer sites, individuals buried nearby may exhibit fewer markers of strenuous physical labour than individuals buried at producer *-quoy* sites. In addition, access to high-quality or more abundant foods at high-status sites (for example, butter or fish obtained through skat taxation) may have meant a lower prevalence of nutritional deficiency indicators. This may have also caused higher

$\delta^{13}C$ and $\delta^{15}N$ values among individuals from high-status sites. Furthermore, if the colonizing or settling of prominent land features were of strategic importance to the Scandinavians, such sites may contain the highest concentration of non-locals, observable through strontium and oxygen isotope analysis.

2.1.4.2. Differences in bioarchaeological assemblages by site

In addition to place-name evidence, there is archaeobotanical and zooarchaeological evidence that supports the development of VA site specialisation. According to Julie Bond, the Northern Isles relied on a combination of cattle, sheep and pigs, "though percentages of each differed somewhat depending on situation and social status of the site" (2003, 106; 2004). Increasing demand for agricultural products seems to have necessitated site specialisation, with a growing distinction between "producer" and "consumer" sites in the VA (Griffiths 2013). Producer sites began to specialise as well, with a predominance of certain crops or animals at certain sites, depending on the environment and need from high-status settlements (Griffiths 2013).

Differences in the proportions of juvenile cattle remains from the different sites suggest that while dairying became more important at some sites in the VA, other sites continued to focus more on meat procurement. While methods for discerning slaughtering seasonality are still debated, dental eruption and wear patterns have provided indicators of diverse and evolving husbandry practices at PVP and VA sites (Ervynck 2005, 154). One of the Iron Age sites best explored for evidence of dietary patterns is Mine Howe, a Middle to Late Iron Age high-status feasting site. Mainland et al. (2016, 846) found that slaughter patterns at Mine Howe indicated a primary reliance on meat, with little focus on dairying. It is possible that since there is evidence for this site being used for high-status feasting and ceremonial purposes (Card and Downes 2003, 17; Balasse et al. 2009; Mainland et al. 2016), meat was a primary focus while dairying could have been conducted at outlying sites and dairy products brought in. Likewise, the proportion of juvenile cattle bones found in PVP contexts at Pool suggest that dairying was being practiced, though most cattle were grown to full capacity and used for meat (Bond 2003, 108). Barbara Noddle concluded that at Skaill, Deerness it appeared that most livestock were killed for their meat before reaching maturity, though cattle were also used for milk production, especially in the VA (Noddle 1997, 235). While juvenile calf mortality at Pool shows evidence of dairying in the PVP, there is a subsequent increase in cattle under the age of 6 months old, indicating an intensification of dairying through the VA in the ninth and tenth centuries (Bond 2003, 108). The younger cattle slaughter age in the VA also meant less beef being available and hence an increasing reliance on sheep/goats and pigs for meat (*ibid)*. As Bond argues, dairy in the form of cheese and butter can be easily stored and used as trade, taxes or kept in case of future shortages (Bond 2003). Similar patterns of increased dairying have been observed in Late Norse Shetland (Bigelow 1992).

Faunal osteometric data from Pool, Skaill and Howe suggests cattle and sheep/goats were not brought to Orkney by Scandinavian settlers, but that stock remained consistent from the PVP through the VA (Bond 2003, 108). While significant differences in the kill patterns of cattle from the PVP to the VA (observed at sites like Deerness and Saevar Howe) signal a shifting emphasis on product (from meat to dairy), other sites show no significant differences in mortality patterns or animal proportions through time (Hedges 1983, 111). For example, a similar proportion of faunal remains were recovered from Buckquoy and showed little difference between the pre-Viking and Viking periods (Ritchie 1977, 191; Foster 1996, 54). It has been argued that the shift towards a higher proportion of cattle at Buckquoy was partly to provide meat and dairy for the growing VA population at the Brough of Birsay (Graham-Campbell and Batey 1998, 207). The apparent disinterest in dairying at these two sites is uncharacteristic of sites throughout the Iron and VA North Atlantic. Interestingly, there were differences in the way livestock were reared, as evidenced by the stress and nutrition of livestock between both sites. While there is evidence of sheep being made to graze on seaweed, no such evidence has been found for cattle (Balasse et al. 2009; Mainland et al. 2016). The use of seaweed as fodder would have significantly increased the animals’

$\delta^{13}C$ and $\delta^{15}N$ values. Differences in consumption of sheep versus cattle products between sites may then have created differences in human $\delta^{13}C$ and $\delta^{15}N$ values between those sites.

Archaeobotanical remains indicate that like changes in animal management strategies, crop focus also began to diversify between sites in the VA. While sites like Birsay Bay show evidence for an enduring dominance of barley in the VA, other sites like Tuquoy, Pool and Orphir demonstrate a growing emphasis on the cultivation of oats (Batey 1992, 25; Graham-Campbell and Batey 1998, 210). According to Bond, the cultivation of oats began in the Pictish or Norse period, both oats (*Avena sativa*) and flax possibly being Scandinavian introductions in the VA (1998, 88; 2007, 185). While oats would have been used as food and fodder, flax was likely used to produce oil and textile fibres. Land clearing and the ability to cultivate crops on sandier soils would have likely contributed to a rise in agricultural production. Both the predominance of certain crops at different sites, as well as slight differences in the proportions of animal species (and proportions of species age groups) are indicative of site diversification, a decline in subsistence farming and a rising dependence on the distribution of surplus goods between sites.

While increased site specialisation and differences in subsistence practices have been insinuated from place-name evidence and growing differences in husbandry focus based on the faunal and botanical remains, can these different methods of subsistence between sites be seen osteologically and/or isotopically? While $\delta^{13}C$ and $\delta^{15}N$ values may not vary significantly between terrestrial herbivores grazing on similar fodder, the grazing of sheep (and not cattle) on seaweed may have produced differences in $\delta^{13}C$ and $\delta^{15}N$ values between sites predominantly relying on cattle versus sheep/goat for meat. Likewise, relying on pigs (terrestrial omnivores) for meat would also produce higher $\delta^{13}C$ and $\delta^{15}N$ values than relying on cattle (Hamilton and Thomas 2012, 238; Hammond and O'Connor 2013). It is possible, therefore, that individuals from sites relying on cattle for meat may exhibit slightly lower $\delta^{13}C$ and $\delta^{15}N$ values than individuals from sites relying on sheep/goat or pigs for meat. Additionally, the consumption of fish (which raises $\delta^{13}C$ and $\delta^{15}N$ values) with Omega-3 fatty acids has beneficial effects on inflammatory conditions like osteoarthritis and periodontal disease. Sites with evidence for increased fish exploitation are likely to exhibit lower prevalence rates of both conditions, as well as increased $\delta^{13}C$ and $\delta^{15}N$ values indicative of marine resource consumption. If individuals from sites with archaeoichthyological evidence for deep-sea fishing do not exhibit higher $\delta^{13}C$ and $\delta^{15}N$ values, however, it is possible the fish were being caught and processed as a form of moveable wealth or were being redistributed rather than consumed locally. It is also possible that differences in animal use (dairying, meat or traction), crop focus and site function would have had a substantial impact on osteological indicators of load-bearing and health. For example, high-status (*skaill* or *-by*) sites would have had preferential access to foods through skat and may not have had to labour physically in food production like those on farmstead (*-quoy*) sites. Ideas of social status and osteological and isotopic indicators of health and diet will be further discussed below.

2.2. Nordification and the Christianisation of Orkney

In addition to the socioeconomic drivers of change, two factors may have had an even larger impact on subsistence and dietary practices in VA and LNP Orkney: the influx of Scandinavian culture and Christianisation. As Ceilidh Lerwick's 2014 Ph.D. thesis examined, cultural and religious ideas of diet may have had an impact on eighth through thirteenth century Pictish populations who interacted with Scandinavian immigrants (Lerwick 2014). While Lerwick's thesis focused on potential differences in osteological markers between religious and ethnic identities in eighth through thirteenth century Scotland, there may have been stronger factors influencing changes in the prevalence of certain diseases, nutritional deficiencies and occupational stress markers than just differences in identity. This thesis seeks to understand whether differences in the prevalence of osteological indicators of stress and diet could have been affected largely by changes in subsistence practices as well as religious and ethnic influence.

2.2.1. Scandinavian impact

A diaspora of Scandinavian peoples dispersed through Northern Europe carried socio-cultural norms involving the economy and social hierarchy, not to mention gender, subsistence and diet. To what extent did Orkney already resemble Scandinavian society and to what extent did Scandinavian migrants influence the social structure in Orkney? Can we see this in the archaeological record? And how can our understanding of Pictish-Norse relations benefit from using osteological and stable isotope analysis?

As mentioned in Chapter 1, family and site structure shifted in the VA, with a transition from lobular or cellular house structures to recognizably Norse rectangular or longhouses. In itself, the structure of houses could be seen to represent the centralization of power and the strength of community. Evidence of the emergence of a Scandinavian ruling elite in VA and LNP Orkney is predominantly written. The *Orkneyinga Saga*, for example, details the ongoing fight over the position of earl of Orkney between members of the Norse elite. PVP Orkney had thrived as a chiefdom society, with a system of reciprocity, gift-giving and feasting between the Pictish ruling families and the common people. Scandinavian society was not very different in this regard. Julie Bond suggests that cattle were at the centre of the Viking economy, as one of the prime tokens of gift-giving (Bond 1998, 88; Christensen 1991, 161). The lack of discernible change in the prevalence of cattle from the PVP through the VA suggests a shared notion of the importance of cattle between Scandinavian migrants and the native Picts (Bond 1998, 88).

While archaeological evidence for feasting has been recovered from Orcadian sites like Mine Howe and Orphir in the form of large faunal bone deposits (Mainland et al. 2016), the importance of feasting can likewise be seen throughout Scandinavia, such as at the Oseberg boat burial which contained the remains of oxen and kitchen utensils (Sanmark 2005, 205). According to Alexandra Sanmark, feasting was perhaps “the most important social institution in pre-Christian Scandinavia and the keystone of the Scandinavian political system” (Gurevič 1985; Roesdahl 1998; Sanmark

2005, 205). Zooarchaeological and written accounts aside, however, is it possible to detect feasting from human carbon and nitrogen stable isotopes? Unfortunately, while better overall nutrition and long-term diet may signal those of higher social status, sporadic feasting events are unlikely to have affected long-term bone or tooth formation. Concerning stable isotope values, it is unlikely that one would be able to interpret feasting based solely on bone collagen $\delta^{13}C$ and $\delta^{15}N$ values, unless animals (predominantly cattle) used for feasting events had significantly different diets to regularly-consumed animals (Mainland et al. 2016, 838; Vaiglova et al. 2018).

State formation in Iron Age Scandinavia and the transition from “chiefly societies” to a more centralised social structure resulted in a rise in long-distance trade, elite aggrandizement, personal status with the manufacturing of status-items and the emergence of richly-furnished burials (Thurston 2002, 7; Hedeager 1992, 31; Feinman 2000; Sindbaek 2007; Dobat 2009). We see a reflection of these changes in the early phases of Scandinavian colonization of Orkney - the emergence of richly-furnished boat burials such as that at Westness and Pierowall (described further below), the emergence of earls as the elite ruling class with the institution of ancient broch sites as assembly (*thing*) sites and the restructuring of subsistence strategies towards the redistribution of goods to high-status sites such as Birsay Bay (Morris 1989). The aggrandizement of elites in Orcadian VA burials has an overtly Scandinavian style, which includes boat graves and artefacts of Scandinavian manufacture and/or style. Cemeteries with Scandinavian grave goods included in this study are Scar, Pierowall, Westness, Buckquoy, the Brough of Gurness and Brough Road; more about each site is available in Chapter 4. Scar, Westness and Pierowall also have remains of boat burials. Although the Sutton Hoo is an obvious example of a pre-Viking boat burial in Britain, the motif is predominantly observed throughout Bronze and Iron Age Scandinavia (Major 1924; Müller-Wille 1995; Unterweger and Smith 2014).

As addressed by various authors over the years (Barrett et al. 2001; Härke 2014; Jones 1997, 106; Sayer 2013; etc.), we must always be wary of inferring identity or ethnicity from grave goods. We can, however, use grave goods to explore possible social roles, status and occupations of the buried individual in life. Grave goods from VA sites in Orkney include weapons, jewellery, textile implements, agricultural tools, gaming pieces, daggers, whetstones and combs (Morris 1989; Owen and Dalland 1999; Sellevold 1999; Thorsteinsson 1965). Some of the burials from Pierowall and Westness also contain the remains of horses and/or riding materials. While some grave goods appear in Orcadian burials of both sexes (including beads, agricultural tools, gaming pieces, combs and daggers), weapons have only been found in male graves and textile implements have only been found in female graves. The sword and spear are among the most common weapons recovered from male graves, both possibly representing a "warrior's death" (Davidson 1982, 35; Harrison 2015; Sayer et al. 2019; Solberg 1985). Although it is possible that women were involved in Scandinavian raiding and/or colonisation early on (as evidenced by the female warrior grave at Birka; see Price et al. 2019; Price 2020), to date there have not been any weapons burials belonging to females uncovered in Orkney. In Norway, the 'complete set' of Viking weapons includes swords (most commonly), axes, spears, shields and arrows (Owen and Dalland 1999; Sjøvold 1958). While no graves in Orkney contain all these pieces, most furnished male burials include at least a sword and/or shield boss (such as at Scar). The widely held idea that burials with weapons were meant to symbolise the death of a "warrior" has been rebutted by experts like Heinrich Härke (1990; 2000). Despite the argument against, if Viking weapons graves were, in fact, meant to distinguish Viking warriors, we might expect to see a greater prevalence of violent trauma among males with weapons than males without. In addition, these warriors (or warrior groups, referred to as *lið;* Price 2020, 313) may have had differential access to nutritional resources because of their status. The inclusion of agricultural tools (including sickles and an adze hoe) in both male and female graves from Westness, Scar and Pierowall provides us with another opportunity to test the validity of inferring occupational roles from the inclusion of grave goods. A comparison of osteological evidence of load-bearing (platymeria, OA, etc.) and diet (calculus, caries, etc.) can provide evidence on whether these males and females buried with agricultural tools varied in their diets and regular physical activities to individuals not buried with these tools.

The use of osteological and carbon and nitrogen stable isotope analysis to discern health and dietary patterns between social groups has also been applied to sites in England, Scotland and Scandinavia, such as at Birka, Berinsfield, Portmahomack and potentially Newark Bay, some sites having exhibited what has been interpreted as a difference in $\delta^{13}C$ or $\delta^{15}N$ values between social strata (Barrett and Richards 2004; Linderholm et al. 2007; Privat et al. 2002). To understand how Scandinavian grave goods may have been used to ascribe status or identity and how these constructs may have influenced diet and health, it is necessary to look at previous analyses of Scandinavian grave goods and stable isotope evidence of diet back in Norway. A study by Linderholm and colleagues (2007), which analysed human remains from Birka, found approximately 0.5 ‰ lower carbon and 0.6‰ higher nitrogen isotopes among individuals with weapons burials than without, similar to previous studies on Orkney collections done by Barrett et al. (2001) and Richards et al. (2006). The difference in $\delta^{13}C$ and $\delta^{15}N$ values between high-status burials at Birka and those in Berinsfield (where high-status individuals had lower $\delta^{15}N$ values) has been interpreted to reflect differences in culturally preferred foods (Linderholm 2007, 458). The study also found a surprising degree of variability in the diets of both individuals with and without grave goods, which has also been observed in VA Norwegian and Orkney populations (Barrett et al. 2001; 2004; Jarman 2012, 62; Naumann et al. 2014b, 327). In the case of the Oseberg boat burial, the individual presumed to be of higher social status exhibited fewer osteological indicators of load-bearing and physical stress (Holck 2006). Without proof of which individual the richly-furnished burial was primarily for, however, the argument on determining who was of a higher status from osteological indicators of stress quickly becomes circular.

Aside from social status, cultural ideas of gender roles can be explored using osteological and stable isotope methods. As described by Neil Price (2020), the Scandinavian world was comprised of two realms of power: the household dominated by women and the outdoors/political realm dominated by men. While these two were regarded as being of relatively equal importance and power, they were different in their responsibilities (Price 2020, 156). Such a sex-based division of labour is likely to have resulted in differences in the prevalence of osteological markers of stress and load-bearing between sexes. Anna Kjellström's study on the Mälaren Valley remains found a difference in osteological indicators of health between males and females, reflecting different gender roles between them (Kjellström et al. 2016, 200). As suggested by Barrett et al. (2000b; 2001; 2004), differences in social roles could have also resulted in differences in diet between sexes. Naumann et al. 2014's study on Merovingian (MA, AD 550-800) and VA (AD 800-1050) sites found higher $\delta^{15}N$ values and greater variability in both $\delta^{13}C$ and $\delta^{15}N$ values among females in the MA, but higher, "more marine," $\delta^{15}N$ values among males in the VA, suggesting a change in the division of labour or gender-related ideas of diet (Naumann et al. 2014, 328-329).

2.2.2. Christianity and diet

Undoubtedly, the relationship between diet, Christianity and mortuary practices is complex. This section evaluates the evidence for changes in diet that may have been due to religious practices and the (re)introduction of Christianity to the Orkney Islands with Scandinavian settlement. What effect could Christian fasting or dietary restrictions have had on dietary stable isotope evidence of diet and osteological evidence of health and nutrition? There is some evidence of pre-Scandinavian Christianity in Orkney, though Scandinavian settlement brought with it a pre-Christian belief system that likely persisted to some degree until the Christianisation of Norway in the eleventh century (this date is still debatable; Abrams 1995). Dietary regulations were introduced shortly after this, as evidenced by the early *Borgarthing* and *Gulathing* Laws (Sanmark 2005, 204). The dietary restrictions mentioned in these laws prohibited consumption of blood, meats offered as sacrifices to idols, or meats from animals that died of natural causes, strangled or killed by wild animals (Sanmark 2005, 207). Despite codification of dietary restrictions in a recently Christianized Norway, the extent to which these laws would have impacted a large proportion of the Orcadian population (Ruffoni 2011, 13), let alone osteological indicators of health and stable isotope indicators of diet, is debatable. Nor would there intrinsically be an isotopic distinction between meat from animals killed by strangulation and those killed in a "clean" way.

Other Christian dietary restrictions likely included fasting for several days and Christian holidays (Curtis-Summers et al. 2010). Studies including those by Beaumont and Montgomery (2016), Doi et al. (2017), Hatch 2012, Hertz et al. (2015) and Neuberger et al. (2013), have looked at the effects of starvation and fasting on bone and dentine $\delta^{13}C$ and $\delta^{15}N$ isotopes of humans and other species. While $\delta^{15}N$ isotopes increase when the body is in starvation (due to self-metabolisation), the resulting increase depends on the length of time the individual was abstaining from food, as well as bone turnover rates and the type of tissue sampled (Beaumont and Montgomery 2016; Doi et al. 2017; Hertz et al. 2015). While it is possible to detect short-term periods of starvation or fasting using sequential tooth dentine (see Chapter 3 for more detail), fasts lasting up to three days (Curtis-Summers et al. 2010) are unlikely to be detectable isotopically. More likely than suffering starvation would have been the replacement of meat for fish on fasting days (Mills 1992, 150; Curtis-Summers et al. 2014). The sheer number of fasting days where fish consumption would have been preferable could have possibly led to the increase in $\delta^{13}C$ and $\delta^{15}N$ isotopes observed at sites throughout Scotland, including Portmahomack and in previous studies at Newark Bay and Westness (Barrett et al. 2004; Barrett and Richards 2004; Curtis-Summers et al. 2010). A study by Gundula Müldner and Mike Richards (2005) found the significantly higher $\delta^{13}C$ and $\delta^{15}N$ isotopes observed at St. Giles, Towton and Warrington compared to Wharram Percy, Berinsfield and Poundbury could have been due to the Christian institution of dietary regulations regarding fasting (2005, 45). In contrast, isotopic comparisons in Sweden between Christian cemeteries (such as at Björned) and contemporary pre-Christian cemeteries have not shown differences in diet (Jarman 2012, 45). While Barrett and Richards (2004) have found a rise in $\delta^{13}C$ and $\delta^{15}N$ isotopes around the turn of the first millennium in Orkney, it has been hard to tease out whether this is due mostly to economic, cultural or religious factors. In fact, the rise in $\delta^{13}C$ and $\delta^{15}N$ isotopes are likely due to a combination of all three elements (Barrett and Richards 2004; Barrett et al. 2000b; Barrett et al. 2001).

The classification of 'Christian' versus 'pagan' burials in this period is in any case debatable (Barrett 2003a). While there were no grave goods definitively buried in churchyard graves, that is not enough to deem any individual buried with grave goods 'pagan' (Lerwick 2014). While the presence of grave goods could potentially be indicative of a 'pagan' individual, most grave goods were of Scandinavian type and/or manufacture. Therefore, one could potentially use grave goods as an indication of ethnicity just as well as religion. Did someone's Scandinavian ethnicity alone necessarily preclude them from being 'Christian'? Was Scandinavian identity used as an emulation of social status rather than cultural identity or religion? The lines between religion, culture and social status quickly become blurred.

In this study (as discussed in Chapter 1), differences in $\delta^{13}C$ and $\delta^{15}N$ isotopes, as well as osteological indicators of health and diet, were compared between individuals buried within and outside of known VA churchyards, as well as between individuals with grave goods. To address the debate over the impact Christian dietary restrictions had on the Orcadian VA populations, $\delta^{13}C$ and $\delta^{15}N$ stable isotopes will be compared between individuals buried within and outside of churchyards, while grave goods will be considered both indicative of social status and ethnicity. The emulation of Scandinavian ethnicity as elite or high-status will be further explored using strontium and oxygen stable isotope analysis. With archaeological evidence of transitions in economic, subsistence, cultural and religious practices in VA and LNP Orkney, it may or may not be possible to pinpoint causes of changes in nutrition and diet throughout this phase (Barrett et al. 2004; Kosiba et al. 2007). It is the aim of this study to identify potential connections between changes in physical activities related to subsistence, cultural and religious ideologies on the one hand and patterns in osteological indicators of health and stable isotope indicators of diet and mobility on the other.

Chapter 3. Methodology

This chapter details what methods were used for the osteological and stable isotope analysis done on the collections in this study and justifies why particular methods were used, their potential, limitations and caveats.

3.1. Osteological methodology

3.1.1. Demography

Demography is the study of population composition and includes information on mortality, life expectancy, the ratio of males to females, fertility and population density (Chamberlain 2006, 2). Changes in the population's structure and life expectancy are vital to interpretations of population health, specifically regarding population growth. Barrett and colleagues (2000; Barrett and Richards 2004), Bond (2003), Jones and Mulville (2018), Morris (1993) and others have asserted that economic growth and agricultural production in VA Orkney was meant to support a growing population. There is little evidence for an increase in population size in the VA, however, aside from site re-occupation and rebuilding at sites like Buckquoy and Birsay Bay. In addition, if it was primarily male Scandinavian immigrants settling in Orkney and taking local wives (perhaps to form political alliances or because of male over-population in Scandinavia, see Raffield et al. 2017), we may see a rise in the ratio of males (mostly young and middle adult) to females in the early VA. Based on age estimates calculated from the following criteria, life tables were constructed for each phase (PVP, VA and LNP).

3.1.1.1. Age

Estimations of age-at-death were made from both cranial and pelvic morphology wherever possible. Because of genetic and phenotypic variation, the accurate determination of an individual's age-at-death from skeletal remains is always benefitted by assessment of as many osteological features as possible (Bedford et al. 1993; Lovejoy et al. 1985, 1;). The most widely used processes for estimating age-at-death from cranial and mandibular elements require systematic characterization of dental eruption, dental wear and suture closure (Brothwell 1981; Key et al. 1994; Lovejoy et al. 1985; Steele and Bramblett 1988; White 2000; etc.). These methods are particularly useful for incomplete or poorly preserved individuals, as was observed in populations like Deerness and Buckquoy. Because of its reliable timeline, dental eruption is one of the primary methods for aging individuals from birth up to approximately twenty-three years of age. The Atlas of Tooth Development and Eruption (AlQahtani 2009) was consulted as the primary reference. Aging based on dental attrition was also employed in this study, where available (after Brothwell 1981). This method, developed by Miles (1962), Scott (1979), Smith (1984) and others (see also Gilmore and Grote 2012; Hillson 2013; Lovejoy 1985), scores teeth (primarily molars and premolars) based on levels of wear compared to expected rates of attrition, on a scale of 0 to 3 (Table 3.1). Although dental attrition has been used in numerous studies, with reliability ranging from 63% to 86% (Kim et al. 2000; Santini et al. 2017, 59), it is highly variable by population due to differences in diet. The high average attrition rates observed in the Orkney populations suggested the need for multiple age estimation techniques.

Score	*Wear*
0	None
1	Minimal
2	Moderate
3	Heavy wear, with only small amounts of surviving enamel

Table 3.1. Stages of dental attrition (Gilmore and Grote 2012; Hillson 1996; Lovejoy 1985; Miles 1962; Scott 1979; Smith 1984).

As per the standards set out by Buikstra and Ubelaker (1994, 32) and those in the BABAO standards (2004), a series of seventeen endocranial, ectocranial and palatal suture landmarks was evaluated on a scale of zero to three. “Zero” was characterized as showing no evidence of suture closure and “three” demonstrated complete fusion and obliteration of the suture (Meindl and Lovejoy 1985, 60). Meindl and Lovejoy's testing of this method showed it to be "superior to traditional pubic component systems, equal to radiographic aging of the femur and inferior to the auricular surface, functional dental wear and revised pubic systems" (Meindl and Lovejoy 1985, 65). Therefore, this method was used alongside methods involving the pelvis: the auricular surface and pubic symphysis assessment methods.

Age estimation based on morphological stages of the auricular surface and pubic symphyses was employed wherever possible. As these methods are arguably some of the most accurate (Meindl and Lovejoy 1985; Steele and Bramblett 1988, 205), they were used as primary methods of age-at-death estimation for this study. Where recordable, auricular surfaces were referenced with photos providing a progression of auricular morphology by age, as provided in Meindl and Lovejoy (1985) and referenced in Buikstra and Ubelaker (2004). A similar comparison was done for assessing pubic symphyses, using the progressions developed by Brooks and Suchey (1990), McKern and Stewart (1957) and Todd (1921). After an age range was determined by averaging both cranial and pelvic features, individuals were separated into the age categories in Table 3.2. Where age was classified as "adult", the individual was grouped into the Middle Adult category.

Category	*Age Range*
Infant	Foetus until 1 year old
Child	1-4 years
Juvenile	5-10 years
Adolescent	11-17 years
Young Adult	18-34 years
Middle Adult	35-49 years
Older Adult	50+ years

Table 3.2. Age categories used in this study.

3.1.1.2. Sex

The two most readily used elements for sex estimation are the cranium and the pelvis. In adults the pelvis is arguably the most helpful skeletal element in determining sex; however, the cranium also exhibits several sexually dimorphic traits that can provide an accurate estimation in approximately 80-90% of cases (Maat et al. 1997, 575; White 2000, 362). Female remains are generally characterized as more gracile, however, a widely accepted methodological standard for estimating sex based on five of the most sexually dimorphic craniofacial traits has been established and employed by Acsádi and Nemeskéri (1970) and Ferembach (1980, 523; see also Buikstra and Ubelaker 1994, 20). Assessment of the crania involves scoring the nuchal crest, mastoid process, supra-orbital margin, supra-orbital ridge/glabella and the mental eminence; scores range between 1 and 5, 1 being the most feminine or gracile and 5 being the most robust or masculine (Figure 3.1) (Acsádi and Nemeskéri 1970). Estimation of sex from the pelvis is considered more accurate than estimation based on the cranium alone because its role in parturition (Brothwell 1981, 62; Buikstra and Ubelaker 1994, 16; Figure 3.2). It involves assessing variations in the ventral arc, subpubic concavity, ischiopubic ramus ridge, greater sciatic notch and the depth and breadth of the preauricular sulcus (Buikstra and Ubelaker 1994; Phenice 1969;). Sexual dimorphism spikes in puberty, as hormone levels based on biological sex begin to differentiate. This means that visually estimating the sex of a pre-pubescent juvenile is much more difficult and there is no widely accepted sexing method for juveniles (Buikstra and Ubelaker 1994). Although DNA analysis examining the amelogenin gene on the X and Y chromosomes can be used to accurately differentiate between males and females where osteological techniques cannot, such methods require destructive analysis and run the risk of contamination (Götherström et al. 1997; Stone et al. 1996).

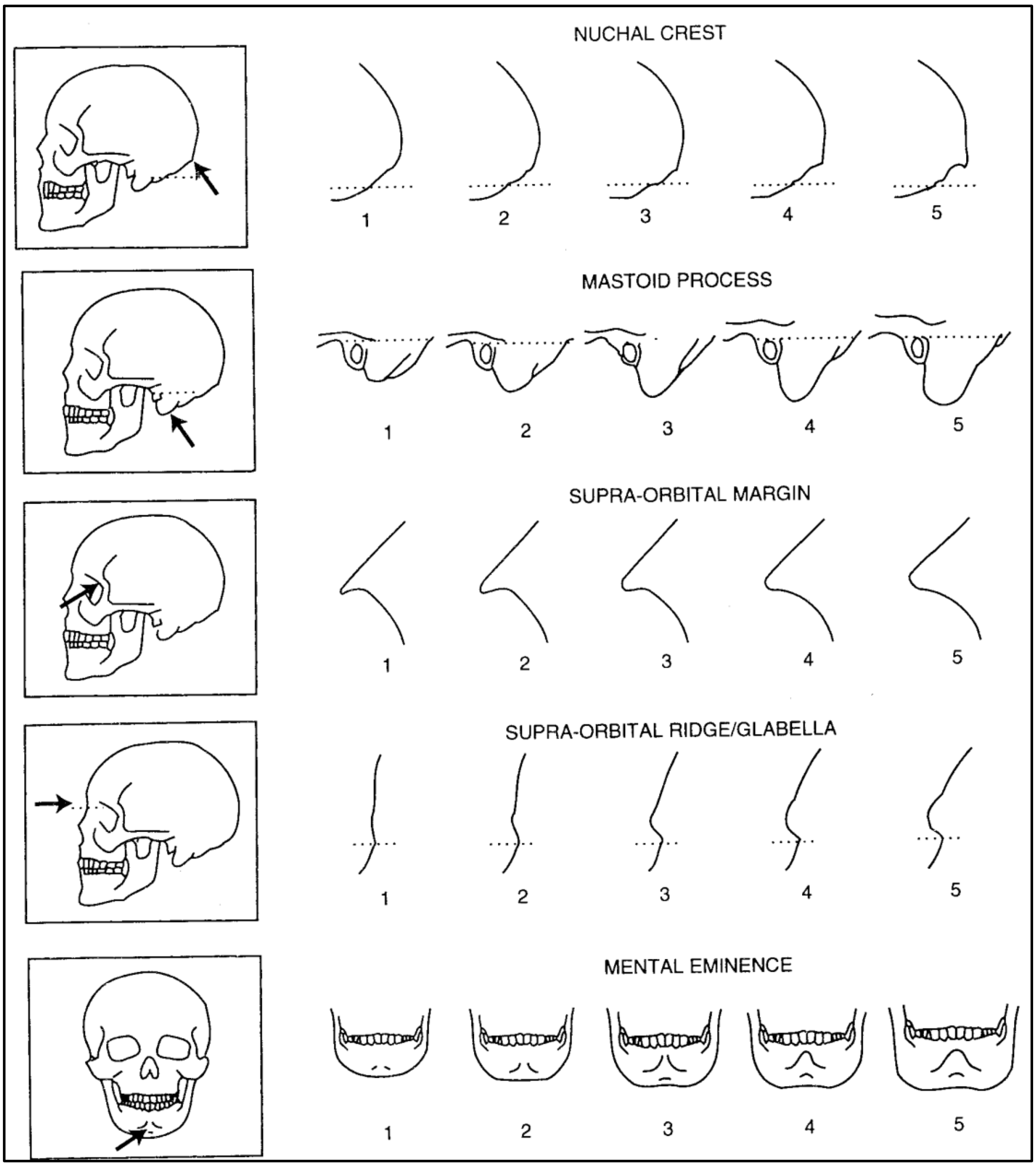

Figure 3.1. Craniofacial sexually dimorphic traits (after Acsádi and Nemeskéri 1970, Figure 16).

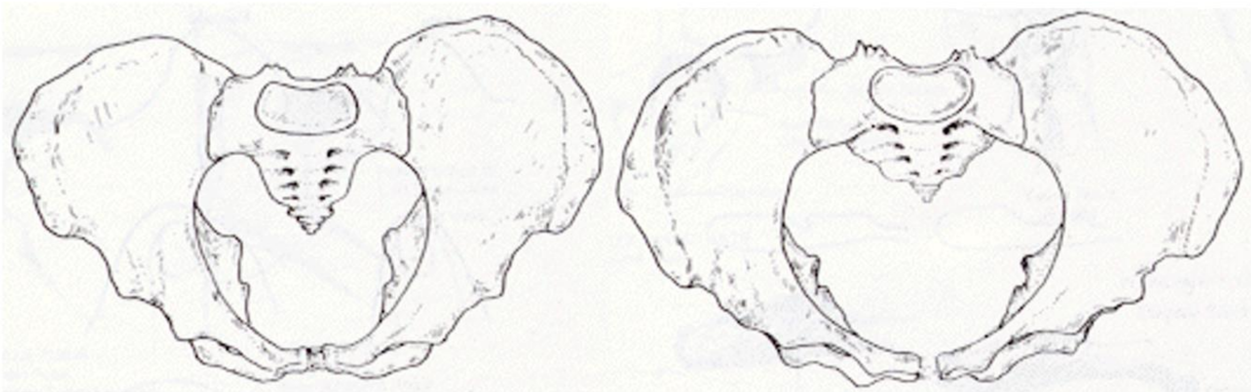

Figure 3.2. Morphological differences between the male (left) and female (right) pelvis (after Bass 1971, 206; reproduced with permission from the Missouri Archaeological Society).

3.1.2. Stature

Frequently used as a measure of population health, any observable decrease in stature means during the VA and LNP may be the result of increased nutritional stress and/or a result of increased consumption of plant proteins relative to animal proteins (Grasgruber et al. 2014; Mays 2016). An increase in stature, however, could either be indicative of improved nutrition and health and/or an influx of haplotypes associated with greater stature (Grasgruber et al. 2014). Numerous studies have found stature to be both the result of genetics and environmental conditions- including climate, health and nutritional intake (Grasguber et al. 2014; Mays 2016; Miles and Bulman 1994; Steckel 2009; Visser 1998; Waldron 1998; etc.). A study by Grasguber and colleagues (2014) found that while certain haplotypes correlated with increased stature in modern European males, stature was even more affected by the amount of animal protein an individual consumed- particularly milk and milk products, pork and fish (90). According to Mays, “subadults whose growth is retarded [due to deficient nutritional intake in relation to requirements] may, on completion of growth, fail to reach their genetic potential regarding stature… [and] has been used by social scientists as a measure of the welfare of modern human groups” (Mays 2016, 646; see also Steckel 2009). This indicates that although there may have been a genetic predisposition for significant differences in stature between Scandinavians and Orcadians, differences in the stature of Orcadian individuals from the PVP through the LNP may be largely reflective of changes access to nutritional resources and could suggest a change in the consumption of animal versus “low-quality” plant proteins, such as cereals and vegetables (Grasguber et al. 2014, 90).

Despite repeated attempts to refine Trotter and Gleser’s stature estimate formulae (including Maijanen 2009; Raxter et al. 2006; Ruff et al. 2012; Sjøvold 1990; Vercellotti et al. 2009 and nine others), a recent study testing the reliability of these various methods on English archaeological individuals by Mays (2016, 650) found the lowest standard error of estimate and lowest percentage error when using Trotter and Glesser’s regression formulae. Therefore, stature formulae were employed per methods accepted by Buikstra and Ubelaker (1994), Trotter and Gleser (1958). The equations used are provided in Table 3.3.

Element	*Male*	*Female*
Humerus	3.08Hum + 70.45 ± 4.05	3.36Hum + 57.97 ± 4.45
Radius	3.78Rad + 79.01 ± 4.32	4.74Rad + 54.93 ± 4.24
Ulna	3.7Uln + 74.05 ± 4.32	4.27Uln + 57.76 ± 4.3
Femur	2.38Fem + 61.41 ± 3.27	2.47Fem + 54.1 ±3.72
Fibula	2.68Fib + 71.78 ± 3.29	2.93Fib + 59.61 ± 3.57
Tibia	2.575Tib + 71.361 ±2.943	2.691Tib + 65.344 ± 1.974

Table 3.3. Stature formulae (after Banerjee 2015, 30 and Trotter 1958 and White 2000, 372; Table 17.2).

3.1.3. Pathology

Pathology is a large component of osteological analysis. For this study, indicators of pathology have been separated into categories of nutritional deficiencies, dental pathology, degenerative joint disease, developmental and non-specific and specific infection. Chronic imbalances in diet and nutritional intake can cause pathological susceptibility, meaning many times individuals may exhibit indicators of multiple infections or deficiencies. Differences in the prevalence of nutritional deficiencies among certain age groups or sexes imply differential access to nutritional resources such as fresh meat and fish, or differences in the amount of sunlight (vitamin D). While a rise in the prevalence of nutritional deficiencies at one site may be indicative of a site-specific problem such as disease outbreak or local socioeconomic stability, a prevalence increase across all of Orkney may indicate environmental or widespread conditions. Additionally, an increase in population density- like that which is suggested by the re-occupation of previously abandoned farmsteads and archaeobotanical evidence for increases in agricultural production (see Chapter 2)- would have typically resulted in increases in infectious diseases such as tuberculosis due to more confined living conditions and sewage issues (Roberts and Cox 2003, 229).

Osteological markers such as bone remodelling, porosity and abnormalities in texture, thickness or colour can be indicative of pathology (Ortner and Putschar 1985; Roberts and Manchester 2007;

White 2000). One of the most observed indicators of infection is periostitis, or inflammation of the cortical surface resulting in pitting and striated new bone formation (Roberts and Manchester 2007, 172). Although periostitis indicates infection, a more specific diagnosis is not typically possible solely based on its presence or even location (Roberts and Manchester 2007, 168). Together with periostitis and dental indications, porotic hyperostosis and cribra orbitalia are the most instrumental indications of overall health when relying on solely cranial evidence. A visual inspection with the aid of a 40x magnifying lens was conducted to evaluate each of the crania for any such sign of infectious, congenital, circulatory, metabolic, or neoplastic pathology. Table 3.4. presents the most common osteological markers of pathology and their aetiologies:

Osteological Markers	*Pathology*	*Type*
Cribra orbitalia	Nutritional deficiency; commonly thought to be associated with iron deficiency anaemia	Metabolic
Porotic hyperostosis	Nutritional deficiency or infection	Metabolic or infectious
Periostitis	Non-specific infections due to trauma, or nutritional deficiency	Infectious, trauma, congenital, or metabolic
Eburnation, osteophytic lipping, pitting on joint surface, or new bone formation	Osteoarthritis	Degenerative
Vertebral kyphosis	Tuberculosis, stress on vertebrae, DISH, etc.	Degenerative, metabolic, or infectious
Schmorl's nodes	Stress on vertebrae, strenuous activity	Degenerative
Cribra femora	Nutritional deficiency	Metabolic
Asymmetrical erosion of articular tissues, Martel's hooks	Gout	Metabolic
Vertebral ossification and fusion, ossification of spinal ligaments	DISH	Metabolic or degenerative
Loss of bone from phalanges, feet, or rhinomaxillary area	Leprosy	Infectious
Caries sicca, or Hutchinson's teeth/Mulberry molars	Syphilis	Infectious or congenital
Osteoporosis circumscripta, thickening of cranial vault	Paget's disease	Metabolic
Thickening of frontal bone	Hyperostosis frontalis interna; caused by diabetes or post-menopausal hormones	Metabolic
Bowing of weight-bearing long-bones, enlarged or porous epiphyses	Rickets/Osteomalacia (vitamin D deficiency)	Metabolic
Unfused sacral laminae	Spina bifida occulta	Developmental
Bone overgrowth or tumour in ear canal	External auditory exostosis/osteoma; caused by chronic exposure to cold wind and water	Neoplastic

Table 3.4. Common osteological markers of pathology (Armelagos et al. 2014; Aufderheide and Rodriguez-Martin 2005; Brickley and Ives 2008; Ortner and Putschar 1985; Roberts and Manchester 2007; Waldron 2009; Walker et al. 2009; White 2000).

3.1.3.1. Nutritional deficiencies

Significant alterations to subsistence patterns can sometimes lead to significant differences in the prevalence of nutritional deficiencies. Increased consumption of cereals and foods high in phytates and tannins, for example, has been shown to increase the prevalence of iron-deficiency anaemia in both modern and archaeological populations (Al Hasan et al. 2016; Bennike and Alexandersen 2007, 145; Hallberg 1987; Larsen et al. 2007, 25). If the VA Orcadian population consumed increased amounts of cereals as a result of a rise in agricultural production, a rise in the prevalence of iron-deficiency anaemia might be visible. Cribra orbitalia and porotic hyperostosis are two of the most observed pathologies when dealing with the cranium and both are indicators of nutritional deficiency. Porotic hyperostosis (PH) and cribra orbitalia (CO) are defined as porosities on the cranial vault (mainly parietals, frontal and occipital) and orbital roof, respectively (Walker et al. 2009, 109). More specifically, PH and CO result from the expansion of the trabecular or diploic bone and resorption of the outer table or cortical surface, leading to the diploic bone being exposed (Aufderheide and Rodriguez-Martin 2005, 348; Figure 3.3). While the exact aetiology of these conditions is unknown, they have been shown to indicate infection, nutritional deficiency, or possibly parasite infestations (Walker et al. 2009). Cribra femora (CF) is characterised as porous lesions on the anterior neck of the femur and is also referred to as Allen’s fossa (Wasterlain et al. 2018). Despite past debate on whether CF is a normal variant (non-metric trait) or evidence of nutritional deficiency, a recent study by Christine Erkelens (2017) has argued its aetiology could be related to anaemia.

Scurvy, or vitamin C deficiency, is caused by a deficit in the consumption of fresh fruits and vegetables high in ascorbic acid. It remains one of the most common, yet difficult diseases to diagnose and the difficulties in diagnosing scurvy likely mean it was far more widespread in antiquity than previously thought (Armelagos et al. 2014, 10; Roberts and Manchester 2008, 54). In this study, scurvy was only diagnosed when at least three sites of scorbutic lesions were observed (i.e., porotic hyperostosis, periodontal disease evidence of gingival haemorrhage and porosity on alae of sphenoid). In some archaeological populations, scurvy has been attributed to seasonal unavailability of food in the winter months and may have contributed to infant mortality (Maat 2004; Roberts and Manchester 2008). Scurvy results in the weakening of blood vessel walls, causing hemorrhaging particularly in large muscle groups and areas of high circulation. As hemorrhaging causes inflammation, new blood vessels are formed to alleviate excess blood and supply the site with white blood cells. The formation of these new blood vessels is aided by osteoclasts paving the way through bone, which then creates porosity of the cortical surface (Brickley and Ives 2008, 47; Brown and Ortner 2011, 198; Jacobi and Danforth 2002). The most commonly affected areas are the greater wings of the sphenoid, the parietals, the supraorbital margins and the alveolar margin (Armelagos et al. 2014, 11; Brickley and Ives 2008, 48; Ortner and Putschar 1985, 272; Roberts and Manchester 2008, 236). The diagnosis of scurvy is difficult, especially with only the cranial and mandibular elements to rely upon. An attempt was made to identify potential signs of scurvy based on cranial elements exhibiting ectocranial porosity and bone remodeling along the superior and posterior parietals, above the temporal line (bilaterally) and the superior portion of the occipital, above the nuchal crest (C. Boston pers.com., April 28, 2015; Walker et al. 2009, 109; Figure 4). In elements where the alveolar margin and/or greater wing of the sphenoid were observable, signs of pathology were evaluated.

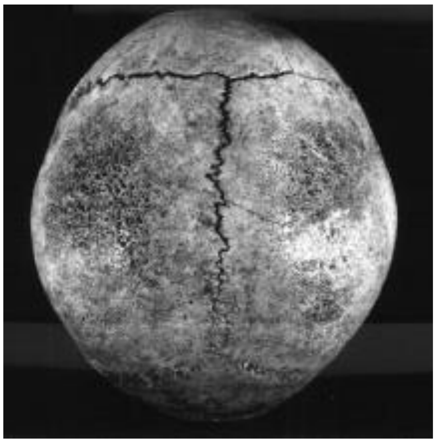

Figure 3.3. Porotic hyperostosis of parietal cortical bone due to scurvy (Jacobi and Danforth 2002, Figure 5; ©John Wiley & Sons Inc.).

Vitamin D deficiency is known as rickets in juveniles and osteomalacia in adults. The body depends on vitamin D from sources like sunlight and foods including oily fishes and fortified milk. It aids in the resorption of bone and release of calcium back into the blood for the process of new bone formation (Brickley and Ives 2008, 75). Like scurvy, it is possible that rickets was largely a seasonal condition in the Orkney Isles, developing in the winter months due to the lack of sunlight (Molleson 2005, 113). Despite its similar appearance to scurvy, "deformities of osteomalacia rarely occur [on the skull] except in young, still growing individuals" due to slower remodelling than in bones like the ribs or vertebrae (Ortner 2003, 399). CO, PH and CF can indicate a deficiency in iron, although a lack of Vitamin B6, B12, or folic acid have also been proposed as primary causes (Walker et al. 2009, 112). Iron, vitamin C and vitamin D deficiencies result in similar porotic processes, each affecting the ability of bone resorption or formation. To make diagnosis more complicated, nutritional deficiencies are rarely isolated ailments. As Stirland explained, "rickets, scurvy or iron deficiency anaemia can occur in any combination with any or all of the other diseases of malnutrition, making differential diagnoses between the three conditions difficult in an individual skeleton" (Stirland 2013).

3.1.3.2. Dentition and dental pathology

Inventory of dentition was taken for each maxilla and mandibular fragment, as well as of loose teeth found in association with the individual. This involved marking each tooth as present, lost ante-mortem (AMTL), lost post-mortem, or loose and included deciduous teeth and teeth unerupted but visible within the crypts. The stage of attrition (wear) was recorded, as well as pathologies including calculus, caries and periodontal disease or abscesses. The stage of attrition and level of calculus was recorded for each tooth and scored on a scale of 0-3, after methodology developed by Brothwell (1981) and Dawson and Brown (2013; Figure 3.4). Upon entering into the database, the average attrition and calculus levels were recorded per individual along with the number of observable teeth. The presence and size of dental caries was recorded by tooth and their location was categorized into anterior teeth (incisors and canines) or posterior teeth (premolars and molars).

Calculus (commonly known as plaque), caries (commonly known as cavities) and periodontal abscesses are three of the most observed dental pathologies. Dental pathology offers insight into dietary variation or stress and can complement interpretations of skeletal indicators of pathology (Roberts and Manchester 2007, 63). A high level of dental calculus indicates a diet dependent on proteins, while a high frequency of caries indicates a diet higher in carbohydrates like agricultural produce (Hillson 2001, 250; Lieverse 1999, 219). If an increase in agricultural produce suggested by the archaeobotanical evidence led to increased consumption of cereals, an increase in dental caries is probable. Periodontal disease, however, can result from a diet high in fats and proteins (calculus causes irritation of the gums). If there is a transition to consuming more marine protein (lower in fat) rather than terrestrial protein (higher in fat), there may be a decline in periodontal disease and AMTL (Blasco-Baque et al. 2012; Najeeb et al. 2016). Additionally, the fats in fish are predominantly Omega-3, known to be beneficial for periodontal health (*ibid.*; Kruse et al. 2020). Table 3.4. presents the most common indicators of dental pathology and their aetiologies.

Evidence	Aetiology
Calculus	Diet high in proteins leading to bacterial infection
Caries	Diet high in carbohydrates
Linear enamel hypoplasia (LEH)	Period of developmental physical or extreme psychological stress
Abscess	Bacterial infection
Periodontal Disease	Gingivitis, calculus and bacterial infection caused by food, high-fat diet
Ante-mortem Tooth Loss (AMTL)	Chronic Periodontitis, caries and abscesses

Table 3.5. Dental pathologies and their aetiologies (Aufderheide and Rodriguez-Martin 2005; Ortner and Putschar 1985; Roberts and Manchester 2007).

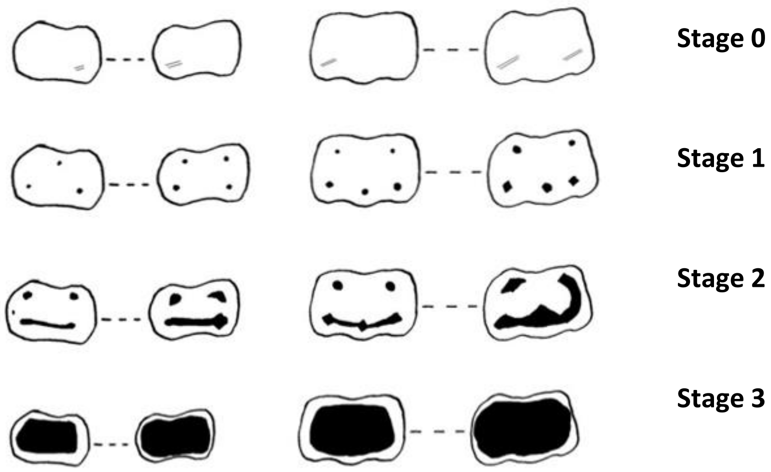

Figure 3.4. Diagram showing varying stages of dental attrition (adapted from Dawson and Brown 2013, 437; Figure 2; ©John Wiley & Sons Inc.).

3.1.3.3. Developmental stress

3.1.3.3.1. Dental enamel hypoplasias

Dental enamel hypoplasias (DEHs) are deformities in the enamel due to arrested growth caused by physical or extreme psychological stress (Alfonso 2005, 394; Goodman et al. 1991; Ribot and Roberts 1996). The presence of DEHs and a description of the location(s) were recorded, per Moore and Corbett (1971). While linear enamel hypoplasias (LEHs) are most common, pitting or grooves can also be observed. All three of these manifestations are believed to have similar aetiologies (Ribot and Roberts 1996, 68). Since tooth enamel does not remodel through life as bone does, any periods of stress experienced by an individual during the development of the tooth that result in the formation of a DEH will be observable throughout adulthood (unless eroded by attrition or obscured by calculus). By employing the method developed by Reid and Dean (2000), the age at which the DEH formed was estimated to infer the causes of underlying stressors (Figure 3.5). For example, multiple studies have found that the nutritional and physical stress undergone by infants during weaning (between the ages of 1.5 and 3.5 years old) corresponds with the appearances of LEHs during this age range. Another period of high DEH prevalence is between the ages of 5 and 7.5, which corresponds to a period of common childhood illness (Goodman and Rose 1991, 283; Goodman and Song 1999; Malley 2004, 20; Moggi-Cecchi et al. 1994; Wood 1996). The timing and frequency of DEH formation can be compared between individuals and between sites throughout Orkney to discern whether certain age groups or sexes were undergoing more frequent or intense periods of nutritional or physical stress. Timing of DEH formation can also be used alongisde dietary stable isotope values from sequential dentine samples to provide evidence for the cause of DEH formation- whether indicative of weaning or periods of nutritional stress and dietary change during development (further described in section 3.2.2). As studies like that by Berry (1985) have shown, however, not all episodes of stress cause DEHs in each person. Events necessary to cause the manifestation of DEHs can differ between populations (Aufderheide and Rodriguez-Martin 2005, 407). Furthermore, dental attrition can make identification of DEHs early in tooth development impossible.

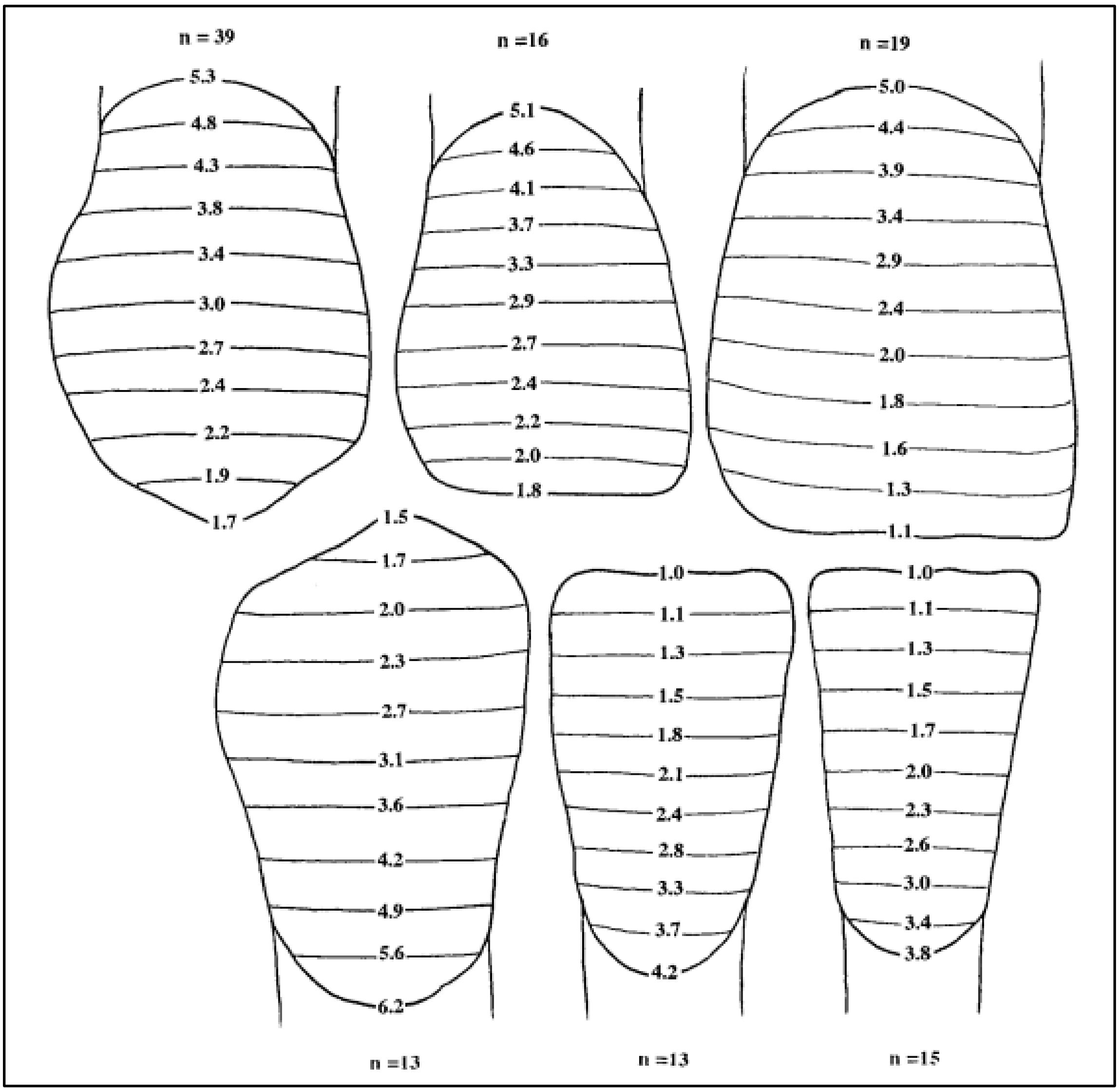

Figure 3.5. Timing of LEHs (Reid and Deen 2000, 138; Figure 1; ©John Wiley & Sons Inc.).

3.1.3.3.2. Harris lines

Harris lines are lines of arrested growth during the development of the individual (Alfonso 2005, 393; White 2000, 382). Much like DEHs, Harris Lines indicate a period of physical or extreme psychological stress. Although the exact causes are debatable, Harris Lines contribute to an overall picture of health and stress. The presence of Harris lines was recorded in a sample of the population using a portable X-ray machine. Radiographs were then produced digitally for analysis.

3.1.3.4. Evidence of load-bearing and occupational stress markers

As detailed in Chapter 2, there is archaeological evidence for an increase in deep-sea fishing, the expansion of arable land and crop diversification in the VA and LNP. A significant deviation in subsistence would likely have affected the amount of manual labour required and potentially changed the types of physical activities. For example, carrying heavier loads because of increased agricultural production may have led to an increased prevalence of platymeria/platycnemia or vertebral crush fractures. Additionally, the shift in subsistence away from self-sustaining farmsteads to a system of specialised farmstead sites like Pool and Buckquoy supporting high-status sites (see above, Chapter 2) would likely result in the differential prevalence of load-bearing and occupational stress indicators between individuals buried at different sites. This section details the methods used to score evidence of changes in pathological indicators that are associated with manual labour or arduous physical activity. Evidence of heavy load-bearing in this study is limited to a specific set of pathological indicators including platymeria and platycnemia, osteoarthritis (OA, particularly of the weight-bearing joints including the spine, shoulders, hips and knees), osteochondritis dissecans and occupational or non-violent trauma including, crush or wedge fractures, as well os acromiale.

3.1.3.4.1. Platymeria and platycnemia

Femoral platymeria and tibial platycnemia refer to the anterior-posterior flattening of the femur or the lateral flattening of the tibia, respectively and are likely associated with habitual activities such as sea fishing, squatting or lifting heavy objects from squatting position (Dutt 2012, 49; Lucas 2007, 337). Platymeria is thought to result from chronic flexion, torsion and compression of the upper legs, primarily involving the vastus lateralis, medialis and intermedius (Cunningham et al. 2016, 390; Lovejoy et al. 1976, 491). Likewise, platycnemia refers to the anteroposterior flattening of the tibia involving strenuous use of the tibialis posterior muscle, used extensively for walking or running on hilly terrain (Bloomfield Moore 1999, 179). Where possible, the platymeric and platycnemic indices were calculated following Larsen (2002, 222):

Platymeric index: (anteroposterior diameter/ mediolateral diameter) x 100
Platycnemic index: (mediolateral diameter /anteroposterior diameter) x 100

Individuals with platymeric indices less than or equal to 84.9 are considered platymeric (Brothwell 1981, 88; McIlvaine and Schepartz 2015, 80) and individuals with a platycnemic index between 55 and 62.9 were considered platycnemic (Brothwell 1981, 89). Unfortunately, platymeric and platycnemic indices are not a straightforward sign of physical activity across populations, as they have been found to vary significantly by ancestry (*ibid.*; Tallman and Winburn 2015; Wescott 2005; 2008). Significant differences have also been found between sexes, some like Ruff (1987) suggesting the disparity in indices between sexes may be rooted in a sex-based division of labour.

3.1.3.4.2. Osteoarthritis

Osteoarthritis (OA) is the most common form of degenerative joint disease (DJD) and is characterized by eburnation and/or enthesopathy (pitting or lipping) of a joint surface (Aufderheide and Rodriguez-Martinez 2005, 93; Roberts et al. 2007). Multiple studies have found that repetitive heavy use of the joint is the primary cause of OA, especially in the knee and hip joints (Capasso et al. 1998; Harris and Coggon 2015; Larsen 1995, 200; Palmer 2012; Thelin et al. 2004). If increased agricultural production and the expansion of cultivated land (as discussed in Chapter 2) led to a larger workforce for manual labour, a larger proportion of the population is likely to exhibit OA of weight-bearing joints (knees, hips, verts, etc.). Interestingly, some studies on North American populations like that at Amelia Island and the southeastern United States have shown a negative correlation between OA and agriculture, with frequencies declining from the hunter-gatherers (Larsen 1999, 200; Larsen et al. 2007). OA has been directly linked with physical stress and used as an indicator of habitual activity in prehistoric populations (Bridges 1992, 68), however, it is not only common with advanced age but there is also evidence of a hereditary predisposition to develop OA later in life (Weiss and Jurmain 2007). For each individual, each joint surface was examined for osteoarthritic changes. For a joint to be marked as observable for OA, at least one joint surface needed to be preserved. For example, if the right proximal humeral joint surface was the only observable joint surface of the right shoulder and it displayed no evidence of OA, the right shoulder was marked as not exhibiting OA. In the interest of time, OA was only recorded as present, absent or not observable.

3.1.3.4.3. Osteochondritis dissecans

Osteochondritis dissecans (OD) is a lesion that forms when cartilage and bone fracture due to lack of blood flow and repetitive stress on the joint- typically the knee, elbow, ankle or shoulder joints (*ibid.,* 154). The loosening and dislocation of bone from the joint surface results in pain, swelling, crackling during movement or locking of the joint (Mayo Clinic 2019). It is also possible, however, that osteochondritis has a genetic component that would make individuals more likely to develop lesions (Mayo Clinic 2019; Nordqvist 2017). Os acromiale is the result of fusion not occurring between the acromion process and the scapula due to continuous strenuous use of the supraspinatus muscle. The condition is associated with tearing of the rotator cuff from repeated heavy loading (Atoun et al. 2016; Boehm et al. 2005; Capasso et al. 1998, 60; Park et al. 1994; however, see Ouellette et al. 2007 for opposing view). Os acromiale was marked as either present, absent or not observable for each individual.

3.1.3.4.4. Occupational or non-violent trauma

Trauma was first classified as either ante-mortem, peri-mortem or post-mortem (Galloway et al. 2013; Walker 2001). The identification of trauma and differentiation between peri- and post-mortem breakage is fundamental to osteological analysis. The differences are not always abundantly clear, however. Instances of trauma were identified by assessing indications of healing, internal or external bone beveling, coloration and texture of the fracture, etc.; as per methodology explained by Wedel and Galloway (2013, 50). Trauma can be the result of either deliberate or accidental activities, due to an array of causes including interpersonal violence or surgery, or as the result of an occupational hazard (Waldron 2009, 138). In this study, trauma was classified as either violent or likely non-violent. Non-violent trauma includes dislocations as well as stress, crush, wedge and most spiral fractures, which are commonly the result of heavy physical strain and used as evidence of load-bearing or occupational stress. Stress or crush fracture types commonly affect the vertebral bodies and are caused by carrying or lifting heavy objects (Martin and McCulloch 1998; Waldron 2009, 152). Other common types of occupational or non-violent fractures are listed in Table 3.6. below.

Fracture site	*Activity producing fracture*
Distal humerus	Throwing
Spinous process of lower cervical or upper thoracic vertebrae	Shovelling
Proximal fibula	Jumping
Calcaneus	Jumping; prolonged standing
Metatarsal shafts	Prolonged standing
Ribs	Carrying heavy objects, prolonged coughing
Sesamoid bones of foot	Prolonged standing

Table 3.6. Common stress fractures by site and activity (after Waldron 2009, 152; Table 8.7).

When trauma occurs at these attachment sites, it commonly results in enthesopathy, pathological bone reactions (as osteophytic or osteolytic activity) at the site of ligament or tendon attachment (Mariotti et al. 2004). While it is not usually possible to identify the exact activity that is the culprit, good preservation of the skeleton can provide clues as to what movements were being performed and what muscle groups were employed. For example, lifting heavy loads not only requires arm strength but puts stress on vertebrae and various joint surfaces. Patterns in the distribution and frequency of enthesopathies in populations can provide us an idea of large-scale shifts in physical activity and the overall quality of life (*ibid.*, 145). OA itself is pathological and can either be primary or secondary- a condition developing in response to trauma. Both forms of OA were included as evidence of occupational stress. For each individual, each joint surface was examined for osteoarthritic changes as described above.

3.1.3.4.5. Activity-related non-metric traits

In addition to trauma, two activity-related non-metric traits were evaluated in this study: squatting facets and mandibular tori. Non-metric traits are typically asymptomatic, normal variations in the morphology of the human skeleton. While the aetiology of most is unclear, some are thought to be genetically dependent while others are environmentally dependent and some are a combination of the two (Berry and Berry 1967; Brasili et al. 1999; Buikstra and Ubelaker 1994, 85; Brothwell 1981, 91; Finnegan 1978). Although there are hundreds of non-metric trains, this study focused specifically on the two most prominent activity-related or heritable traits relevant to the Orkney populations based on previous studies: squatting facets and mandibular tori (Hauser and De Stefano 1989; Lorimer 1998; Molleson 2005). Each was scored as present, absent or not observable.

3.1.3.5. Non-specific and specific infections

Any signs of non-specific infection, specific diseases or developmental abnormalities were recorded. The ability to diagnose specific diseases or infections is rare when dealing with fragmentary remains, however, any pathognomonic indications of leprosy, tuberculosis, etc. were recorded. These included instances of developmental abnormalities such as cranial asymmetry or deformity, irregularities in suture closure and dental deformation. As shown by Roberts and Manchester (2007, 46), malformations or abnormalities are seldom isolated occurrences; the presence of a malformation is usually the result of a larger pathological issue. Non-specific infections are observable as periostitis, osteitis or osteomyelitis. The presence and distribution of any pathological lesions were recorded.

3.1.4. Violent trauma

One of the more long-standing debates in VA archaeology is the nature of the interaction between Norse immigrants and native peoples. If a narrative of the violent decimation of the native population is to be believed, osteological evidence is required. Yet does evidence of widespread violent trauma exist from VA Orkney? To address this question, traumatic lesions were examined from the available collections. Violent trauma included sharp force trauma likely the result of blades or axes, as well as blunt force breaks to multiple ribs, nasal fractures, fractured teeth, zygomatics, frontals or parietals, as well as fractures of the distal radius and/or ulna, commonly referred to as "parry" or defensive fractures (Berryman and Haun 1996; Brink 1998; Crandall et al. 2003; McNulty 2016; Waldron 2009; Walker 2001; Wedel and Galloway 2013). In some cases, it was not possible to state definitively whether the trauma resulted from interpersonal violence. While an increase in trauma could be indicative of increased interpersonal violence, trauma could also result from accidents such as slips and falls and may not have resulted directly from violence. Interpretations of changes in the frequency of trauma can therefore vary widely depending on the type of trauma. For example, a significant increase in trauma during the Viking Age could be the result of Viking raids leading to a spike in confrontation and violence. It is possible, however, that an increase in non-violent trauma could be the result of accidental injuries.

3.2. Isotopes indicative of diet and mobility

In addition to osteological analysis, carbon ($\delta^{13}C$), nitrogen ($\delta^{15}N$), strontium ($^{87}Sr/^{86}Sr$) and oxygen ($\delta^{18}O$) isotopic analysis from bone collagen and dental enamel and dentine will be undertaken. Carbon and nitrogen from bone collagen provide evidence of protein dietary intake, especially regarding the ratio of marine to C3 terrestrial resource consumption. If there was an increase in marine resource consumption at the turn of the millennium, as has been evidenced by fishbone analysis and previous stable isotope data (see Chapter 2), the result will be increased carbon and nitrogen isotope values. In addition, differences in dietary isotope values between sexes were investigated, as Barrett and colleagues (2000b) found significantly higher carbon and nitrogen values among males than females in the VA, indicative of sex-based differences in diet. The inclusion of more sites and a larger dataset should serve either to substantiate or discount their previous findings. Finally, Barrett (2003, 90) asserts that fish consumption was likely viewed as low-status in VA Orkney. Whether or not that can be substantiated using osteological evidence has here been tested by comparing dietary isotope values between individuals in richly furnished and unfurnished graves and individuals with and without osteological indicators of pathology.

Strontium (Sr) and oxygen (O) isotopes from teeth indicate whether an individual lived in Orkney for most of their lives or if they had recently moved from a region with differing a geological substrate. Using the results of Sr and O isotope analysis, the question of whether ethnic identity was grounded in direct Scandinavian origin (first-generation immigrants) was tested by analysing the isotope signals of individuals with and without Scandinavian grave goods. Additionally, evidence of pathology, stature and trauma were compared between “local” and “non-local” individuals to determine if individuals with Scandinavian origin may have been considered higher status. Finally, dietary isotope values were compared between individuals with different mobility isotope signals to determine whether non-locals and locals consumed similar sources of protein and if a preference for marine proteins may have been cultural (as suggested by Barrett et al. 2001).

3.2.1. Carbon and nitrogen isotopes as indicators of diet

Bone collagen offers an average of stable isotope values over the last 10-30 years of an individual’s life (depending on the bone sampled and the age of the individual) and provides a broad profile of diet (Hedges et al. 2007, 815). Bone collagen samples have been taken from a rib or long bone, where available, as detailed below in section 3.2.4. In addition to bone collagen analysis, enamel and sequential dentine analyses provide for more detailed timelines for changes in diet throughout an individual’s development and are discussed further below (Balasse 2002; Buckberry et al. 2014, 421; Hedges et al. 2007). The distinction between short- and long-term dietary changes could contribute substantially to understanding what could have caused these changes in diet. For example, while environmental factors like sand-blows may have contributed to crop failure and resulted in a short-term reliance on other food sources (such as marine protein), a large-scale economic shift would have been more likely to cause long-term dietary changes. The osteological data in the relevant site reports (particularly analysis of kill-off patterns) provide clues to how terrestrial animal resources were being consumed or utilised for secondary products like milk or fat.

While the faunal osteology analysis provides information on what animals are being exploited and for what purposes, the isotopic values provide a baseline for diet resources. If fluctuations in human bone collagen $\delta^{15}N$ and $\delta^{13}C$ values are attributed to a change in husbandry practices (such as increased manuring) rather than a change in diet, these fluctuations should be reflected in the bone collagen of livestock remains. It is therefore imperative to incorporate faunal isotope data from nearby sites into an interpretation of human isotope data. Faunal assemblages from Pool (Bond 2007), Quoygrew (Milner et al. 2007), Newark Bay (Richards et al. 2006), Sanday (Nicholson 2007), Buckquoy (Noddle 1976), Skaill at Deerness (Noddle 1997), Mine Howe and Earl's Bu (Mainland 2016) were used as references for dietary isotope values when interpreting the human populations. Isotope values for an array of fish remains from Orcadian sites have been analysed and compiled by Barrett and colleagues (2008; 2011) and Jones and Mulville have collated faunal isotopic and zooarchaeological data from Iron Age sites in Orkney including Skaill, Pool and Buckquoy (Jones and Mulville 2015).

While it may be difficult to discern differences in terrestrial animal consumption using stable isotopes, a diet heavy in omnivorous animals (i.e., pigs) should cause higher $\delta^{15}N$ values than a diet reliant on strictly herbivorous animals (Lai 2008, 280). Likewise, $\delta^{15}N$ is generally higher in marine fish than in freshwater fish (though this cannot be said for particular carnivorous fish like pike), while $\delta^{13}C$ values are generally lower in freshwater fish (Schoeninger and DeNiro 1984, 632; France

1994, 205; Hobson 2007; Mays and Beavan 2012, 869-70). Understanding agricultural trends may thus provide insights into changes in isotopic values. While higher $\delta^{15}N$ values are usually interpreted as reflecting a diet high in marine resource consumption, other factors could contribute to this enrichment (Dolphin et al. 2013, 1778). An experimental study by Amy Bogaard and colleagues (2007) showed that consuming manured cereals significantly raised $\delta^{15}N$ isotope values. Their study suggests that manuring may have contributed to higher $\delta^{15}N$ values found in Neolithic populations in Scotland and Denmark, which had been interpreted as reflecting a diet high in animal protein (Bogaard et al. 2007, 340). A more recent study by Bogaard and colleagues found that "in the absence of crop nitrogen isotope determinations, paleodietary reconstructions based on $\delta^{15}N$ offsets between human and herbivore collagen at early farming sites in central and Northwest Europe have likely overestimated consumption of animal protein…" (Bogaard et al. 2013, 12589). Though the use of seaweed and manure to improve arability of land in northern Scotland likely began in (or prior to) the Iron Age, "the most extensive expression of this process can be tentatively dated to the Middle Ages" (Barrett et al. 2000b, 20). Although difficult to detect or diagnose, another factor that could affect $\delta^{15}N$ values is nutritional stress resulting in the loss of muscle mass, trauma and starvation (Fuller et al. 2005; Olsen et al. 2010). This is merely one example that illustrates the importance of considering osteological findings when interpreting stable isotope data. Being able to correlate osteologically manifested markers of nutritional stress with isotopic values will improve our ability to form reliable interpretations of diachronic or regional isotopic fluctuations.

3.2.2. Sequential dentine micro-sampling

Dentine develops in a "ring-like manner" and leaves "growth lines" as it develops, which are visible under a microscope (Kang et al. 2004, 1608). While the roots of the first molars finish developing between the ages of twelve and thirteen, the second molars typically finish between ages fourteen and sixteen. Third molars are more variable, but typically finish developing at around eighteen years of age (AlQahtani 2009; American Academy of Paediatric Dentistry 2003; Figure 3.6). Between ten and fifteen samples will be taken from each tooth: from the enamel-dentine junction down to the inferior tip of the root. This will provide a high-resolution diet profile for the individual throughout tooth development. Where possible, a first, second and third molar will be taken from the same individual to reconstruct a profile of diet from childhood into adulthood. If there was a significant difference in diet between males and females in the VA, this should help identify at what point an individual began eating greater amounts of marine foods, or at what age dietary patterns diverged between male and female individuals. If profiles suggest diets diverged between Viking Age male and female individuals once they reached puberty, this may imply cultural ideas of gender or sex-based division of labour.

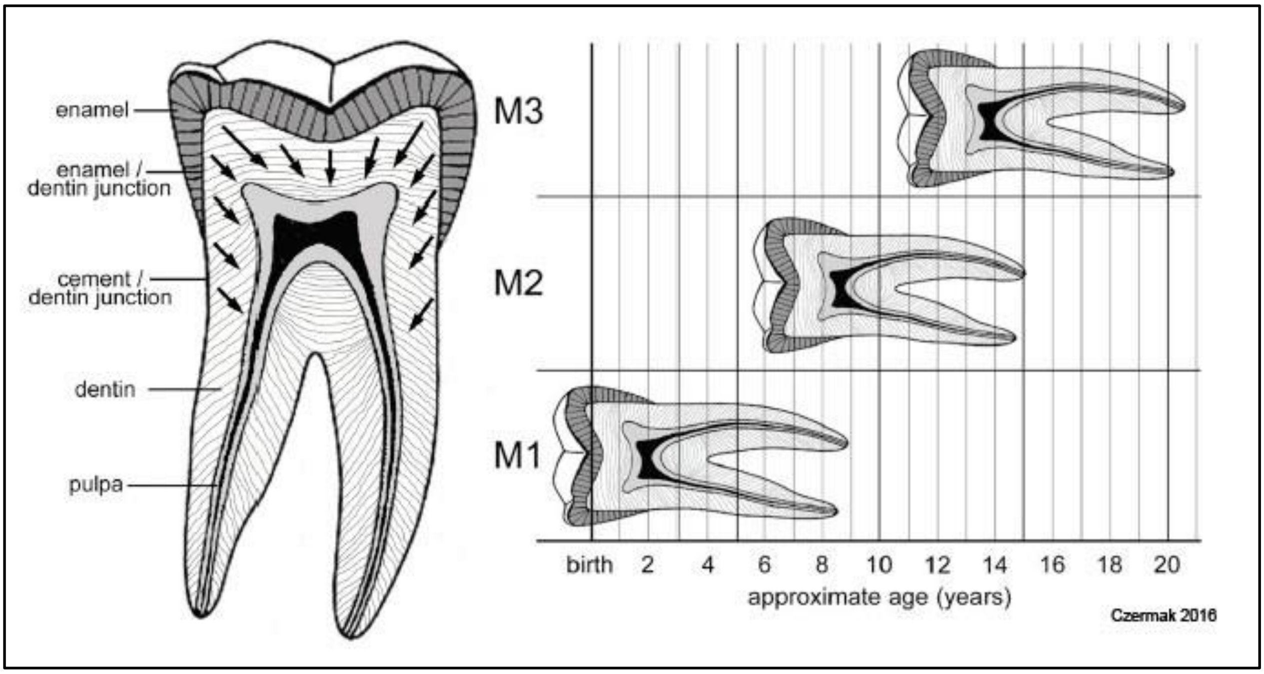

Figure 3.6. Diagram of molar anatomy and chronology of development for first, second and third molars (Czermak 2020).

3.2.3. Strontium and oxygen isotopes as indicators of mobility

Mapped strontium values provide a baseline for what can be expected from individuals from Orkney compared with other parts of Europe and Scandinavia. The differences in underlying geology provide variations in strontium isotope values. Scotland's geology means that the highest value for Scottish individuals has been recorded as 0.7165, while the maximum strontium isotope for archaeological humans excavated from England and Wales is 0.7142 (Evans et al. 2012, 756). While modern Orcadian plants have produced isotopes between 0.7092 and 0.7100, in coastal areas, sea-spray causes strontium values to average with that of seawater (0.7092), making local values either slightly lower or higher (Montgomery et al. 2014; Price and Naumann 2015). This makes it sometimes difficult or even impossible to tease out locals from non-locals in coastal environments. While it is not yet possible to demonstrate conclusively that an individual is from a specific region (e.g., Scandinavia), it is possible to determine whether the individual is likely to be of either local or non-local origin. Oxygen isotope ratios, reflective of water source and rainfall, have been mapped from modern water sources throughout the UK. The mean $\delta^{18}O_{dw}$ from Orkney is -5.8 ± 1.0‰ (2SD), which would likely result in mean $\delta^{18}O_p$ values of between 17.2‰ and 19.2‰ (with 95% confidence; Evans et al. 2012, 759). However, the regression equation used to convert oxygen values from carbonate to phosphate has a margin of error of ± 0.56‰ (per Chenery et al. 2012). Because of the additional error margins involved when converting $\delta^{18}O_p$ to $\delta^{18}O_{dw,}$ $\delta^{18}O_p$ (between ± 1.0‰ and ± 3.5‰, Pollard et al. 2011), results in this study will not be converted to drinking water but compared with $\delta^{18}O_p$ from referenced studies. While one sample was taken per individual for bone collagen carbon and nitrogen analysis and one sample for enamel strontium and oxygen analysis, several dentine samples were taken per tooth to create a 'life history' of carbon and nitrogen values.

3.2.4. Sample selection, preparation and collagen extraction procedures

Photographs were taken before and after sampling to document each of the bone specimens. Analysis was conducted in a two-stage approach. In the first stage, individuals were sampled for bone collagen. A maximum of 1 gram of skeletal material was extracted from each specimen (preferably a rib, femur or other long bone and in areas of pre-existing breaks) using a hand-held Dremel, which allowed for $\delta^{13}C$ and $\delta^{15}N$ measurements to be made in duplicate and triplicate where necessary. Teeth were selected based on preservation and third molars were preferred. Each tooth was photographed 20-30 times to capture tooth morphology in full prior to destruction and so that a 3D model could be generated. Laboratory methods followed the standard laboratory procedures of the Research Laboratory for Archaeology and the History of Art at the University of Oxford, Vrije Universiteit Brussel and Université Libre de Bruxelles.

3.2.4.1. Sample selection

Sampling locations were decided upon as being in areas that minimised visible damage and avoided osteological or pathological markers. Specimens were sampled with great care to avoid any diagnostic features or osteological landmarks. Preserving the remains for osteological analysis is equally important to sampling and special care was taken to minimize the effects of destructive sampling. Approximately 150 individuals from these collections were sampled for bone collagen, 69 for enamel and 40 for sequential dentine. Individuals that had already been sampled for both $\delta^{13}C$ and $\delta^{15}N$ in previous studies were not re-sampled. The second stage of analysis was to identify individuals for tooth enamel and sequential dentine sampling. Identifying the individuals most suitable for this phase depended on the results of the bone collagen analysis. Where a suitable molar was well preserved, one tooth per selected individual (preferably M3) was selected. In cases of exceptional preservation, a first, second and third molar was extracted from the same individual, to provide a chronology of diet from birth through adolescence and early adulthood. Each tooth sampled was photographed prior to analysis and sectioning and half of the tooth was returned to the Orkney Museum for future research. In addition, tooth moulds were created using dentistry-grade Coltene President Putty and high-resolution moulds of the crowns were created (for potential future microwear analysis) using the same putty along with light body a-silicon wash material. Per methodology established by Dr. Andrea Czermak (Post-doctoral researcher at the University of Oxford) and under her instruction, I demineralized and sequentially sampled each tooth (Czermak 2020). I initially estimated that a total of eight to ten transverse dentine samples would be possible per tooth to provide a resolution of nine to twelve-month increments (Beaumont et al. 2012), however, I was able to take an average of 15 transverse sections per tooth and an average of 4 transverse sections of the crown alone. This number of transverse sections provides a resolution of approximately five to seven months per sample. A total of 70 teeth have been collected for sampling, 30 of which have been demineralised and sectioned.

3.2.4.2. Sample preparation and collagen extraction

3.2.4.2.1. Bone collagen (carbon and nitrogen isotopes)

Approximately one gram of bone material from each individual was weighed, put in test tubes and demineralised over two weeks. Demineralisation was done by letting the sample sit in 0.5mole hydrochloric acid (HCl). The acid in each test tube was changed every two to three days. Once samples were demineralised, they were soaked in de-ionised H_2O for three to four days. The H^2O in each tube was changed three times to ensure that all acid had been released from the bone. To extract the collagen from the bone samples, each tube was filled 2/3 full of hydrogen phosphide (pH^3), covered with aluminium foil and heated to 65-70 degrees for 48 hours. Following this process, the remaining liquid from each tube was transferred to a transport tube, topped with parafilm and put in the freezer for two to three days. Once samples were completely frozen, they were transferred to the freeze drier (approximately -35^oC), where they remained for another two to three days, until they were completely dried. Samples were then weighed to 1g, within 15%. Alanine, cow and seal were used as standards for calibration and drift correction of the Sercon Europa EA-GSL mass spectrometer (also weighed within 15% of 1g) and provided an analytical error of ±0.2‰.

3.2.4.2.2. Tooth dentine (carbon and nitrogen stable isotopes)

For sequential dentine sampling, the same process of demineralisation that was used for the bone was then followed for demineralisation of the teeth however, gelatinization with pH^3 was not conducted. Demineralised teeth were then sliced horizontally using a scalpel and then put in the freezer for 1-2 days. Once they were completely frozen, they were put in the freeze drier overnight. Each dried sample was weighed into a 3.2mm or 4mm tin capsule. Any sample/tooth section weighing less than 0.3g was combined with the next section to achieve the most accurate results possible. The samples were then sorted by weight. Samples within 30% of each other were grouped into the same mass spectrometer run. Again, Alanine, cow and seal were used as standards for calibration and drift correction of the Sercon Europa EA-GSL mass spectrometer (weighed within 30% of the sample weights for each run) and provided an analytical error of ±0.2‰.

3.2.4.2.3. Tooth enamel (strontium and oxygen isotopes)

Prior to demineralization, most of the teeth (69) were sampled for strontium and oxygen analysis. This process involved first shot-blasting the tooth to remove any surface debris and calculus, then using a burr-tipped Dremel to grind 2-3 µm of enamel from the surface of the tooth to remove material vulnerable to diagenetic change before enamel powder for sampling was collected. Enamel samples were taken from the cusp down to the cemento-enamel junction and approximately 30mg of powder enamel was collected from each tooth for both strontium and oxygen analysis. Strontium and oxygen samples were then taken to Dr. Christophe Snoeck at the isotope laboratory at the Vrije Universiteit Brussel Université Libre de Bruxelles for analysis. As per laboratory protocols set forth by Vrije Universiteit Brussel and Université Libre de Bruxelles, oxygen and carbonate samples (approximately 5-10mg of enamel) were leached using calcium acetace 1M acetic acid for 30 minutes, shaken and put in a centrifuge for 5 minutes. The acid was then removed and samples were rinsed with deionised H2o three times, each time shaken and put in centrifuge for 5 minutes. After the three H_2O washes were completed, the liquid was pipetted out and the sample was put in an oven to dry overnight at 60^o Celsius. The samples were then run on a gas isotope ratio mass spectrometer (IRMS).

Strontium samples (approximately 15-20mg of enamel) were pre-treated with 0.1M acetic acid and left to sit for 30 minutes, then shaken and put in a centrifuge for 5 minutes. After sitting in acid, samples were rinsed with deionised H_2O three times, each time shaken and put in a centrifuge for 5 minutes before the liquid was pipetted out and the sample was put in an oven to dry overnight at 60 degrees Celsius. Strontium samples were then weighed, moved to Savillex containers and taken to a clean lab. Each sample was diluted with 2.5ml of HNO2 2M and put in an ultrasound bath for 30 minutes. Then 0.5ml of each sample was pipetted into a separate tube for Sr concentration. Columns for strontium filtration were prepared using between 80-90mg SR Resin- B per column. Each column was flushed with 0.5ml HNO3 3M four times. Then, 1ml of diluted sample was put into the column, one sample per column, twice. To rinse the sample, 1ml of HNO3 2M was then put through each column, once. Following that, three rinses of 1ml HNO3 7M were pipetted into each column. Finally, one rinse with 1ml HNO3 3M was pipetted into each column. To extract the Sr from each column, the Savillex were replaced beneath the column with their respective samples and 1ml of HNO3 0.05M was pipetted into each column, twice. Samples were left to dry on a heating block overnight. Strontium isotopes were then measured on a Nu Instrument MC-ICP-MS at the Université Libre de Bruxelles, by Dr. Snoeck (see Snoeck et al. 2015 for more details). Both oxygen and strontium concentrations were run in duplicate and the means calculated. NBS 987 (0.710250) was used as a standard for the normalization of strontium results, measured using the double bracketing method (Weis et al. 2006), while NBS 19 was used to normalise oxygen results, with an analytical precision of within 0.05‰.

3.3. Burial practices, site types and archaeological evidence of subsistence practices

This section provides the methodology used for comparing the prevalence of osteological indicators of diet and stress and isotope evidence of diet and mobility with archaeological evidence for ethnicity, social status, gender and social roles as interpreted by grave inclusions, burial practices and archaeological evidence of subsistence.

3.3.1. Burial practices and osteological analysis

The VA saw substantial changes in burial practices throughout Orkney, some religious and some likely to be more culturally driven, as detailed in Chapter 2. Archaeological evidence for some of the earliest churches in Orkney date to the tenth century (Brend and Gibbon 2016) and is closely followed by the tradition of churchyard burials at sites like Newark Bay and Deerness. The tenth-century also saw burial at non-churchyard cemeteries like Pierowall and Westness, as well isolated burials like those at Buckquoy, Scar and Skara Brae. By the LNP all the burials (aside from one female at Westness) were in cemeteries with known churches (Newark Bay and Deerness) or in cemeteries that likely had associated churches, but where the remains have not yet been uncovered through archaeological investigation (Skaill House and Bu of Cairston). While cist burials were most common in the PVP, they continue through the VA and LNP, declining in fashion through time among both males and females (p=0.000). There was no significant difference in the prevalence of cist burials among females or males in any of the phases (p=0.121, 0.577 and 0.539), suggesting sex was not a primary factor in the decision to include a cist. Boat burials and burials with grave goods (such as Westness and Scar) began in the VA and signal cultural change throughout the Orkney Islands. Aside from cist burials, individuals in the PVP, VA and LNP were sometimes found with evidence of having been buried in wooden coffins, evidence in the form of wood remains or pieces of nails (described further in Chapter 2). Due to varying levels of preservation and recording at each site, however, it was sometimes difficult for excavators to differentiate individuals who were buried in a wooden coffin from those buried in a simple shroud. For this reason, comparisons were not made between the two, only between cist and non-cist burials.

Aside from finds of a bone pin, lignite bangle and bone comb potentially associated with VA graves at Newark Bay (context is uncertain; Lerwick 2014, 167), no grave goods were recovered from the churchyard burials. The most commonly recorded grave goods from non-churchyard VA graves included daggers, weapons (mainly swords, shield bosses, arrows and parts of bows), tools associated with textile working (loom weights, a weaving baton and shears), jewellery (composite oval brooches, necklaces and beads), combs, gaming pieces and agricultural tools (sickles and adz hoes). If individuals buried with Scandinavian grave goods or those buried in Scandinavian traditions such as in boats were culturally different from the individuals buried in the simple graves around them, did they differ in the prevalence of osteological markers of nutrition and manual labour from their neighbours? Were grave goods indicative of the individual's occupation or social status? Were there differences in nutrition and physiological health between individuals buried in churchyards or secular cemeteries and could differences result from different religious practices?

Grave goods were only observed in the VA, except for one furnished burial from Westness (36) dating to the early LNP. Because of the lack of other graves with goods from the LNP, all comparisons were made solely within the VA. There were approximately 25 burials with grave goods (some excavation records are unclear) from the sites of Westness, Birsay Bay, Pierowall, Buckquoy, Scar and the Brough of Gurness (Table 3.7). Osteological data was only available for eleven of these individuals, as the current location of the Pierowall skeletal assemblage is unknown (only two un-provenanced Pierowall crania reside at NMS). While Scandinavian grave goods were found in both male and female graves (with no significant difference in the prevalence of grave goods between sexes, p=0.554), there were significant differences in the types of grave goods afforded to each sex, with weapons only present in male graves and textile-related implements only being present in female graves. Jewellery was also significantly more prevalent among female graves (p=0.007), though not completely absent from male graves (brooches were found in two adult male graves from Pierowall). While 13/26 (50%) of the VA females in this study were from churchyard cemeteries, only 6/24 (25%) of VA males were buried in churchyard cemeteries (Table 3.8). Individuals of all age groups were identified in the churchyards (at Newark Bay and Deerness), though radiocarbon dating at Newark Bay has thus far only resulted in the dating of one VA and one LNP infant. Two VA and one LNP infant were also recovered from Deerness.

Sex	*None*	*Any*	*Weapons*	*Textile*	*Jewellery*	*Agricultural Tools*	*Daggers*	*Combs*	*Gaming pieces*
Females	17	9	0	5	9	5	1	6	1
Males	9	13	12	0	1	2	4	3	2
All	37	25	13	5	11	7	5	9	3

Table 3.7. Numbers of VA burials with grave goods by type and sex (Lorimer 1970; Morris 1989; Owen and Dalland 1999; Robertson 1969; Sellevold 1999; Thorsteinsson 1965).

Sex	*Churchyards*	*Non-churchyard cemetery*	*Isolated*	*Cists*	*Boat graves*
Females	13/26	11/26	1/26	8/26	1/26
Males	6/24	16/24	2/24	6/22	4/22
All	26/64	32/64	5/64	25/62	6/62

Table 3.8. VA burial settings (Lorimer 1970; Morris 1989; Owen and Dalland 1999; Robertson 1969; Sellevold 1999; Thorsteinsson 1965).

3.3.2. Subsistence practices

The developments in agriculture discussed in Chapter 2, including raised soils and improved drainage, the development of mills (Batey 1992, 1993), the cultivation of flax, the specialisation of sites and an increase in dairying would have had a significant impact on the economic growth of Orkney and potentially the health and diet of its occupants. Previous studies have argued that diet in VA and LNP Orkney changed to reflect Scandinavian practices brought over by immigrants- a diet more focused on marine resources, increased dairying and the cultivation of oats and flax in addition to the traditional barley (as explained in Chapter 2; Barrett et al. 2000b; Bond 2007; etc.). To test whether the changes in subsistence practices, agricultural focus, marine exploitation and site specialisation that have been evidenced in the archaeobotanical and zooarchaeological analysis of VA and LNP Orkney (explained in Chapter 2) may be detectable in the osteological remains of the inhabitants, four different lines of evidence were employed. First, zooarchaeological and archaeobotanical reports of livestock and crop foci from the burial sites were consulted. Where burial sites were not on settlement/ farmstead sites, or where excavation reports of biological remains were not available, the closest farmstead or settlement sites (of the same phase) with biological remains reports were used as a proxy for inferring nearby subsistence practices (Chapter 2 and Tables 3.9-3.11, below).

The following variables were created based on land quality and the excavated remains of crops and livestock: predominant cereal (barley/oat/flax), predominant livestock (cattle/sheep/pig) and predominant marine resource type (offshore/freshwater/near-shore/none). The percentage of each mammalian species present at each farmstead site was also recorded in separate variables. Based on faunal aging methods, primary animal usage (whether livestock was predominantly slaughtered for meat, raised for dairy or wool, etc.) was recorded by site (see references below). It is important to note that in the cases where a farmstead site differs from the burial site, the proxy farmstead site may not have been associated with the burial site (which may have had its own yet-unexcavated farmstead with slightly different subsistence practices). The sites provided as proxies are the closest well-documented excavated farmsteads. Unfortunately, there were no comparable farmstead sites or biological assemblage reports for Skara Brae, Westness or Bu of Cairston. Next, to estimate land quality, each burial and farmstead site and was mapped onto an ArcMap shapefile containing land classification codes (LC codes) detailing capability for agriculture and mixed farming, based on The James Hutton Institute (2020). All burial and nearby farmstead sites were then also plotted onto Ian Simpson and colleagues' (Davidson et al. 1984; Simpson 1993; Simpson et al. 1998; 2005) surveys of anthropogenic (plaggen) soil formation throughout the Orkney Mainland, Stronsay and Sanday. It is also important to note that evidence of plaggen soil formation in Orkney did not begin until the VA. Finally, site name categories were assigned by etymological type: skaill/*skali*, *-by* or *-boe*r, *-quoy*, *-bu*, or names based on the presence of fortifications (*broch*) and land features (*-ness*, *-brae*, *-wall,* etc.). Though the vast majority of Orcadian site names are of Scandinavian origin and therefore may not be relevant for interpreting the function of sites in the PVP, the different categories of site names may offer a clue as to VA and LNP site use. Thus, VA and LNP site name types were compared for osteological indicators of nutrition and physical stress that might indicate physical labour or subsistence practices. An overview of each site's predominant crop, animal, animal use, marine resource type, LC code, nearby farmstead site, plaggen soil data and site name categories are provided in Tables 3.9-3.11, below. In the PVP, all published excavation reports on farmsteads near the burial sites included in this study reported a predominance of cattle over other livestock and an agricultural focus on barley.

When the variables for site types were tested against each other, the VA sites showed a significant positive correlation between the presence of plaggen soils and LC code (p=0.005, r=0.404). Both the presence of plaggen soils and LC code varied significantly between sites on the eastern and western halves of the Orkney Isles (p=0.000 and 0.000), with higher LC codes on the western side of the islands. When percentages of cattle, sheep/goat and pig were compared between VA sites in the east and west of the Orkney Isles, there was a significantly higher proportion of cattle and sheep/goat in eastern sites (p=0.000 and 0.000). Among LNP sites, there were higher percentages of cattle and pig (p=0.000 and 0.000) from eastern sites than western sites. This suggests soil quality could have influenced the choice of predominant livestock. Importantly, differences in preservation and excavation methods between sites may have contributed to perceived differences in land use between sites; excavation of additional sites throughout Orkney may affect this pattern. Predominant animal use also varied significantly between eastern and western sites. All the sites with zooarchaeological evidence for an economic focus on meat were on the west side while the sites with stronger evidence for dairying were in the east, though there was also evidence for dairying at the western site of Brough Road (p=0.000).

Key points:

- VA sites with plaggen soil formation fell on better land quality LC codes, suggesting targeted areas of cultivation based on soil quality.
- VA sites on the eastern half of the archipelago had better LC codes and more evidence for plaggen soil formation, which could have precipitated differences in subsistence between eastern and western sites.

- Eastern sites in the VA also had a higher proportion of sheep/goat than western sites.
- In the LNP, there were higher proportions of pig from eastern sites than western sites.
- Overall, there is stronger evidence of dairying at the western sites, except for Brough Road in the east.

Site	*LCCODE*	*Name cat*	*Nearby Farmstead*	*Predominant Animal*	*Predominant Cereal*	*Predominant fish*	*Animal Use*	*Plaggen*	*East/West*	*Churchyard*	*References*
Newark Bay	4.2	*-by*	Skaill, Deerness	Cattle	Barley	None	Dairying	No	East	Yes	Brend and Gibbon 2016; Buteux et al. 1997; Nicholson 1997; Noddle 1997
Westness	4.2	Land feature	Swandro	Unknown	Barley	Offshore	Unknown	Unknown	West	No	Kaland 1993
Skaill Cist	5.2	*Skaill/skali*	Unknown	Unknown	Unknown	Unknown	Unknown	No	West	No	James 1999; Simpson 1993
Skara Brae	5.2	Land feature	Unknown	Unknown	Unknown	Unknown	Unknown	No	West	No	Simpson 1993
Buckquoy	6.2	*-quoy*	Buckquoy	Cattle	Barley	Nearshore	Meat	No	West	No	Ritchie 1977; Hedges 1977; Simpson 1993
Brough Road	5.2	Fortification	Saevar Howe, Buckquoy	Cattle	Barley	Unknown	Meat and Dairying	No	West	No	Ritchie 1977; Hedges 1977; Simpson 1993

Table 3.9. Site categorizations based on archaeological and geological evidence for subsistence in the PVP.

Site	LCCODE	Name cat	Nearby Farmstead	Predominant Animal	Predominant Cereal	Predominant fish	Animal Use	Plaggen	East/West	Churchyard	References
Broch of Gurness	4.1	Land feature	Unknown	Unknown	Unknown	Unknown	Unknown	No	West	No	Simpson 1993
Scar	4.1	Unknown	Pool, Tofts Ness	Sheep/goat	Oats	Offshore	Dairying	Yes	East	No	Bond 1998; 2007; Dockrill Hunter 2007; Nicholson 2007; Simpson et al. 1998; Towers et al. 2017
Buckquoy	6.2	*-quoy*	Buckquoy	Cattle	Barley	Nearshore	Meat	Yes	West	No	Ritchie 1977; Hedges 1977
Brough Road	5.2	Fortification	Saevar Howe, Buckquoy	Cattle	Barley	Offshore	Meat and Dairying	Yes	West	No	Ritchie 1977; Hedges 1977; Morris 1989
Westness	4.2	Land feature	Swandro	Unknown	Barley	Offshore	Unknown	Unknown	West	No	Kaland 1993
Newark Bay	4.2	*-by*	Skaill, Deerness	Cattle	Barley	Offshore	Dairying	Yes	Eat	Yes	Brend and Gibbon 2016; Buteux et al. 1997; Nicholson 1997; Noddle 1997
Pierowall	4.2	Land feature	Quoygrew	Cattle and sheep/goat	Barley	Offshore	Meat	Yes	West	No	Barrett 2012c; Harland 2012; Harland and Barrett 2012; Simpson et al. 2005
Deerness	5.3	Land feature	Skaill, Deerness	Cattle	Barley	Offshore	Dairying	Yes	East	Yes	Buteux et al. 1997; Nicholson 1997; Noddle 1997
Skara Brae	5.2	Land feature	Snusgar	Cattle	Oats	Offshore	Dairying	Yes	West	No	Alldritt 2019; Mainland et al. 2019; Nicholson 2019

Table 3.10. Site categorizations based on archaeological and geological evidence for subsistence in the VA.

Site	LCCODE	Name cat	Nearby Farmstead	Predominant Animal	Predominant Cereal	Predominant fish	Animal Use	Plaggen	East/West	Churchyard	References
Skaill House	5.2	*Skaill/skali*	Snusgar	Cattle	Oats	Offshore	Dairying	Yes	West	Probable	James 1999
Bu of Cairston	4.2	*-by*	Unknown	Unknown	Unknown	Unknown	Unknown	No	West	Probable	Stevens et al. 2005
Westness	4.2	Land Feature	Swandro	Unknown	Barley	Offshore	Unknown	Unknown	West	No	Kaland 1993
Newark Bay	4.2	*-by*	Skaill, Deerness	Cattle	Barley	Offshore	Dairying	Yes	East	Yes	Brend and Gibbon 2016; Buteux et al. 1997; Nicholson 1997; Noddle 1997
Deerness	5.3	Land Feature	Skaill, Deerness	Cattle	Barley	Offshore	Dairying	Yes	East	Yes	Buteux et al. 1997; Nicholson 1997; Noddle 1997

Table 3.11. Site categorizations based on archaeological and geological evidence for subsistence in the LNP.

Variables	*Correlating Variables*	*p*	*Correlation Coefficient*
Phase	Sex	0.015	0.180
	% Cattle	0.000	0.488
	% Pig	0.000	0.409
	East/West	0.002	0.224
	Plaggen	0.000	-0.489
	Predominant cereal	0.002	0.307
	Name cat.	0.017	-0.178
	Predominant fish	0.003	-0.306
Sex	% Sheep/Goat	0.021	0.260
	plaggen	0.005	-0.220
	animal use	0.038	0.141
% Cattle	% Sheep/Goat	0.009	0.294
	% Pig	0.000	0.627
	East/West	0.000	-0.659
	Animal use	0.001	0.379
	Name cat	0.000	-0.447
% Sheep/Goat	East/West	0.000	-0.415
	Predominant animal	0.002	0.337
	Predominant cereal	0.000	0.648
	Name cat	0.000	-0.845
	Predominant fish	0.010	0.310
% Pig	LCCODE	0.000	0.531
	Animal use	0.000	0.554
	Name cat	0.001	-0.379
East/ West	Plaggen	0.000	-0.541
	LCCODE	0.000	0.232
	Animal use	0.000	-0.517
	Predominant cereal	0.000	0.267
	Name cat	0.000	0.808
Plaggen	LCCODE	0.001	0.248
	Animal use	0.031	-0.248
	Name cat	0.000	-0.421
	Predominant fish	0.000	-0.606
LC code	Predominant animal	0.000	-0.353
	Predominant cereal	0.000	0.340
Animal use	Predominant cereal	0.000	-0.435
Predominant animal	Predominant cereal	0.000	0.469

Table 3.12. Statistically significant correlations (p values indicate a statistical significance at α= 0.05) between site type variables in all individuals, juvenile (5-10 years) and older, with correlation coefficients.

Chapter 4. Site backgrounds and skeletal collections

This chapter details the corpus of skeletal material included in this study. It also provides a background for each site studied and reviews the history of archaeological research on each collection, as well as a description of site type categorization based on written and place-name evidence, subsistence strategies and burial practices.

4.1. Introduction

Osteological and isotope analysis of 498 individuals from the following sites was undertaken: Newark Bay, Skaill Cist, Skaill House, Bu of Cairston, Buckquoy, Deerness, Skara Brae, Scar, Pierowall, Brough Road, Broch of Gurness and Westness (Table 4.1. and Figure 4.1). The twelve sites were selected from throughout the Orkney Islands based on the condition of the collections and their potential to contribute to further research. The individuals from Brough Road, Buckquoy, Deerness, Skaill Cist, Skaill House, Bu of Cairston, Scar and a portion of the Newark Bay remains are housed at the Orkney Museum in Kirkwall. The remaining portion of the Newark Bay collection is housed at the Natural History Museum (NHM) in London and the University of Highlands and Islands (UHI) in Kirkwall. The extant Pierowall remains, as well as those from Skara Brae, the Broch of Gurness and Westness are housed at the National Museums Scotland (NMS) in Edinburgh. A discussion of each of these sites follows. The twelve sites span the seventh to early fifteenth centuries AD, from the Late Iron Age Pre-Viking phase (PVP) through Viking Age (VA) and the Late Norse Phase (LNP), in which Viking raids had ceased completely but Orkney was still under Norwegian rule. The transition from Viking raiding to long-term settlement meant continued Scandinavian presence (though of a different nature) and analysis of human remains from the post-Viking period allows a glimpse of lasting impact and nutritional/dietary shifts. To divide these individuals into clear phases, the radiocarbon dates provided by previous studies (e.g., Ashmore 2003; James 1999; Morris 1989, 123; Sellevold 1999; etc.) were recalibrated in OxCal and the median date used (date plot provided in Catalogue A-2).

Site	*Number of Burials*	*Dates*
Buckquoy	2	232-1095
Brough Road	9	240-980
Newark Bay	250+	551-1449
Skaill Cist	1	600-762
Westness	34	635-1230
Pierowall	17	8^{th} c
Skara Brae	3	438-983
Broch of Gurness	1	10th c
Scar	3	965-1025
Deerness	7	966-1260
Bu of Cairston	113	1030-1220
Skaill House	17	1050-1350

Table 4.1. Sites included in the study with their respective numbers of burials, listed in order of date range (Ashmore 2003; Barrett et al. 2000a; Barrett and Richards 2004; James 1999; Sellevold 1999).

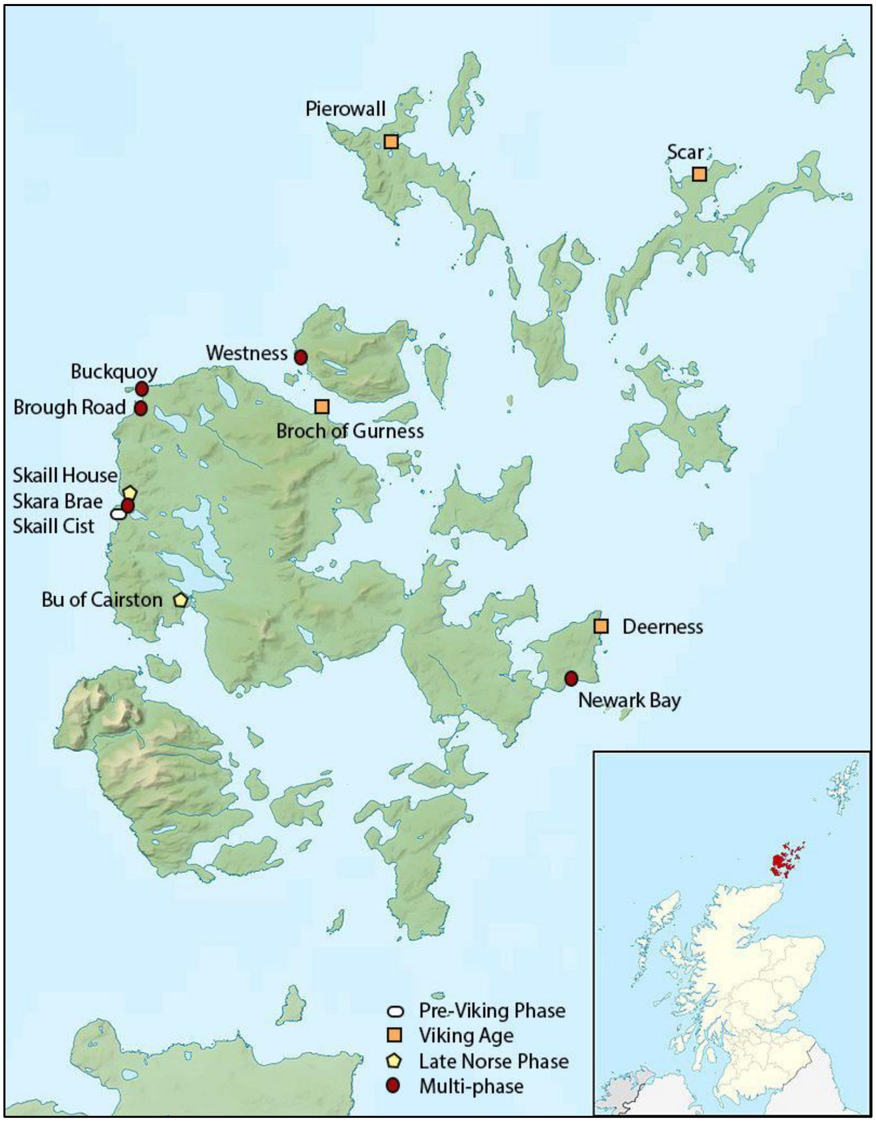

Figure 4.1. Map of sites included in this study.

4.2. Site backgrounds

Descriptions of the sites included in this study are listed in order of location from North to South- beginning with Pierowall and Scar, followed by Westness, the Broch of Gurness, the sites in Birsay Bay (Buckquoy and Brough Road), the sites in the Bay of Skaill (Skaill House, Skara Brae and Skaill Cist), then the Bu of Cairston, followed by the eastern sites of Deerness and Newark Bay.

4.2.1. Pierowall, Westray

The Viking cemetery at Pierowall was named for a land feature, as *-wall* or *-vel* means field in Old Norse (Towrie 2020). The inclusion of Scandinavian grave goods in most of the burials suggests the site was a high-status burial ground in the VA. The site was excavated in the early to mid-nineteenth century by William Rendall and James Farrer who recorded a total of 17 graves between 1839 and 1863, resulting in multiple confused accounts of the graves and findings (Thorsteinsson 1965). The accounts by George Petrie, William Rendall and James Farrer seem to concur that the graves at Pierowall were likely found amongst either naturally occurring sand dunes or potentially VA man-made mounds (*ibid.,* 163). The confusion regarding the number, contents and exact locations of the graves has yet to be cleared and what Thorsteinsson was able to provide in his 1965 paper was an estimation he gathered from the artefacts and records he was able to track down. The 17 graves he listed contained the remains of six females, eight males and two individuals of undetermined sex. All but two of the graves contained goods including weaponry and jewellery and three of those also contained the remains of horses (*ibid*). Weaponry (including shield bosses, axes, spearheads and swords) was only observed in male graves, while textile equipment (including a weaving sword and spindle-whorls) was only observed in female graves. Jewellery was predominantly (but not exclusively) found among female graves and included tortoise and penannular brooches, ring-headed pins and beads. Other grave inclusions comprised boat rivets, iron buckles, a drinking horn, combs, a whetstone, riding equipment and sickle blades.

Two crania probably from the "pre-Christian Norse grave at Pierowall" are housed at NMS in Edinburgh, labelled "ET62" and "ET63". According to curator Alison Sheridan and descriptions archived with the remains at the museum, ET63 is likely that described by William Rendall as being from the Norse cemetery at Pierowall and likely corresponds with the description of grave number 15 accorded by Thorsteinsson (1965). ET62 is likely that found from the nearby mounds at Pierowall by Farrer and

Petrie in 1841 and 1855 and likely corresponds to either Thorsteinsson's grave numbers 16 or 17 (Thorsteinsson 1965, 171; Turner 1915). Although neither ET62 nor ET63 was available for tooth or bone collagen sampling, osteological analysis of these two crania is included in this study.

The nearest farmstead sites to the Pierowall cemetery in the VA were Quoygrew and Tofts Ness. According to analyses conducted at Quoygrew, there was archaeoichthyological evidence of commercial-scale fish processing at the site (Harland and Barrett 2012). Faunal analysis has indicated cattle was the predominant domesticated mammal, with kill-off patterns suggesting cattle were raised for both meat procurement and dairying (Harland 2012). The artefact assemblage of steatite vessels and combs (among other things) speaks to the overtly Scandinavian nature of the site (Barrett 2012c, 278). Pierowall's location along the western trade route from Norway and Shetland to the Scottish Mainland (including Dál Riata) and Ireland, along with the (particularly Norse) economic importance of fish processing at a nearby farmstead may have been two of the reasons Pierowall was a high-status Scandinavian burial ground in the VA.

4.2.2. Scar, Sanday

Excavation of a 6.5m long Viking boat burial at Scar was conducted in 1991 (Dalland 1992; Owen and Dalland 1999, 26). It contained three individuals: one male (middle adult), one female (older adult) and one juvenile (approximately ten years of age) (Lorimer 1999, 52; Figure 4.2). The burials displayed evidence of being disturbed by coastal erosion, with portions of each skeleton being washed away. The female's grave also displayed evidence of burrowing by otters (Owen and Dalland 1999, 29). The two adult burials both contained grave goods. A comb, sword, bundle of arrows, fragmentary bronze object and a set of bone gaming pieces were buried with the male (Sk134), while a whalebone plaque, spindle-whorl, pair of iron shears, needles and the iron fittings of a wooden box were found associated with the female burial, Sk133 (*ibid.*, 30-31). Although no artefacts were found to be definitively associated with Sk135, any grave goods originally buried with this individual have been lost to coastal erosion (*ibid)*. An osteological analysis was conducted by Daphne Lorimer in 1999, which provided details on age, sex and pathology (Lorimer 1999, 52). While skeleton 135 is dated between AD 970-1260, skeleton 134 is dated between AD 880-1130 and skeleton 133 between AD 730 and 1020, at a 95.4% range (Ashmore 2003, 38; Owen and Dalland 1999, 162). Although the three individuals differ slightly in radiocarbon date, it has been suggested by Owen and Dalland that they are contemporaneous and that all three individuals were likely to have died the same year (1999, 163). Analysis of the $\delta^{13}C$ values has led the investigators to believe the differences in dates are not due to a marine reservoir effect from the consumption of marine resources; however, more details regarding isotopic analysis were not provided (Dalland 1992). Further dating is being undertaken as part of David Reich and Ron Pinhasi's 'GenScot' project, using a molar from one individual; however, the results are not yet available (A. Sheridan, pers. comm., March 14, 2017). An osteological reassessment using Standards for Recording Human Skeletal Remains (Buikstra and Ubelaker 1994) has been completed as part of the present study to standardise analysis across assemblages. High-resolution dietary isotope analysis from tooth dentine (from the same tooth being dated by Reich and Pinhasi) was undertaken in this study to provide a chronology of changes in diet throughout the individual's development (results provided in Chapter 6).

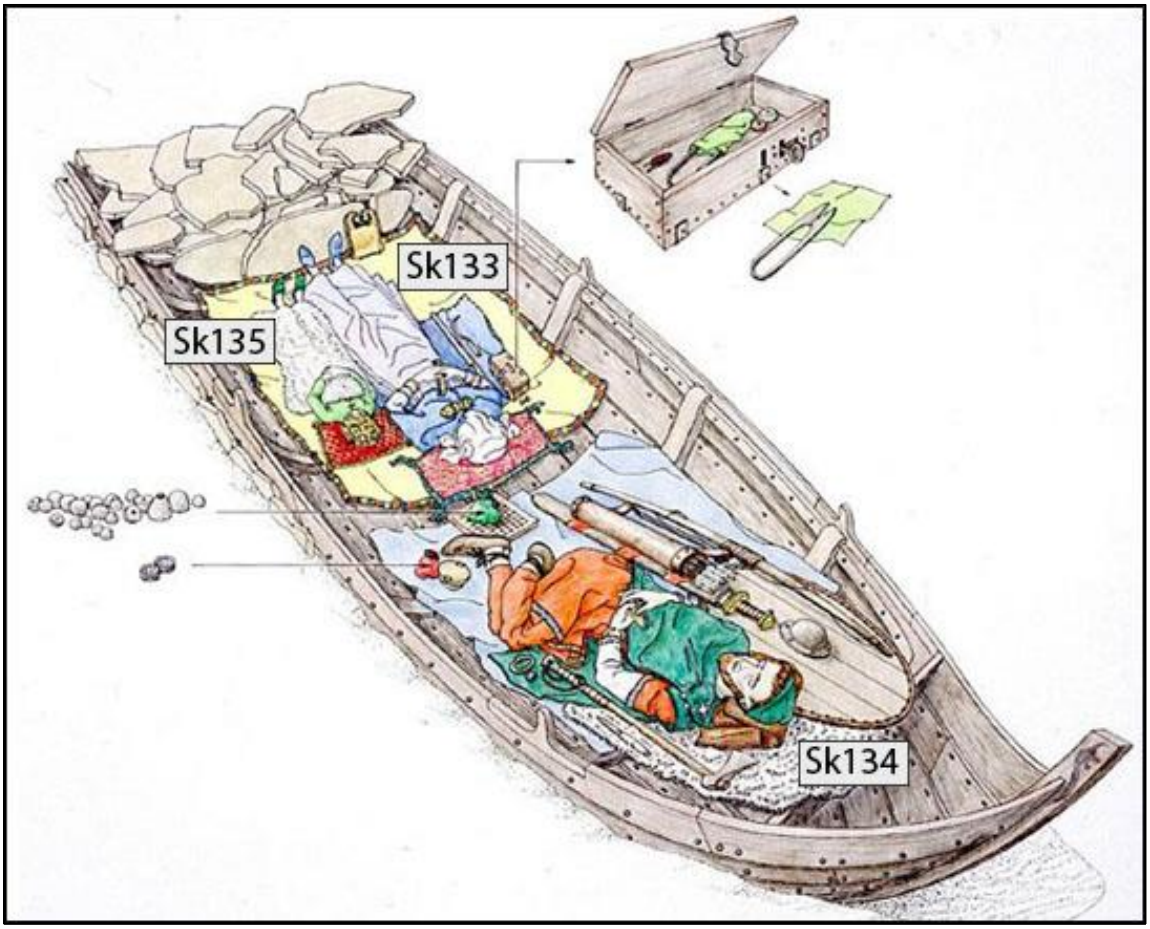

Figure 4.2. Artist reconstruction of Scar boat burial with skeleton numbers (after Christina Unwin's illustration in Owen and Dalland 1999, 150; Fig. 105; reproduced with permission from Historic Environment Scotland).

The nearest excavated VA farmstead to the Scar boat burial site, Pool, provides us with evidence of subsistence practices in the area. According to Julie Bond, archaeobotanical samples recovered through flotation and sieving revealed the prevalence of oats (which grow in sandier soil) over barley in the VA (Bond 1998; 2007, 175). Faunal analysis of the Pool assemblage indicates sheep/goat and cattle were the predominant mammals at Pool, with the rearing of cattle was mainly for the purpose of dairying (Bond 2012, 214). As at Quoygrew, fish remains at Pool were substantially more abundant in the VA and included predominantly large gadids like cod, saithe and pollack (Harland and Barrett 2012, 271). Nicholson concluded that, based on the presence of all skeletal elements, whole fish were being brought to the site and probably not with the intention of export as stockfish (*ibid.,* 277).

4.2.3. Westness, Rousay

The Westness area was settled from at least the Neolithic (5,500 years ago) and was continually occupied throughout the pre-Viking, Viking and post-Viking periods (Discover Rousay 2013). Sites in the area include the remains of farmsteads at Swandro and a VA or LNP long-house at Skaill by the Swandro-Orkney Coastal Archaeology Trust and the University of Highlands and Islands (Lisle 2019). Unfortunately, these sites are still under excavation and reports have not yet been published. A range of radiocarbon dates from burials at Westness demonstrates that the site was used for centuries spanning the pre- to post-Viking Age. The variety of burial rites observed at the site have contributed to interpretations of cultural affinity and general sentiment between Scandinavian and native peoples (Sellevold 1999). The cemetery includes both seemingly Pictish and Scandinavian graves, although defining each based on the presence or absence of grave goods alone can be misleading. Weapons, tools and jewellery were among the grave goods recovered from the inhumations. The cemetery contains three boat graves, two males and one individual of indeterminate sex: grave 11, 31 and 34, respectively (Figure 4.3). Among the earliest Norse graves, one was boat-shaped while another individual was interred in a cist, perhaps indicating differences in social status or ideology (Ashmore 2003, 37). The inclusion of three infant burials at the cemetery suggests that it may have been used as a family cemetery and familial ties between some individuals have been suggested (Sellevold 1999). The site was originally recorded in 1826 when two Viking graves were discovered. Since then, the site has been investigated at least eight times between 1963 and 1993 (Canmore 2015). In 1999, an in-depth osteological report was composed by Berit J. Sellevold, complete with radiocarbon dating. Twenty-two dates were obtained and are provided in Catalogue A-2. In addition, $\partial^{13}C$ values were measured to determine the percentage of marine protein in each individual's diet. Based on the $\partial^{13}C$ values, Sellevold estimates a range of between 9% and 51% reliance on marine resources (Sellevold 1999, 7). Macroscopic osteological analysis was also conducted, including an assessment of demographic and pathological data, dentition, non-metric traits and instances of trauma. Sellevold found a significant increase in stature in “Viking” remains in comparison with earlier, pre-Viking remains (*ibid.*, 24). In addition, several individuals were recorded as exhibiting degenerative, congenital, or non-specific diseases. According to Sellevold, “differences in physical appearance between the Picts and the Vikings are detectable in the skeletal material” (*ibid.*, 25). In 2014, Montgomery and colleagues conducted oxygen and strontium isotope analysis of teeth from six individuals from Westness. Their results indicated the presence of both “local” and “non-local” individuals in the Westness assemblage and demonstrated the ability to discern Pictish from (potentially) Scandinavian individuals (Montgomery et al. 2014). A comparison of osteological indicators of pathology, as well as occupational stress markers and non-metric traits from the PVP through the LNP was undertaken in the present study. Bone collagen was sampled from six previously unsampled individuals for $\delta^{13}C$ and $\delta^{15}N$ isotopes and tooth enamel has been sampled for Sr and O from three previously unsampled individuals to provide a larger dataset for analysis of diet and mobility within the population. In addition, one molar from each of six individuals was sequentially micro-sampled for tooth dentine $\delta^{13}C$ and $\delta^{15}N$ isotopes.

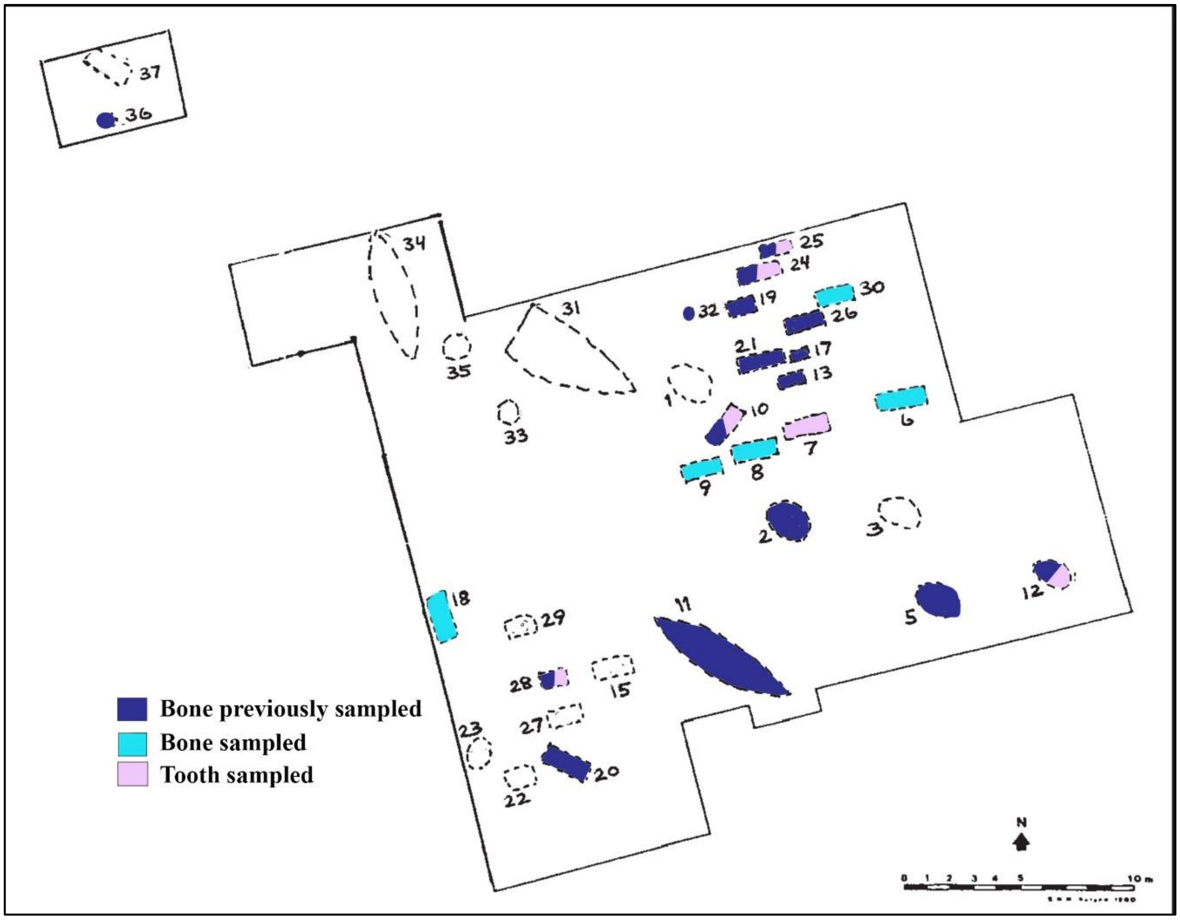

Figure 4.3. Plan of Westness cemetery with isotope sampled individuals indicated (after Sellevold 1999, 8; Fig. 3). Previous bone sampling was done by Barrett and Richards 2004, 252).

4.2.4. Bay of Skaill

The Bay of Skaill is an inlet on the western face of Orkney Mainland and the location of several sites spanning the Neolithic through the early modern periods. Individuals from three sites along the Bay of Skaill are included in this study: Skaill House, Skaill Cist and Skara Brae. While it is only these three sites that are included in this study due to relevance, access and preservation, it is important to note that burials spanning thousands of years have been discovered from around the bay. Occupation of the Bay of Skaill dates back at least to the Neolithic, with the settlement of Skara Brae spanning 3,200 BC to 2,200 BC (Griffiths 2019; Towrie 2019). V. Gordon Childe's excavation found two Neolithic burials at the settlement (in addition to likely Pictish burials) between 1927-1930. Since their discovery, multiple cists (possibly dating to the Bronze Age) have been discovered on the northern side of the bay (several were found in 1772, one in 1989 and one in 2021), near the Skaill hoard and the Castle of Snusgar (not featured in Figure 4.4.; Griffiths 2019; Lysaght 1974; Morris et al. 1985). A separate Viking grave (thought to be male) was excavated near Skara Brae and the Skaill Cist in the nineteenth century and although the remains have disappeared since their excavation, reports detail that the individual was buried with a comb and comb case, iron arrow-head, spearhead, knife, whetstone and at least portions of a horse, bird and fish (Morris et al. 1985, 82). Because of the relatively few discovered burials from this area despite it having been occupied for millennia, it seems likely that many more remain undiscovered, hidden from time by wind-blown sand (Graham-Campbell and Batey 1998, 59; Morris et al. 1985, 89). Skaill Bay is also the site of a large silver hoard found in 1858, as well as a Viking settlement excavated in 2004-2011 by University of Oxford archaeologists David Griffiths and Jane Harrison. Excavations uncovered a Viking Age longhouse, as well as evidence of "a large farm complex, perhaps encompassing several residences, exploiting both terrestrial and marine resources" (Griffiths and Harrison 2011a; 2011b, 17; Griffiths et al. 2019).

A recent publication of excavations by David Griffiths, Jane Harrison, Michael Athanson and colleagues have revealed several phases of settlement at the 'Castle of Snusgar' and the east mound, dating to the VA and LNP (2019, 8). The two sites are near Skara Brae, Skaill Cist and Skaill House and can be used to interpret subsistence practices at these nearby sites. It is important to note, however, that the chronology for Snusgar and the east mound place it after Skaill Cist and the earlier burial at Skara Brae (PVP) and before the burials at Skaill House (LNP). Faunal analysis concluded the predominant domesticated mammal was cattle, but there were also large proportions of sheep/goat, pig and horse (Mainland et al. 2019, 178). Animal kill-off patterns suggest a focus on dairying with cattle, but also the use of sheep/goat and pig for meat procurement (*ibid.*, 187). While early phases of occupation left very few fish remains at the site, later VA and LNP contexts produced a small range of taxa indicative of selective offshore fishing, targeting large gadids like cod and ling (Nicholson 2019, 208). While there was a large assemblage of VA and LNP fish remains, there was no evidence of commercial-scale processing or stockfish production for export (*ibid.*, 211). Environmental analysis at Snusgar and the east mound revealed a predominance of both barley and oats, as well as flax in smaller amounts. Weed flora provided evidence of heavily fertilized, well manured and plaggen soils (Alldritt 2019, 154).

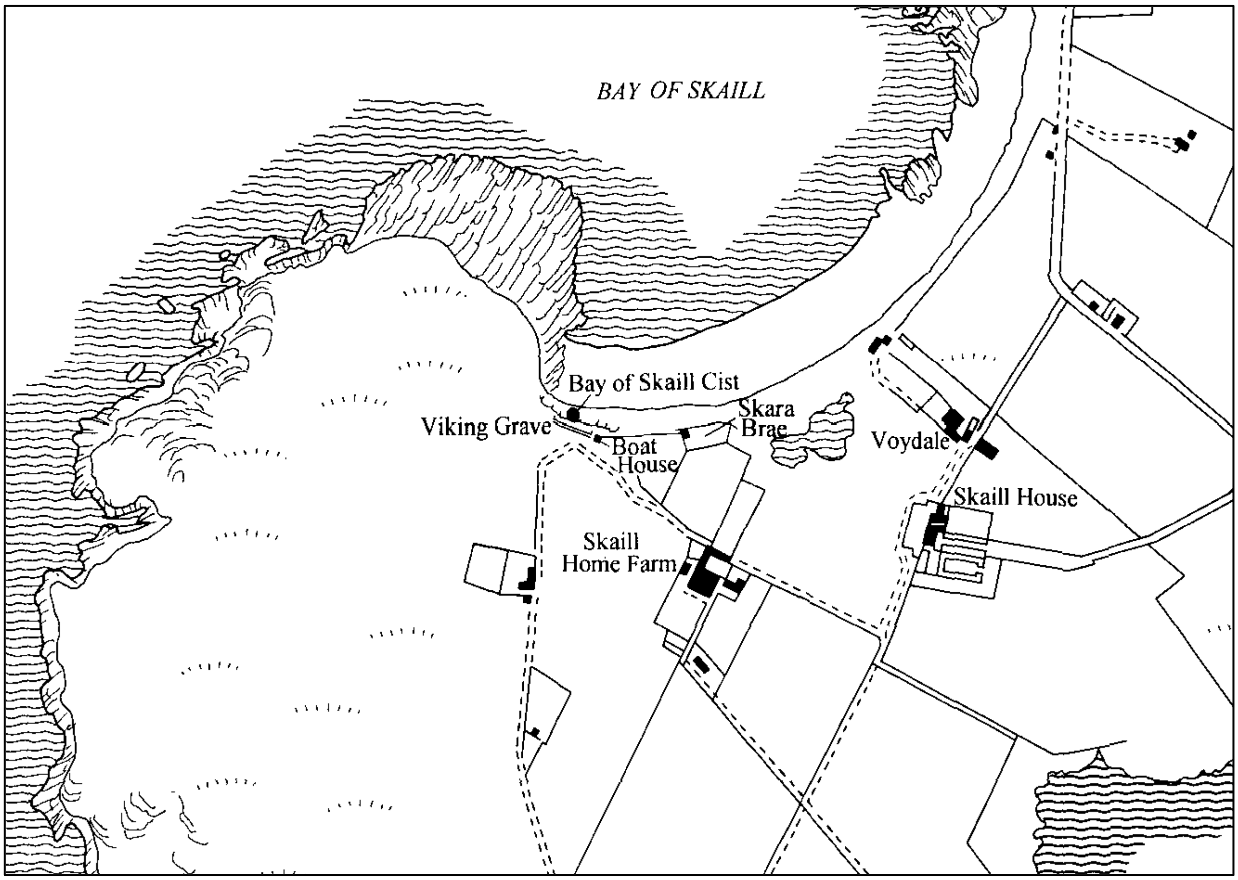

Figure 4.4. Map of the Bay of Skaill detailing the location of Skaill House as well as the Skaill Cist and Skara Brae (after James 1999, 754; Illus. 1; reproduced with the author's permission).

4.2.4.1. Skaill House

Rescue excavations of the cemetery at Skaill house were performed in 1996. A total of 27 individuals (12 adults and 15 subadults, both articulated and disarticulated) were uncovered from the cemetery (Figure 4.5). Only two of the skeletons (1 and 3) from the cemetery were exhumed (as they had already been disturbed) and a long bone was sampled from skeletons 5, 7, 8 and 10 for radiocarbon dating (James 1999, 775). The five bone samples yielded dates between AD 1040 and AD 1392 (*ibid.,* 762; see Catalogue A-2 for individual dates). Osteological analysis was undertaken of four of the individuals by Daphne Lorimer and an additional seven by Julie Roberts. Platymeria of the femur was observed in one of the individuals, which has been attributed to "squatting and to extra strain on the femur during childhood… now considered to be of dietary significance" due to a deficit in calcium intake (*ibid.*, 762). The two individuals exhumed and housed at the Orkney Museum (Sk1 and Sk3) were re-analysed as part of the present study and bone collagen was sampled for carbon and nitrogen stable isotope analysis. In addition, one molar was sampled from each of the two individuals for enamel strontium and oxygen isotopes and sequential dentine micro-samples were taken for carbon and nitrogen isotopes.

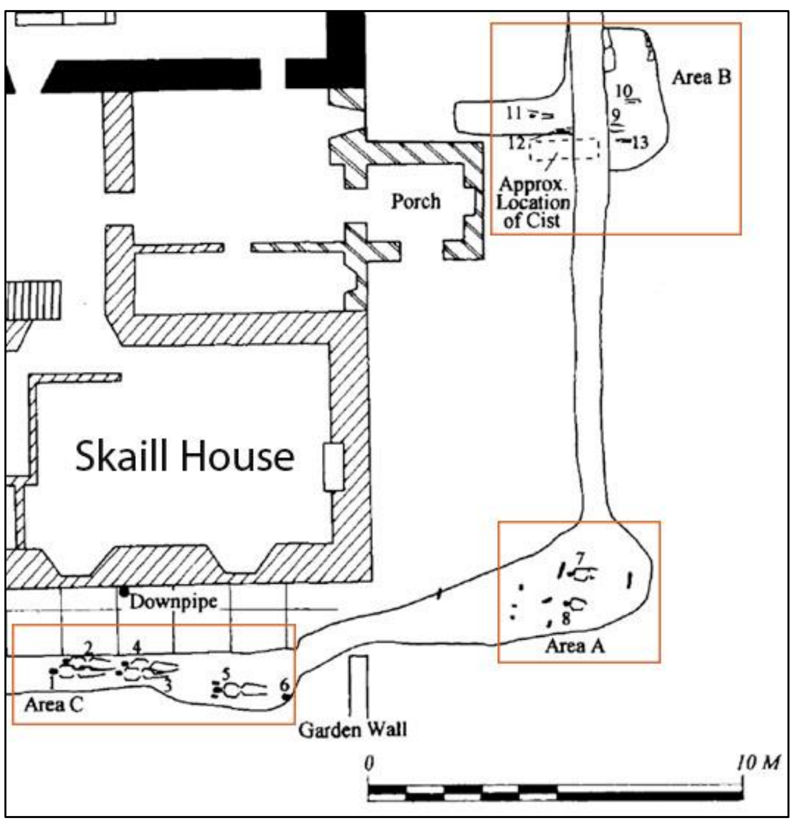

Figure 4.5. Map of burial locations (Areas A, B and C) in relation to Skaill House; individuals Sk1 and SK3 are both located in Area C (adapted from James 1999, 757; Illus. 2; reproduced with the author's permission).

4.2.4.2. Skaill Cist

During excavations at Skaill House, the cist burial was also exhumed as a salvage excavation to avoid it falling into the sea (James 1999). Previous excavation of the cist had resulted in the part of the skeleton below the pelvis being retained in storage (*ibid.*, 755). Inside the cist were the prone remains of a young adult male who produced a radiocarbon date of AD 546-880 (*ibid.*, 773; Figure 4.6). Although estimated to be only 18-25 years old, there were signs of trauma possibly caused by heavy load-bearing, along with degenerative changes to the vertebrae. “A pathological lesion at the left knee and development changes on the left scapula and humerus suggested the use of a crutch” (*ibid.*, 773). It was suggested by Daphne Lorimer that the prone position of the individual, who exhibited signs of a disability, could have been a deliberate form of indignity. Bone collagen was sampled for carbon and nitrogen isotopes. In addition, three molars (right maxillary first, second and third molars) were sampled for strontium and oxygen (enamel) and carbon and nitrogen (dentine). Sampling of all three molars provides a chronology of diet spanning from birth up to approximately 21 years of age (explained previously in Chapter 3).

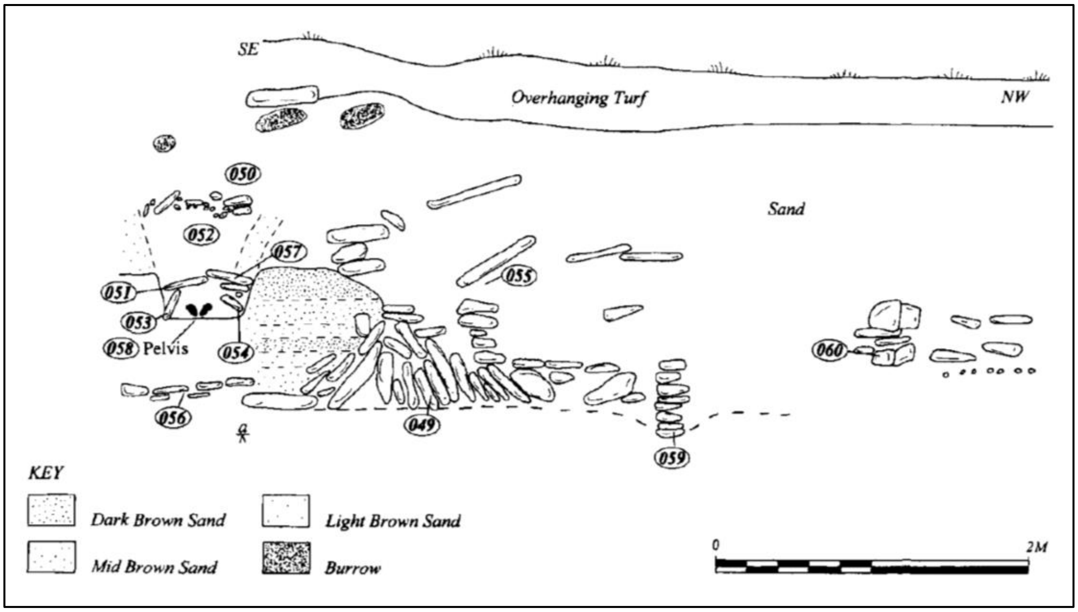

Figure 4.6. Section of the Skaill Cist burial (after James 1999, 772; Illus. 5; reproduced with the author's permission).

4.2.4.3. Skara Brae

Over the past 150 years, several burials and isolated finds have been uncovered at or around the Neolithic site of Skara Brae (Schulting et al. n.d.). Two individuals- one Bronze Age and one Iron Age uncovered in 1879 have been recently analysed osteologically and isotopically by Schulting et al. (n.d.). The skull of the Iron Age individual (346B) was likely found in the passageway, but its provenance is unclear (Garson 1884; Schulting et al. n.d.). In addition, two cist inhumations were uncovered in 1927 from wind-blown sand overlying the Neolithic settlement at Skara Brae (Childe 1931, 143; Morris et al. 1985, 82). Although no grave goods were found, Childe thought them to be VA. The remains of the first individual (Sk1) appeared to belong to a young adult female and the second individual (Sk2) was a middle adult male. The North-South orientation of both individuals suggested to Childe that they were non-Christian. Dating of the first individual in 2018 provided a calibrated C14 date of AD 430-610 (at 95.4% probability) and a similar date was assigned to the second individual based on its context (Tucker and Armit 2009). An additional adult of unidentifiable sex (SK3) was recovered from Skara Brae in 1976, following a storm that had exposed the burial and washed away the leg bones. Preliminary osteological analysis was done by Dr. Linda Fibiger in 2014 and radiocarbon dating of this individual in 2018 provided a calibrated C14 date of AD 776-983 (at 95.4% probability). All three individuals were re-examined for signs of pathology or trauma as part of the present study. A bone collagen sample was taken from Sk1 for carbon and nitrogen isotopes. Due to the limited preservation of SK2 and previous sampling of Sk3 by HES, these individuals were not sampled for isotope analysis.

4.2.5. Birsay Bay

Birsay Bay is regarded as the power centre of PVP and VA Orkney and has provided much fuel for the debate regarding whether Pictish/Norse interactions were mainly violent or peaceful- a debate that remains far from settled (Curle 1982; Griffiths et al. 2019, 25; Morris 1989; Morris and Barrowman forthcoming; Ritchie 1977). Located on the western coast of the Orkney Mainland, the site lies on a prominent spit of land that would have been along a major trade route (Barrett and Slater 2008). Birsay Bay is referred to as the seat of the Earl of Orkney in the *Orkneyinga Saga* and became the earldom's first bishopric before Kirkwall became the first urban centre and site of St. Magnus cathedral in the twelfth century (Gibbon 2007, 246; Morris 1989, 13). Along Birsay Bay are two major sites of recorded human remains: Buckquoy and along Brough Road (Figure 4.7). Anna Ritchie was the first to excavate the site of Buckquoy, which was later revisited in 1977, 1978, 1980 and 1982 as part of a larger survey of Birsay Bay by Christopher Morris. This project included geophysical survey and excavations resulting in the uncovering of both PVP and VA burials along with evidence of multiple phases of settlement.

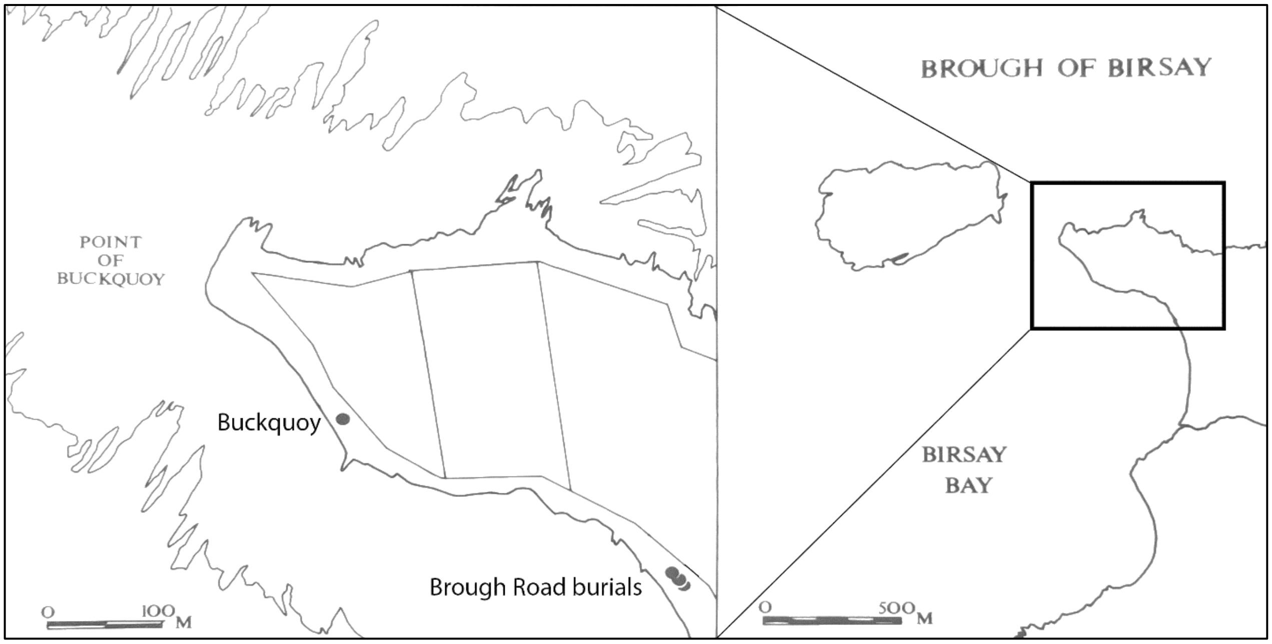

Figure 4.7. Map of Buckquoy and Brough Road burials along Birsay Bay (adapted from Morris 1989, 37; Illus. 20; reproduced with the author's permission).

4.2.5.1. Buckquoy

Buckquoy is the site of a settlement with five phases of both pre-Viking and Viking Age occupation and two isolated inhumations, a "Viking" grave (B7) and long cist burial (M12) (Brundle et al. 2003, 95; Ritchie 1977, 175). Rescue excavation of Buckquoy was conducted by Anna Ritchie from 1970-71, the results of which yielded a profile of subsistence at the site spanning the PVP and VA. The archaeobotanical and faunal assemblages indicated the cultivation of barley and the rearing of predominantly cattle primarily for meat procurement. While no fish remains were recovered from the PVP, the VA fish remains indicate only a limited amount of near-shore fishing (Ritchie 1977).

The individual in the long-cist burial was identified as a male between the ages of 25 and 30, while the individual from the Viking grave was also identified as male, older than 40 years of age (Ritchie 1977, 184 and 190). Radiocarbon dating was completed decades after the excavation and carbon values dated the burials to the fifth to sixth centuries. This is not a plausible date for the Viking burial, which was stratigraphically later than a Norse longhouse and included a tenth-century coin and ring-pin

(Brundle et al. 2003, 99; Ritchie 1977, 190). The grave goods found with this burial also included a bone comb, knife, whetstone, iron buckle and spearhead, similar goods to those described in the records of graves found at Pierowall. Osteological re-evaluation by Daphne Lorimer in 2003 resulted in new observations relating to previous pathological and non-metric analyses, with a previous diagnosis of tuberculosis being attributed to taphonomic damage-related pseudopathology (Brundle et al. 2003, 100). Bone collagen samples were collected for both individuals B7 and M12 for dietary isotope analysis. In addition, one molar from M12 was sampled for enamel and dentine isotopes. Due to the lack of preserved dentition, tooth sampling of B7 was not possible. A bone sample from B7 has been collected and is awaiting radiocarbon dating. This sample from the likely "Viking" grave may provide a date range closer to that expected from the inclusion of a tenth-century coin.

4.2.5.2. Brough Road

A total of six articulated individuals were excavated, along with the disarticulated remains of several others. Radiocarbon dating of the individuals revealed a span of dates, with three dating to the PVP, two dating to the Late PVP/early VA and one dating to the VA/LNP. The earlier phase (A) of burials consisted of PVP long cist graves with stone cairns, while the later VA (phase E) consisted of a rough cist grave cut into a midden and a burial of one individual over one of the cairns, the two phases divided by a thick layer of deposited sand (plans provided in Figures 4.8. and 4.9.; Morris 1989, 123). One of the VA disarticulated individuals buried in a "poorly constructed cist," included iron artefacts and a complete hog-backed antler comb (*ibid.*, 127). Due to the large amount of disarticulated bone, an exact total number of individuals from the site could not be ascertained. Nine individuals were included in the study, however, due to their relatively secure context and previous dating and analysis by Morris (1989). This included the six articulated individuals and the remains of three disarticulated individuals. Of these nine individuals, eight were sampled for bone collagen and five were sampled for tooth enamel and dentine based on preservation and dating.

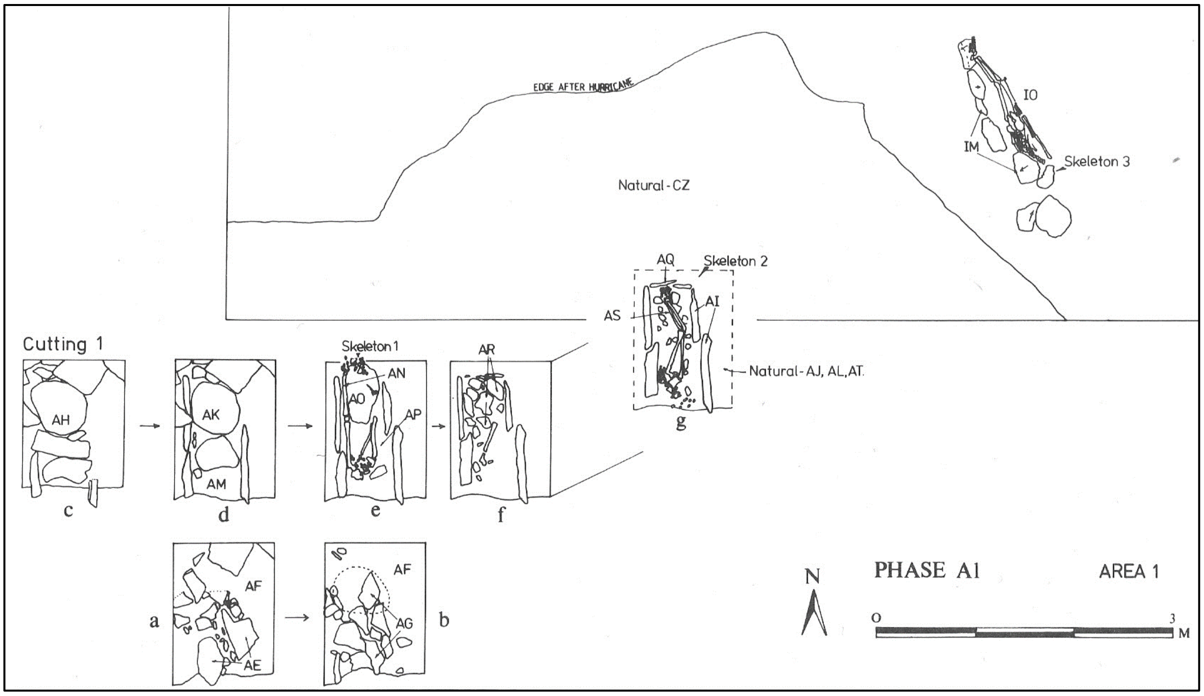

Figure 4.8. Plan of burials at Brough Road, Phase A (PVP) (after Morris 1989, 110; Illus. 70; reproduced with the author's permission).

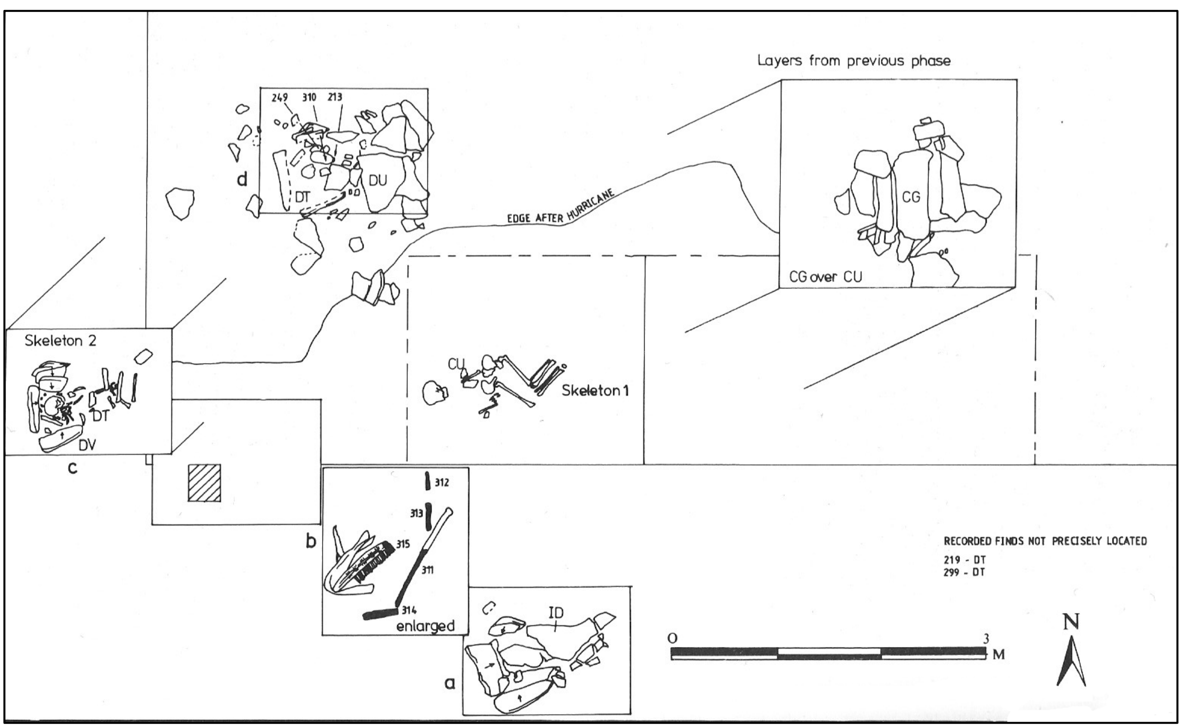

Figure 4.9. Plan of Brough Road burials Phase E (VA) (after Morris 1989, 120; Illus. 82; reproduced with the author's permission).

4.2.6. Broch of Gurness

The Broch of Gurness is an Iron Age broch site that was likely abandoned and later re-occupied during the Viking Age. Aside from the remains of the Iron Age settlement, another set of remains was uncovered in 1939. The grave belonged to a young adult female, dressed in finely woven wool and buried in a richly furnished grave with two tortoise brooches, a knife with a wooden handle, an iron sickle and a sea-shell necklet (Robertson 1968-9; 290). Unfortunately, all post-cranial elements were recorded as having been destroyed. The cranium itself survives and is housed by NMS in Edinburgh. The individual appears to have been buried in a cist constructed from the remains of a stone wall unexpectedly uncovered during burial (*ibid)*. As one of only four known richly-furnished VA female burials found in Orkney with skeletal remains still preserved, this individual has the potential to contribute significantly to our understanding of female health and diet in the VA. Since its discovery teeth in both mandibles have been glued into the bone, making tooth sampling impractical. According to NMS curator Alison Sheridan, the remains had been sampled for a radiocarbon date, as well as DNA and isotopes by the Pagan Norse Graves project, so further sampling was not needed. Osteological analysis of the cranium was done by the author as part of the current study.

4.2.7. Bu of Cairston

The Bu of Cairston was once the site of a Late Norse castle, mentioned in the *Orkneyinga Saga* in AD 1152 (Gibbon 2017; Stevens et al. 2005, 372). Its 'Bu' place-name (indicating it was an estate) suggests the site was of high status in the LNP, if not earlier (Stevens et al. 2005, 373). As an estate, it would likely have had a chapel and written accounts mention as much, though no chapel has thus far been found during archaeological investigation (*ibid.,* 374). As the largest excavated LNP site in Orkney, it has the potential to provide insight into activity, health and diet in this phase. Unfortunately, bioarchaeological evidence of agriculture and/or husbandry have so far not been published for the site.

The cemetery at the Bu of Cairston was excavated by the AOC Archaeology Group between September and October 2002. While the cemetery dates to the 13th to 14th centuries, the presence of Neolithic features and an Iron Age settlement indicate prior occupation of the site. A total of 120 individuals were uncovered, though the cemetery was not completely excavated. The burials were aligned east/west and contained no grave goods, which is typical of this phase (*ibid*., 371). While this cemetery dates slightly later than the other sites in this study, this relatively large assemblage has the potential to provide information regarding insights into the enduring impact endurance or otherwise of Scandinavian diet patterns and practices. If trends are significantly different at this site, it is possible that factors specific to this site (e.g., environment or resources) had a larger effect on diet and health than Scandinavian influence or that Scandinavian influence at this site somehow varied from the other sites. Melissa Melikian undertook a full osteological analysis of the 109 articulated burials (and some disarticulated remains) following excavation. Although osteoarthritis was only observed in seven individuals, females were more commonly affected than males, which could indicate differences in labour between sexes (*ibid*., 388). Previous investigations included sampling of two individuals for radiocarbon, DNA and isotope analysis. The two radiocarbon dates from the human remains (SUERC-1201 and SUERC-1202) place them in the period AD 1030-1220 (895±35 BP, at the 95.4% range) and their carbon and nitrogen values indicated a diet constituted of approximately 36% marine protein (Stevens et al. 2005, 376; Stuiver et al. 1998). Julie Gibson collected fifty teeth from the site for DNA analysis, however, this analysis has not yet been done. As part of the present study, 110 individuals were osteologically examined and bone collagen was sampled from 71 individuals from Bu of Cairston for carbon and nitrogen stable isotopes. Eighteen individuals were also sampled for tooth enamel and sequential dentine (discussed further in Chapter 6.2. The size of this LNP cemetery means the bulk of LNP isotope data for the study come from this site, in addition to several samples from Newark Bay, the Brough of Deerness, Skaill House and Westness.

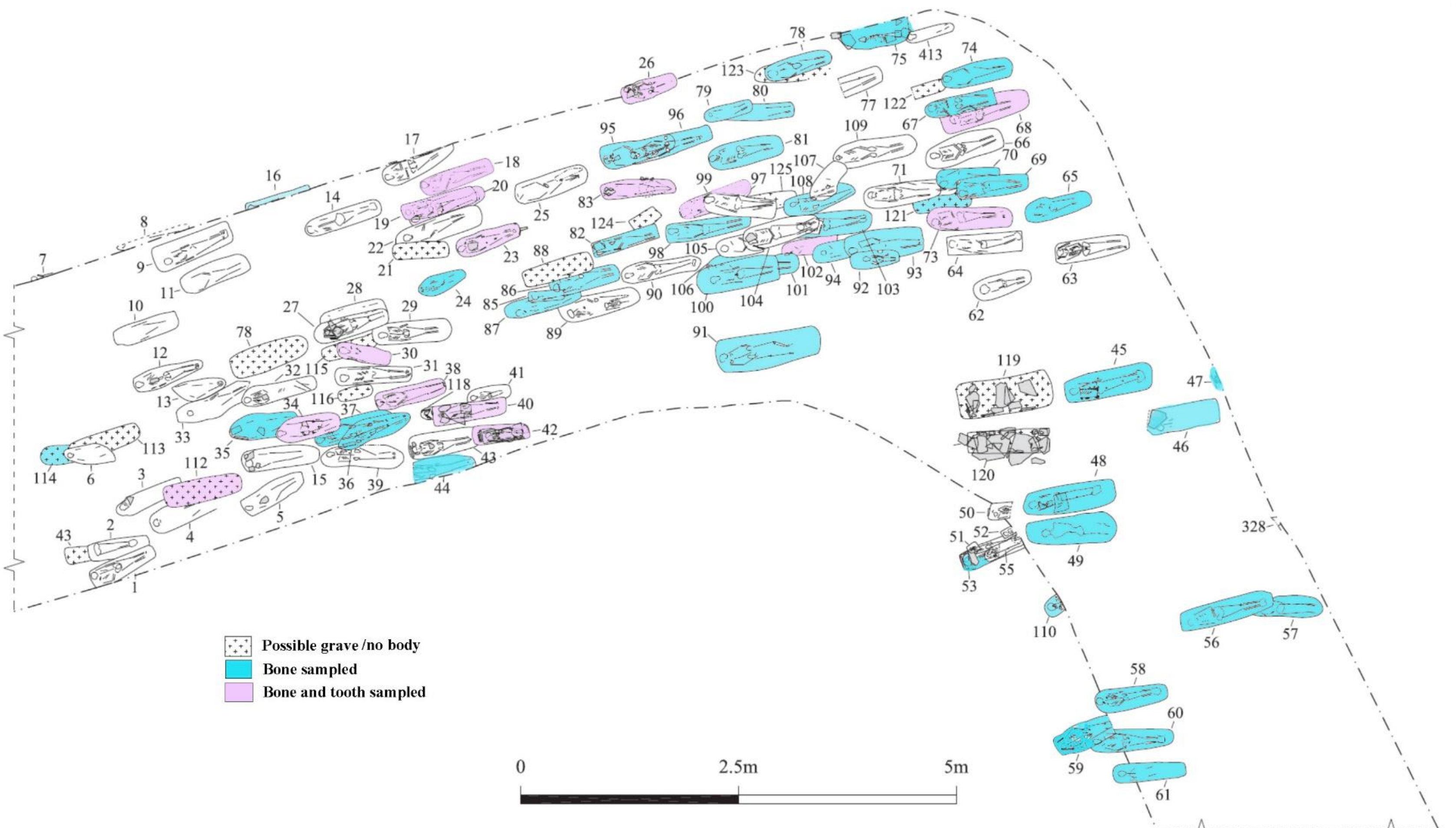

Figure 4.10. Plan of individuals sampled from Bu of Cairston (adapted from Stevens et al. 2005, 379; Illus. 5; reproduced with permission from the Society of Antiquaries of Scotland).

4.2.8. Newark Bay

The cemetery at Newark Bay is by far the largest collection of PVP and VA burials to have been excavated in Orkney, comprising over 250 individuals (Graham-Campbell and Batey 1998, 50). The size of the Newark Bay cemetery suggests individuals living in surrounding areas were brought there to be buried (S.J. Gibbons, pers. comm.). A coin found beneath the floor of the chapel provides a tenth-century date, and it is possible the chapel "may represent one of the earliest Viking Age churches in Orkney" (Barrett 2004, 262; Brend and Gibbon 2016, 7). There is evidence of a medieval settlement (Barns of Ayre) close to Newark that may have been associated, but it has not yet been excavated (S. J. Gibbon, pers. comm., 16 October 2020). The closest excavated nearby farmstead to Newark Bay is the multi-phase settlement at Skaill, Deerness. The *skaill* place-name indicates the site was likely a high-status one, at least by the time of its Scandinavian occupation. According to Raymond Lamb, Skaill, Deerness in the eleventh and twelfth centuries was likely the home of the prominent and wealthy Norse elite Amudi and Thorkel, described in the *Orkneyinga Saga* (Lamb 1997, 13). Lamb described Newark and Skaill as "the prime bay-head sites in the parish" (*ibid.,* 16; S. J. Gibbon, pers. comm., 16 October 2020). Excavations of Skaill in the 1960s and 70s revealed a transition in subsistence practices from the PVP through the LNP phases. Faunal analysis concluded that cattle were the predominant domesticated mammal, followed by sheep/goat, then pig. Throughout the site's chronology, it appears very few cattle reached maturity and there was likely a focus on dairying dating back to the Neolithic (Noddle 1997, 236). Very few fish remains were attributable to the PVP phase, suggesting very little marine resource exploitation. It is important to note, though, that sieving was not standard practice during excavation, so fish remains may have been under-collected (Nicholson 1997, 244). Marine exploitation seems to have expanded substantially in the VA and LNP to include mostly large, offshore gadid species. Even in the LNP, though, the scale of fish processing appears to have been limited to local consumption and not large enough for commercial gain (*ibid.,* 245). Regarding agricultural practices, ard-marks from ploughing dating to the Iron Age suggest an early focus on agriculture at Skaill (Limbrey 1997, 17-18). A subsequent period of more intensive manuring resulted in the formation of deep or plaggen soils, likely in the VA or LNP (*ibid.,* 21).

In unpublished manuscripts written by Don Brothwell detailing his excavations between 1968 and 1972, he mentioned that the area's arable farmland and access to the sea would likely have provided for a population of an estimated 660 people (Brothwell, n.d). Newark Bay's proximity to the Brough of Deerness and other sites with Norse names indicative of farmsteads (see Chapter 2) suggests that Newark Bay was just one of several sites in the vicinity that were occupied in the VA (*ibid)*. Nearly all the inhumations excavated by Brothwell were recorded as being extended and orientated approximately east-west. Brothwell noted that 16 out of the 63 intact and undisturbed burials at Newark Bay included seashells, which he argued were intentionally included in the grave, possibly symbolic of Norse interest in marine resources (*ibid)*. In addition to seashells, a lignite bangle and bone comb were recorded as being found in association with two "Christian" burials, though in which exact burials these items were found were not accurately recorded (Brothwell, n.d). The bangle was recorded as being found in grave 69/104, though whether it was with individual 104A or 104B is not specified.

The site was first recorded in the seventeenth century as "Danish graves eroding from the coast", along with combs, knives and the remains of a dog (*ibid.*, 129). The site was surveyed between 1969 and 1972 by Don Brothwell, which included excavation of the chapel which resulted in a "good series" of dates for the Scandinavian burials. The condition that the site was left in following excavation led to an increase in erosion (Lowe 2000) which, unfortunately, has meant the loss of innumerable burials to the sea (Brothwell, n.d.; see also Lerwick 2014, 167). According to Gail Drinkall, curator at the Orkney Museum, human remains are constantly being found at the site and reported to county archaeologist Julie Gibson (G. Drinkall, pers. comm., 4 November 2015). The Newark Bay collection is currently housed in three separate facilities: The Orkney Museum in Kirkwall, the University of Highlands and Islands (UHI) and the Natural History Museum (NHM) in

London. Because the collection is being held in separate facilities, analysis of the collection as a whole has not been undertaken. As part of the present study, first-hand osteological analysis was undertaken of the Newark Bay remains housed at the Orkney Museum and UHI, which constituted approximately 85 individuals. Of those individuals, 68 were sampled for bone collagen and 22 teeth from 18 individuals were sampled for tooth enamel. Due to time and cost restrictions, only 14 of these teeth from 12 individuals were sequentially micro-sampled for tooth dentine.

Osteological analysis of the remains at NHM was carried out under the supervision of Dr. Theya Molleson over several years and the manuscript data recording forms for 214 individuals are kept at NHM. With the permission of Dr. Molleson, the data recording sheets were photographed and entered into a database including the entirety of the known Newark Bay collection as part of the current study. Due to restricted access to the collection (because of facility restructuring), only eight of the individuals were osteologically re-analysed first-hand by the author to check for consistency in methodology (explained further in Chapter 5). None of these individuals were sampled for isotopes as part of this study. Recent isotopic analysis of the portion of the Newark Bay collection (an estimated 60 adult individuals) held by NHM, however, was undertaken by James Barrett (Barrett et al. 2000a; 2000b, Barrett et al. 2001, Barrett and Richards 2004).

4.2.9. Brough of Deerness

The Brough of Deerness is a VA and LNP chapel site. Dated to before AD 975, the chapel is "thus among the earliest known evidence for Viking Age Christianity in the Scandinavian North Atlantic region- possibly predating the conversion date of AD 995" (Barrett and Slater 2008, 1; see also Barrett 2002; Morris 1996a). The Brough was excavated by Christopher Morris between 1973 and 1982, and more recently in 2008 and 2009 by the University of Cambridge. The site contains a tenth to twelfth century timber chapel among thirty buildings that constituted a Viking settlement (Barrett and Slater 2008; Gerrard and Barrett 2009, 1). Despite the presence of a chapel, only seven graves have been found including the remains of three infants, one child and one adult (Figures

4.11. and 4.12). No cross-incised stone slabs have been found to mark the graves and the burials themselves were all rather plain. It appears at least two of the infant burials were likely "illicit" burials (Morris and Emery 1986, 358). Two of the individuals have been radiocarbon dated to the eleventh to thirteenth centuries (Ashmore 2003, 38). A brief osteological report was provided by Simon Hillson in 1986, along with radiocarbon dates for two burials. An osteological re-assessment was completed for the individuals as part of the present study. Although there are no surviving human teeth for high-resolution dentine isotope analysis, sampling bone collagen for dietary isotope values was conducted as part of the present study.

The Brough's remote location and limited space for farming mean produce was probably brought to the site from Skaill, which was likely part of a large estate including Newark Bay (Morris and Slater 2008, 20). Therefore, archaeological reports of Skaill, Deerness were used to infer subsistence practices. As detailed in 4.2.8., LNP subsistence at Skaill consisted mainly of rearing cattle for dairying, exploiting offshore marine resources for local consumption and intensifying arability by manuring and the formation of plaggen soils to grow predominantly barley (Buteux 1997; Limbrey 1997; Nicholson 1997; Noddle 1997).

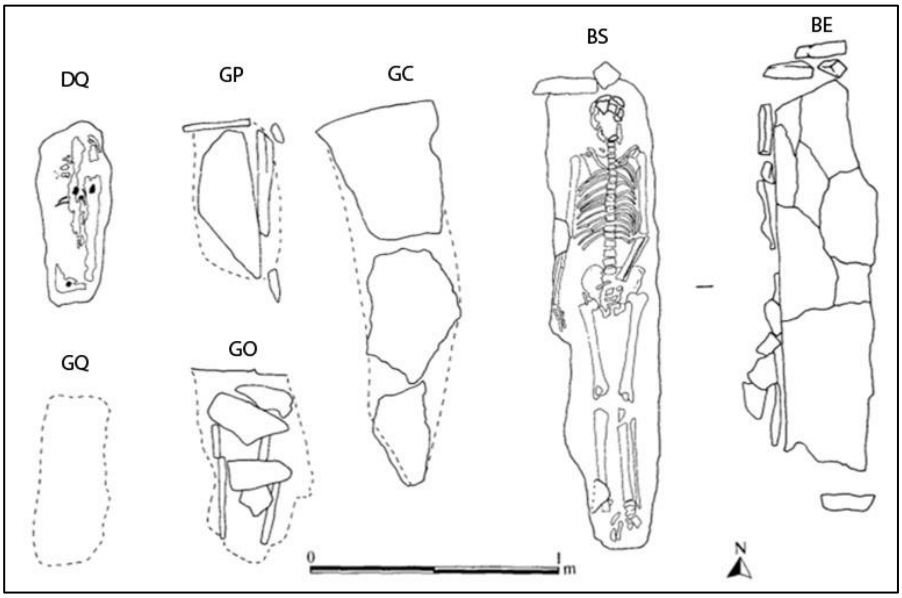

Figure 4.11. Plans of the graves found at the site of the Brough of Deerness including one adult, one child and four infants (after Morris and Emery 1986, 359; Illus. 28; reproduced with permission from the author and from the Society of Antiquaries of Scotland).

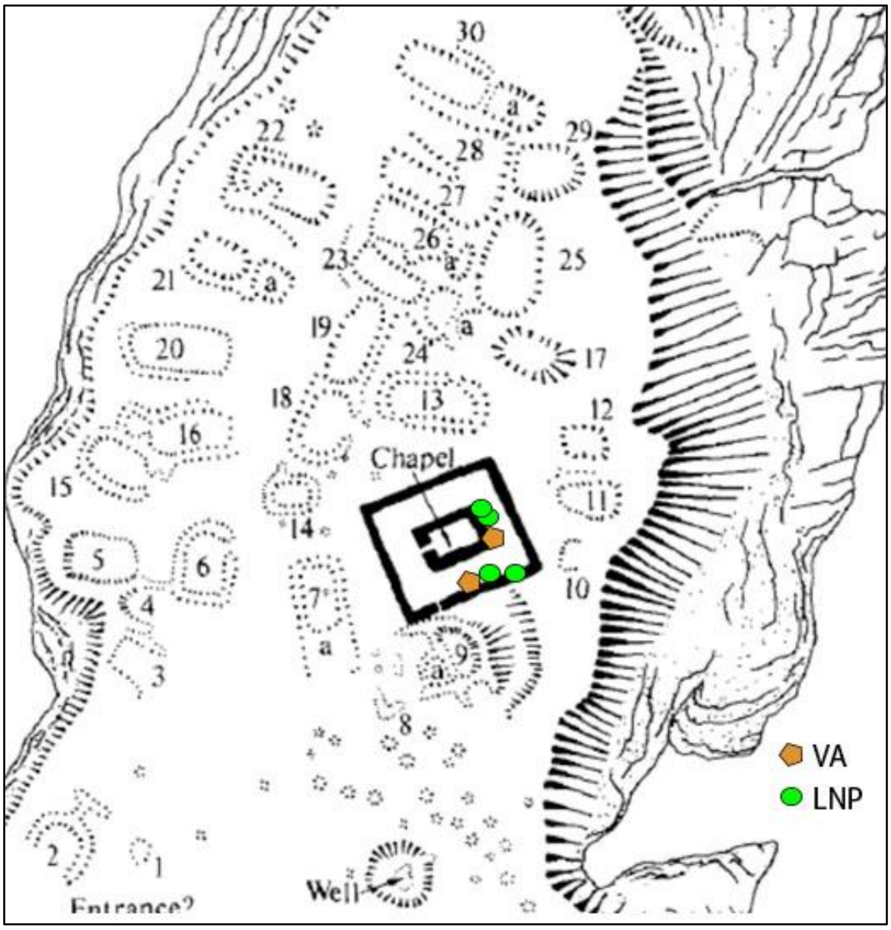

Figure 4.12. Plan of VA and LNP burials around the chapel at the Brough of Deerness (adapted from Morris and Emery 1986, 311; Illus. 6. The child's grave is not depicted on plans; reproduced with permission from the author and from the Society of Antiquaries of Scotland).

4.3. Overview

Unfortunately, what has been published from Orkney consists mainly of site-based osteological assessments from sites like Buckquoy, Birsay Bay, Westness, Skara Brae and Newark Bay. The nineteenth-century saw an increase in antiquarian interest and the beginning of PVP and VA burials being recorded in Orkney. Some remains found in the early decades of archaeology are now lost and the written records provide few relevant details. This includes the remains found at Saevar Howe and Pierowall (Farrer 1863; Hedges 1983; Thorsteinsson 1965). From Pierowall, the only documentary evidence includes Thorsteinsson's 1965 article detailing previous accounts and grave descriptions which likely describe the two surviving crania at NMS. At the other end of the spectrum, the most comprehensive osteological reports from PVP, VA and LNP Orkney include those from Westness, Newark Bay, Buckquoy, Bu of Cairston, Birsay Bay and Skaill House and Cist. In particular, those from Westness and Newark Bay make inter-site comparisons possible and bring the data into the wider context of PVP and VA Orkney.

Berit Sellevold's analysis of the Westness cemetery found a longer life expectancy for females than males, with females grouping in the younger and older adult categories, while males grouped into the middle adult category (Sellevold 1999, 24). Mean stature was estimated at 173.9cm for males and 160.4cm for females, with the two tallest males being those buried in Viking boat graves. Sellevold found evidence for degenerative joint disease and spondylosis in 20 of 29 individuals (predominantly in older individuals) and several individuals displayed evidence of trauma. Periodontal disease was observed in several individuals, however, a "low prevalence" of caries was observed in the 505 surviving teeth, with only 21 teeth (8 individuals) exhibiting caries (*ibid)*. A comparison of pathologies between PVP and VA populations was not attempted, however.

Theya Molleson has done extensive work on the Newark Bay collection housed at the NHM in London. Her analysis of the infant remains found that 24 out of the 51 displayed signs of chronic pathology, likely a result of nutritional deficiency, which she attributed to poor weaning diet and a lack of sunlight in the winter months (Molleson 2005, 113). As with the Westness population, Molleson found females lived longer, on average than males. Mean stature was estimated at 159cm for females and 172cm for males, slightly shorter than estimates for Westness (*ibid.,* 114). The differences in stature between males and females, along with other sexually dimorphic characteristics, led Molleson to speculate that there was "adequate nutrition" and plentiful resources (*ibid)*. Despite the low prevalence of infections, one individual was diagnosed with leprosy and one individual had symptoms of tapeworms. More prevalent than infections were signs of degenerative joint disease. Occupational injuries were interpreted as the cause of several instances of trauma.

> "*Hard work began at an early age, before growth was complete. The form of bones is often modified by the stresses of long arduous physical*

activity and can culminate in arthritic joints. Both men and women variously carried heavy 'cassies' (baskets), rowed boats, ground grain on rotary querns and rode horses" (ibid., 115).

James Barrett and colleagues began undertaking isotope analysis of individuals from Newark Bay, starting in 1999 (Barrett et al. 2000a). As discussed in Chapter 2, Barrett et al. found an increase in marine resource consumption around the turn of the millennium, later termed the "fish event horizon" (Barrett et al. 2004). Changes in dietary patterns through time have been attributed to not only Scandinavian cultural preferences, but also to the emergence of long-distance trading networks and the Christianisation of the population (Barrett et al. 2001; Barrett and Richards 2004; van der Sluis et al. 2016, 121).

The twelve sites included in this study comprise the best documented and best-preserved PVP, VA and LNP human remains collections in Orkney. While some were excavated in the earlier years of archaeology, such as Pierowall, Skara Brae, portions of Newark Bay and the Broch of Gurness, some have been subject to more modern rigorous documentation and recording such as Bu of Cairston, Birsay Bay and the Bay of Skaill. What is presented in this chapter is an overview of each site, the context in which human remains have been researched, the Pictish/Norse transition as it pertains to burial practices and archaeological evidence of subsistence strategies at nearby farmstead sites that may aid in interpreting osteological and isotope patterns in diet and health through time. One of the goals of the current study is to bring together data from previous studies (both published and unpublished) from these sites in Orkney to afford a more complete view of patterns in diet and health from the PVP through the VA and LNP. While the majority of these sites have had previous osteological and/or isotopic analyses done, never before have all 450+ individuals from these twelve sites been collectively compared and systematically osteologically analysed to provide answers to long-standing questions about Scandinavian impact on the subsistence, diet and quality of life of the Orcadian populations during this time of transition.

Chapter 5. Osteological Results

This chapter presents the results of an osteological examination of 485 individuals from the Pre-Viking Phase (PVP), Viking Age (VA) and Late Norse Phase (LNP) sites throughout Orkney. This includes age-at-death and stature profiles, as well as crude prevalence rates (CPRs) and true prevalence rates (TPRs) (where possible) for indicators of nutritional deficiencies, dental pathology, developmental stress, load-bearing and occupational stress, specific and non-specific infection and trauma. CPRs were calculated as the number of afflicted individuals out of the total number of individuals in each category, while TPRs were calculated as the number of affected elements (e.g., teeth, femora, etc.) out of the total number of observable elements. The purpose of which was to test whether indicators of nutrition, diet and physical labour changed significantly with the onset of the VA and its cultural and economic transitions. How did the overall structure of the population change? Were changes in nutrition and health experienced differently by different subsets of the population (a specific age group or sex)? How did health vary between sites and could these differences be symptomatic of increasing site specialisation and a growing market-based economy, or were changes more reflective of cultural and ethnic differences? Before incorporating the bioarchaeological data for differing agricultural focus and/or animal husbandry practices between sites, stature means, demographic patterns and prevalence rates of osteological indicators of nutrition and health were compared between phases and sites to identify phase or site-specific trends in activity and diet. Statistical analyses were run using SPSS to test for patterns between phases as well as between sites, grave goods and archaeological evidence of subsistence practices. It should be noted that there was considerable variability in the sizes of site populations, which may have affected inter-site statistical comparison. A synopsis of the results of each section will be provided at the end of that section.

5.1. A caveat concerning consistency

The results are based on data recorded by the author during this study, as well as from previous analyses where re-assessment during this study was not possible. Due to restrictions in accessing the collection from Newark Bay that is housed at the NHM, a subset of 8 of these individuals (out of 240) were re-analysed by the author. This was done to confirm the consistency of methodology between the current study and previous analysis by Dr. Theya Molleson at NHM. It is with her consent that I have incorporated her analysis of 232 individuals into this study. It is important to note that regarding the eight individuals re-analysed by the author of this study, consistency was found in methods of aging, sexing and the presence or absence of most pathological indicators including porotic hyperostosis, osteoarthritis, osteochondritis dissecans, attrition and calculus levels, the presence and number of dental caries and evidence of trauma. Although there was consistent recording in the presence or absence of cribra orbitalia, the severity of CO was not scored consistently in the manuscript record sheets. Nor were the presence/absence or timing of LEHs recorded consistently in the manuscript sheets, an issue further addressed in section 5.4.3.1. Platymeric and platycnemic indices were recalculated by the author for all elements with detailed measurements, as previous diagnoses on the manuscript sheets were also inconsistent.

Regarding the other sites, the author conducted osteological analysis before referencing previous analyses. Once an independent analysis by the author was completed, previous analysis (where applicable) was referred to. Any discrepancies found between the author’s observations and previous studies were then settled by consultation with photographs and notes- following methodologies outlined in Chapter 3 and with the author’s best judgment. Individuals that were not analysed by the author and for which previous analysis has been relied upon are so indicated in the inventory provided in Catalogue A-1. Further tables of statistical results are provided in Catalogue C.

5.2 Demographic patterns

Sex and age-at-death estimations were used to reconstruct population demographics. As there are not yet any widely accepted methods for sexing subadults (Buikstra and Ubelaker 1994, 16; Franklin et al. 2007; Silva Braz 2016, 201; etc.), all estimates of sex in subadults by previous studies were disregarded. Individuals were separated into three sex categories (male, female and unknown) and seven age categories (infant, child, juvenile, adolescent, young adult, middle adult and older adult), as per Table 5.1. (and per methods detailed in Chapter 3). Life tables for each phase are provided in Catalogue C, Tables 1-4.

Category Name	*Age Range*
Infant	foetus through 1 year
Child	1-4 years
Juvenile	5-10 years
Adolescent	11-17 years
Young Adult (YA)	18-34 years
Middle Adult (MA)	35-49 years
Older Adult (OA)	50+ years

Table 5.1. Age categories by number, name and age range.

Population structure (sex ratio, juvenility index, mean age at death category, life expectancy and crude death rate) was compared between phases to estimate whether Scandinavian migration or agricultural improvements may have acted as catalysts for demographic transition in terms of population growth, altering the sex ratios or age at death distributions through time. According to Chamberlain's book *Demography in Archaeology* (2006, 39), migrations typically predominantly involve the movement of infants and their young adult parents (usually in their early 20s), so a rise in the proportions of infants and children and young adult groups in the VA could serve as evidence of immigration in the VA. Although an age-at-death distribution chart (Figure 5.1) suggests overall infant mortality (between foetus and one year) of between 18.8% and 26.5% (within 95% CI) for all three phases combined (Lowry 2020; Newcombe 1998), the number of undated infant burials (approximately 86) could significantly alter the numbers of infant deaths for one or more phases. When comparing adolescents and older, there were no significant differences in the proportion of males and females (p=0.989) between phases. The proportion of males and females in none of the individual age groups changed significantly by phase (adolescents p=0.293, young adults p=0.250, middle adults p=0.317 and older adults p=0.107). Nor was there a significant difference in the proportions of the different age groups by phase (p=0.434). A juvenility index (the proportion of young individuals in the population) was per phase and calculated as the number of individuals in the population aged 0-14 years/ number of individuals in the population aged 15+ years. This is used to estimate fertility rates by comparing the number of juveniles to the number of adults in the population (Chamberlain 2006, 282). The PVP juvenility index was 0.2 (4/20), VA index was 0.1 (6/60) and the LNP juvenility index was 0.44 (35/80), showing a decline in the proportion of individuals younger than 14 from the PVP to the VA, followed by an increase in juveniles from the VA to the LNP. Unfortunately, this could not be tested statistically. Within each phase, Kruskal-Wallis tests showed no significant differences in the proportions of the different age groups of either males or females (males PVP: 0.494, VA: 0.535, LNP: 0.324 and females PVP: p=0.419, VA: 0.535, LNP: 0.789; Table 5.2).

	Sex ratio	***Juvenility index***	***Mean age at death***	***Life expectancy****	***CDR*****
PVP	1 M:1 F	0.2	20-35	35	0.03
VA	1 M:1.08 F	0.1	20-35	32.2	0.03
LNP	1 M:1.06 F	0.44	20-35	29.1	0.04
P value	0.989		0.434	0.949	

** Represented as ex on life tables, Catalogue C, Tables 1-4.*

*** Calculated as 1/e^0, as per Chamberlain 2006, 35*

Table 5.2. Population structure calculations for all three phases, along with Kruskal Wallis results for significance (p value) (this study; James 1999; Lorimer 1970; Molleson n.d.; 2005; Morris 1989; Morris and Emery 1986; Owen and Dalland 1999; Sellevold 1999; Stevens et al. 2005; Thorsteinsson 1965).

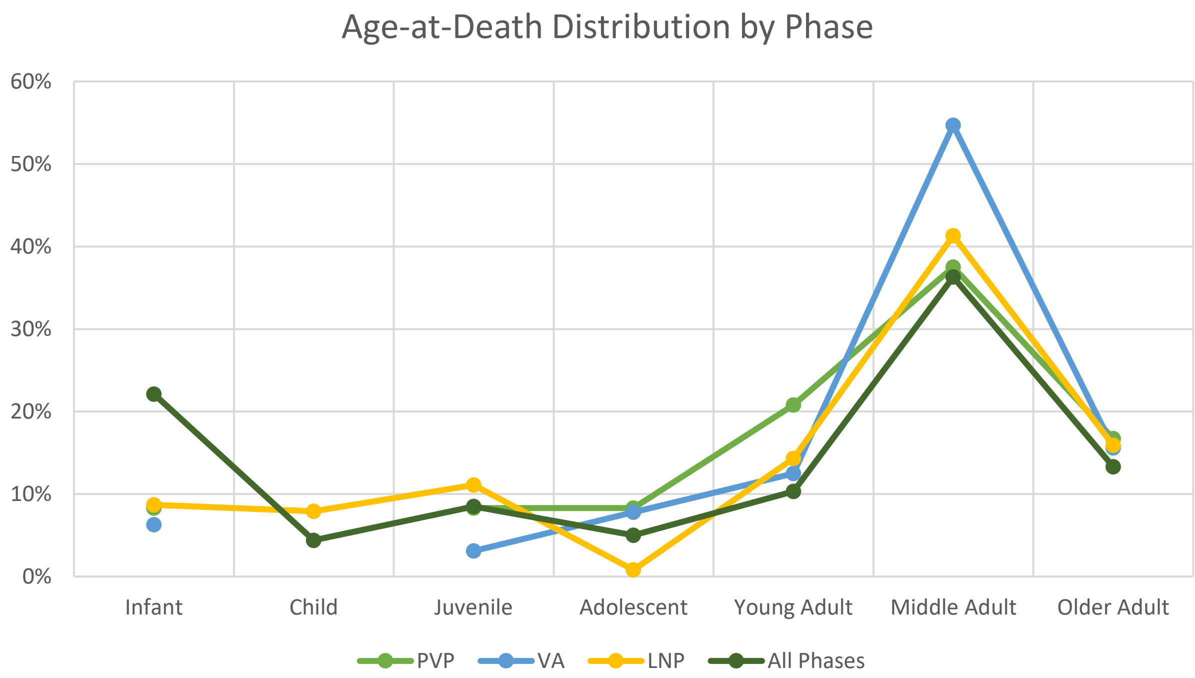

Figure 5.1. Age-at-death distribution by phase (this study; James 1999; Lorimer 1970; Molleson n.d.; 2005; Morris 1989; Morris and Emery 1986; Owen and Dalland 1999; Sellevold 1999; Stevens et al. 2005; Thorsteinsson 1965).

Age Category	***PVP***		***VA***		***LNP***		***All Phases***	
	No.	Proportion	No.	Proportion	No.	Proportion	No.	Proportion
Infant	2	8.3%	4	6.3%	11	8.7%	101	22.1%
Child	0		0		10	7.9%	20	4.4%
Juvenile	2	8.3%	2	3.1%	14	11.1%	39	8.5%
Adolescent	2	8.3%	5	7.8%	1	0.8%	23	5.0%
Young Adult	5	20.8%	8	12.5%	18	14.30%	47	10.3%
Middle Adult	9	37.5%	35	54.7%	52	41.3%	166	36.3%
Older Adult	4	16.7%	10	15.6%	20	15.9%	61	13.3%

Table 5.3. Age-at-Death distribution by phase (this study; James 1999; Lorimer 1970; Molleson n.d.; 2005; Morris 1989; Morris and Emery 1986; Owen and Dalland 1999; Sellevold 1999; Stevens et al. 2005; Thorsteinsson 1965).

5.3 Stature

Greater stature has been used as a proxy for better nutrition and health in past populations, as well as being at least partially genetically heritable (discussed in Chapter 3). If nutrition and overall health improved in the LNP with increased social stability and the production of agricultural surplus (per Chapter 2), or if we are to support the argument that a large group of Scandinavian immigrants (with genes for above-average stature; Ruff 2018, 372) arrived in Orkney in the VA or LNP, we might expect a significant rise in stature means. Stature estimates were calculated for those individuals with intact long bones suitable for measurement. When possible, stature was estimated from femoral or tibial lengths (elements and raw data used are provided in Catalogue C, Table 5). Where intact femoral or tibial elements were not present, however, humeri, ulna or radii were used. Left-sided elements were used when possible. In some cases where previous studies were relied upon for stature measurements, the exact element used for stature estimation was not disclosed. This included a total of 118 individuals: 60 males, 51 females and 7 individuals of undetermined sex. Fourteen of these individuals dated to the PVP, 26 individuals dated to the VA and 30 individuals dated to the LNP. An additional 47 individuals providing stature estimations were undated. Included are the author's measurements as well as measurements taken from previous investigators where my own measurements were not possible (James 1999; Lorimer 1970; Molleson n.d.; Morris 1989; Owen and Dalland 1999; Sellevold 1999; Stevens et al. 2005). As stated in the Methodology, the stature formulae used in this study were those developed by Trotter and Gleser (1958). An ANOVA test showed no significant difference in male stature means between phases (p=0.286), though there was significantly greater variability in stature estimates in the VA (1SD= 7.2cm) than in the PVP or LNP (1SD= 3.4cm and 5.7cm, respectively) (Figure 5.2. and Table 5.4). An ANOVA test of female stature estimates likewise showed no differences between phases (p=0.808), nor was there a difference in the variability of stature estimates between phases (p=0.858).

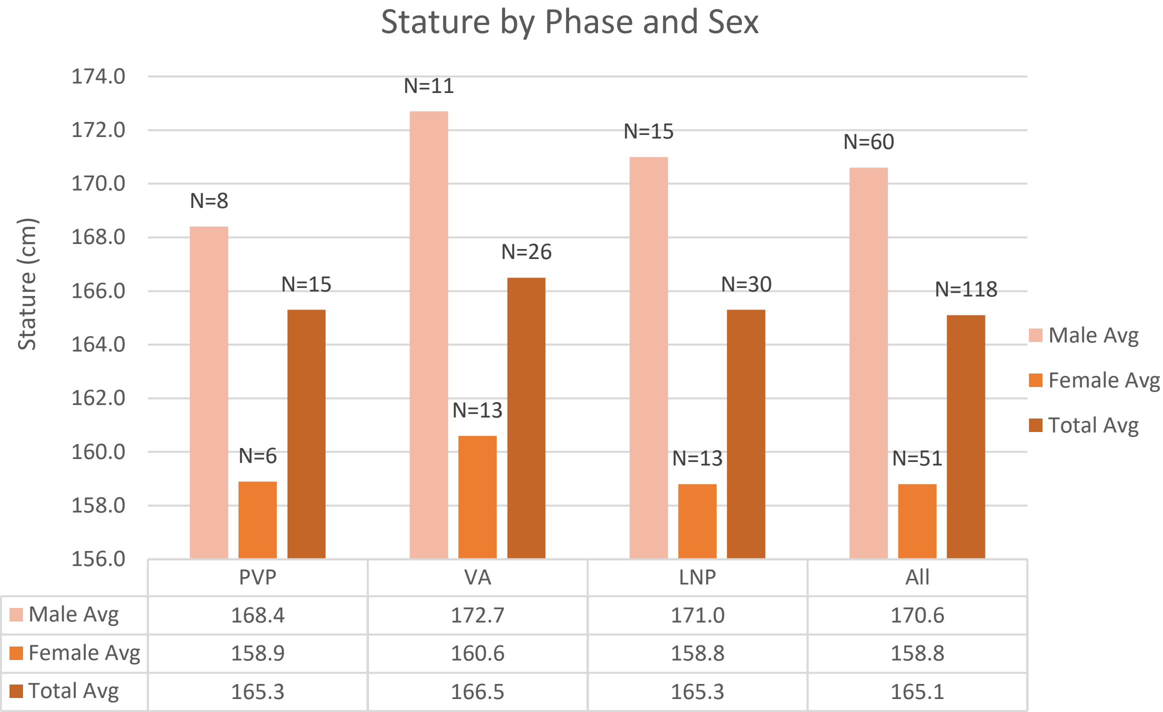

Figure 5.2. Stature means in Orkney by phase and sex (this study; James 1999; Molleson n.d.; Sellevold 1999; Stevens et al. 2005).

Stature

Phase	Male	N	Female	N	All	N
PVP	168.4	8	158.9	6	165.3	15
VA	172.7	11	160.6	13	166.5	26
LNP	170.9	15	158.8	13	165.3	30

Table 5.4. Stature means in Orkney by phase and sex (this study; James 1999; Molleson n.d.; Sellevold 1999; Stevens et al. 2005).

To determine whether stature may have varied between individuals from different Orcadian sites, males and females from all phases were compared and there was no significant difference in mean statures of either (p=0.881 and 0.635, respectively). Nor were there any sites that varied significantly in stature within the PVP (p=0.178), VA (p=0.292), or LNP (p=0.063) among males or females.

Next, to test if stature (as a proxy for nutritional health) differed significantly between different burial settings, VA individuals in churchyard cemeteries were compared with those in non-churchyard cemeteries and isolated burials. There was no difference in male (p=0.595) or female (p=0.652) stature between those buried in churchyards or non-churchyard settings. Nor was there any significant difference in stature between VA males (p=0.928) or females (p=0.604) buried in or without cists or VA males (p=0.110) in or without boat graves. To test whether individuals in furnished graves may have had access to more nutritional foods or better health care, the presence and type of grave goods were then statistically compared with stature. Males with grave goods exhibited significantly greater stature means than those without (0.033). The mean stature amongst males with grave goods was 176 ± 6.5cm (n=8), while those males without grave goods provided a mean of 166.9 ± 4cm (n=4). There was no significant difference between VA females with and without grave goods, however, there was only one female with grave goods for whom stature was estimated (152cm, compared with those without grave goods 160.6 ± 6cm; p=0.144, n=12). While the mean stature of VA males with grave goods was significantly greater than that of females with grave goods (p=0.034), there was no significant difference between sexes among those without grave goods (p=0.094).

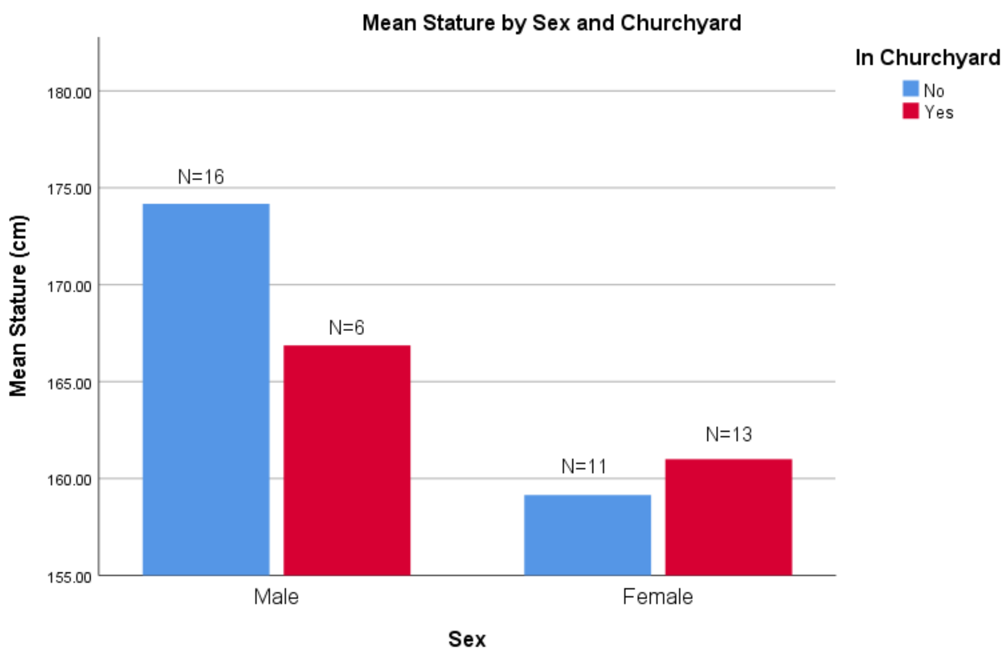

Figure 5.3. Comparison of VA male and female mean statures of those buried within and without churchyards.

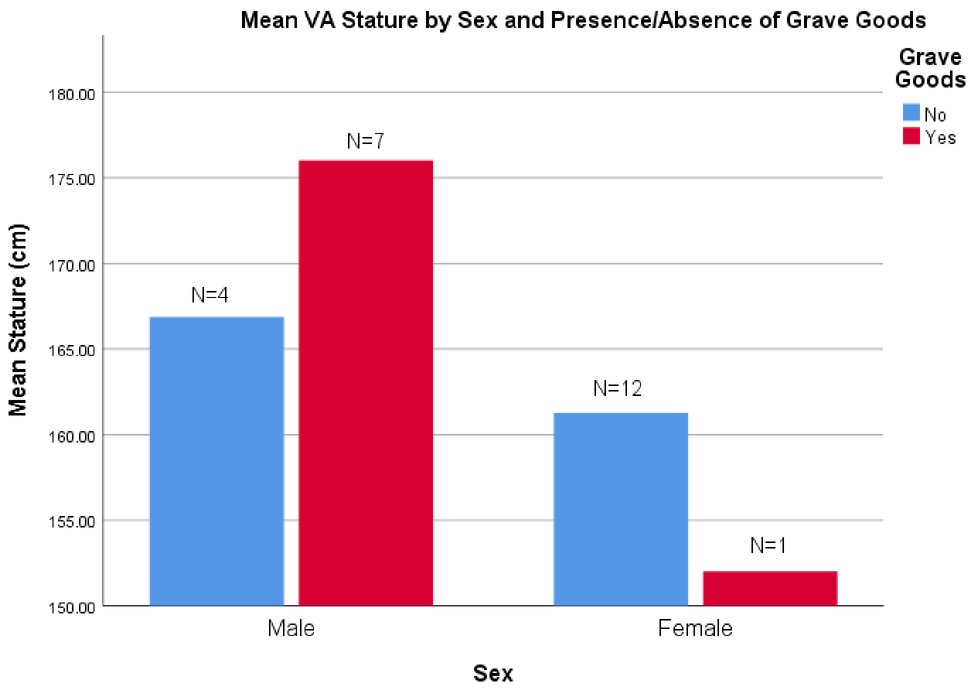

Figure 5.4. Male and female stature means for VA individuals with and without grave goods.

Finally, to test whether stature was affected by subsistence strategies that may have varied between sites of the same phase, stature means were compared between sites with zooarchaeological evidence for a different predominant domesticated animal, animal use, or cereal focus (see Catalogue C, Table 6). All excavated farmsteads in the PVP exhibited zooarchaeological and botanical evidence that showed cattle to be the predominant domesticated mammal and barley to be the predominant crop. Thus, comparison between these variables was not possible within the PVP. There were no significant differences in mean statures of VA or LNP males or females between any of the subsistence variables. When all individuals from all phases were compared, there were no significant differences in mean statures of males or females between sites with evidence for different predominant animals (cattle, sheep/goat or pig), animal uses (meat, dairying or traction), or predominant crops (barley, oat, or flax). Nor was there a difference in male or female stature between sites in different LC codes, evidence of plaggen soil, or sites with different name types. Tables with the statistical results of each combination of variables are provided in Catalogue C.

5.4 Pathology

As discussed in Chapter 3, evidence of skeletal and dental pathology was recorded to reconstruct patterns in nutrition and overall health from the PVP through the VA and LNP. This included evidence of nutritional deficiency, developmental stress, occupational stress markers (including degenerative diseases) and specific and non-specific infections. The prevalence rates of indicators of nutritional deficiency were compared by phase, as well as by sex and age group to discern whether certain demographic groups may have been more physically affected by changes in their environment and access to nutrition and whether this changed through time. In addition, indicators of pathology were compared by site, burial setting (churchyard or non-churchyard and plain, cist or boat burial) as well as by grave goods to determine whether individuals buried with certain cultural or ethnic indicators had access to better nutrition. Finally, nutritional deficiency indicators were compared between individuals from sites with evidence of differing subsistence strategies. This included archaeobotanical evidence of predominant crops and zooarchaeological evidence of predominant domesticated mammals as well as mammal use (i.e., meat, dairying or traction).

For each section, the number of individuals affected out of the total number of observable individuals in each phase/category is reported as the crude prevalence rate (CPR). Where applicable (and where possible, due to limited preservation in some cases), true prevalence rates (TPRs) were calculated as the number of affected elements out of the total number of observable elements. The two-tailed significance results of statistical tests (i.e., Chi^2, ANOVA, Spearman's rho, etc.) are reported as p values. Results include data collected as part of this study, as well as data collected by James 1999; Lorimer 1970; Molleson 2005; n.d.; Morris 1989; Owen and Dalland 1999; Sellevold 1999; and Stevens et al. 2005. Tables with additional prevalence rates and statistical data for each section are presented in Catalogue C, Tables 7-48.

5.4.1. Nutritional deficiency

Rickets and scurvy are perhaps the most under-identified nutritional deficiencies in archaeological populations (Aufderheide and Rodriguez-Martin 1998, 313; Ortner and Putschar 1981, 272). Rickets (the manifestation of vitamin D deficiency) primarily affects subadults but is referred to in adults as osteomalacia and can manifest as porosity on the ribs of infants, as well as porosity on the cranial and/or orbital vault (Brickley et al. 2010; Ortner and Mays 1998). Osteological evidence of rickets/osteomalacia (bending of the long bones, especially leg bones) is indicative of vitamin D deficiency. Scurvy, however, is the manifestation of vitamin C deficiency and can cause a combination of CO, PH above the nuchal crest and along the sagittal suture, as well as increased vascularisation and porosity along large muscle attachment sites (Fain 2005; Geber and Murphy 2012). Although CO (Figure 5.5) and PH (Figure 5.6) can be indicators of scurvy and/or rickets, both CO and PH, as well as cribra femora (CF; Figure 5.7) may also indicate iron-deficiency anaemia (Brickley et al. 2010; Hutchinson et al. 2007, 57; Klaus 2017; Ortner and Mays 1998). While CF is a relatively poorly understood condition (as further discussed in Chapter 3), its aetiology has been shown to correlate with nutritional deficiency (Erkelens 2017). In some cases, the distribution of the abovementioned individual markers of nutritional deficiency (CO, PH, as well as periosteal reactions) across the skeleton of an individual allowed for a probable diagnosis of rickets and/or scurvy, as described in Chapter 3. It is important to mention that the number of diagnosable cases of rickets and scurvy is conservative, only including individuals with enough preserved skeletal material for a diagnosis. Because of the potentially different aetiologies of the skeletal indicators of nutritional deficiency observed in the study, it is best to review their prevalence one at a time.

The primary osteological markers of nutritional deficiency, as mentioned above, include cribra orbitalia (CO), porotic hyperostosis (PH) and cribra femora (CF). Since CO and PH were observable in all age categories, individuals of all ages were included in the statistical analyses of CO and PH. Per methods in Chapter 3, CO was recorded by orbit as present or absent, along with the stage of severity. PH was recorded as either present or absent and the portion of the cranial vault affected was recorded. CF was scored as either present or absent in each observable femur. The youngest age category with observable CF was the juvenile category, so infants and children were not included in statistical analysis. If a growing proportion of the diet was reliant on agricultural products (particularly phytate-rich foods such as cereals) in the VA and/or LNP, one may expect a rise in one or more of these osteological indicators of iron deficiency anaemia. This would hold especially true for females if, as previously hypothesized, females had significantly different diets as a result of divisions in labour (as discussed in Chapter 2).

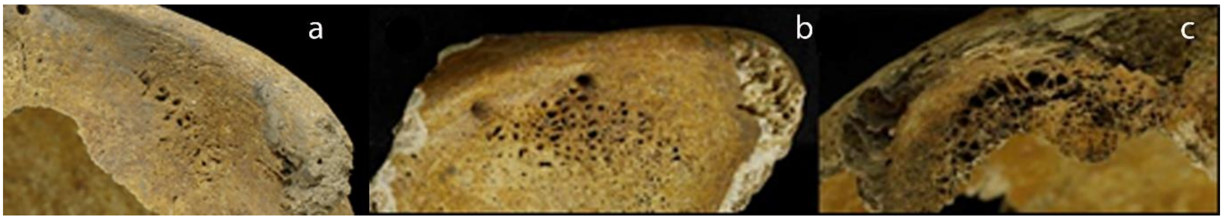

Figure 5.5. Orbital margins exhibiting CO; a. Stage 1 CO on right orbital roof of individual 205 from Bu of Cairston; b. Stage 2 CO on left orbital roof of individual 087 from Bu of Cairston; c. Stage 3 CO in individual 303 from Bu of Cairston.

Figure 5.6. Porotic hyperostosis on the external cranial vault of individual 370 from Bu of Cairston.

Figure 5.7. Cribra femora on right femoral neck of individual 154 from Bu of Cairston.

In the PVP, 8/16 individuals exhibited CO in either or both orbits, while the CPR of CO was 10/22 in the VA, increasing to 35/45 in the LNP (Table 5.5). A Pearson Chi^2 test showed a significant difference in the overall prevalence of CO by phase (p=0.042), with the greatest prevalence in the LNP and the lowest prevalence in the PVP. Among males (age was controlled for using a univariate linear model), there was a significantly greater prevalence of CO in the LNP than in the PVP (p=0.049). Among females, however, there was no significant difference in the prevalence of CO by phase (p=0.412). Next, the mean stage of CO was assessed, using the scale set forth by Stuart-MacAdam (1989) of 0 to 3. According to a Kruskal-Wallis test, there were no significant differences in the severity of CO by phase, even when sexes were compared separately, and age was controlled for (p=0.281). In none of the phases were there significant differences in the prevalence of CO between males and females (p=0.558, 0.102 and 0.164).

The prevalence of PH did not differ significantly by phase among females (p=0.939), though there were significantly more cases of PH among males in the LNP and VA than in the PVP (p=0.043). In none of the phases were there differences in the prevalence of PH between males and females (p=0.125, 0.428 and 0.089, respectively). Females exhibited a significant correlation between CO and PH (p=0.008, r=0.339), while males did not (p=0.101).

Phase	CO	CPR	95% CI	Affected Orbits	TPR	95% CI	Stage of CO	PH	CPR	95% CI
PVP	8/16	50.0	28.0 - 72.0	14/29	48.3	31.4 - 65.6	1.3	2/17	11.8	3.3 - 34.3
VA	10/22	45.0	26.9 - 65.3	18/41	43.9	29.9 - 59.0	1.0	11/27	40.7	24.5 - 59.3
LNP	35/45	77.8	63.7 - 87.5	54/72	75.0	63.9 - 83.6	1.4	16/73	21.9	14.0 - 32.7
P value	**0.042**			0.086			0.281	0.065		
Test	Chi2			ANOVA			KW	Chi2		

Table 5.5. Numbers and prevalence rates of CO and PH by phase, along with statistical significance. Bold p values indicate a statistical significance at α= 0.05 (this study; James 1999; Lorimer 1970; Molleson n.d.; 2005; Morris 1989; Morris and Emery 1986; Owen and Dalland 1999; Sellevold 1999; Stevens et al. 2005).

There was no significant difference in the prevalence of CF between phases (p=0.213) when all individuals were considered, or when males and females were compared separately (p=0.723 and 0.398, respectively). Nor was there a significant difference in the prevalence of CF between males and females in the PVP, VA or LNP (p=0.438, 1.000 and 0.826, respectively), as seen in Table 5.6.

Phase	Males	CPR (%)	Femora	TPR (%)	Females	CPR (%)	Femora	TPR (%)	All	CPR (%)	Femora	TPR (%)	p
PVP	2/7	28.6	4/12	33.3	1/8	12.5	2/15	13.3	4/18	22.2	8/33	24.2	0.438
VA	3/9	33.3	3/15	20.0	5/15	33.3	7/25	28.0	9/26	34.6	12/44	27.3	1.000
LNP	4/20	20.0	4/33	12	4/24	16.7	4/36	11.1	9/54	16.7	9/86	10.5	0.826
All	16/65	24.6	23/102	22.5	15/67	22.4	21/107	19.6	42/220	19.1	61/363	16.8	0.728

Table 5.6. Prevalence of cribra femora by sex and phase, along with the results (p value) of Pearson's Chi2 tests. Bold p values indicate a statistical significance at α= 0.05

Although statistically insignificant (p=0.180), there was a slight increase in the CPR of rickets from 4.2% to 10% from the PVP to the VA, before decreasing to 1.9% in the LNP. The prevalence of scurvy increased significantly from 0% in the PVP to 27.5% in the VA before falling to 12.3% in the LNP (p=0.000). When individuals showing any osteological indicators of nutritional deficiency were combined, there was no statistically significant difference in the prevalence of indicators of nutritional deficiency between phases (p=0.084), even when males and females were tested separately (p=0.782 and 0.698, respectively). Nor was there any significant difference in prevalence between males and females in any of the three phases (p=1.000, 0.503 and 0.179). CPRs of all individual osteological indicators of nutritional deficiency are provided by sex and phase, along with the results of Chi^2 tests in Catalogue C, Tables 7-10.

Phase	Males	CPR	95% CI	Females	CPR	95% CI	All	CPR	95% CI	p value	Test
PVP	0/10	0.0%	0-27.8%	0/10	0.0%	0-27.8%	1/24	4.2%	0.7-20.3%	0.157	Chi^2
VA	1/14	7.1%	1.3-31.5%	3/20	15.0%	5-36%	4/40	10.0%	4-23.1%	NA	Chi^2
LNP	1/33	3.0%	0.5-15.3%	0/34	0%	0-10.2%	2/106	1.9%	0.5-6.6%	NA	Chi^2
All	5/103	4.9%	2.1-10.9%	6/113	5.3%	2.5-11.1%	44/388	11.3%	8.6-14.9%	0.350	Chi^2

Table 5.7. Prevalence rates of rickets in males and females by phase. Bold p values indicate a statistical significance at α= 0.05 (this study; James 1999; Lorimer 1970; Molleson n.d.; 2005; Morris 1989; Morris and Emery 1986; Owen and Dalland 1999; Sellevold 1999; Stevens et al. 2005).

Phase	Males	CPR	95% CI	Females	CPR	95% CI	All	CPR	95% CI	p value	Test
PVP	0/10	0.0%	0-27.8%	0/10	0.0%	0-27.8%	0/24	0%	0-13.8%	NA	Chi^2
VA	6/14	42.9%	21.4-67.4%	2/20	10.0%	2.8-30.1%	11/40	27.5%	16.1-42.8%	NA	Chi^2
LNP	6/33	18.2%	8.6-34.4%	5/34	14.7%	6.5-30.1%	13/106	12.3%	7.3-19.9%	NA	Chi^2
All	17/103	16.5%	10.6-24.9%	18/113	16.5%	10.3-23.8%	54/388	14%	10.8-17.7%	0.209	Chi^2

Table 5.8. Prevalence rates of scurvy in males and females by phase. Bold p values indicate a statistical significance at α= 0.05 (this study; James 1999; Lorimer 1970; Molleson n.d.; 2005; Morris 1989; Morris and Emery 1986; Owen and Dalland 1999; Sellevold 1999; Stevens et al. 2005).

The prevalence of nutritional deficiency indicators was then assessed by age group within each phase to determine whether certain age groups were more at risk than others and whether this changed through time. If migrants in the VA primarily consisted of infants and young adults, one might expect those age groups to be the most at risk for nutritional deficiencies like scurvy. When individuals from all phases were included, 56.3% - 75.7% of infants (within 95% CI) and 45.4% - 88.3% of children exhibited at least one indicator of nutritional deficiency, which may have contributed to the death rate. Keeping in mind the small sample sizes, there were no significant differences in the prevalence of CO (0.223), PH (p=0.435), or any indicators of nutritional deficiency (p=0.084) in infants between the three phases, nor was there a correlation between nutritional deficiency and trauma (p=0.215). Because of the lack of children in the PVP and VA phases, statistical tests for differences between phases were not possible for this age category. Juveniles did not show a significant difference in the prevalence of CO (p=0.792) or any indicators of nutritional deficiency (p=0.922) between phases, nor did adolescents. Amongst the young adults, there was a significant increase in the prevalence of CO from the PVP (40%) to the LNP (82%), p=0.008. There was no significant difference in the prevalence of rickets in any of the age categories or throughout any of the phases. There was, however, an increase in scurvy in young adults from the PVP (0%) to the VA (44.4%), but a decline in the LNP (23.5%, p=0.011). Finally, there was a significantly higher prevalence of CF among older females in the VA (60%) than in the PVP (0%) and LNP (9.1%), p=0.043.

In the PVP and VA, there were no age groups that experienced a significantly higher prevalence of CO, PH, or any other indicators of nutritional deficiency over other age groups. The only exception was that in the PVP there was a significantly higher prevalence of CF among juveniles and adolescents (p=0.042), though there was only one individual in each of the two age groups. The LNP children, however, experienced a significantly higher prevalence of nutritional deficiency (75%) than other age groups (p=0.036), most markedly higher than the middle adults who only exhibited a prevalence of 27.9%. In none of the phases was there a significant difference in the prevalence of CO, PH, rickets, scurvy, CF (Table 5.9), or any indicators of nutritional deficiency between sexes.

Pathology	PVP	VA	LNP	All	Test
CO	0.280	0.387	0.067	0.252	Chi^2
Mean CO stage	0.313	0.313	0.239	0.340	KW
PH	0.078	0.193	0.587	0.616	Chi^2
CF	0.438	1.000	0.826	0.728	Chi^2
Nutri. Def.	1.000	0.503	0.179	0.194	Chi^2
Rickets	0.157	NA	NA	0.350	Chi^2
Scurvy	NA	NA	NA	0.209	Chi^2

Table 5.9. Table of statistical results (p values) testing differences in prevalence of indicators of nutritional deficiency between males and females in each phase. Bold p values indicate a statistical significance at α= 0.05 (this study; James 1999; Lorimer 1970; Molleson n.d., 2005; Morris 1989; Morris and Emery 1986; Sellevold 1999; Owen and Dalland 1999; Stevens et al. 2005).

When evidence for nutritional deficiencies was compared between sites of all three phases, Brough Road and Skaill House had significantly higher CO stage means than the other sites (p=0.021). When males and females were tested separately, there was a higher prevalence of rickets among males at Newark Bay (p=0.014) than among males from the other sites. The females from Skaill House had a significantly higher mean CO stage than the females from the other sites (p=0.046). Additional tables with male and female nutritional deficiency prevalence rates are provided in Catalogue C, Tables 14-17.

When PVP sites were compared, females from Westness had a higher prevalence of CO than PVP females from the other sites (p=0.050). When VA males and females were compared separately, there were higher rates of PH (p=0.036) and non-statistically higher cases of diagnosable scurvy (p=0.057) among males from the western sites of Brough Road, Buckquoy and Pierowall than among the males from Newark Bay, Scar or the Brough of Deerness. In the LNP, females from Bu of Cairston had a higher prevalence of diagnosable scurvy (13.8%) than those from Newark Bay (p=0.046), though Skaill House females had a higher mean CO stage (p=0.047) than females at other LNP sites. Among LNP males, there was a significantly higher prevalence of CO at Bu of Cairston (90%) than at Newark or the Brough of Deerness (p=0.016). When the multi-phase sites were tested for differences in the prevalence of nutritional deficiencies by phase, both Westness (p=0.012) and Brough Road (p=0.025) exhibited a greater prevalence of scurvy in the VA than in the PVP, while Newark Bay did not (p=0.525).

Next, indicators of nutritional deficiency were compared between males and females within and without churchyards as well as in plain graves, cists or boat burials. PVP females in cists had a significantly higher prevalence of nutritional deficiency than PVP females without cists (p=0.010), however, neither females nor males in and without cists exhibited a different prevalence of nutritional deficiencies in any other phases. As there were no known churchyards in the PVP, comparisons regarding churchyard burials were limited to VA sites. VA PH and diagnosable cases of scurvy were only observed in males buried outside churchyards (p=0.006 and 0.010, respectively). There were no significant differences, however, in the prevalence of any indicators of nutritional deficiency among females buried within or outside of churchyards. VA males in boat graves exhibited a significantly greater prevalence of diagnosable scurvy than VA males not in boat graves (p=0.028). Explanations for this will be explored in Chapter 8. All LNP individuals were found in churchyards or at sites that likely had churches, except for one female (grave 36) from Westness. Aside from this one female, there were no furnished or boat burials in the LNP.

VA males with grave goods had a higher prevalence of PH than VA males without grave goods (p=0.016) or females with or without grave goods (p=0.034). They also had a higher prevalence of diagnosable scurvy than males without grave goods (p=0.004). When CPRs were tested by types of grave goods, the males with weapons or combs showed a significantly high prevalence of scurvy than males without those goods (p=0.001). Females with grave goods of any type showed no significant difference in any osteological indicators of nutritional deficiencies between VA females without grave goods (Table 5.10). Nor were there any differences in prevalence rates of any nutritional deficiencies among females with any particular grave good (jewellery, textile implements, combs, daggers, gaming pieces or farming tools, see Catalogue C, Table 21).

Pathology	Males	N	Females	N	All	N
CO	0.414	6	0.782	11	0.492	20
PH	**0.016**	9	0.248	12	0.102	26
CF	0.635	9	0.171	15	0.592	26
Rickets	0.377	12	0.718	20	0.818	40
Scurvy	**0.004**	12	0.389	20	0.057	40
Nutritional Deficiency	0.198	12	0.606	20	0.443	40

Table 5.10. Results (p values) of Chi^2 tests showing the differences in prevalence of indicators of nutritional deficiency between individuals with and without grave goods in the VA (this study; Lorimer 1970; Morris and Emery 1986; Morris 1989; James 1999; Sellevold 1999; Owen and Dalland 1999; Molleson n.d.; 2005; Stevens et al. 2005). Bold p values indicate a statistical significance at α= 0.05

Prevalence rates of nutritional deficiency indicators in males and females from different site types and evidence of subsistence were then compared to test if differences in site function, location or subsistence practices may have resulted in differences in nutritional indicators. PVP females from sites named after land features (Westness and Skara Brae) had a significantly higher prevalence of nutritional deficiencies than females from sites with *-by* names (i.e., Newark Bay; p=0.038). Females from the only site with evidence of offshore fishing in the PVP (Westness) had a higher prevalence of CO than females from sites with evidence for either no or near-shore fishing (p=0.025). Due to the lack of female remains from other western sites, it was impossible to determine whether they might have exhibited a similarly higher prevalence in CO or whether this trend was limited to Westness and Skara Brae. Whether the females from Westness and Skara Brae exhibited a higher prevalence of CO indirectly as the result of their location on the western side of the islands (p=0.025) and/or whether differences in subsistence strategies between PVP sites may have been the underlying cause will be explored further in Chapter 8.

When VA males and females were tested separately, males exhibited a negative correlation between the percentage of cattle and PH (p=0.001, r=-0.909), diagnosable scurvy (p=0.000. r=-0.915) and nutritional deficiency (p=0.042, r=-0.621). In other words, there was a higher prevalence of PH (and its related variables- scurvy and nutritional deficiency) among individuals from sites with lower proportions of cattle in the VA (Pierowall and Scar). These correlations were not observed in VA females. VA males from western sites and sites with evidence of plaggen soil (Buckquoy, Brough Road and Pierowall) had a significantly higher prevalence of PH (p=0.036 and 0.028, respectively) than VA males from sites on the eastern side of the islands or without plaggen soil formation (Scar, Newark Bay or the Brough of Deerness). Despite site names related to land features being present on both sides of the islands, males from sites named for land features also exhibited a higher prevalence of PH (p=0.019) and diagnosable scurvy (p=0.042) than males from sites named for fortifications or *-by* sites.

In the LNP, males from Bu of Cairston had a higher prevalence of CO than LNP males from the other sites (p=0.016). Females from sites near farmsteads where oats were the predominant crop had a higher prevalence of diagnosable scurvy than females from sites near farmsteads where barley was the predominant crop (p=0.046). Females from sites with a greater focus on rearing mammals for meat than for dairying also had a greater prevalence of diagnosable scurvy (p=0.046). Finally, females from plaggen sites and sites within LC code 5.2 (rather than 4.2) had a higher prevalence of diagnosable scurvy (p=0.016 and 0.016).

5.4.2. Dental pathology

Many of the markers of dental pathology are indicative of diet, including dental wear (attrition), calculus, caries and periodontal abscesses and ante-mortem tooth loss (AMTL). This section presents the results of dental pathology as it relates to diet. According to a Spearman's rho test, the presence of each dental pathology correlated significantly with age category. Thus, age was controlled for using ANCOVA. Additional tables and the results of statistical tests relating to dental pathology are provided in Catalogue C, Tables 22-31.

5.4.2.1. Dental attrition

Patterns in dental attrition are arguably population-specific, in part because they reflect differences in diet (Clement and Hillson 2012, 517; Davies 1955; Deter 2009; Molnar 1971). A diet consisting of coarse, less refined foods (like grains) results in higher rates of dental attrition, as opposed to a diet of more refined foods (though this also depends on how the foods are prepared, Dawson and Brown 2013, 433; Powell 1985). While previous studies have shown a decrease in attrition from hunter-gatherer populations to agriculturalists (Larsen 1995, 195), increased consumption of agricultural products or a changing focus on grains from barley to oat may not have resulted in any temporal differences in dental attrition. Greater variability in dietary indicators such as dental attrition among individuals of the same population may reflect a more socially stratified society or changing social organization (Dawson and Brown 2013, 434). As teeth were used in several occupational activities which could also have affected wear, patterns of wear typically associated with occupational activities were noted (Figure 5.8).

There was no significant difference in the attrition rates of males ($p=0.776$) or females ($p=0.125$) between phases. In the PVP, there were significantly greater attrition averages in females than in males ($p=0.001$, $n=16$) once age was controlled for. There were no significant differences between males and females in the VA ($p=0.272$, $n=28$) or in the LNP ($p=0.593$, $n=62$). While the average attrition stage did not vary significantly by phase, there were increasing proportions of individuals with moderate and severe wear in the VA and LNP. When age groups (adolescents and older) were tested individually across phases using Kruskal-Wallis tests, young adults showed significantly greater attrition in the VA and LNP than in the PVP ($p=0.038$). No other age categories showed significant differences in attrition between phases. Prevalence rates of each attrition stage by phase are provided in Table 5.11. and Figure 5.9.

Figure 5.8. Severely worn dentition of NB1 (left) and 69(8) (right), from Newark Bay.

PVP

Attrition Stage	**Male (n=9)**	**95% CI**	**Female (n=7)**	**95% CI**	**All (n=17)**	**95% CI**
None	1 (11.1%)	2-43.5	0 (0%)	0-35.4	1 (5.9%)	1.1-27
Slight	3 (33.3%)	12.1-64.6	2 (28.6%)	8.2-64.1	6 (35.3%)	17.3-58.7
Moderate	0 (0%)	0-29.9	1 (14.3%)	2.6-51.3	1 (5.9%)	1.1-27
Severe	5 (55.6%)	26.7-81.1	4 (57.1%)	25-84.2	9 (52.9%)	31-73.8
Average stage	2		2		2	

VA

Attrition Stage	**Male (n=12)**	**95% CI**	**Female (n=17)**	**95% CI**	**All (n=35)**	**95% CI**
None	0 (0%)	0-24.3	0 (0%)	0-18.4	3 (8.6%)	3-22.4
Slight	2 (16.7%)	4.7-44.8	2 (11.8%)	3.3-34.3	5 (14.3%)	6.3-29.4
Moderate	3 (25%)	8.9-53.2	3 (17.6%)	6.2-41	6 (17.1%)	8.1-32.7
Severe	7 (58.3%)	32-80.7	12 (70.6%)	46.9-86.7	21 (60%)	43.6-74.5
Average stage	2		3		2	

LNP

Attrition Stage	**Male (n=29)**	**95% CI**	**Female (n=33)**	**95% CI**	**All (n=87)**	**95% CI**
None	1 (3.4%)	0.6-17.2	0 (0%)	0-10.4	2 (2.3%)	0.6-8
Slight	3 (10.3%)	3.6-26.4	2 (15.4%)	1.7-19.6	13 (14.9%)	8.9-23.9
Moderate	3 (10.3%)	3.6-26.4	8 (24.2%)	12.8-41	17 (19.5%)	12.6-29.1
Severe	22 (75.9%)	57.9-87.8	23 (69.7%)	52.7-82.6	55 (63.2%)	52.7-72.6
Average stage	3		3		2	

Table 5.11. Numbers and percentages of individuals (adolescents and older) with various stages of wear (none through severe) in the PVP, VA and LNP (this study; James 1999; Lorimer 1970; Molleson, n.d.; Morris and Emery 1986; Sellevold 1999).

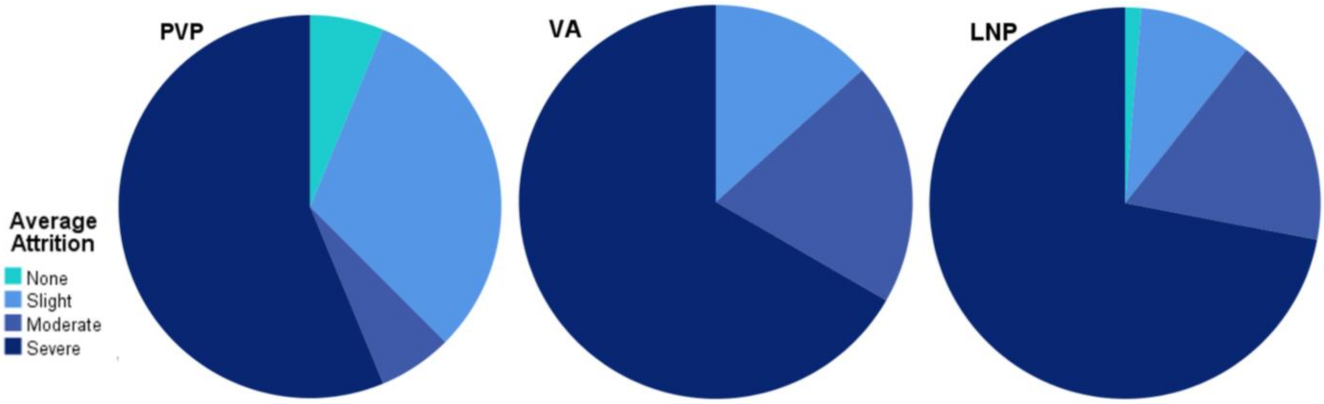

Figure 5.9. Proportions of individuals (adolescent and older) with differing average dental wear stages by phase (this study; James 1999; Molleson n.d.; Morris and Emery 1986; Sellevold 1999).

There were no significant differences in average attrition stages of males or females between sites in any or all phases. When evidence for subsistence practices and site type were compared, there were no significant differences in average attrition stages in males or females between sites with different predominant crops, animals, animal use, site name category, or plaggen soil formation. None of the variables for subsistence or site type correlated with significant differences in average attrition stages of males or females in any or all phases.

5.4.2.2. Calculus

Dental calculus, or tartar (Figure 5.10), is mineralized saliva that accumulates and hardens both above and below the gum line. An accumulation of calculus irritates the gums and causes gingivitis, which can eventually lead to periodontitis and ante-mortem tooth loss (AMTL). While the exact aetiology is still debated, increased levels of calculus have been directly correlated with increased consumption of protein (Lieverse 1999). As per Methodology, calculus stages were scored from 0 to 3, with 0 being none and 3 being severe or heavy. While calculus levels sometimes vary from tooth to tooth, an average stage for all observable teeth was used for each individual.

When age was controlled for as a covariate in ANOVA, there was no significant difference in the levels of calculus between phases in either males (p=0.629) or females (p=0.997). There were no significant differences in the average stages of calculus between males and females in the PVP (p=0.955), VA (p=0.755), or in the LNP (p=0.554) when age was factored in as a covariate. A Kruskal-Wallis test showed that when separated by age groups (adolescents and older), there were no significant differences between calculus levels of any age groups by phase. The prevalence of each calculus stage by phase is provided in Table 5.12.

When each site was compared, there were no significant differences in the average levels of calculus in males or females at any of the sites in any or all phases. When all phases were included, there were no sites with significantly different average calculus stages. Nor were there significant differences between sites in any particular phase. When evidence for subsistence practices and site type were compared, there were no significant differences in average calculus stages in males or females between sites with different predominant crops, animals, animal use, site name category, or plaggen soil formation.

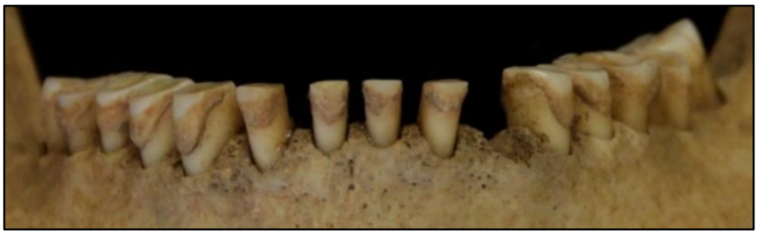

Figure 5.10. Moderate calculus deposits on mandibular dentition of Sk011 (Newark Bay).

PVP

Calculus Stage	**Male (n=8)**	**95% CI**	**Female (n=7)**	**95% CI**	**All (n=16)**	**95% CI**
None	1 (12.5%)	2.2-47.1	2 (28.6%)	8.2-64.1	4 (25%)	10.2-49.5
Slight	3 (42.9%)	13.7-69.4	1 (14.3%)	2.6-51.3	4 (25%)	10.2-49.5
Moderate	3 (42.9%)	13.7-69.4	3 (42.9%)	15.8-75	6 (37.5%)	18.5-61.4
Severe	1 (12.5%)	2.2-47.1	1 (14.3%)	2.6-51.3	2 (12.5%)	3.5-36
Average stage	1.5		1.4		1.4	

VA

Calculus Stage	**Male (n=12)**	**95% CI**	**Female (n=17)**	**95% CI**	**All (n=35)**	**95% CI**
None	4 (33.3%)	13.8-60.9	5 (29.4%)	13.3-53.1	13 (37.1%)	23.2-53.7
Slight	4 (33.3%)	13.8-60.9	6 (35.3%)	17.3-58.7	11 (31.4%)	18.6-48
Moderate	0 (0%)	0-24.3	1 (2.9%)	1.1-27	2 (5.5%)	1.6-18.6
Severe	4 (33.3%)	13.8-60.9	5 (29.4%)	13.3-53.1	8 (22.9%)	12.1-39
Average stage	1.3		1.4		1.2	

Calculus Stage	LNP Male (n=29)	95% CI	Female (n=34)	95% CI	All (n=88)	95% CI
None	11 (37.9%)	22.7-56	10 (29.4%)	16.8-46.2	38 (43.2%)	33.3-53.6
Slight	7 (24.1%)	12.2-42.1	7 (20.6%)	10.4-36.8	17 (19.3%)	12.4-28.8
Moderate	4 (13.8%)	5.5-30.6	7 (20.6%)	10.4-36.8	13 (14.8%)	8.8-23.7
Severe	7 (24.1%)	12.2-42.1	10 (29.4%)	16.8-46.2	20 (22.7%)	15.2-32.5
Average stage	1.2		1.5		1.2	

Table 5.12. Number of individuals (adolescents and older) with each level of calculus by phase (this study; James 1999; Molleson n.d.; Morris and Emery 1986; Sellevold 1999).

Figure 5.11. Proportions of individuals (adolescent and older) with differing average levels of calculus by phase (this study; James 1999; Lorimer 1970; Molleson n.d.; Morris and Emery 1986; Sellevold 1999).

5.4.2.3. Caries

Dental caries (as depicted in Figure 5.12) are caused by acid-producing bacteria that thrive on sugars found in food. The prevalence of caries can be indicative of the balance of protein and carbohydrates in ancient diets, as individuals with diets more heavily reliant on carbohydrates have been found to have higher numbers of caries (Hillson 2001). The percentage of carious teeth out of the total number of observable teeth was calculated (TPR) for each phase/category. The percentage of individuals exhibiting at least one carious tooth out of those with observable dentition was also calculated (CPR) and is provided in Table 5.13. The number of undated individuals in the present study with carious teeth (6 individuals, a total of 17 carious teeth) could only slightly skew these temporal trends and were not included in the tables below.

Figure 5.12. A large caries has eroded the disto-lingual cusp of a mandibular first molar from individual 149, Bu of Cairston (LNP).

PVP carious teeth included one premolar and four molars (two M1s, one M2 and one M3), all of which were maxillary. In the VA, there was a greater variation in the teeth affected by caries, including both anterior and posterior teeth (incisors as well as premolars and molars). This included three incisors (from three distinct individuals), three premolars (from three distinct individuals), two M1s, two M2s and two M3s from maxillae and mandibles. Finally, in the LNP the teeth predominantly affected by caries were still posterior teeth (mainly molars), though there was one individual with both a carious incisor and canine and two individuals with a carious premolar. The molars affected consisted of five M1s, five M2s and three M3s from both the maxillary and mandibular jaws.

According to a Chi^2, there was no significant difference in the number of individuals with caries (p=0.878) between phases, even when males and females were tested separately (p=0.882 and 0.682, respectively). According to ANOVA, the TPR of caries among males and females also did not change significantly by phase (p=0.788 and 0.650). In none of the phases was there a significant difference in proportions of males and females with caries (p=0.146, 0.378 and 0.241), nor was there a difference in the numbers of carious teeth between sexes (p=0.084, 0.271 and 0.315).

	Males				***Females***				***All***			
Phase	**CPR**	**95% CI**	**TPR**	**95% CI**	**CPR**	**95% CI**	**TPR**	**95% CI**	**CPR**	**95% CI**	**TPR**	**95% CI**
PVP	1/9	2-43.5	1/195	0.01-2.8	3/7	15.8-75	6/158	1.8-8	4/17	9.6-47.3	7/362	0.01-3.9
VA	2/12	4.7-44.8	3/175	0.6-4.9	5/17	13.3-53.1	12/357	1.9-5.8	8/35	12.1-39	16/617	1.6-4.2
LNP	4/28	3.3-19.6	9/533	0.9-3.2	9/34	14.6-43.1	19/517	2.4-5.7	18/86	13.7-30.7	41/1357	2.2-4.1

Table 5.13. CPRs of individuals (adolescents and older) with caries and TPRs of carious teeth by phase and sex (this study; James 1999; Molleson n.d.; Morris and Emery 1986; Sellevold 1999).

The CPR and TPR of dental caries did not differ significantly between sites in the PVP or VA, either in males or females. In the LNP, however, females from Skaill House and Newark Bay had a significantly higher prevalence (both 66.7% CPR) and TPR of dental caries (11.4% and 7.9%, respectively) than LNP females from the other sites (p=0.011 and 0.007). When variables for site type and subsistence strategies were incorporated, the LNP females from plaggen sites (Skaill House and Newark Bay) and sites with poorer land quality (Skaill House, code 5.2 as opposed to Newark Bay, Westness or Bu of Cairston, code 4.2) still exhibited a higher CPR and TPR of dental caries (plaggen: p=0.017 and 0.036; land quality: p=0.017 and 0.036).

VA females in cists exhibited a lower prevalence of dental caries than those without cists (p=0.049), which may have resulted from differences in diet. While VA females with and without agricultural tools showed no significant difference in the prevalence of any dental pathologies, males with agricultural tools exhibited significantly greater CPRs and TPRs of caries (suggesting greater consumption of cariogenic foods like carbohydrates) than males not buried with agricultural tools (p=0.047 and 0.002, respectively).

5.4.2.4. AMTL, periodontal disease and abscesses

Ante-mortem tooth loss (or AMTL, as seen in Figure 5.13) can be caused by both tooth decay (caries) and/or chronic inflammation and irritation of the gums (periodontitis or periodontal disease), which loosens ligaments that hold teeth in place (US Department of Health and Human Services, n.d.). Periodontal disease is one of the leading causes of AMTL (US Department of Health and Human Services, n.d.) and like caries, periodontal disease can be caused by a diet high in sugars and fatty acids (Petersen and Ogawa 2005, 2190). Abscesses (Figure 5.14) are like dental caries in that they result from bacterial infection either at the root of the tooth (periapical abscesses) or along the gingival margin like periodontitis (periodontal abscesses). The recording of abscesses included both periodontal abscesses and periapical abscesses. As with caries, the CPR of teeth lost ante-mortem and abscesses are provided below. Since consumption of fish leads to lower instances of periodontal disease (Iwasaki et al. 2010; Kaye 2010; Warner 2010), it is expected that increases in marine resource consumption in the VA and LNP would have a significant negative effect on the prevalence of periodontal disease and this potentially AMTL and abscesses as well.

Among individuals of adolescent age and older (those with only permanent dentition), there was no significant difference in the prevalence of AMTL between phases (p=0.531). When sexes were tested separately, there were no significant differences in the CPRs (p=0.700) of males or females (p=0.719 and 0.917, respectively). Nor was there a significant difference in the CPR of AMTL between males and females in the PVP (p=0.772), VA (p=0.973), or LNP (p=0.982).

Figure 5.13. Nearly edentulous mandible of a middle adult male from Brough Road (individual IO) illustrating extensive AMTL, though incisors have been lost post-mortem.

	Males		***Females***		***All***	
Phase	**CPR**	95% CI	**CPR**	95% CI	**CPR**	95% CI
PVP	5/10	23.7-76.3	3/7	15.8-75	8/18	24.6-66.3
VA	4/11	15.2-64.6	5/15	15.2-58.3	9/31	16.1-46.6
LNP	8/23	18.8-55.1	11/29	22.7-56	20/63	21.6-44

Table 5.14. CPRs of AMTL by phase and sex (this study; James 1999; Molleson n.d.; Morris and Emery 1986; Sellevold 1999).

When the prevalence of periodontal disease was compared between all phases and included all ages and sexes, there was a significant decline from the VA to the LNP (p=0.005). When males were analysed, there was not a significant difference in the prevalence of periodontal disease between the PVP and VA (p=0.537) or between the VA and LNP (p=0.498) or between all three phases (p=0.769). Among females, however, there was a significant increase in periodontal disease from the PVP to the VA (p=0.006), before a sharp decrease in the prevalence of periodontal disease between the VA and LNP (p=0.000). There was no significant difference in the prevalence of periodontal disease between sexes in the PVP or the LNP (p=0.627 and 0.145), though a significantly greater proportion of females (p=0.002) had periodontal disease in the VA.

	Males		**Females**		**All**	
Phase	**CPR**	**95% CI**	**CPR**	**95% CI**	**CPR**	**95% CI**
PVP	4/10	16.8-68.7	2/7	8.2-64.1	6/19	15.4-54
VA	3/11	9.7-56.6	13/15	7.1-45.2	16/32	33.6-66.4
LNP	9/23	22.2-59.2	6/29	9.9-38.4	15/68	13.9-33.3

Table 5.15. CPR of periodontal disease by sex and phase (this study; James 1999; Molleson n.d.; Morris and Emery 1986; Sellevold 1999).

The CPR and the number of abscesses per person were calculated and compared between phases and sexes. Due to time constraints, however, tooth crypts were not counted so the TPR of abscesses per tooth place was not calculable. There was no significant difference in the CPR of abscesses among males (p=0.302) or females (p=0.888) between phases. There was no significant difference in the CPR of abscesses between males and females in the PVP (p=0.116), VA (p=1.000) or LNP (p=0.757). Neither Males (p=0.535) nor females (p=0.626) showed a significant difference in the number of abscesses per individual by phase. There was no significant difference in the number of observable abscesses per individual between males and females in the PVP (p=0.199), VA (p=0.276), or in the LNP (p=0.715).

Figure 5.14. Periodontal abscess above right maxillary canine from individual CU (top) and abscess above left maxillary canine of individual DT (bottom), both from Brough Road.

	Males				Females				All			
Phase	**CPR**	**95% CI**	**No. Abscesses**	**Per person**	**CPR**	**95% CI**	**No. Abscesses**	**Per person**	**CPR**	**95% CI**	**No. Abscesses**	**Per person**
PVP	1/10	1.8-40.4	2	2	3/7	15.8-75	5	1.66	6/18	16.3-56.3	7	1.2
VA	4/10	16.8-68.7	5	1.25	6/16	18.5-61.4	17	2.8	10/31	18.6-49.9	22	2.2
LNP	8/29	14.7-45.7	16	2	11/32	20.4-51.7	22	2	20/85	15.7-33.6	39	1.95

Table 5.16. CPR and mean numbers of abscesses per individual by sex and phase (this study; James 1999; Molleson n.d.; Morris and Emery 1986; Sellevold 1999).

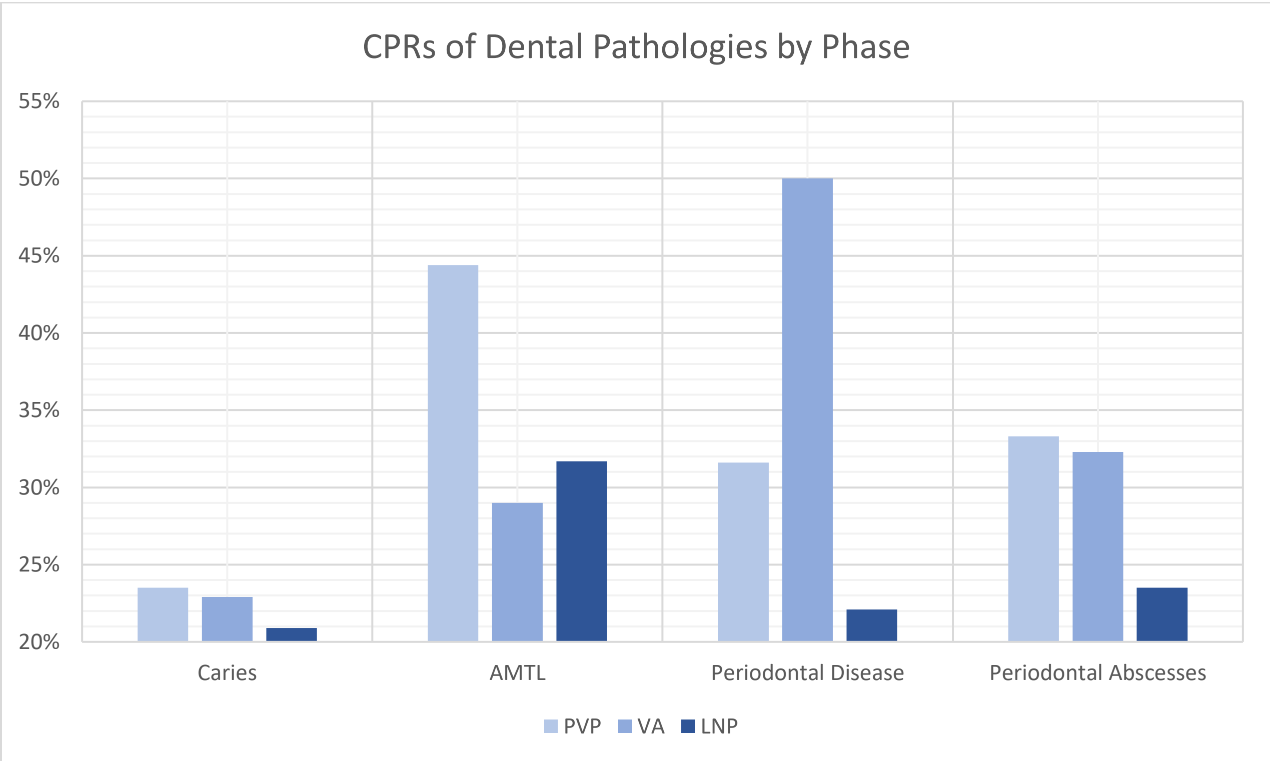

Figure 5.15. CPRs of dental pathologies indicative of diet, by phase. CPRs available in each section above (this study; James 1999; Lorimer 1970; Molleson n.d.; 2005; Morris 1989; Morris and Emery 1986; Owen and Dalland 1999; Sellevold 1999; Stevens et al.2005).

	PVP			*VA*			*LNP*			Chi^2
Pathology	**CPR**	**%**	**95% CI**	**CPR**	**%**	**95% CI**	**CPR**	**%**	**95% CI**	**P value**
Caries	4/17	23.5	9.6-47.3	8/35	22.9%	12.1-39	18/86	20.9	13.7-30.7	0.878
AMTL	8/18	44.4	24.6-66.3	9/31	29.0%	16.1-46.6	20/63	31.7	21.6-44	0.531
Periodontal Disease	18/21	81.8	15.4-54	16/33	48.5%	33.6-66.4	15/64	23.4	13.9-33.3	**0.005**
Periodontal Abscesses	6/18	33.3	16.3-56.3	10/31	32.3%	18.6-49.9	20/85	23.5	15.7-33.6	0.391

Table 0.17. Dental pathology CPR by phase. Bold p values indicate a statistical significance at α= 0.05 (this study; James 1999; Molleson n.d.; Morris and Emery 1986; Sellevold 1999).

	PVP			**VA**			**LNP**			**ANOVA**
Pathology	**TPR**	**%**	**95% CI**	**TPR**	**%**	**95% CI**	**TPR**	**%**	**95% CI**	**P value**
Caries	7/362	1.9	0.01-3.9	16/617	2.6	1.6-4.2	41/1357	3	2.2-4.1	0.973

Table 5.18. TPRs of caries by phase, along with the results of ANOVA comparing TPRs between phases. Bold p values indicate a statistical significance at α= 0.05 (this study; James 1999; Molleson n.d.; Morris and Emery 1986; Sellevold 1999).

Next, AMTL, periodontal disease and abscesses were compared between VA individuals buried within and outside of churchyards. Males buried in churchyards had a significantly higher prevalence of periodontal abscesses (p=0.039), as well as a higher number of abscesses than males buried outside churchyards (p=0.017). Abscesses were more prevalent among females than males when individuals buried outside of churchyards were compared (p=0.018), however, there was no difference in prevalence between sexes within churchyard sites (p=1.000). VA males in boat graves did not exhibit any differences in the prevalence of dental pathologies than VA males without boat graves.

Males with grave goods (p=0.11) had significantly fewer abscesses and less variability in the number of abscesses per individual than males without grave goods, particularly weapons (p=0.002). When individuals juvenile and older (5+ years) were compared, those with grave goods had a significantly lower CPR of abscesses than individuals without grave goods (p=0.031). There was no significant difference in the CPR of AMTL (p=0.786), periodontal disease (p=0.809), or the CPR of abscesses (p=0.960) between individuals with or without farming tools in the VA.

There was a significantly higher prevalence of abscesses among females from sites with zooarchaeological evidence for a focus on raising animals for meat rather than dairying (p=0.011).

There was also a negative correlation between the proportion of sheep/goat at the nearby farmstead and the prevalence of periodontal disease in females (p=0.039, r=-0.491) and a positive correlation between the proportion of pig at the nearby farmstead and the prevalence of abscesses (p=0.031, r=0.508). These correlations suggest that females from sites with a focus on rearing sheep/goats primarily for dairying (including Scar) exhibited a lower prevalence of periodontal disease and abscesses than sites with a greater focus on rearing pigs for meat production (including Brough Road). Females from plaggen sites also exhibited a significantly greater prevalence of periodontal disease and abscesses than those from non-plaggen sites (p=0.000 and 0.045). Both males and females from eastern sites exhibited a higher prevalence of periodontal disease (p=0.007 and 0.000) than individuals from western sites (east/west did not correlate with and males from eastern sites also exhibited a higher prevalence of abscesses (p=0.016) than males from eastern sites.

In the PVP, males from sites with archaeoichthyological evidence for offshore fishing and marine resource exploitation had a significantly lower prevalence of periodontal abscesses, however, there was no difference among PVP females. There was a positive correlation between the percentage of sheep/goat remains at the associated farmstead and the prevalence of periodontal disease (p=0.030, r=0.913) and periodontal abscesses (p=0.030, r=0.913) in all individuals juvenile and older. There was also an equal but negative correlation between the percentage of pigs at the associated site and periodontal disease (p=0.030, r=-0.913) and periodontal abscesses (p=0.030, r=-0.913). There were no significant differences in any dental pathologies between males or females from sites with different place-name types, land quality codes, or evidence for primary animal use in the PVP.

In the VA, males exhibited a significant correlation between land quality code (LC code) and the prevalence of AMTL (p=0.047, r=0.608), meaning males from sites with poorer soils (land codes 6.2 and 5.2, Buckquoy and Brough Road) had a higher prevalence of teeth lost ante-mortem than males from sites with better soil quality (code 4.1- Scar and code 4.2- Westness, Newark Bay and Pierowall). VA females exhibited the opposite trend, with higher prevalence rates of teeth lost ante-mortem in females from sites with the better soil quality (code 4.1- Brough of Gurness and Scar) than from sites with the relatively poorer land quality (code 4.2-Westness, Newark Bay and Pierowall and code 5.2- Brough Road). Although there was only one VA male from a site with evidence for predominantly near-shore fishing (Buckquoy), that male exhibited significantly more teeth lost ante-mortem than the males from the other VA sites (p=0.000). When site name types were compared, the individual from Buckquoy (the only VA individual from a *-quoy* site) still had a significantly greater prevalence of AMTL than VA males from other site name types (p=0.001). When tested between individual VA sites, Brough Road females did not show a significant difference in the prevalence of abscesses than females from the other sites (p=0.071). When compared by name category and land quality, however, Brough Road ('fortification' name category and LC code 5.2) females exhibited a higher prevalence of abscesses than VA females from sites with other name types and better soil quality (p=0.030 and 0.046).

In the LNP, both males and females from sites on the eastern side of the islands (Newark Bay and the Brough of Deerness) exhibited a higher prevalence of periodontal disease than individuals from western sites (Skaill House, Bu of Cairston and Westness) (p=0.036 and 0.000). Females from eastern sites also exhibited a higher prevalence and number of abscesses (p=0.008 and 0.008). LNP females did not exhibit different prevalence rates in dental pathologies between individual sites and there were no significant differences in the prevalence rates of any dental pathologies in LNP males or females between sites with evidence for different predominant crops or livestock.

Variables	*Correlating Variables*	*p*	*Correlation Coefficient*
Age	Calculus scale	0	0.363
	Caries	0.001	0.208
	No. of caries	0	0.224
	Average attrition	0	0.79
	No. abscesses	0	0.434
	Periodontal disease	0	0.425
	Abscess y/n	0	0.448
	AMTL	0	0.522
Calculus Scale	Caries	0.011	0.163
	No. of caries	0.01	0.165
	Average attrition	0	0.398
	No. abscesses	0	0.307
	Periodontal disease	0	0.346
	Abscess y/n	0	0.336
	AMTL	0	0.3
Caries y/n	No. caries	0	0.996
	Average attrition	0	0.242
	No. abscesses	0	0.283
	Periodontal disease	0	0.269
	Abscess y/n	0	0.268
No. Caries	Average attrition	0	0.251
	No. abscesses	0	0.287
	Periodontal disease	0	0.27
	Abscess y/n	0	0.271
Average attrition	No. abscesses	0	0.436
	Periodontal disease	0	0.359
	Abscess y/n	0	0.453
	AMTL y/n	0	0.498
No. Abscesses	Periodontal disease	0	0.479
	Abscess y/n	0	0.983
	AMTL y/n	0	0.542
Periodontal Disease	Abscess y/n	0	0.484
	AMTL y/n	0	0.371
Abscess y/n	AMTL y/n	0	0.537

Table 5.19. Results of a non-parametric correlation test between different dental pathologies, as generated by SPSS. Underlined and boldened sig. values indicate a correlation with significance at the ≤0.05 level.

When all sites were compared regardless of phase, there was a significantly greater prevalence of periodontal disease at Newark Bay (p=0.000) than at the other sites, as well as a higher prevalence and number of abscesses (p=0.014 and 0.018). When tested separately, both males and females (p=0.036 and 0.000) from all phases of Newark Bay exhibited higher prevalence rates of periodontal disease than males and females from other sites.

Individuals from PVP Newark Bay also had significantly more periodontal abscesses than individuals from the other PVP sites (p=0.023). There were no significant differences in the prevalence of the other dental pathologies between sites in the PVP, however, even when males and females were tested separately. In the VA, Brough Road had the highest proportion of individuals with periodontal disease, followed by Newark Bay (p=0.028). Significantly, the highest numbers of AMTL came from Gurness for the females (p=0.006) and Buckquoy for males (p=0.008), both of which are isolated burials on the northwest side of the mainland. Again, in the LNP Newark Bay had the highest proportion of individuals with periodontal disease (p=0.000), also seen among males (p=0.016) and females (p=0.000) when tested separately. Newark Bay individuals also exhibited the highest prevalence (p=0.013) and number of abscesses (p=0.001) of individuals from the LNP. When the multiphase sites were tested, Brough Road exhibited a higher prevalence of periodontal abscesses in the VA than in the PVP (p=0.025), though Westness (p=0.231) and Newark Bay (p=0.183) did not.

5.4.2.5. Dental pathology digest

The primary dental pathologies evaluated in this study included dental attrition, calculus, caries, AMTL, periodontal disease and abscesses. The statistically significant results of Spearman's rho correlation tests between the different dental pathologies are presented in Table 5.19. Because of the above-stated aetiologies of AMTL, it was of no surprise that periodontal disease, abscesses (both the number of individuals with abscesses and the number of abscesses) and average attrition all positively and significantly correlated with AMTL. The level of calculus also correlated positively with the average attrition stage. When all age groups were included, age correlated significantly with every variable. Once individuals younger than adolescents were excluded, however, calculus scale (p=0.223), CPRs of caries (p=0.157) and TPRs of caries (0.111) no longer correlated significantly with age. The number of individuals with caries and the prevalence of carious teeth both significantly correlated with attrition (r=0.197, p=0.020 and 0.199, p=0.019, respectively). Although greater levels of attrition would mean less of the tooth is observable for caries, individuals with greater attrition levels, periodontal disease and AMTL were likely older individuals relying more heavily on a diet of soft, cariogenic foods like cereals.

Despite hypotheses that the differences in diet between sexes in the VA (suggested by previous studies, see Chapter 2) may have resulted in different prevalence rates of dental pathologies such as calculus scale, dental caries, AMTL and abscesses, the only two dental indicators of diet that differed significantly between sexes were levels of attrition in the PVP (with females exhibiting greater attrition averages) and periodontal disease in the VA (with females exhibiting greater prevalence of periodontal disease). When prevalence rates were compared by phases, females exhibited a significant increase in the prevalence of periodontal disease from the PVP to the VA before a decrease in prevalence from the VA to the LNP. Explanations for these changes in prevalence will be discussed in Chapter 8.

5.4.3. Developmental stress

5.4.3.1. LEHs

There are three types of manifestations of dental enamel hypoplasias (linear, grooves and pitting) in archaeological populations, all interpreted as indicators of systemic stress affecting ameloblast activity during tooth development (Goodman et al. 1980; Goodman and Rose 1991, 281). Linear hypoplasias (LEHs, Figure 5.16) were the most commonly observed form of enamel hypoplasias in this study, with only three individuals exhibiting pitting of the top half of the tooth crown (indicative of stress during the earliest stages of crown development). One of these was undated, one was from the PVP and one was from the LNP. Because of inconsistent recording of LEHs from the portion of the Newark Bay collection housed in the NHM (as previously mentioned), that portion of the collection was not included in analyses of LEHs.

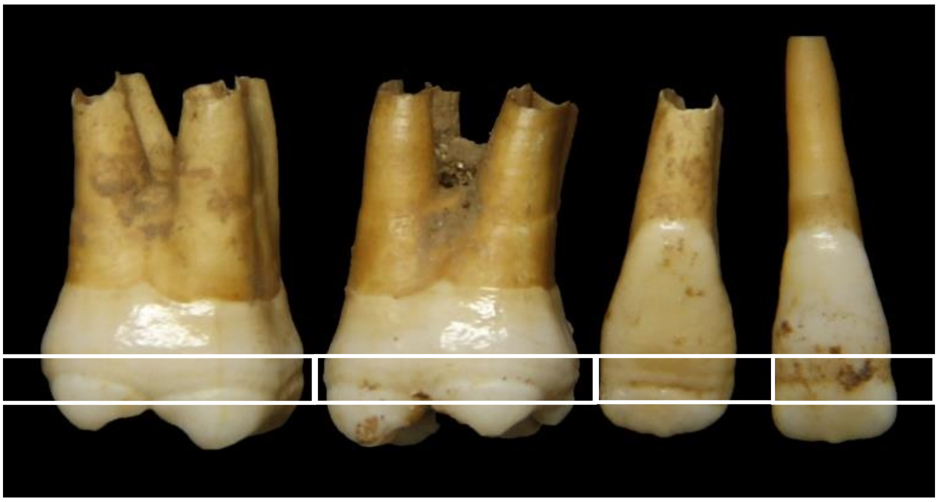

Figure 5.16. LEHs visible on still-forming permanent first molars and incisors from individual NB2, Newark Bay.

Out of individuals with observable dentition dated to the PVP, VA or LNP (90 individuals and a total of 1680 teeth), 34 individuals had observable LEHs. As shown in Table 5.20., a Chi^2 test showed that the number of individuals exhibiting LEHs did not significantly vary by phase (p=0.201). Neither did an ANOVA show a significant difference in the total number of teeth with LEHs by phase (p=0.571). Only in the LNP was there a significant difference between the number of males and females with at least one LEH (p=0.038). While a greater proportion of males had at least one LEH, there was no significant difference in the number of teeth with LEHs between males and females (p=0.761). Physical and nutritional stress during development can not only cause the formation of LEHs in enamel but can also result in decreased adult stature. To test this connection, ANOVA tests compared male and female stature means by the presence or absence of LEHs. Neither males with and without LEHs nor females with and without LEHs showed any significant difference in stature means (p=0.135 and 0.5532). There was no significant correlation in stature means with the number of teeth with LEHs either in males or females (p=0.107 and 0.628).

Phase	Indiv. with LEHs	CPR	95% CI	Teeth with LEHs	TPR	95% CI
PVP	8/14	57.1	32.6-78.6	30/365	8.2	5.8-11.5%
VA	6/16	31	18.5-61.4	24/295	8.1	5.5-11.8%
LNP	20/60	33.3	22.7-45.9	85/1020	8.3	6.8-10.2%
p value	0.201			0.571		
Test	Chi^2			ANOVA		

Table 5.20. CPRs and TPRs of LEHs by phase with statistical tests for significance. Bold p values indicate a statistical significance at α= 0.05 (this study; James 1999; Molleson n.d.; Morris and Emery 1986; Sellevold 1999).

As expected, the number of individuals with LEHs and the number of teeth with LEHs both correlated negatively with average wear (p=0.017, -0.165 and p=0.003, -0.205, respectively), since greater levels of attrition obscure the ability to observe and record the presence of any LEHs that may have developed in earlier life. When age at death was compared between those with and without LEHs, there was no significant difference after controlling for attrition stage (p=0.088). The following tables, 5.21-5.23 present the number CPRs and TPRs individuals with LEHs corresponding to each age at time of the event. CPRs are calculated as the number of affected individuals out of the total number of individuals with observable dentition in that phase. TPRs are calculated as the number of affected teeth out of all observable teeth in that phase. The possibility of multiple LEHs per individual (or even per tooth) allows for some individuals and teeth to be counted multiple age categories.

Out of the 34 individuals with LEHs, eight individuals exhibited LEHs at more than one age (Primeau et al. 2015, 386). In some of these cases, the multiple LEHs were observable on the same tooth, but in some cases, multiple teeth exhibited a single LEH. The mean age at LEH development was recorded for each occurrence, as per Primeau et al. 2015 (previously described in Chapter 3). In all three phases, the two age groups exhibiting the most LEHs were birth to 2 years old and 2 to 4 years old (Tables 5.21-5.23). The correlation between weaning and LEHs between 2 and 4 years old is explored further in Chapter 8. Among males of all phases, there were a higher proportion of teeth with LEHs at the Brough of Deerness (p=0.035) and among females of all phases, there was a higher prevalence of LEHs at Westness and Bu of Cairston than at the other sites (p=0.035). The young adult male from the Brough of Deerness exhibited a greater number of LEHs than any of the individuals from the other LNP sites (p=0.011). When compared by burial setting, VA females buried in churchyards exhibited both a lower prevalence (p=0.036) and a lower number of LEHs (p=0.027) than females buried outside churchyards. When sexes were compared within churchyard sites, males had a higher prevalence and a higher number of LEHs than females (p=0.015 and 0.017). There was no significant difference, however, in the prevalence (p=0.170) or number of LEHs (p=0.057) between sexes among those not buried in churchyards. When evidence for site type and subsistence strategies were compared, there was a significantly higher number of LEHs among females from sites with zooarchaeological evidence for a focus on dairying (p=0.003). When divided by phase, this pattern was observed only in the VA, with a higher prevalence of LEHs in females from sites with plaggen soils and sites with evidence of dairying (p=0.038 and 0.039).

Age at LEH events	*Affected Indiv.*	*CPR*	*95% CI*	*Affected Teeth*	*TPR*	*95%CI*
<2	3/14	21.4%	7.6-47.6	3/365	0.8%	0.3-2.4
2-4	6/14	42.9%	21.4-67.4	7/365	1.9%	0.9-3.9
5-6	3/14	21.4%	7.6-47.6	4/365	1.1%	0.4-2.8
9-11	0/14	0.0%	0-21.5	0/365	0.0%	0-1.0
All ages	8/14	57.1%	32.6-78.6	30/365	8.2%	5.8-11.5

Table 5.21. The number of individuals and teeth with LEHs that correspond to different age groups in the PVP (this study; Molleson n.d.; Morris 1989; Morris and Emery 1986; Sellevold 1999).

Age at LEH events	*Affected Indiv.*	*CPR*	*95% CI*	*Affected Teeth*	*TPR*	*95%CI*
<2	3/16	33.3%	6.6-43	7/295	2.4%	1.2-4.8
2-4	6/16	100.0%	18.5-61.4	17/295	5.8%	3.6-9.0
5-6	0/16	0%	0-19.4	0/295	0.0%	0-1.3
9-11	0/16	0%	0-19.4	0/295	0%	0-1.3
All ages	6/16	31.0%	18.5-61.4	24/295	8.1%	5.5-11.8

Table 5.22. The number of individuals and teeth with LEHs that correspond to different age groups in the VA (this study; Molleson n.d.; Morris 1989; Morris and Emery 1986; Owen and Dalland 1999; Sellevold 1999; Stevens et al. 2005).

Age at LEH events	*Affected Indiv.*	*CPR*	*95% CI*	*Affected Teeth*	*TPR*	*95%CI*
<2	8/60	13.3%	6.9-24.2	53/1020	5.2%	4-6.7
2-4	7/60	11.7%	5.8-22.2	16/1020	1.6%	0.9-2.5
5-6	3/60	5.0%	1.7-13.7	10/1020	1.0%	0.5-1.8
9-11	2/60	3.3%	0.9-11.4	4/1020	0.4%	0.2-1.0
All ages	20/60	33.30%	22.7-45.9	85/1020	8.3	6.8-10.2

Table 5.23. The number of individuals and teeth with LEHs that correspond to different age groups in the LNP (this study; James 1999; Morris 1989; Morris and Emery 1986; Owen and Dalland 1999; Sellevold 1999; Stevens et al. 2005).

5.4.3.2. Harris lines

Due to loan time constraints of the portable x-ray machine, only eleven individuals were radiographed for Harris Lines, of which eight exhibited Harris Lines (72%). This included the left distal tibia of Scar 134 (Figure 36), the right distal tibia from Skaill House SK1, the proximal end of a tibia from Skaill House SK3, the left distal tibia of Newark Bay 68(17), the right proximal tibia of Newark Bay 71(11), the distal end of a long bone from Newark Bay NB3, the proximal end of a tibia from Newark Bay SK005A and the right distal tibia from Newark Bay Sk008(2). Those with no visible Harris Lines on radiographs included Buckquoy M12, Newark Bay SK005B and Newark Bay SK005E. According to a Chi^2 test, the prevalence of Harris lines did not significantly differ by phase, though the small sample size may have been a factor here (p=0.494).

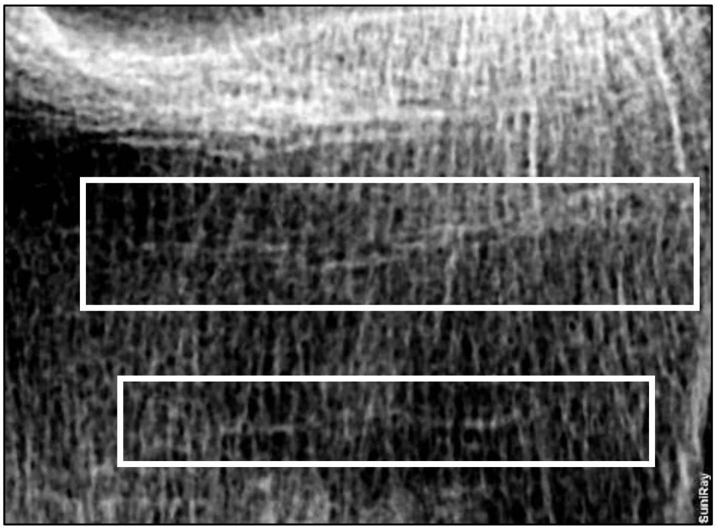

Figure 5.17. Harris lines visible on a radiograph of the left distal tibia of individual 134, an adult male from the Scar boat burial.

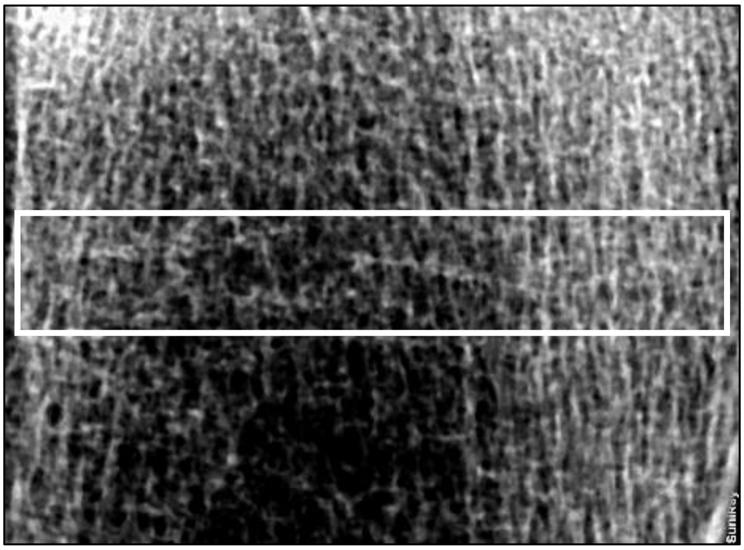

Figure 5.18. Harris line visible on the radiograph of a distal tibia of Newark Bay individual 68(17), an adult of unidentified sex.

5.4.4. Evidence of load-bearing and occupational stress markers

As previously discussed in Chapter 3, archaeological evidence suggests an extension of land under the plough and an increase in agricultural production throughout VA and LNP Orkney (McGovern 1988; Simpson 1995; etc.). To look for osteological evidence for increases in manual labour, several osteological indicators were assessed. These included platymeria and platycnemia, osteoarthritis (prevalence and distribution), osteochondritis dissecans, squatting facets and mandibular tori, which were combined into a single category based on their classification as occupational markers by Capasso et al. 1999. Juveniles were the youngest to display each of these indicators and CPRs reflect prevalence out of juveniles, adolescents, younger, middle and older adult individuals.

5.4.4.1. Platymeria and platycnemia

Platymeria and platycnemia, flattening of the femur and tibia, respectively, are included under evidence for occupational stress due to evidence for these features being linked to biomechanical force and increased physical stress during development (Brown 2006, 33; Cunningham et al. 2016, 390). The platymeric and platycnemic indices were calculated where possible, following the formula set out in Chapter 3. Where measurements were not taken by the author due to access or time constraints, previous studies were referred to (Lorimer 1970; James 1999; Molleson n.d.; 2005; Morris 1989; Owen and Dalland 1999; Sellevold 1999; Stevens et al. 2005). Per the results of a Chi^2 test, there was no significant difference in the prevalence of platymeria in either males or females by phase (p=0.845 and 0.676, respectively). Nor was there a significant difference in the prevalence of platycnemia in females by phase (p=0.755). There were not enough males with platycnemia to compare prevalence statistically between phases. When TPRs were compared between phases using ANOVA, females showed no significant difference in the prevalence of platymeria or platycnemia through time (p=0.384 and 0.543), nor did males show any difference in the TPR of platymeric femora (p=0.737). There were also no differences in the prevalence of platymeria or platycnemia between males and females in any phases (Tables 5.24-5.27). In the PVP there was a significantly greater prevalence of platymeria among young adults (25-35 years old) than middle and older adults, however, there were no differences in the prevalence of platymeria between age groups of the other two phases. Among middle adults, there was a significant decrease in the prevalence of platymeria from the PVP to the VA (p=0.048), though not from the VA to the LNP (p=0.679). No other age groups exhibited a difference in prevalence by phase.

Figure 5.19. Lateral view of platymeric right femur from individual SK001, Newark Bay.

Phase	Females	CPR	95% CI	Males	CPR	95% CI	All Indiv.	CPR	95% CI	p value
PVP	4/6	67%	30-90.3	3/7	42.9%	15.8-75	7/14	50%	26.8-73.2	0.391
VA	6/11	54.5%	28-78.7	4/7	57.1%	25-84.2	11/20	55%	34.2-74.2	0.914
LNP	2/5	40%	11.8-76.9	5/11	45.5%	21.3-72	7/18	38.9%	20.3-61.4	0.838
p value	0.676			0.845			0.602			

Table 5.24. CPRs of platymeria with statistical results (p values) from Chi^2 tests. Bold p values indicate a statistical significance at α= 0.05.

Phase	Female Femora	TPR	95% CI	Male Femora	TPR	95% CI	All Femora	TPR	95% CI	p value
PVP	8/12	66.7%	39.1-86.2	4/11	36.4%	15.2-64.6	12/24	50.0%	31.4-68.6	0.159
VA	10/16	62.5%	38.6-81.5	5/9	55.6%	26.7-81.1	16/28	57.1%	39.1-73.5	0.760
LNP	3/6	50.0%	18.8-81.2	10/17	58.8%	36-78.4	13/24	54.2%	35.1-72.1	0.577
p value	0.383			0.737			0.944			

Table 5.25. TPRs of platymeria with statistical results (p values) from ANOVA tests. Bold p values indicate a statistical significance at α= 0.05.

Phase	Females	CPR	95% CI	Males	CPR	95% CI	All Indiv.	CPR	95% CI	p value
PVP	1/6	16.7%	3-56.4	0/7	0%	0-35.4	1/13	7.7%	1.4-33.3	0.261
VA	2/9	22.2%	6.3-54.7	0/5	0%	0-43.4	2/15	13.3%	3.7-37.9	0.255
LNP	0/2	0%	0-65.8	0/7	0%	0-35.4	0/10	0%	0-27.8	NA
p value	0.755			NA			0.48			

Table 5.26. CPRs of platycnemia with statistical results (p values) from Chi^2 tests. Bold p values indicate a statistical significance at α= 0.05.

Phase	Female Tibiae	TPR	95% CI	Male Tibiae	TPR	95% CI	All Tibiae	TPR	95% CI	p value
PVP	1/12	8.3%	1.5-35.4	0/11	0%	0-25.9	1/23	4.4%	0.7-21	0.300
VA	5/13	38.5%	17.7-64.5	0/13	0%	0-22.8	5/24	20.8%	9.2-40.5	0.192
LNP	0/2	0%	0-65.8	0/12	0%	0-24.3	0/14	0%	0-21.5	NA
p value	0.543			NA			0.241			

Table 5.27. TPRs of platycnemia with statistical results (p values) from ANOVA tests. Bold p values indicate a statistical significance at α= 0.05.

5.4.4.2. Osteoarthritis

Osteoarthritis (OA) is a degenerative joint disease that manifests as eburnation, osteophytic formation and/or pitting and porosity of the joint surface. OA was observed at every major joint surface: the temporo-mandibular (TMJ), neck and vertebrae, shoulders, elbows, fingers, sternocostal (STC) joints, hips, knees, ankles and toes (following Larsen 1982; Larsen et al. 1995; Lieverse et al. 2006). Following analysis (where possible), previous studies were consulted (James 1999; Lorimer 1970; Molleson 2005, n.d.; Morris 1989; Owen and Dalland 1999; Sellevold 1999; Stevens et al. 2005). A substantial shift in subsistence practices (e.g., a new focus in deep-sea fishing or a shift from subsistence to market-based farming) may have led to an increased prevalence of OA in certain demographic groups or a change in prevalence by joint (see Chapter 2 for more on this). As expected, there was a positive correlation between OA and age (r=0.542, p=0.000). Therefore, it was important to control for age (using a general linear model) when making statistical comparisons between demographic groups and phases. When males, females and individuals of unknown sex (juveniles and older) were analysed together, there was a significant difference in the prevalence of OA through the three phases (p=0.001), with the highest CPR in the PVP (86.4%), the second-highest in the VA (61.9%) and the lowest in the LNP (46.7%). When divided by joint, there was a significantly higher prevalence of vertebral OA (p=0.002) in the PVP (85%) and VA (70.4%) than in the LNP (45%). There was no significant difference in the prevalence of OA at any other joint surfaces between phases (Table 5.28., below). When analysed separately, females exhibited a significantly higher prevalence of OA of vertebral joints in the PVP than in the LNP (p=0.034). Males, however, showed no significant difference in the prevalence of OA at any joint by phase (Table 5.28). Tables with prevalence rates (CPRs and TPRs where applicable) for each joint by phase and sex are presented in Tables 5.29-5.31). In each of the phases, there was found to be no significant difference in the prevalence or distribution of OA between males and females. A diagram of CPRs (representing all individuals juvenile and older) for the different joints by phase is provided in Figure 5.20.

In adolescent and young adult females, there was no significant difference in the prevalence of OA by phase (p=0.075 and 0.110, respectively). When middle and older adult women were compared, however, there was a significantly greater CPR of OA in the PVP (100%) than in the LNP (51.9%) (p=0.017). The individual joints with a significant difference in CPR by phase were vertebral joints (p=0.006) and foot joints (p=0.005). When the same method was applied to middle and older adult males, there was a significant difference in the prevalence of OA by phase (p=0.019), with the highest CPR in the PVP (100%) and the lowest in the LNP (50%). Although there was a significant decrease in the prevalence of individuals with OA observable on at least one joint surface, there was no significant difference in the CPR of OA at any specific joint by phase. Tables with the CPRs and results of statistical tests of OA in middle and older adults by joint, phase and sex are provided in Catalogue C, Table 35.

OA Joint	***Females***	***N***	***Males***	***N***	***All***	***N***
Any	0.075	66	0.075	57	**0.002**	**156**
Verts	**0.034**	**39**	0.179	40	**0.006**	**87**
Shoulders	0.907	40	0.685	45	0.575	95
Hands	0.704	47	0.269	44	0.265	103
Knees	0.328	50	0.986	45	0.591	112
Feet	0.052	34	0.349	38	0.757	89
Elbows	0.587	50	0.584	41	0.530	102
Hips	0.723	52	0.351	42	0.315	110
Jaws	0.320	44	0.381	42	0.089	101
Sternocostal	0.637	31	0.239	35	0.591	73

Table 5.28. Results of Chi^2 tests for significant difference (p values) in the CPR of OA by joint surface by phase. Bold p values indicate a statistical significance at α= 0.05 (this study; James 1999; Molleson n.d.; Morris and Emery 1986; Sellevold 1999).

	Female				Males				All				Chi²	
OA	**CPR**	**%**	**TPR**	**%**	**CPR**	**%**	**TPR**	**%**	**CPR**	**%**	**TPR**	**%**	**P**	**N**
Any	9/10	90%	NA	NA	9/10	90%	NA	NA	19/22	86%	NA	NA	1.000	20
Verts	9/10	90%	44/150	29.3%	8/9	88.9%	31/151	20.5%	17/20	85%	75/325	23.1%	0.937	19
Shoulders	3/8	37.5%	4/13	30.8%	3/8	37.5%	4/15	26.7%	6/17	35.3%	8/30	26.7%	1.000	16
Hands	1/7	14.3%	2/12	16.7%	0/7	0%	0/14	0.0%	1/16	6.3%	2/29	7%	0.299	14
Knees	2/8	25%	3/16	18.8%	1/8	12.5%	3/14	21.4%	3/18	17%	6/33	18.2%	0.522	16
Feet	3/7	42.9%	5/14	35.7%	1/7	14.3%	2/14	14.3%	4/16	25%	7/32	21.9%	0.237	14
Elbows	1/9	11.1%	1/14	7.1%	1/9	11.1%	2/16	12.5%	2/19	10.5%	3/32	9.4%	1.000	18
Hips	4/8	50%	6/16	37.5%	4/8	50%	8/16	50%	9/18	50%	15/36	41.7%	1.000	16
Jaws	0/7	0%	0/13	0%	0/10	0%	0/20	0%	0/18	0%	0/35	0%	NA	17
Sternocostal	2/7	28.6%	NA	NA	3/7	42.9%	NA	NA	6/16	37.5%	NA	NA	0.398	15

Table 5.29. CPRs and TPRs of osteoarthritis by joint and sex in the PVP (this study; Lorimer 1970; Molleson n.d.; 2005; Morris 1989; Sellevold 1999). Bold p values indicate a statistical significance at α= 0.05

	Female				Males				All				Chi²	
OA	**CPR**	**%**	**TPR**	**%**	**CPR**	**%**	**TPR**	**%**	**CPR**	**%**	**TPR**	**%**	**P**	**N**
Any	14/20	70%	NA	NA	11/15	73.3%	NA	NA	25/40	62.5%	NA	NA	0.829	35
Verts	12/17	70.6%	65/297	21.9%	8/11	72.7%	32/162	19.8%	19/27	70.4%	97/459	21.1%	0.824	27
Shoulders	4/14	28.6%	6/27	22.2%	5/12	41.7%	4/19	21.1%	9/26	34.6%	10/46	21.7%	0.484	26
Hands	5/17	29.4%	5/31	16.1%	3/13	23.1%	3/22	13.6%	8/31	25.8%	8/54	14.8%	0.697	30
Knees	3/15	20%	4/27	14.8%	1/10	10%	1/20	5%	4/28	14.3%	5/51	9.8%	0.504	25
Feet	4/10	40%	6/16	37.5%	1/11	9.1%	1/20	5%	5/25	20%	7/44	15.9%	0.097	21
Elbows	1/14	7.4%	1/27	3.7%	1/10	10%	1/18	5.6%	2/24	8.3%	2/45	4.4%	0.803	24
Hips	6/18	33.3%	10/31	32.3%	5/11	45.5%	6/20	30%	11/30	36.7%	16/53	30.2%	0.514	29
Jaws	2/13	15.4%	2/25	6.9%	1/7	14.3%	1/14	7.1%	3/22	13.6%	4/42	9.5%	0.948	20
Sternocostal	7/14	50%	NA	NA	1/8	12.5%	NA	NA	8/22	36.4%	NA	NA	0.079	22

Table 5.30. CPRs and TPRs of osteoarthritis by joint and sex in the VA (this study; Lorimer 1970; Molleson n.d.; 2005; Morris 1989; Owen and Dalland 1999; Sellevold 1999). Bold p values indicate a statistical significance at α= 0.05

	Female				Males				All				Chi²	
OA	**CPR**	**%**	**TPR**	**%**	**CPR**	**%**	**TPR**	**%**	**CPR**	**%**	**TPR**	**%**	**P**	**N**
Any	19/36	52.8%	NA	NA	17/32	53.1%	NA	NA	43/94	45.7%	NA	NA	0.977	68
Verts	5/13	38.5%	23/104	22.1%	11/20	55%	54/261	20.7%	18/40	45%	77/400	19.3%	0.353	33

Shoulders	6/18	33.3%	7/30	23.3%	7/25	28%	10/41	24.4%	13/52	25%	17/84	20.2%	0.707	43
Hands	5/23	21.7%	7/39	18%	7/24	29.2%	11/42	26.2%	13/56	23.2%	19/94	20.2%	0.559	47
Knees	2/27	7.4%	2/47	4.3%	3/27	11.1%	6/49	12.2%	6/67	9%	10/116	8.6%	0.639	54
Feet	1/17	5.9%	2/29	6.9%	6/20	30%	9/38	23.7%	8/49	16.3%	12/86	14%	0.062	37
Elbows	5/27	18.5%	5/47	10.6%	5/22	22.7%	7/43	16.3%	10/60	16.7%	12/107	11.2%	0.716	49
Hips	10/26	38.5%	12/47	25.5%	6/23	26.1%	8/43	18.6%	19/63	30.2%	25/108	23.2%	0.357	49
Jaws	1/24	4.2%	2/40	5%	1/25	4%	1/43	2.3%	2/62	3.2%	3/102	2.9%	0.976	49
Sternocostal	4/10	40%	NA	NA	5/19	26.3%	NA	NA	9/36	25%	NA	NA	0.449	29

Table 5.31. CPRs and TPRs of osteoarthritis by joint and sex in the LNP (this study; James 1999; Molleson n.d.; 2005; Morris 1989; Sellevold 1999; Stevens et al. 2005). Bold p values indicate a statistical significance at α= 0.05

	OA			***Verts***			***Shoulders***			***Hands***			***Knees***		
Age cat	**CPR**	**TPR**	**N**	**CPR**	**TPR**	**N**	**CPR**	**TPR**	**N**	**CPR**	**TPR**	**N**	**CPR**	**TPR**	**N**
Subadults (juvs and adol)	**0.043**	**NA**	**21**	0.411	0.340	8	NA	NA	9	NA	NA	10	NA	NA	13
YA	0.122	NA	30	0.576	0.864	20	0.194	**0.050**	21	0.431	0.467	23	0.074	0.033	24
MA	**0.002**	**NA**	**73**	**0.002**	**0.069**	**40**	0.196	0.288	43	0.278	0.365	47	0.965	0.401	48
OA	0.155	NA	33	0.377	0.744	19	0.805	0.345	23	0.862	0.911	23	0.594	0.893	27
Total	**0.001**	**NA**	**157**	**0.006**	**0.129**	**87**	0.478	0.692	96	0.265	0.422	103	0.591	0.272	112

	Feet			***Elbows***			***Hips***			***Jaw***			***STC***		
Age cat	CPR	TPR	N	CPR	TPR	N	CPR	TPR	N	CPR	TPR	N	CPR	TPR	N
Subadults (juvs and adol)	NA	NA	10	NA	NA	11	0.139	0.162	14	NA	NA	13	0.140	0.178	9
YA	0.368	0.475	16	0.431	0.467	23	**0.036**	**0.000**	**25**	NA	NA	24	0.880	0.808	19
MA	**0.041**	**0.033**	**44**	0.938	0.935	48	0.612	0.747	47	0.248	0.307	39	0.921	0.875	29
OA	0.524	0.613	19	0.885	0.796	21	0.741	0.442	24	0.125	0.135	25	0.768	0.702	17
Total	0.757	0.621	89	0.722	0.734	103	0.315	0.065	110	0.089	0.157	101	0.630	0.387	74

Table 5.32. Results of statistical tests (p values) comparing the prevalence of OA by joint by age group between phases. Significant results (α ≤0.050) are in bold.

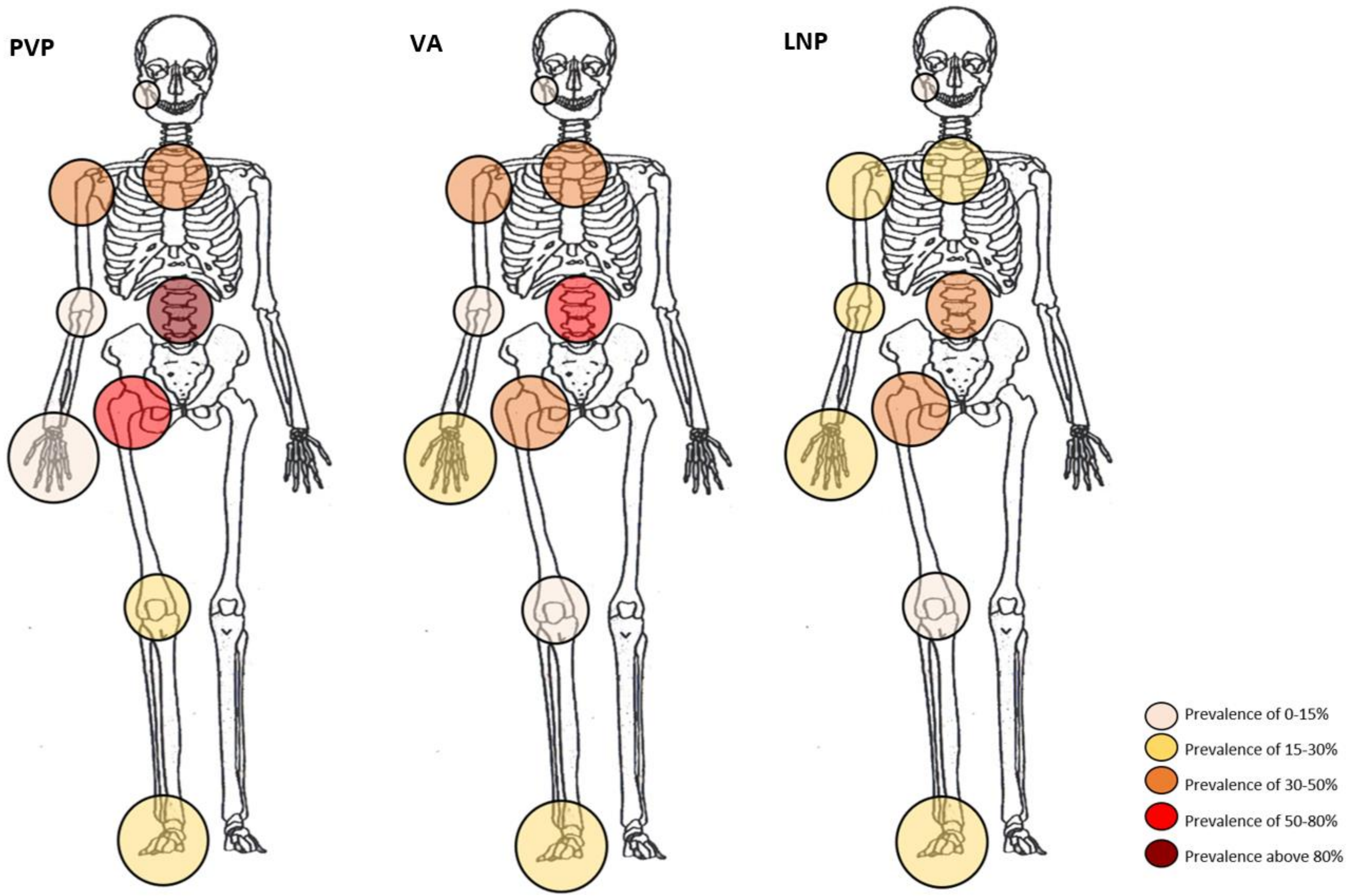

Figure 5.20. OA CPRs by joint for the PVP, VA and LNP (this study; James 1999; Lorimer 1970; Molleson n.d.; 2005; Morris 1989; Owen and Dalland 1999; Sellevold 1999; Stevens et al. 2005)

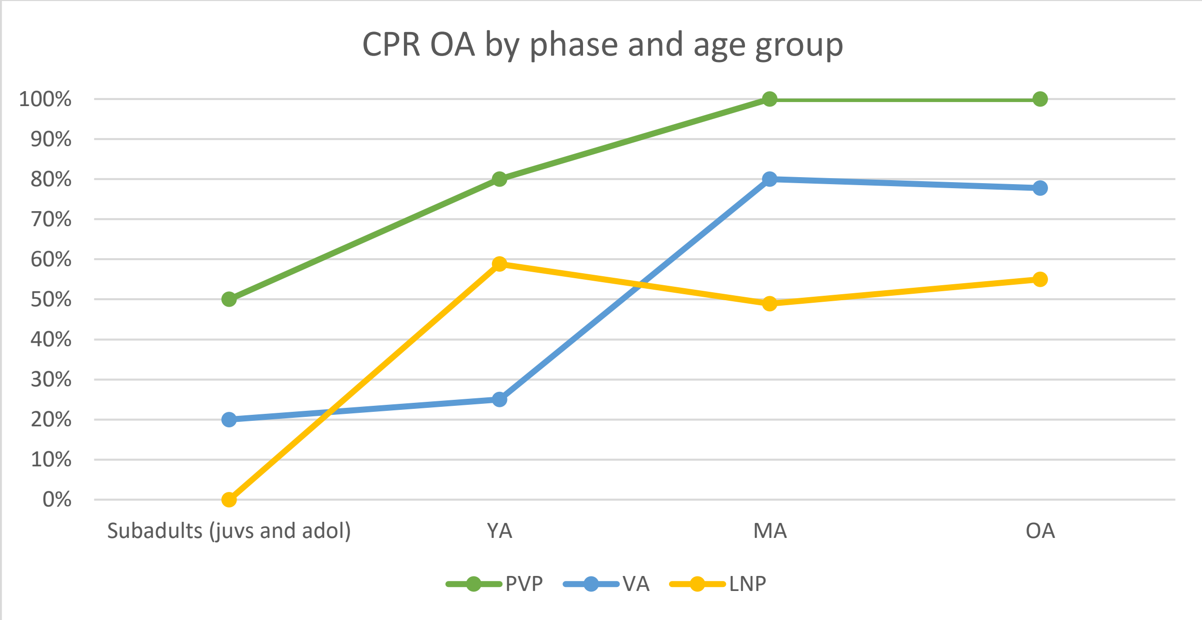

Figure 5.21. CPR (%) of OA of any joint in all sexes by phase and age group.

Age cat	*PVP*	*VA*	*LNP*	*All*
Subadults (juvs and adol)	50%	20%	0%	26%
YA	80%	25.0%	58.8%	46.7%
MA	100%	80.0%	48.9%	60.4%
OA	100%	77.8%	55%	77.2%
Total	86.4%	61.9%	46.7%	55%

Table 5.33. CPR (%) of OA of any joint in all sexes by phase and age group.

5.4.4.3. Osteochondritis dissecans

Osteochondritis dissecans (OD) is a lytic lesion that develops where blood flow has been cut off, sometimes due to trauma or repeated strenuous activity (Figure 5.22). Although osteochondritis may have a hereditary factor and its aetiology is not completely known, various studies have related it to physical labour (Mayo Clinic 2018). While OD is most observed on the distal joint surface of femurs, it is also observable at nearly any major joint surface. When all individuals juvenile and older were combined, there was no significant correlation between OD and age (p=0.518). There was also no significant difference (p=0.273) in the prevalence of OD between phases, even when males and females were tested separately (p=0.496 and 0.702). There were no significant differences in the CPRs of OD between males and females in any of the phases. Nor were there differences in prevalence rates between age groups (juvenile or older) in any of the three phases (p=0.260, 0.278 and 0.602).

Figure 5.22. Osteochondritis dissecans lesion on the distal joint surface of left femur from Scar individual 133 (older adult female).

5.4.4.4. Non-violent trauma

This section includes cases of occupational and accidental trauma, or any trauma lacking evidence of violence. Non-violent trauma predominantly includes vertebral fractures (body crush fractures, spondylolisthesis, etc.), os acromiale (detachment of the pars acromiale; Figure 5.23), hallux valgus and compression fractures in long bones. Recorded lesions included both ante-mortem and peri-mortem trauma. Results involving cranial injuries and those commonly associated with violence are addressed in section 5.5., below. Neither males nor females showed a significant difference in the CPRs of non-violent trauma between phases. VA males, however, showed a significantly higher prevalence of trauma than VA females (p=0.004).

	Females			***Males***			***All***			***Chi²***	
Phase	***CPR***	***%***	***95% CI***	***CPR***	***%***	***95% CI***	***CPR***	***%***	***95% CI***	***p value***	**N**
PVP	2/9	22.2%	6.3-54.7	4/10	40	16.8-68.7	6/23	26.1	12.6-46.5	0.405	19
VA	2/20	10%	2.8-30.1	9/17	52.9	31-73.8	14/46	30.4	19.1-44.8	**0.004**	**37**
LNP	6/36	16.7%	7.9-31.9	11/33	33.3	19.8-50.4	20/120	16.7	11.1-24.4	0.109	69
p value	0.666			0.407			0.125				
N	65			60			189				

Table 5.34. CPRs of non-violent trauma by phase and sex, along with results of Chi² tests (p values). Bold p values indicate a statistical significance at α= 0.05 (this study; James 1999; Molleson n.d.; Morris and Emery 1986; Sellevold 1999).

Figure 5.23. Os acromiale of the left scapula of individual 110 from Bu of Cairston, likely the result of non-fusion due to intensive physical strain on the deltoid and trapezius muscles.

Figure 5.24. Stress fractures on superior surface of thoracic vertebrae (individual 70(7) from Newark Bay).

5.4.4.5. Squatting facets

Squatting facets (Figure 5.25) are articular facets created from dorsiflexion of the foot where the tibia meets the talus. They can be observed on the anterior margin of the distal tibial joint surface or the anterior superior surface of the talus. While the facet is associated with squatting, it has also been found to correlate with repeated kneeling (Capasso et al. 1999, 127). Although they are not direct evidence of strenuous labour, squatting facets are an indicator of consistent physical activity (further detailed in Chapter 3) and if there were an increase in activities requiring dorsiflexion of the foot, that may have led to an increased CPR of squatting facets. There was a significant difference in the prevalence of squatting facets throughout the three phases (p=0.003), with the highest CPR of squatting facets in the PVP (57.1%) and the lowest CPR in the LNP (12.5%). When tested separately, females exhibited a significantly lower CPR of squatting facets in the LNP (p=0.013), while males did not (p=0.077). Tables of CPR by site, subsistence and grave goods are provided in Catalogue C, Tables 36-42.

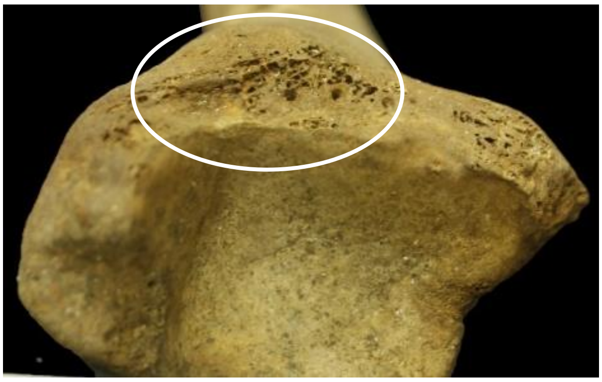

Figure 5.25. Squatting facet on the anterior margin of the distal tibial (left) joint surface, individual 134 from Scar.

Phase	*Females*	*CPR (%)*	*Males*	*CPR (%)*	*All*	*CPR (%)*	*p value*	*N*
PVP	7/7	100	4/5	80	11/12	91.7	0.217	12
VA	2/8	25	5/8	62.5	7/17	41.2	0.131	17
LNP	1/2	50	0/3	0	1/6	16.7	0.171	6
p value	**0.013**		0.077		**0.003**			
N	17		16		35			

Table 5.35. CPR of squatting facets by phase and sex, along with results of Chi2 tests (p values). Bold p values indicate a statistical significance at α= 0.05.

5.4.4.6. Mandibular tori

The growth of bone along the lingual sides (usually bilateral; Figure 5.26) of the mandible, known as mandibular tori, has a complex aetiology. Some have suggested a strong genetic predisposition while others have suggested a combination of nutrition or physical activity (Capasso et al. 1999, 18; Rodriguez Gonzalez Cortes et al. 2014; Scott 2016; Sellevold 1980). Previous studies (Brundle et al. 2003; Lorimer 1970; Molleson 2005; Scott 2016) have found a markedly higher prevalence of mandibular tori amongst northern populations such as those in Iceland and Greenland than Scandinavians from Denmark or Norway. This study found a significantly higher prevalence (p=0.000) of mandibular tori amongst individuals in the PVP (CPR of 70.6%) than in the VA (31.3% CPR) and LNP (14.3% CPR). When males and females were tested separately, males exhibited a significantly higher prevalence in the PVP than in the LNP (p=0.020), while females did not (p=0.137). In none of the phases, however, was there a significant difference in the CPR of mandibular tori between sexes (p=0.217, 0.131 and 0.171). While the middle adults (35-45) were the only age group to exhibit a significant decrease in the prevalence of mandibular tori from the PVP to the VA (p=0.013), the young adults were the only age group to show a significant decrease in prevalence from the VA to the LNP (p=0.003). Tables of CPR by site, subsistence and grave goods are provided in Catalogue C, Tables 36-42.

Figure 5.26. Mandibular torus observable on individual DT from Brough Road, a VA older adult male.

Phase	Females	CPR	Males	CPR	All	CPR	p value	Test
PVP	4/6	66.7	7/9	77.8	12/16	75	0.634	16
VA	3/8	37.5	2/7	28.6	5/15	33.3	0.714	15
LNP	2/11	18.2	2/11	18.2	4/23	17.4	1.0	23
p value	0.137		**0.020**		**0.000**			
N	25		27		58			

Table 5.36. CPR of mandibular tori by phase and sex, along with results of Chi2 tests (p values). Bold p values indicate a statistical significance at α= 0.05.

5.4.4.7. Indicators of "load-bearing"

Similar to section 5.4.1 on nutritional deficiencies, a composite variable entitled "load-bearing" was created after each osteological indicator of physical labour was tested separately. This category included individuals with any of the indicators of strenuous physical activity or heavy labour such as OA, OD, platymeria/platycnemia, as well as non-violent trauma, osteophytosis, enthesopathy, Schmorl's nodes, Osgood-Schlatter's disease, etc. (Capasso et al. 1999). Although OA is observable on nearly any major joint surface, OA on load-bearing joint surfaces, namely the knees, vertebrae, hips and potentially shoulders, are more indicative of load-bearing and physical stress (Capasso et al. 1999, 80, 90, 132; Vincent et al. 2012). Only OA observed at these joints was included in the load-bearing category. There was a significant difference in the prevalence of individuals exhibiting indicators of load-bearing between the three phases (see Table 5.373., below). The phases with the highest prevalence were the PVP (95.5% CPR) and VA (88.1% CPR) before decreasing in the LNP (33% CPR). In none of the phases was there a significant difference in the prevalence of "load-bearing" between males and females.

	Females			***Males***			***All***			***Chi²***	
Phase	***CPR***	***%***	***95% CI***	***CPR***	***%***	***95% CI***	***CPR***	***%***	***95% CI***	***P value***	**N**
PVP	10/10	100%	72.3-100	10/10	100%	72.3	21/22	95.5%	78.2-99.2	NA	20
VA	16/19	84.2%	62.4-94.5	13/13	100%	77.2-100	31/37	83.8%	68.9-92.4	0.132	32
LNP	17/35	48.6%	33-64.4	19/33	57.6%	40.8-72.8	43/95	45.3%	35.6-55.3	0.457	68
p value	**0.002**			**0.001**			**0.000**				
N	64			56			154				

Table 5.37. Numbers and CPRs of "load-bearing" individuals by phase. P values are the results of Chi² tests, bold p values indicate a statistical significance at α= 0.05 (this study; James 1999; Lorimer 1970; Molleson n.d.; 2005; Morris 1989; Owen and Dalland 1999; Sellevold 1999; Stevens et al. 2005).

While "load-bearing" was a catch-all term for any osteological indicator of physical stress on weight-bearing joints, the possibility for varying etiologies of some of these indicators (i.e., mandibular tori, squatting facets, OA, OD, etc. as discussed in Chapter 3) warrants a look at each indicator separately as well as collectively. While the prevalence of individuals with at least one indicator of physical stress or manual labour decreased significantly from the PVP through the LNP, it is important to note that this was not the case for all individual indicators. Figure 5.27. provides an overview of each indicator's CPR by phase. Discussion and interpretation of these results will be presented in Chapter 8.

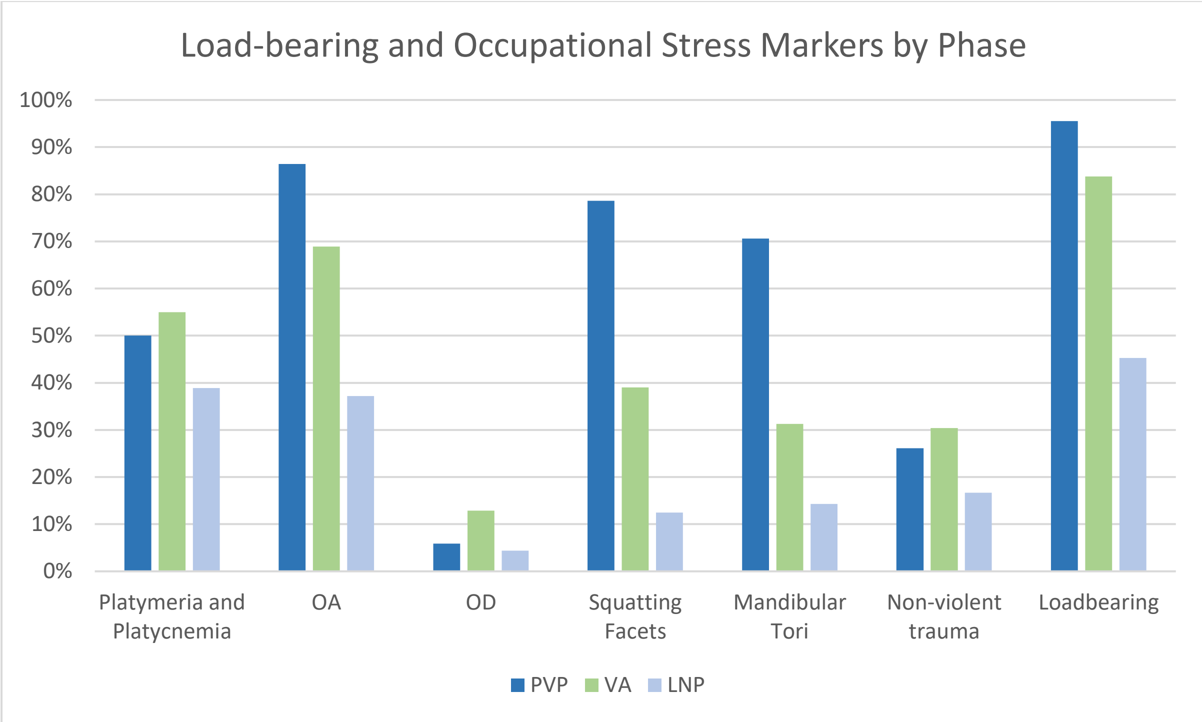

Figure 5.27. CPRs of each indicator of load-bearing and occupational stress by phase (this study; James 1999; Lorimer 1970; Molleson n.d.; 2005; Morris 1989; Owen and Dalland 1999; Sellevold 1999; Stevens et al. 2005).

Phase	***Platymeria and Platycnemia***	***%***	***OA***	***%***	***OD***	***%***	***Squatting facets***	***%***	***Mandibular tori***	***%***	***Non-violent trauma***	***%***	***Load-bearing***	***%***
PVP	7/14	50%	19/22	86.4%	1/17	5.9%	11/14	78.6%	12/17	70.6%	6/23	26.1%	21/22	95.5%
VA	11/20	55%	25/40	68.9%	4/31	12.9%	7/18	39%	5/16	31.3%	14/46	30.4%	31/37	83.8%
LNP	7/18	38.9%	43/94	37.2%	3/69	4.4%	1/8	12.5%	4/28	14.3%	20/120	16.7%	43/95	45.3%

Table 5.38. Table of CPRs of osteological indicators of load-bearing and occupational stress by phase, as shown in Figure 5.27., above (this study; James 1999; Lorimer 1970; Molleson n.d.; 2005; Morris 1989; Owen and Dalland 1999; Sellevold 1999; Stevens et al. 2005).

VA males and females were next compared for osteological indicators of OA, load-bearing and occupational stress between burial settings. VA females buried in churchyards exhibited a significantly lower prevalence of OA of the hip joints than females outside of churchyards (p=0.034), while VA males in churchyards exhibited significantly lower prevalence of squatting facets than males buried outside churchyards (p=0.005). Among individuals buried at churchyards, evidence of accidental or occupational trauma was more common in males than females (p=0.007), though there was no difference in the prevalence of accidental/occupational trauma between sexes from non-churchyard settings (p=0.171). When individuals with and without cists were compared, PVP females in cists had a higher prevalence of OA of the hip joints (p=0.028), while VA females in cists had a lower prevalence of OA in any joint than females without cists (p=0.040). VA males in boat graves showed no significant differences in prevalence rates of any indicators of OA, load-bearing or occupational stress. Results of the one VA female from a boat grave (Scar 133) are provided below.

Among males and females with grave goods, males exhibited a higher CPR of occupational or accidental trauma than females did (p=0.000), though no other indicators of OA, load-bearing or physical labour were significantly different between sexes among those with grave goods or those without grave goods (Catalogue C, Table 42). Males with grave goods exhibited a significantly higher CPRs of OA of the shoulder joint (p=0.048) and squatting facets (p=0.005) than males without grave goods. When CPRs were compared by types of grave goods, males with weapons exhibited significantly higher CPRs of OA of the elbow (p=0.038) and shoulder joints (p=0.015) as well as squatting facets (p=0.005). Males with agricultural tools and males with daggers also showed significantly higher prevalence rates of OA of elbow joints (p=0.002 and 0.011) than males without those items. A significantly higher prevalence of OA of the elbows was the only osteological sign of physical labour that distinguished males buried with agricultural tools from males without.

When VA females were compared, those with grave goods had significantly a higher CPR of OA of the hip joints (p=0.007). More specifically, the three females buried with textile implements, jewellery, agricultural tools and combs (Westness 1963A, Westness 5 and Scar Sk133) together had a greater CPR of OA of the hip joints than the rest of the VA females. While indicative of developmental stress rather than manual labour, these same females showed a significantly higher CPR and TPR of LEHs (Catalogue C, Table 34). These three females also exhibited a higher CPR of non-specific infection (Catalogue C, Table 49. The only female buried with gaming pieces (Westness 36) showed no signs of load-bearing, or any pathology, which made her significantly different than the other VA females (p=0.040 and 0.035). The only female in a boat grave (Sk133 from Scar) exhibited OD and OA of the knees, which also made her significantly different from the other VA females (p=0.004 and 0.038). Interpretations for this difference in pathological prevalence between these females are provided in Chapter 8.

Pathology	Males	N	Females	N	All*	N
Platymeria	0.659	7	0.251	11	0.822	20
Platycnemia	NA	5	0.571	9	0.448	15
Loadbearing	NA	13	0.780	20	0.219	23
OD	0.428	11	0.180	18	0.901	31
OA	0.605	15	0.717	21	0.751	24
OA Verts	0.387	11	0.938	17	0.701	28
OA Shoulder	**0.048**	**13**	0.334	14	0.159	27
OA Hands	0.612	13	0.331	17	0.318	31
OA Knees	0.292	10	0.519	15	0.864	28
OA Feet	0.338	11	0.197	10	0.119	25
OA Elbows	0.154	11	0.685	15	0.152	26
OA Hips	0.740	11	**0.007**	**18**	**0.026**	**30**
OA Jaw	0.439	6	0.512	13	0.364	21
OA Sternocostal	0.343	9	0.127	14	0.591	23
Squatting facets	**0.005**	**8**	0.064	8	**0.000**	**17**
Mandibular torus	0.290	7	0.206	8	0.714	15
Occupational/ Accidental Trauma	0.205	15	0.361	21	0.527	41

*Includes all individuals juvenile and older.

Table 5.39. Results of Chi2 tests (p values) for significant differences between VA males and females with and without grave goods (this study; Lorimer 1970; Morris and Emery 1986; Morris 1989; James 1999; Sellevold

1999; Owen and Dalland 1999; Molleson n.d.; 2005; Stevens et al. 2005). Bold p values indicate a statistical significance at α= 0.05.

When all sites were compared regardless of phase, Newark Bay had the highest prevalence of OA of vertebral joints (p=0.002), platymeria (p=0.001), OD (p=0.002) and load-bearing (p=0.000) among individuals juvenile and older. When sexes were tested separately, Newark Bay had the highest prevalence of males with load-bearing (p=0.019), OA of any joint (p=0.050) and platymeria (p=0.020). Among females, Westness had significantly higher prevalence rates of OA of vertebral joints (p=0.024) and squatting facets (p=0.040) than the other sites. Bu of Cairston exhibited the highest proportion of females with any indicators of load-bearing (p=0.022).

In the PVP, there was a greater proportion of females with OA of any joint at Newark Bay (p=0.007), though there was a higher proportion of females with OA of vertebral joints (p=007) and mandibular torus (p=0.050) at Westness. In the VA, Westness exhibited a significantly higher proportion of males with squatting facets (p=0.046), while Brough Road exhibited a higher proportion of females with OA of elbow joints (p=0.031) than other sites. There were no other significant differences in the prevalence rates of the other indicators of occupational or physical stress between VA sites. In the LNP, both males and females from Newark Bay exhibited the highest proportions of individuals with platymeria (p=0.004 and 0.025). There was also a significantly higher proportion at Newark Bay of males with OA of vertebral joints (p=0.039) and females with OA of the jaw (p=0.026) in the LNP. Bu of Cairston, however, had the highest proportions of individuals with accidental/occupational trauma (p=0.016), squatting facets (p=0.014), load-bearing indicators (p=0.019) and OA of any joint (p=0.022).

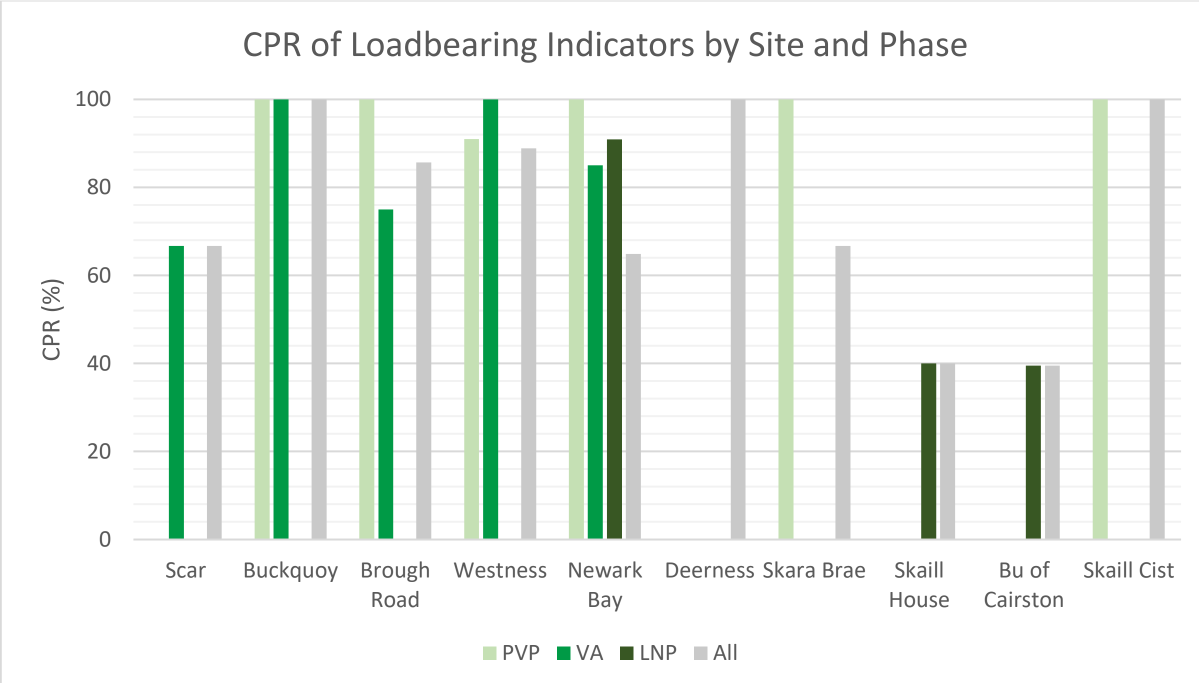

Figure 5.28. CPR of load-bearing indicators by site and phase.

Site	***PVP***			***VA***			***LNP***			***All***		
	No.	%	95%CI	No.	%	95%CI	No.	%	95%CI	No.	%	95%CI
Scar				2/3	66.7	20.8-93.9				2/3	66.7	20.8-93.9
Buckquoy	1/1	100	20.7-100	1/1	100	20.7-100				2/2	100	34.2-100
Brough Road	3/3	100	43.9-100	3/4	75	30.1-95.4				6/7	85.7	48.7-97.4
Westness	10/11	90.9	62.3-90.9	8/8	100	67.6-100	0/1	0	0-79.4	24/27	88.9	71.9-96.2
Newark Bay	4/4	100	51-100	17/20	85	64-94.8	10/11	90.9	62.3-98.4	87/134	64.9	64.9-72.5
Brough of Deerness				0/0			1/1	0	20.7-100	1/1	100	20.7-100
Skara Brae	2/2	100	34.2-100	0/1	0	0-79.4				2/3	66.7	20.8-93.9
Skaill House							2/5	40	11.8-76.9	2/5	40	11.8-76.9
Bu of Cairston							30/76	39.5	39.5-50.7	30/76	39.5	39.5-50.7
Skaill Cist	1/1	100	20.7-100							1/1	100	20.7-100

Table 5.40. Proportions and CPRs of load-bearing indicators by site and phase. Brough of Gurness and Pierowall (both VA sites) were not included above because remains only included skulls and no evidence of load-bearing was recordable.

Finally, OA by joint surface and all indicators of occupational stress or load-bearing were compared between sites with evidence for different subsistence practices. Some of the OA and occupational stress markers correlated significantly with age (see above section 5.4.4), however, ANOVAs comparing prevalence rates of OA/OSM indicators by site type variables while controlling for age category (using general linear models) did not yield any statistical results, significant or otherwise. Therefore, a Kruskal-Wallis was run to test for significant differences in the distribution of age categories among each of the variables in males and females. None of the site type variables exhibited a significant difference in age category distribution.

When all phases were included, females from sites where the predominant crop was oat (i.e., Scar, Skara Brae and Skaill House; p=0.041) had higher prevalence rates of OD, while females from sites where the predominant crop was barley (Brough Road, Westness, Newark Bay and Pierowall) had a higher prevalence of OA of the vertebrae (p=0.007). Among females there were positive correlations between the proportion of cattle at the nearby farmstead and the presence of OA of hands (p=0.015, r=0.501) and OA of sternocostal joints (p=0.043, r=0.468); the proportion of sheep/goat and the presence of squatting facets (p=0.002, r=0.793); the proportion of pigs and OA of elbow joints (p=0.028, r=0.479). There were significantly greater prevalence rates of load-bearing (p=0.013), OA of foot joints (p=0.043) and OA of the jaw (p=0.023) in females from sites with evidence of plaggen soils. There was also a significantly lower prevalence rate of squatting facets in females from sites with plaggen soils (p=0.012). Among males, there was a significant correlation between the proportion of cattle at the nearby farmstead and the prevalence of platymeria (p=0.000, r=0.816), OA of the knee joints (p=0.036, r=0.484), OA of sternocostal joints (p=0.012, r=0.578) and occupational/accidental trauma (p=0.006, r=0.511). There was also a higher prevalence of platymeria (p=0.026), OD (p=0.021) and cases of occupational/accidental trauma (p=0.018) from sites with evidence of plaggen soil formation.

In the PVP there were higher prevalence rates of OA and OD in PVP females from sites with better land quality (code 4.2 rather than 5.2) (p=0.002 and 0.002) while males from sites with poorer quality soils (6.2) exhibited a higher prevalence of OA of knee joints (p=0.018). There was also a greater prevalence of OA of knee joints in males from sites with evidence of near-shore marine resource exploitation (p=0.000). Females from PVP sites with evidence of offshore marine resource exploitation (Westness) had a significantly greater prevalence of mandibular tori than females from sites with nearshore or no fish remains (p=0.025).

In the VA, females from sites with predominantly sheep/goat (p=0.008) and females from sites with predominantly oats (p=0.004) had higher prevalence rates of OD than females from sites with predominantly cattle and barley. VA females from sites with higher proportions of pig and lower proportions of cattle and sheep/goat had higher prevalence rates of OA of elbow joints (p=0.011, r=0.677). Females from sites with plaggen soils also exhibited a higher prevalence of OA of the elbow joints (p=0.015). Females from sites with better soil quality (4.1 rather than 4.2 or 5.2; p=0.014) had a higher prevalence of OD, while females from sites with poorer soil quality (5.2) had a higher prevalence of OA of elbows (p=0.008). Among males, occupational/accidental trauma correlated positively with the proportion of cattle (p=0.030, r=0.623) and pig (p=0.007, r=0.727). There was also a higher prevalence of squatting facets in males from sites with plaggen soils (p=0.046).

Finally, in the LNP, there was a growing difference in the prevalence of various indicators of occupational stress and load-bearing between eastern and western sites. Males from eastern sites exhibited greater prevalence rates of load-bearing (p=0.026), platymeria (p=0.001), OD (p=0.020), occupational/accidental trauma (p=0.013) and OA of any joint surface (p=0.011)- specifically OA of vertebrae (p=0.006), knee joints (p=0.050) and sternocostal joints (p=0.046). Females from eastern sites exhibited greater prevalence rates of platymeria (p=0.025), OA of vertebral joints (p=0.018), OA of hand joints (p=0.043) and OA of the jaw (p=0.007). When evidence of husbandry practices was considered, both males and females from sites with a focus on dairying rather than meat production had higher prevalence rates of OA of vertebral joints (p=0.046 and 0.011). Among males, the proportion of cattle correlated positively with the prevalence of OA of vertebral joints (p=0.006, r=0.770). There was also a higher prevalence of vertebral OA among both males and females from sites with barley as a predominant crop (p=0.011 and 0.046).

5.4.5. Non-specific and specific infections

The most prevalent infectious disease observed was tuberculosis and one adolescent had lepromatous leprosy (Molleson 2005, 114). Tuberculosis was suspected in six individuals, two from the PVP and two from the LNP. The other two were from Newark Bay and were not dated (70(20) and Sk98). The individuals from the PVP included two females from Westness: one young adult (28a) and an older adult (7). Both females contained calcified pleura within their rib cages and the younger female died while approximately 5-6 months pregnant (Sellevold 1999, 41). A young adult female (Sk110) and an older adult male (Sk081) with suspected tuberculosis from the LNP were both from Bu of Cairston. The adolescent with leprosy (confirmed by DNA testing in a previous study; Figure 5.29) was burial 69/CC4 from Newark Bay. A Chi^2 test showed no significant difference in the prevalence of specific infections by phase (p=0.173). Nor was there a difference in either males or females when tested separately (p=0.344 and 0.127, respectively).

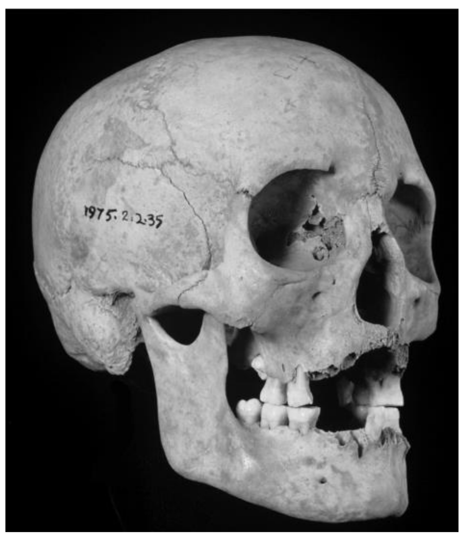

Figure 5.29. Individual 69/CC4 from Newark Bay with erosion of the nasal sill and alveolar process, indicative of leprosy (Molleson 2010, 53; ©The Trustees of the Natural History Museum, London).

Bone reactions to non-specific pathology are typically in the form of periostitis (Figure 5.30), along with osteomyelitis (Figure 5.31) or osteitis. A total of 214 individuals out of 452 observable individuals had signs of non-specific infections, of which six had osteitis and five had osteomyelitis. According to a Chi^2, the prevalence of periostitis did not significantly differ between phases (p=0.965), nor was there a significant difference in the CPR of periostitis between males and females in any of the three phases (p=0.653, 0.600 and 0.978). When periostitis, osteitis and osteomyelitis were combined there was no significant difference in the prevalence of non-specific infections between the three phases (p=0.279) even when males and females were tested separately (p=0.941 and 0.643, respectively). There was also no significant difference in the prevalence of non-specific infection between males and females of any phase (per Table 5.41). In none of the phases was there a significant difference or correlation between age categories and the prevalence of non-specific infection (p=0.503, 0.053 and 0.306).

Phase	***Females***	***CPR***	***95% CI***	***Males***	***CPR***	***95% CI***	***All***	***CPR***	***95% CI***	***P value***	*N*
PVP	4/10	40%	16.8-68.7	5/10	50%	23.7-76.3	11/24	45.8%	27.9-64.9	0.653	20
VA	9/19	47.4%	27.3-68.3	9/16	56.3%	33.2-56.3	21/42	50%	35.5-64.5	0.600	35
LNP	20/36	55.6%	39.6-70.5	19/34	55.9%	39.5-71.1	53/136	39%	31.2-47.4	0.978	70
P value	0.643			0.941			0.279				
N	65			60			206				

Table 5.41. CPR of non-specific infection (periostitis, osteitis and osteomyelitis) by phase and sex along with the results (p values) of Chi2 tests (this study; Lorimer 1970; Morris 1989; James 1999; Owen and Dalland 1999; Sellevold 1999; Molleson n.d.; 2005). Bold p values indicate a statistical significance at α= 0.05

Figure 5.30. Periostitis on the medial surface of the distal left tibia of individual 217 from Bu of Cairston.

Figure 5.31. Osteomyelitis of the distal femur from individual 309 from Bu of Cairston. The cloaca is still visible, where pus would have drained from the infected bone.

There was no significant difference in the prevalence of any osteological indicators of specific or non-specific infections between churchyard and non-churchyard settings, either among males or females. The one male and two females with possible cases of tuberculosis in the PVP were all buried in cists (Skaill cist male and two females from Westness), as was the predominant burial rite in that phase. The only other two females with tuberculosis, one from the VA and one from the LNP, were not buried in cists. There was no significant difference in the prevalence of either specific or non-specific infections between males or females in or without boat graves (p=0.588 and 0.619).

When sites of all phases were compared, Bu of Cairston had a significantly higher proportion of individuals with specific infection (p=0.008) than the other sites. Bu of Cairston was also the site with the highest proportion of individuals with specific infection when only LNP sites were compared (p=0.023). When the PVP sites and VA sites were compared separately, there were no significant differences in the prevalence of non-specific or specific infections. When site type and subsistence practices were compared among all phases, there was a higher prevalence of periostitis among females from sites without evidence of plaggen soil formation than those with (p=0.045). When all LNP individuals (juvenile and older) were compared, there was a higher prevalence of non-specific infection indicators in those from sites without evidence of plaggen soil formation (p=0.040).

5.5. Violent trauma

Out of 187 observable individuals with radiocarbon dates within the PVP, VA or LNP, 15 exhibited what could be interpreted as evidence of violent trauma. This included cranial and mandibular fractures, parry fractures and sharp force and projectile trauma. Both ante-mortem and peri-mortem trauma were included and any evidence of healing was noted. All cases of non-violent or accidental trauma are discussed in section 5.4.4.4. The prevalence (CPR) of violent trauma did not vary significantly (p=0.114) between the PVP (4.4%), the VA (15%.2) and the LNP (5.9%). Even when males and females were tested separately (p=0.427 and 0.363, respectively) there was no significant difference in prevalence between phases. The one individual with potentially violent trauma dated to the PVP (a middle-aged male with a parry fracture to the left ulna) likely did not succumb to his injuries, as there was bone growth evidence of healing. There were seven observed instances of potentially violence-related trauma dated to the VA. This included two males with sharp force trauma to the cranium (possibly the same individual, records are unclear), one female with perforated trauma to the cranium and three individuals with blunt force trauma to the cranium (one of which had partially healed), Table 5.42.

Site	***Burial***	***Phase***	***Sex***	***Age***	***Evidence of Healing***	***Description***	***References***
Brough Road	BJ	VA	Female	MA	No	Unhealed fracture at the base of the skull	This study; Morris 1989
Bu of Cairston	Sk202	LNP	Female	OA	Yes	Healed trauma of skull?	This study; Stevens et al. 2005
Bu of Cairston	Sk214	LNP	Female	MA	Yes	Sharp force trauma to right ulna	This study; Stevens et al. 2005
Bu of Cairston	Sk223	LNP	Male	OA	No	Sharp force trauma to both tibia	This study; Stevens et al. 2005
Bu of Cairston	Sk360	LNP	Unknown	Child	Yes	Healed fracture to mandible?	This study; Stevens et al. 2005
Newark Bay	68/020	VA	Female	YA	Yes	Healed trauma to left gonial angle, squatting facets	Molleson n.d.; 2005
Newark Bay	69/008	LNP	Female	MA	No	Puncture trauma to cranium-	This study

						frontal, right and left parietal	
Newark Bay	69/069	LNP	Male	OA	Yes	Small, rounded crater in frontal	This study
Newark Bay	70/039	LNP	Male	MA	No	Trauma to the face, loss of teeth as a result	Molleson n.d.; 2005
Pierowall	ET62*	VA	Male	YA	No	Sharp force trauma to skull, though lacquering makes analysis difficult	This study; Thorsteinsson 1965
Pierowall	ET63	VA	Male	MA	Yes	Healed cranial fracture	This study; Thorsteinsson 1965
Pierowall	Grave 006*	VA	Male	Adult	No	"[Skull] may have been cleft before being buried"	Thorsteinsson 1965
Westness	005	VA	Female	Adult	No	Possible perforation trauma at bregma, internal beveling and radiating fracture lines	This study; Sellevold 1999
Westness	012	VA	Male	MA	No	Cut marks on first and fourth right metacarpals?	This study; Sellevold 1999
Westness	020	PVP	Male	MA	Yes	Healed fracture of the distal 1/3 of L ulna	This study; Sellevold 1999

**Potentially the same individual, due to confusion over excavation and museum records*

Table 5.42. Dated individuals with evidence of violent trauma, listed by site and burial number with associated references.

It is important to mention that previous studies and osteological analyses have identified very few individuals from the VA with trauma, even fewer with trauma indicative of inter-personal violence that resulted in death (Molleson 2005, 116). This includes the male individual from Westness (grave 34) who was likely shot with arrows (Sellevold 1999, 25), one individual from Newark Bay (69/033, at NHM) with sharp force trauma to the cranium and one individual from Newark Bay (69/12, at NHM) with possible blunt force trauma to the base of the cranium (Molleson 2005). The only other previously identified victims of possible violence resulting in death were a middle adult woman from Brough Road (BJ) who likely suffered a fall and one poorly recorded individual from Pierowall (grave 6, Thorsteinsson

1965). There were five individuals dated to the LNP identified as possibly being the victims of interpersonal violence.

When undated burials were also considered, there were a total of 36 individuals (out 432, or 8.3%) with traumatic lesions possibly the result of violence. Twenty-eight of these individuals had previously been identified (James 1999; Lorimer 1970; Molleson n.d., 2005; Morris 1989; Sellevold 1999; Stevens et al. 2005; Thorsteinsson 1965). This includes one possible victim of torture from Westness (burial 1968A, recorded by Larsen 1972; Sellevold 1999, 27) and twelve individuals from Newark Bay (this study; Molleson 2005, 115). The eight newly-identified cases came from Bu of Cairston (individuals 214 and 223) and Newark Bay (2015/3, 68/031a, Sk?ST12, Sk011, Sk005e and an unlabelled skull). Unfortunately, none of these individuals with newly identified trauma have secure dating. Newark Bay Sk011, a middle adult male, exhibited evidence of blunt force trauma to the left frontal, resulting in concentric and radiating fracture lines. The position of the trauma would be consistent with a blow from a blunt weapon wielded by a right-handed assailant. While the heavy dental attrition and accumulated calculus would suggest the individual likely dates to the VA or LNP, this needs to be confirmed by radiocarbon dating (Figure 5.32).

Figure 5.32. Blunt force trauma to the left frontal, resulting in concentric and radiating fracture lines (Newark Bay, Sk011).

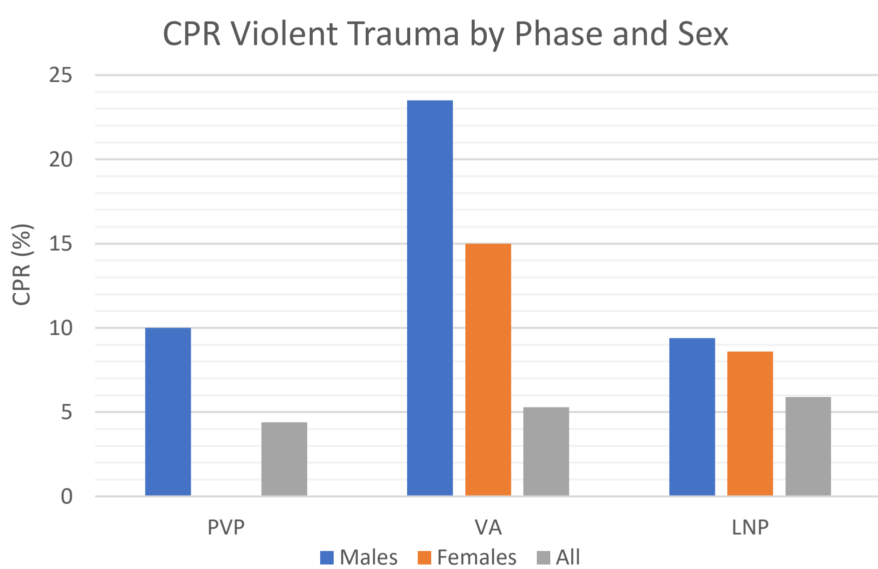

Figure 5.33. Distribution of individuals with evidence of trauma by phase and sex (this study; James 1999; Lorimer 1970; Molleson n.d.; 2005; Morris 1989; Owen and Dalland 1999; Sellevold 1999; Stevens et al. 2005; Thorsteinsson 1965).

Phase	Males	CPR	95%CI	Females	CPR	95% CI	All	CPR	95%CI	p value	N
PVP	1/10	10%	1.8-40.4	0/9	0%	0-30	1/23	4.4%	0.8-21	0.33	19
VA	4/17	23.5%	9.6-47.3	3/20	15%	5.2-36	4/76	5.3%	2.1-12.8	0.298	39
LNP	3/32	9.4%	3.2-24.2	3/35	8.6%	2.2-24.2	7/118	5.9%	2.9-11.7	0.938	66
p value	0.193			0.463			0.062				
N	60			64			188				

Table 5.43. Numbers of individuals and CPRs of trauma by phase and sex. Where it was possible to discern, instances of trauma that looked to be the result of interpersonal violence were noted (this study; James 1999; Lorimer 1970; Molleson n.d.; 2005; Morris 1989; Owen and Dalland 1999; Sellevold 1999; Stevens et al. 2005; Thorsteinsson 1965). Bold p values indicate a statistical significance at α= 0.05

When all sites were compared, Pierowall (100%) and Westness (30.8%) had higher proportions of violent trauma than the other sites (p=0.000). This held true when only VA sites were compared (p=0.012). In the LNP Newark Bay had the highest proportion of individuals with violent trauma (23.1%, p=0.050). Of all three phases, six out of the twelve sites (36 out of 427 individuals) exhibited some form of violent trauma. There was no significant difference in the prevalence of violent trauma between phases at Westness (p=0.238), Newark Bay (p=0.203), or Brough Road (p=0.350). Statistical comparison of violent trauma at the other multi-phase sites (Buckquoy, the Brough of Deerness and Skara Brae) was not possible due to the small population sizes.

There was no difference in the prevalence of trauma among males or females buried within or outside of churchyards, nor was there a significant difference in the prevalence evidence of violent trauma between those with or without grave goods in the VA (Catalogue C, Table 52). Interestingly, there was no significant difference in the prevalence of violent trauma between males buried with or without weapons (p=0.104), suggesting those buried with weapons are not necessarily “warriors” or fighters. Further discussion on this will be presented in Chapter 8.

5.6. Osteology conclusions

Osteological indicators of health and diet are essential for interpreting changes in everyday life and subsistence. This includes demographic patterns, stature, markers of nutritional deficiency, specific and non-specific infections, occupational stress/load-bearing markers and evidence of violent trauma that were compared by phase, site, burial setting and evidence of site subsistence. This study analysed a total of approximately 262 individuals (some ambiguity with labelling) and compiled previous analysis from an additional 223, for a total of 485. This included 234 individuals with dates for which a phase (PVP, VA or LNP) could be assigned.

First, patterns in demography: male to female ratio, juvenility index, life expectancy and crude death rate were calculated to determine whether there was evidence of a substantial shift in the population structure which could have been attributed to large-scale immigration. Unfortunately, none of these calculations indicated a population transition in the VA or LNP. Nor was there a difference in estimated statures between males or females of different phases. Stature did not vary significantly between individuals buried in churchyards and outside of churchyards. There was, however, significantly greater stature among VA males with grave goods than VA males without. Chapter 8 will discuss possible sociocultural interpretations of this relatively considerable difference.

Next, the prevalence rates of nutritional deficiencies in males and females were compared between phases, as well as demographic groups, to determine if the large-scale socioeconomic transitions of the VA/LNP primarily affected certain groups. Males exhibited greater prevalence rates of both CO and PH in the LNP than in the preceding two phases, while females showed no differences in nutritional deficiency indicators. Although juveniles and adolescents exhibited no differences in prevalence rates by phase, young adults experienced greater prevalence rates of CO from the PVP to the LNP and older adult females exhibited a greater prevalence of CF in the VA than in the PVP or LNP. LNP children experienced a significantly higher prevalence of nutritional deficiency (75%) than other age groups, most markedly higher than the middle adults who only exhibited a prevalence of 27.9%. When tested by burial setting, VA males outside churchyards had more PH and scurvy than males within churchyards and males in boat graves had a higher prevalence of scurvy than those not in boat graves. VA males with grave goods (specifically weapons and combs) also had a higher prevalence of PH than males without grave goods or females with or without grave goods. Females exhibited no difference in prevalence rates of nutritional deficiency indicators between those with and without grave goods. Finally, when compared by site, site location and archaeological evidence of subsistence, there were significant differences in the prevalence rates of nutritional deficiencies between sites in all three phases. In the PVP, females from Westness (a western site with evidence of offshore fishing) had a higher prevalence of nutritional deficiency indicators than females from Newark Bay (an eastern site with no substantial evidence of fishing in the PVP). In the VA, males from Brough Road, Buckquoy and Pierowall exhibited higher rates of PH and diagnosable scurvy than males from eastern sites like Newark Bay, Scar and the Brough of Deerness. VA males from sites with plaggen soil formation and males from the western side of the archipelago also exhibited higher prevalence rates of PH and diagnosable scurvy than VA males from eastern or non-plaggen sites. LNP females from sites with plaggen soil formation also exhibited a higher prevalence of scurvy.

Next, the prevalence of dental pathologies (attrition, calculus, caries, abscesses, periodontal disease and AMTL) were compared as osteological indicators of diet. There were no differences in attrition stages or calculus levels in either males or females between phases, though PVP females exhibited greater attrition stages than PVP males. There were also no differences in attrition or calculus levels between individuals from different site types or subsistence practices. The prevalence of dental caries did not change significantly by phase in either males or females, though the types of teeth affected included anterior and posterior teeth only in the VA. Interestingly, VA females in cists exhibited a higher prevalence of caries than VA females without cists and males buried with agricultural tools exhibited a higher CPR and TPR of caries than VA males buried without. VA males with grave goods had significantly fewer abscesses than males without and males buried outside churchyards had fewer abscesses than males buried within churchyards. These results could suggest a difference in the consumption of cariogenic foods between VA individuals of different social statuses or roles in society. This possibility will be further discussed in Chapter 8. Finally, among females, there was a significant increase in the prevalence of periodontal disease from the PVP to the VA, before a sharp decline in the LNP. There was also a greater prevalence of periodontal disease, abscesses and LEHs among females from sites with evidence of a focus on rearing animals for meat production rather than dairy and among females from plaggen versus non-plaggen sites. In the LNP, both males and females from eastern sites (Newark Bay and the Brough of Deerness) exhibited a higher prevalence of periodontal disease and abscesses.

Indicators of occupational stress or load-bearing included platymeria, platycnemia, osteoarthritis of weight-bearing joints, osteochondritis dissecans, squatting facets, mandibular tori and non-violent trauma. Due to archaeological evidence for differences in subsistence practices and economic foci (see Chapter 2), these indicators of occupational or physical stress were compared in males and females between phases. There were no differences in the prevalence of platymeria, platycnemia, osteochondritis dissecans, or accidental/non-violent trauma in either males or females between phases. There was, however, a greater prevalence of OA among middle and older females in the PVP than in the LNP. There was also a greater prevalence of squatting facets among females in the PVP than in the other two phases. While the extent to which environmental or genetic components affect the manifestation of mandibular tori is still debated, there was a decrease in prevalence in males from the PVP to the LNP. The implications of changing prevalence rates of mandibular tori will be further discussed in Chapter 8.

When sites of all phases were compared (and controlled for age using a general linear model), males from Newark Bay exhibited higher prevalence rates of OA, platymeria and load-bearing than males from the other sites. Females from Westness exhibited a significantly higher prevalence of OA of vertebral joints and squatting facets than females from other sites. To determine whether these differences in prevalence rates could have been due to differences in site-specific subsistence practices, archaeological evidence of predominant crop, domesticated animals, the presence of plaggen soils and other indicators of subsistence were then compared. Each phase exhibited slightly different patterns in osteological indicators of load-bearing among males and females. When females from all phases were compared, however, there was a higher prevalence of OD at sites with predominantly sheep/goat rather than cattle and predominantly oats rather than barley. Females exhibited a positive correlation between the proportion of cattle and OA of hand and sternocostal joints. Among males, there was a positive correlation between the proportion of cattle and the prevalence of platymeria, OA of knee joints, OA of sternocostal joints and occupational/accidental trauma. There was also a higher prevalence of platymeria, OD and occupational/accidental trauma at sites with plaggen soil formation.

There were no differences in the prevalence of non-specific diseases between phases, sexes or sites with different profiles of subsistence. The only exception was that in the LNP, individuals from sites with plaggen soil formation exhibited higher prevalence rates of non-specific infection indicators than sites without plaggen soil formation. A total of 36 individuals exhibited traumatic lesions indicative of inter-personal violence. While 28 of these individuals had been identified by previous studies (James 1999; Lorimer 1970; Molleson n.d., 2005; Morris 1989; Sellevold 1999; Stevens et al. 2005; Thorsteinsson 1965), this study identified an additional two individuals dating to the LNP (Bu of Cairston) and six undated individuals from Newark Bay. Westness and Pierowall, the two largest cemeteries with richly furnished Scandinavian grave goods exhibited the highest prevalence of violent trauma.

Chapter 6. Diet: Carbon and Nitrogen Stable Isotopes

This chapter presents the results of carbon and nitrogen stable isotopes from bone collagen and tooth dentine samples taken as part of this study, as well as an amalgamation of previous studies. Approximately 165 individuals from twelve sites across Orkney were sampled for bone collagen (152 individuals), dentine (27) and enamel (54 individuals), or a combination of all three for this study. The total number of individuals is approximate due to inconsistent labelling during excavation and possible duplication of some individuals, especially within the Newark Bay collection. The bone collagen and tooth dentine samples were run for $\delta^{13}C$ and $\delta^{15}N$ isotope values and the tooth enamel carbonate was run for $\delta^{13}C$, strontium and oxygen isotopes. A full list of samples and statistical results is provided in Catalogues B and D, respectively. It is important to note that the number of statistical tests run may have increased the likelihood of at least one erroneous result. For that reason, caution was exercised when interpreting the results of tests on small sub-sample sizes.

Material and Isotope	**Individuals from previous studies**				**Individuals from this study**				**Duplicated**				**Total**			
	PVP	VA	LNP	All	PVP	VA	LNP	All	PVP	VA	LNP	All	PVP	VA	LNP	All
Bone C and N	11	23	16	147	7	14	76	152	0	2	4	7	18	35	88	292
Tooth enamel Sr	3	3	0	6	10	7	23	55	2	1	0	3	11	9	23	58
Tooth enamel O	1	3	0	4	10	7	23	55	2	1	0	3	10	9	23	57
Dentine C and N	0	0	0	0	9	5	9	28	0	0	0	0	9	5	9	28

Table 6.1. Numbers of individuals included in this study, incorporating results from the current study as well as previous isotope studies (Barrett et al. 2004; Barrett and Richards 2006; Montgomery et al. 2014).

6.1 Bone collagen stable isotope results

Bone samples were run in duplicate, except for one sample (Westness 9) which did not provide enough collagen for a duplicate. An additional eight samples did not provide duplicates with C:N ratios between the accepted range of between 2.9 and 3.6 (per DeNiro 1985) and were therefore excluded. In addition to the results from this study, stable isotope results from previously published work on these collections by James Barrett, Mike Richards, Janet Montgomery and colleagues (Barrett et al. 2004; Montgomery et al. 2014; Richards et al. 2006) were included in the following analysis. Previous $\delta^{13}C$ values obtained during radiocarbon dating were excluded, however, as these are not necessarily measured to the same standards as samples run specifically for palaeodietary reconstruction (Ashmore 2003; Barrett et al. 2000a; 2000b; Brundle et al. 2003; James 1999; Morris 1989; Owen and Dalland 1999; Sellevold 1999). A series of seven previously sampled individuals were re-tested as part of the current study to check for consistency in results between laboratories before data integration. A paired- samples t-test showed no significant difference in either $\delta^{13}C$ or $\delta^{15}N$ values between previous studies and the current study (p=0.711 and 0.180, respectively). When previous stable isotope values were included with the results from the current study, there were 292 individuals with bone collagen $\delta^{13}C$ and $\delta^{15}N$ values (Figure 6.1). The 292 bone collagen samples provided non-normally distributed $\delta^{13}C$ and $\delta^{15}N$ values according to a Shapiro-Wilk test of normality (p=0.00 and 0.000, respectively).

To contextualize the human $\delta^{13}C$ and $\delta^{15}N$ data, faunal data from Orkney sites from previous studies were plotted as well (Figure 6.2). The numbers of faunal samples, phases and $\delta^{13}C$ and $\delta^{15}N$ values are provided in Table 6.2. The mean terrestrial herbivore (cattle and sheep/goat) $\delta^{13}C$ and $\delta^{15}N$ were -21.3‰ ± 0.7‰ [n=134] and 6.0‰ ±0.9‰ [n=130], respectively. Terrestrial omnivores (pigs) had a mean $\delta^{13}C$ value of -20.8‰ ± 1.1‰ (n=32) and a mean $\delta^{15}N$ value of 8.6‰ ± 1.6‰ (n=31), while marine fish had a mean $\delta^{13}C$ value of -13.4‰ ± 1.9‰ (n=34) and $\delta^{15}N$ value of 14.0‰ ± 0.7‰ (n=23) (see Table 6.2., below for references).

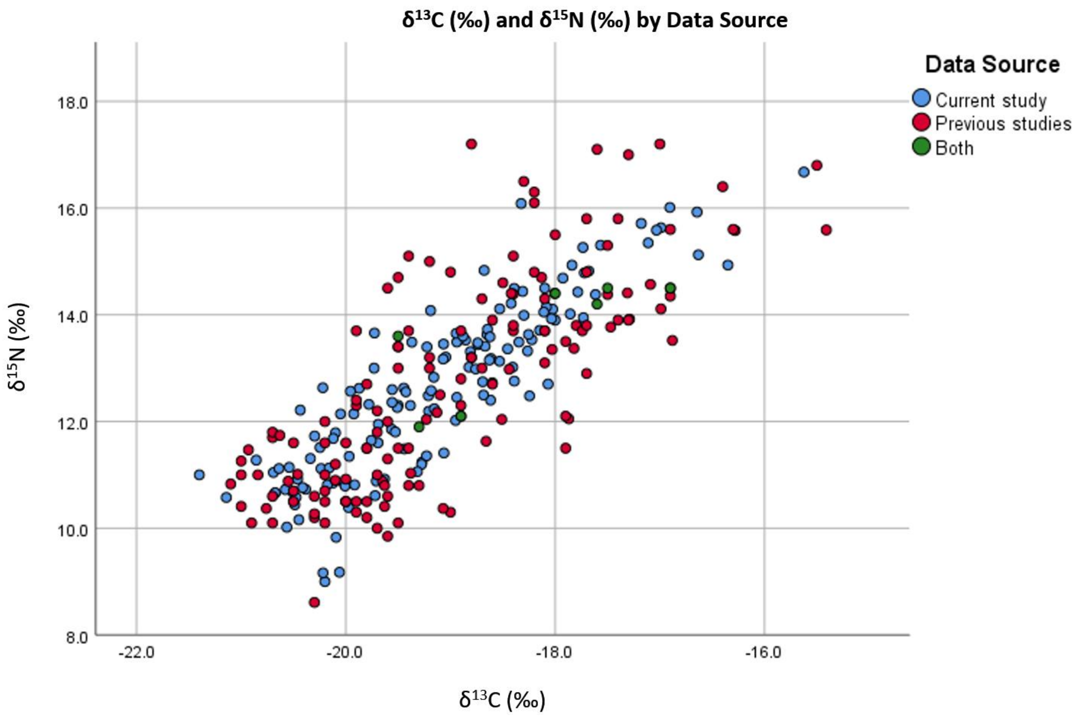

Figure 6.1. Bone collagen $\delta^{13}C$ (‰) and $\delta^{15}N$ (‰) values from the current study plotted with those from previous studies (Barrett et al. 2004; Montgomery et al. 2014; Richards et al. 2006).

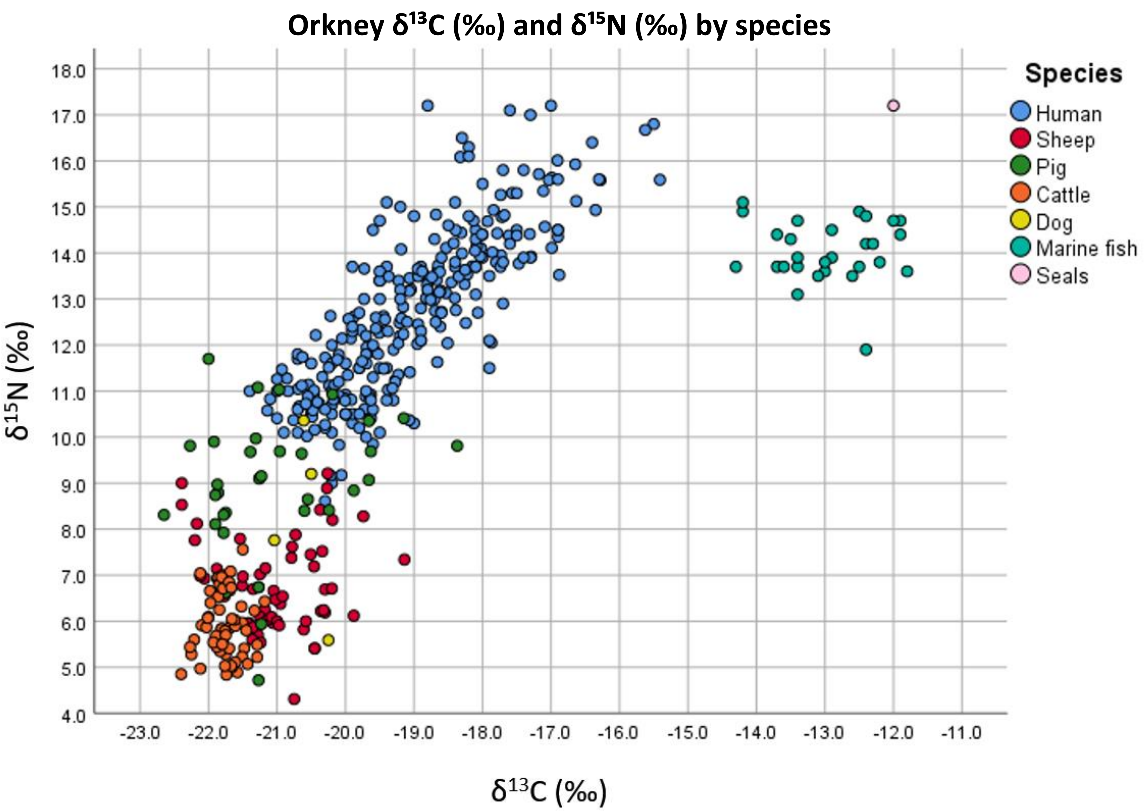

Figure 6.2. Bone collagen $\delta^{13}C$ (‰) and $\delta^{15}N$ (‰) values of humans and animals from all three phases in Orkney (data and references provided in Table 6.2., below).

Phase	Sites	Animal Group	Species	N	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	References
PVP	Knowe o'Skea, Pool, Mine Howe, The Cairns, Tofts Ness	Terrestrial herbivore	Cattle	28	-21.9	5.7	Barrett et al. 2001; Jones et al. 2012; Jones and Mulville 2015
		Terrestrial herbivore	Sheep/goat	27	-21.4	6.8	
		Terrestrial omnivore	Pig	17	-20.6	8.7	
		Marine fish	Fish	7	-20.5		
VA	Westray, Quoygrew, Earl's Bu	Terrestrial herbivore	Cattle	23	-21.8	5.7	Barrett et al. 2000c; 2001; 2011; 2012; Jones et al. 2012; Jones and Mulville 2018; Milner 2007
		Terrestrial herbivore	Sheep/goat	23	-21.8	6.0	
		Terrestrial omnivore	Pig	19	-20.6	8.6	
		Marine fish	Fish	13	-13.0	14.2	
LNP	Quoygrew, Earl's Bu	Terrestrial herbivore	Cattle	11	-21.3	5.6	Barrett et al. 2000c; 2008; 2011; 2012; Jones and Mulville 2018
		Terrestrial herbivore	Sheep/goat	7	-21.6	5.9	
		Terrestrial omnivore	Pig	7	-21.7	9.0	
		Marine fish	Fish	14	-12.9	14.0	

Table 6.2. Faunal isotopes used as background or 'local' $\delta^{13}C$ (‰) and $\delta^{15}N$ (‰) means.

6.1.1. $\delta^{13}C$ and $\delta^{15}N$ by phase

When combined with previously published results, there were 292 individuals with bone collagen results. Once undated individuals and infants and children were excluded for analysis (aged birth to 5 years excluded because of variability in diet from weaning), 131 individuals remained. The ranges for adults in each phase and all dated samples are provided in Figures 6.3. and 6.4. and Table 6.3., below. An ANOVA test indicated significant differences in both $\delta^{13}C$ and $\delta^{15}N$ values between the Pre-Viking phase (PVP), Viking Age (VA) and Late Norse phase (LNP) (p=0.000 and 0.000). Both $\delta^{13}C$ and $\delta^{15}N$ values were also significantly and positively correlated with phase ($\delta^{13}C$: p=0.000, r=0.483 and $\delta^{15}N$: p=0.000, r=0.511). Both $\delta^{13}C$ and $\delta^{15}N$ values were significantly higher in the VA than the PVP (p=0.003 and 0.029, respectively). There was then a significant rise in both $\delta^{15}N$ and $\delta^{13}C$ values between the VA and LNP (p=0.037 and 0.001).

According to a Pearson Correlation, there was no significant correlation between $\delta^{13}C$ and $\delta^{15}N$ values in the PVP (p=0.163). There was a significant positive correlation between $\delta^{13}C$ and $\delta^{15}N$ values in the VA (p=0.000, r=0.866) and the LNP (p=0.000, r=0.794), however. As detailed in Table 6.3., the VA had the greatest variability in both $\delta^{13}C$ values (ranging between -21.4‰ and -15.5‰) and in $\delta^{15}N$ values (ranging between 8.6‰ and 16.8‰). When the three phases were compared, a Levene test for homogeneity of variances showed a significant difference in the variability of $\delta^{13}C$ values and $\delta^{15}N$ between phases (p=0.010 and 0.001). Between the PVP and VA, there were significant differences in the variability of both $\delta^{13}C$ and $\delta^{15}N$ values (p=0.004 and 0.019), with the VA exhibiting significantly increased variability. From the VA to the LNP there were also significant differences in the variability of $\delta^{13}C$ and $\delta^{15}N$ values, with significantly less variation in the LNP (p=0.007 and 0.000).

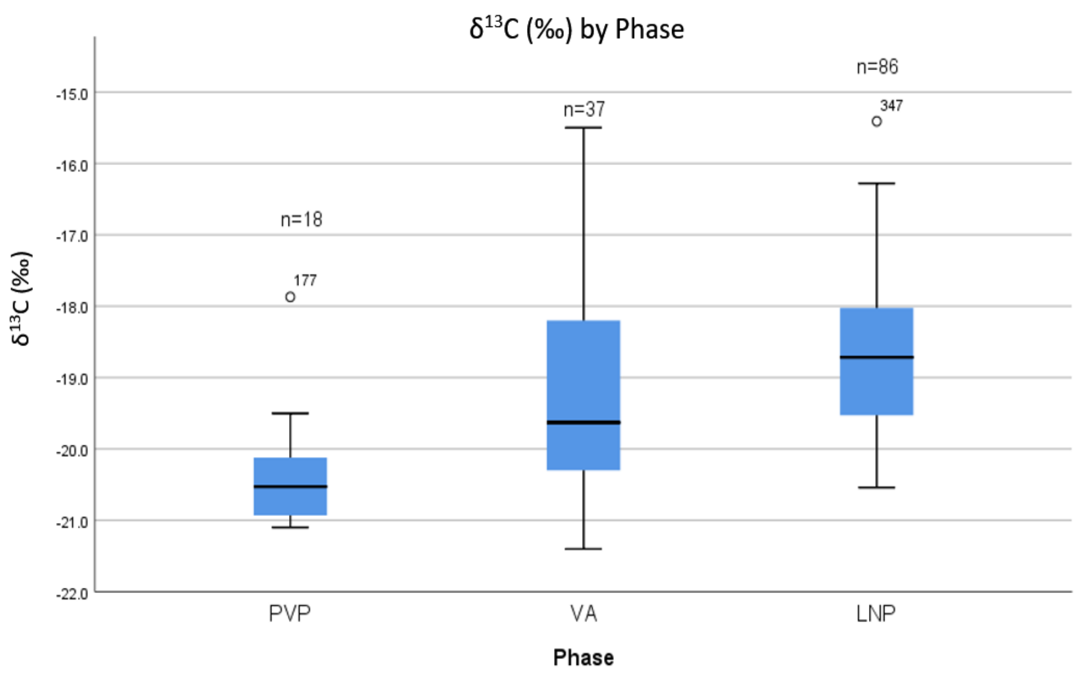

Figure 6.3. Bone collagen $\delta^{13}C$ (‰) ranges of adult individuals by phase.

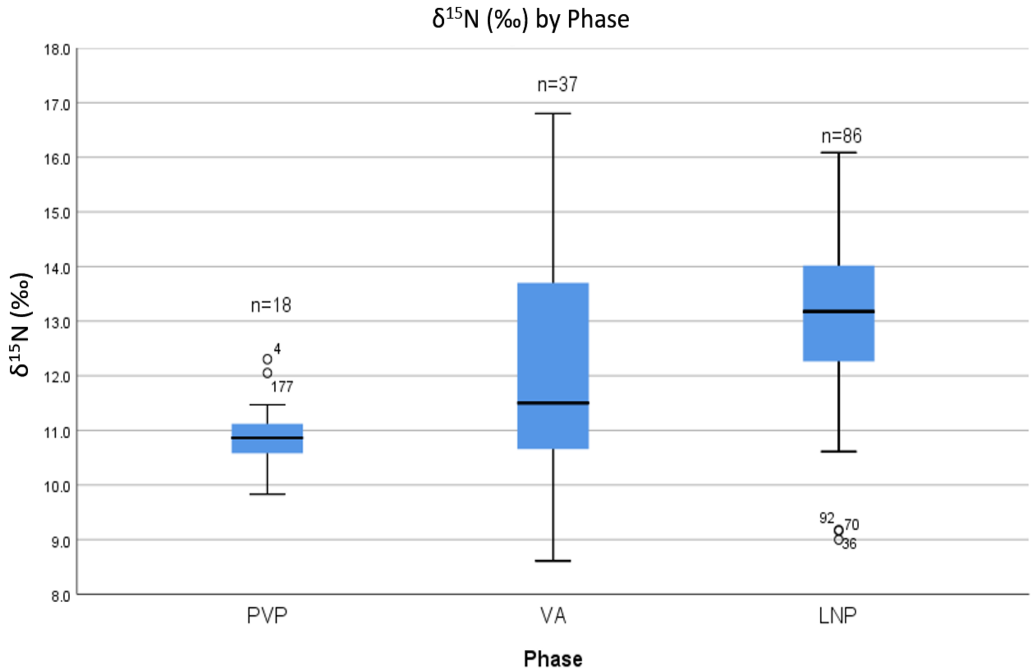

Figure 6.4. Bone collagen $\delta^{15}N$ (‰) ranges of adult individuals by phase.

	PVP *(N=18)*		***VA*** *(N=35)*		***LNP*** *(N=78)*		***All Phases*** *(N=131)*	
	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
Mean	-20.4	10.9	-19.3	11.9	-18.7	13.0	-19.1	12.5
Median	-20.5	10.9	-19.4	11.5	-18.7	13.2	-19.2	12.5
1 SD	0.8	0.6	1.4	1.8	1.1	1.4	1.3	1.6
2 SD	1.6	1.3	2.8	3.5	2.1	2.7	2.5	3.2
Min	-21.9	9.6	-22.1	8.4	-20.8	10.3	-21.6	9.2
Max	-18.8	12.2	-16.6	15.5	-16.5	15.8	-16.6	15.7

Table 6.3. Bone collagen $\delta^{13}C$ (‰) and $\delta^{15}N$ (‰) means, medians and ranges by phase.

6.1.2. $\delta^{13}C$ and $\delta^{15}N$ by demographic group

Next, $\delta^{13}C$ and $\delta^{15}N$ values were compared demographically, between sexes and age groups. A total of 108 individuals with sex estimations were included (Figures 6.5. and 6.6. and Table 6.4). When all dated samples were included and age was controlled for using a general linear model, there was no significant difference in $\delta^{13}C$ and $\delta^{15}N$ values between males and females (p=0.186 and 0.119, respectively). Nor was there a significant difference in $\delta^{13}C$ and $\delta^{15}N$ values between sexes within any of the phases (PVP:

p=0.347 and 0.636; VA: p=0.331 and 0.061; or the LNP: p=0.121 and 0.568, respectively). When only males were considered, there was a significant difference in both $\delta^{13}C$ and $\delta^{15}N$ means between phases (p=0.000 and 0.002). There was also a significant and positive correlation between both $\delta^{13}C$ and $\delta^{15}N$ values and phase ($\delta^{13}C$: p=0.000, r=0.506 and $\delta^{15}N$: p=0.001, r=0.462), with $\delta^{13}C$ and $\delta^{15}N$ means being lowest in the PVP ($\delta^{13}C$= -20.4‰ ± 0.5‰ and $\delta^{15}N$= 11.1‰ ± 0.6‰) and highest in the LNP ($\delta^{13}C$= -18.4‰ ± 1.1‰ and $\delta^{15}N$= 13.2‰ ± 1.2‰). When only females were considered, there was a significant difference in both $\delta^{13}C$ and $\delta^{15}N$ values between phases (p=0.004 and 0.000, respectively). There was also a significant and positive correlation between $\delta^{13}C$ and $\delta^{15}N$ values and phase ($\delta^{13}C$: p=0.001, r=0.424 and $\delta^{15}N$: p=0.000, r=0.541). According to a Levene test, there were no significant differences in the variability of $\delta^{13}C$ and $\delta^{15}N$ values between males and females in the PVP (p=0.405 and 0.732), VA (p=0.307 and 0.182) or the LNP (p=0.755 and 0.623). There was no significant difference in the variability of $\delta^{15}N$ or $\delta^{13}C$ values among females between phases, though there was a significant difference in the variability of both $\delta^{13}C$ and $\delta^{15}N$ values between males in different phases (p=0.005 and 0.000), with the most variability occurring within the VA ($\delta^{13}C$ 1SD = 1.7‰ in the VA, versus 0.5‰ in the PVP and 1.0‰ in the LNP; $\delta^{15}N$ 1SD = 1.9‰ in the VA, versus 0.6‰ in the PVP and 1.2‰ in the LNP).

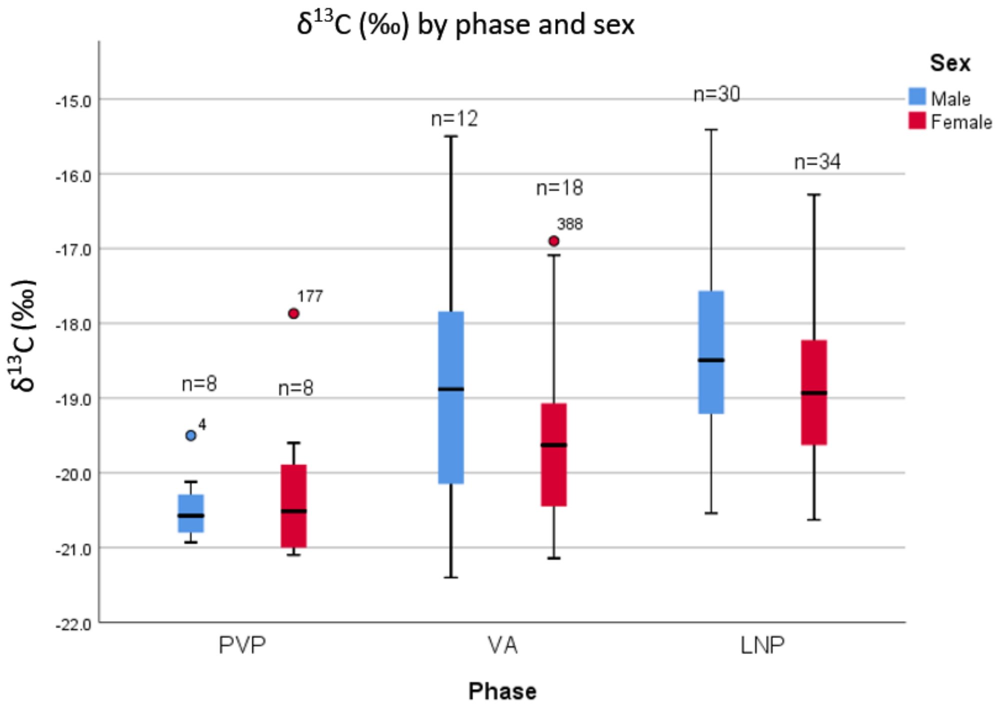

Figure 6.5. Bone collagen δ[13]C (‰) ranges of adults by sex and phase.

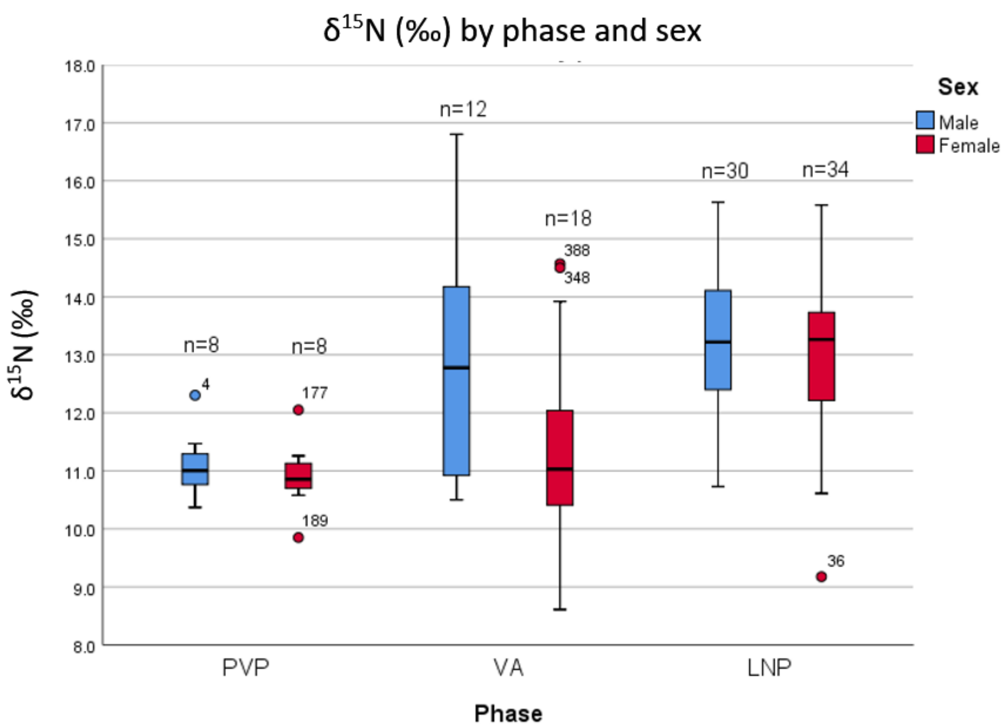

Figure 6.6. Bone collagen δ[15]N (‰) ranges of adults by sex and phases

	PVP					VA					LNP				
Sex	$\delta^{13}C$ (‰)	1 SD	$\delta^{15}N$ (‰)	1 SD	N	$\delta^{13}C$ (‰)	1 SD	$\delta^{15}N$ (‰)	1 SD	N	$\delta^{13}C$ (‰)	1 SD	$\delta^{15}N$ (‰)	1 SD	N
Males	-20.5	0.5	11.1	0.6	8	-18.4	1.7	13.1	1.9	17	-18.7	1.0	13.1	1.2	24
Females	-20.2	1.1	10.9	0.6	8	-19.2	1.5	11.7	1.9	18	-18.9	1.0	13.0	1.3	33
All	-20.4	0.8	10.9	0.6	18	-19.0	1.6	12.3	1.9	40	-18.9	1.0	12.9	1.3	71
ANOVA	0.790		0.145		18	0.370		0.064		40	0.118		0.542		71
Levene	0.298		0.942		18	0.177		0.118		40	0.759		0.739		71

	All Phases					ANOVA		Levene	
Sex	$\delta^{13}C$ (‰)	1 SD	$\delta^{15}N$ (‰)	1 SD	N	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$
Males	-18.9	1.4	12.8	1.6	49	**0.000**	**0.002**	**0.005**	**0.000**
Females	-19.2	1.2	12.3	1.6	59	**0.008**	**0.000**	0.739	0.079
All	-19.1	1.3	12.4	1.6	130	**0.000**	**0.000**	**0.012**	**0.000**
ANOVA (p)	0.183		0.113		130				
Levene (p)	0.162		0.737		130				

Table 6.4. Bone collagen $\delta^{13}C$ (‰) and $\delta^{15}N$ (‰) means and numbers of samples by sex and phase. The 'All' category includes individuals of unidentifiable sex. Results of ANOVA and Levene statistical tests are also provided (p values). Bold p values indicate a statistical significance at α= 0.05.

When all phases were included, there were no significant differences in $\delta^{13}C$ or $\delta^{15}N$ means between age groups (p=0.492 and 0.247). When each phase was considered separately, there were no significant differences in $\delta^{13}C$ or $\delta^{15}N$ means between age groups in the PVP (p=0.352 and 0.417). There was, however, a significant difference in $\delta^{15}N$ means between age groups in the VA (p=0.047), with young adults having the highest $\delta^{15}N$ means and infants (discussed further below) and middle adults having the lowest. Also, a Levene test showed significant variability in both $\delta^{13}C$ or $\delta^{15}N$ values between age groups in the VA (p=0.001 and 0.001). There were no significant differences in $\delta^{13}C$ or $\delta^{15}N$ means between age groups (p=0.696 and 0.069) in the LNP, though the infant age group exhibited the highest $\delta^{13}C$ and $\delta^{15}N$ means in this phase. It is important to note that there is only one infant sampled so far that is dated to the VA (Newark Bay individual 71/005; sampled and dated by Richards et al. 2006). Two infants sampled for bone collagen date to the LNP and 58 infants remain undated ($\delta^{13}C$ and $\delta^{15}N$ values in Figure 6.7). The considerable variability in infant $\delta^{13}C$ and $\delta^{15}N$ values ($\delta^{13}C$ values between -

20.9‰ and -16.3‰ and δ^{15}N values between 10.1‰ and 17.2‰) makes further analysis of diet in infancy difficult, though the variability could be reflective of infants at different stages of weaning.

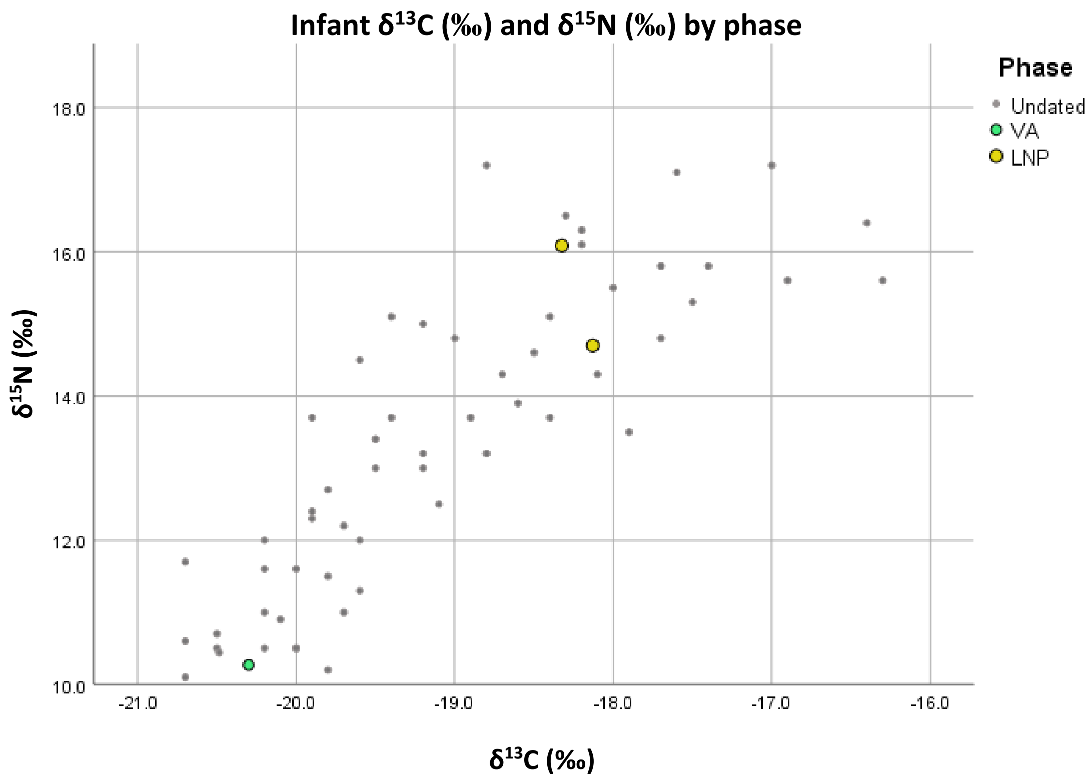

Figure 6.7. Infant bone collagen δ^{13}C (‰) and δ^{15}N (‰) by phase, most infants (58) remain undated (this study; Richards et al. 2006).

Next, mean δ^{13}C and δ^{15}N values of each age group were compared separately between phases. There were not enough dated infant or child samples for statistical comparison, however, so the comparison was limited to juveniles, adolescents, young adults, middle adults and older adults. There were no significant differences in δ^{13}C and δ^{15}N values of juveniles (p=0.095 and 0.109, respectively) or adolescents (p=0.327 and 0.079) between phases. Among young adults (ages 20-35), however, there was a significant difference in both δ^{13}C and δ^{15}N values between phases (p=0.001 and 0.001), with the lowest δ^{13}C mean in the PVP (-2.6‰) and the lowest δ^{15}N mean in the VA (δ^{15}N= 10.4‰). The highest δ^{13}C and δ^{15}N means were in the LNP (δ^{13}C= -18.8‰ and δ^{15}N= 12.7‰). Among the middle adults (ages 35-50), δ^{13}C and δ^{15}N values were both significantly different between phases (p=0.012 and 0.016) with the lowest δ^{13}C and δ^{15}N means in the PVP (δ^{13}C= -20.4‰ and δ^{15}N= 11.0‰). The highest δ^{13}C mean was in the VA (-18.6‰), while the highest δ^{15}N mean was in the LNP (13.0‰). There were also significant differences in δ^{13}C and δ^{15}N means in older adults between phases (p=0.032 and 0.010), with the lowest means in the PVP (-20.8‰ and 10.7‰, respectively) and the highest in the LNP (-18.7‰ and 13.3‰, respectively). Though the older adults were the age group with the lowest δ^{13}C mean in the PVP, they were the group with the highest δ^{13}C and δ^{15}N mean in the LNP. While δ^{13}C and δ^{15}N means were significantly lower in middle adults from the PVP to the VA (p=0.024 and 0.040), there was also an increase in δ^{13}C values in older adults (p=0.033). A Levene test showed a significant difference in the variability of δ^{13}C and δ^{15}N values between different age groups in the PVP based on means (p=0.030 and 0.001) but not in the VA (p=0.265 and 0.489) or in the LNP (p=0.791 and 0.671).

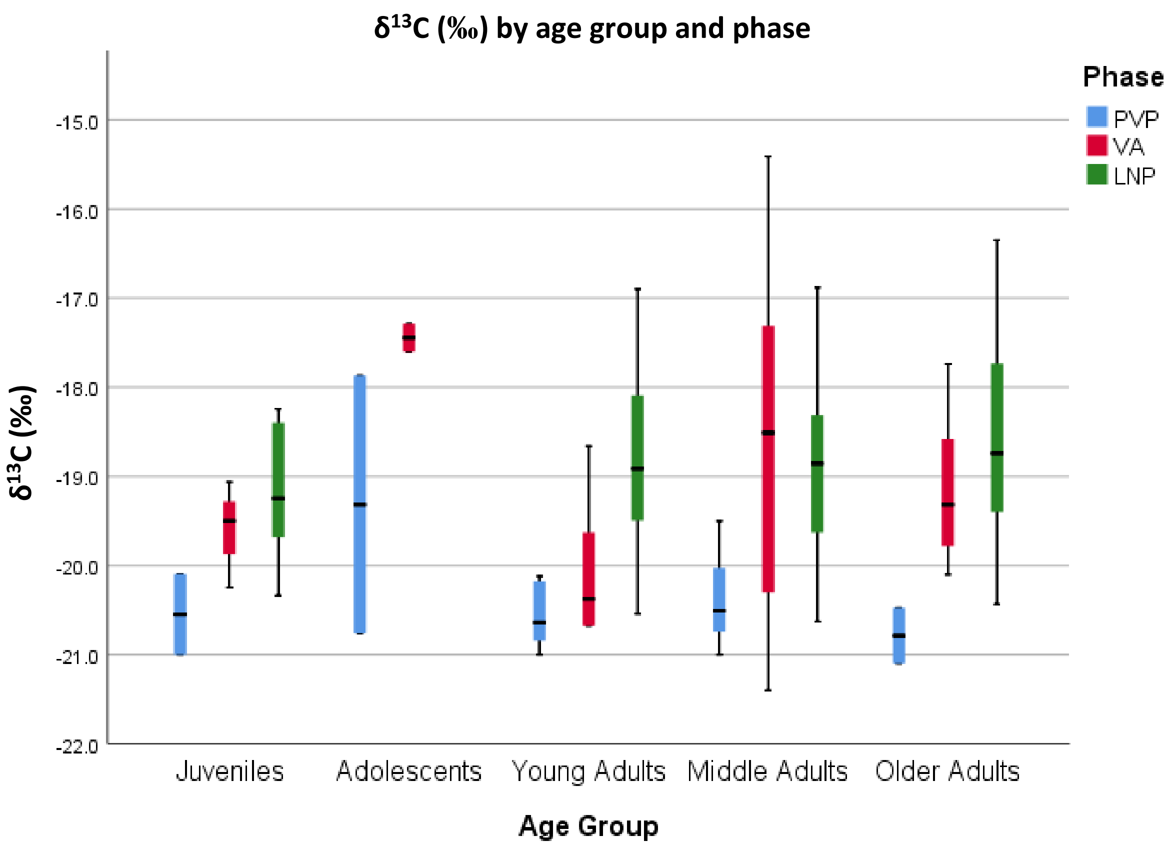

Figure 6.8. Bone collagen δ^{13}C (‰) ranges by age group and phase.

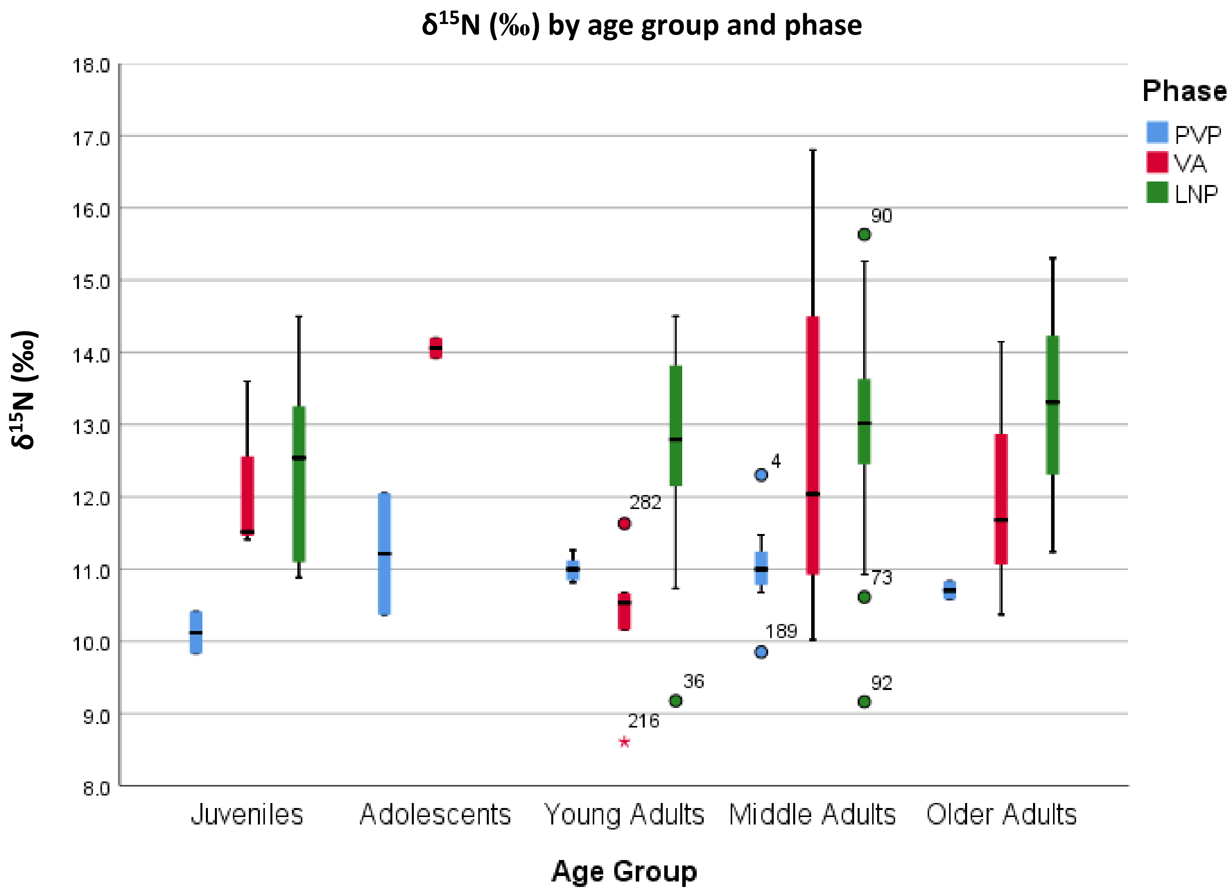

Figure 6.9. Bone collagen δ¹⁵N (‰) ranges by age group and phase.

	PVP			*VA*			*LNP*			*All Phases*		
Age category	$\delta^{13}C$ (‰)	δ15N (‰)	N	$\delta^{13}C$ (‰)	δ15N (‰)	N	$\delta^{13}C$ (‰)	δ15N (‰)	N	$\delta^{13}C$ (‰)	δ15N (‰)	N
Juveniles	-20.5	10.1	2	-19.6	12.2	3	-19.2	12.4	8	-19.4	11.6	19
Adolescents	-19.3	11.2	2	-17.4	14.1	2	NA	NA	0	-18.7	12.4	12
Young Adults	-20.6	11.0	5	-20.1	10.4	6	-18.8	12.7	16	-19.7	11.6	19
Middle Adults	-20.4	11.0	7	-18.6	12.8	21	-18.9	13.0	33	-18.9	12.7	57
Older Adults	-20.8	10.7	2	-19.1	12.0	8	-18.7	13.3	15	-19.2	12.0	24
All Ages	-20.4	10.9	18	-19.0	12.2	41	-18.9	12.9	72	-19.1	12.2	130

Table 6.5. Bone collagen $\delta^{13}C$ (‰) and $\delta^{15}N$ (‰) means by age group and by phase. The VA 'all ages' category includes the only adolescent individual.

Age groups were then divided into three "life categories," one group for subadults (infants, children and juveniles), one for individuals of prime reproductive age (adolescents and young adults) and one for individuals over prime reproductive age (middle and older adults 45+ years, per Chamberlain 2006, 17; Stiner 1991). The first life category displayed a significant increase in $\delta^{13}C$ values from the PVP through the VA and LNP (p=0.030), but not in $\delta^{15}N$ values (p=0.072). The second life category displayed significant increases in both $\delta^{13}C$ and $\delta^{15}N$ means from the PVP through the LNP ($p=0.022$ and 0.017). The third life category also displayed an increase in both $\delta^{13}C$ and $\delta^{15}N$ means ($p=0.002$ and 0.000) from a $\delta^{13}C$ mean of -20.4‰ ± 0.61‰ in the PVP to -18.5‰ ± 1.2‰ in the LNP and a $\delta^{15}N$ mean from 11.0‰ ± 0.77‰ in the PVP to 13.3‰ ± 1.3‰ in the LNP.

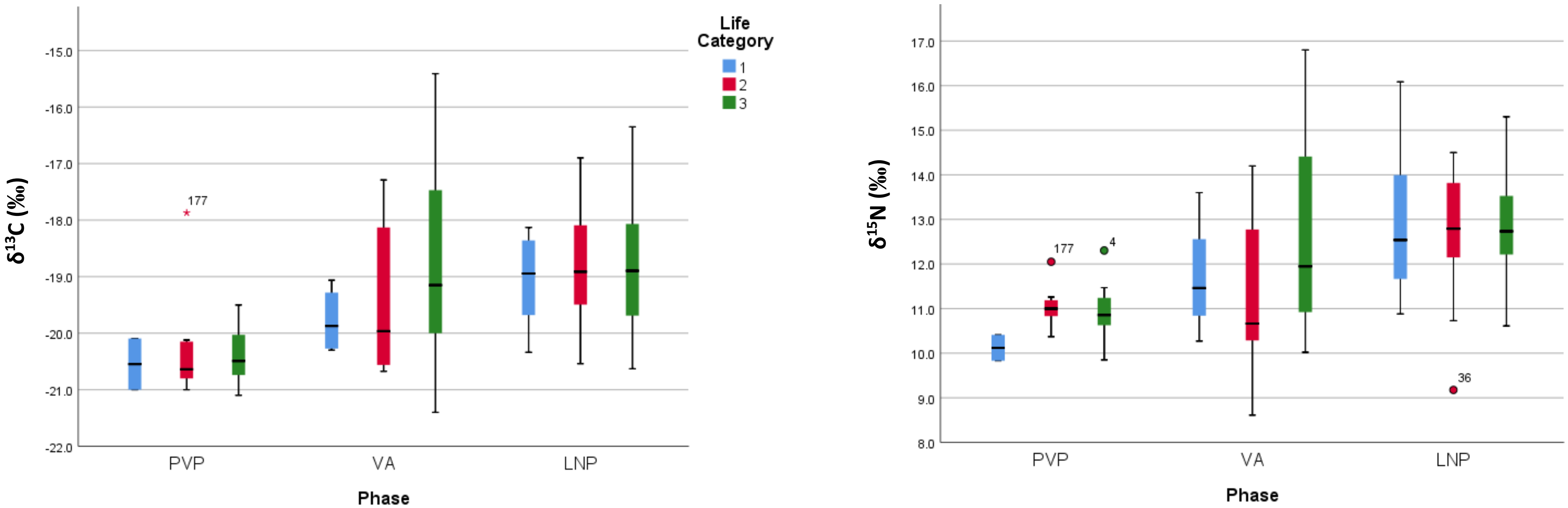

Figure 6.10. Bone collagen $\delta^{13}C$ (‰) and $\delta^{15}N$ (‰) ranges of individuals in different life categories by phase.

	PVP			*VA*			*LNP*			*All Phases*			*ANOVA*		*Levene*	
Life Cat.	$\delta^{13}C$ (‰)	δ15N (‰)	N	$\delta^{13}C$ (‰)	δ15N (‰)	N	$\delta^{13}C$ (‰)	δ15N (‰)	N	$\delta^{13}C$ (‰)	δ15N (‰)	N	$\delta^{13}C$ (‰)	δ15N (‰)	$\delta^{13}C$ (‰)	δ15N (‰)
1	-20.5	10.1	2	-19.8	11.7	4	-19.0	12.8	12	-19.4	12.3	18	**0.030**	0.072	0.496	0.354
2	-20.2	11.1	7	-19.5	11.2	7	-18.7	12.7	18	-19.2	12.0	32	**0.022**	**0.017**	0.374	**0.028**
3	-20.4	11.0	8	-19.1	12.2	23	-18.5	13.2	33	-19.0	12.6	64	**0.002**	**0.000**	0.061	**0.011**
All	-20.3	10.9	17	-19.0	12.2	38	-18.9	12.9	58	-19.1	12.4	113	0.377	0.247	0.115	1.000
ANOVA	0.842	0.189		0.628	0.464		0.409	0.435		0.457	0.320					
Levene	0.633	0.763		0.300	0.550		0.299	0.688		0.109	0.990					

Table 6.6. Bone collagen $\delta^{13}C$ (‰) and $\delta^{15}N$ (‰) means by life categories and by phases, along with the results of ANOVA (p value) and Levene tests for homogeneity of variance. Statistically significant (≤0.050) p values are in bold. Bold p values indicate a statistical significance at α= 0.05.

6.1.3. $\delta^{13}C$ and $\delta^{15}N$ and stature

When all phases were included, there was no significant correlation between either $\delta^{13}C$ or $\delta^{15}N$ and stature in males (p=0.841 and 0.679). Both $\delta^{13}C$ and $\delta^{15}N$, however, correlated negatively with stature in females (p=0.040, r=-0.323 and p=0.013, r=-0.386). When divided by phase, there was no correlation between male $\delta^{13}C$ or $\delta^{15}N$ values and stature in any phase (PVP: p=0.955 and 0.610; VA: p=0.933 and 0.385; or LNP: p=0.803 and 0.484). Nor was there a correlation between female $\delta^{13}C$ or $\delta^{15}N$ values and stature in any phase (PVP p=0.400 and 0.800; VA p=0.442 and 0.077; LNP p=0.727 and 0.957).

6.1.4. $\delta^{13}C$ and $\delta^{15}N$ and osteological indicators of health and pathology

6.1.4.1. Nutritional deficiency

To test for significant differences in $\delta^{13}C$ and $\delta^{15}N$ between individuals with or without osteological indicators of nutritional deficiency, an ANOVA test was run for each variable: individual osteological indicators of malnutrition including presence and stage of cribra orbitalia (CO), porotic hyperostosis (PH) and cribra femora (CF). A composite factor titled 'nutritional deficiency' which included all visible evidence of nutritional deficiency including the aforementioned variables was then created and compared in ANOVA with $\delta^{13}C$ and $\delta^{15}N$ (Catalogue D, Tables 1-3). Individuals with diagnosable rickets and/or scurvy were only found in statistically comparable numbers when all three phases were combined. Because evidence of nutritional deficiency was found in individuals of all age groups, all age groups were included in the analysis. Different prevalence rates of indicators of nutritional deficiency among the different age groups are provided in section 5.4.1. Each ANOVA, Levene and Spearman's rho correlation test was run three times: one including only males, one including only females and one including both sexes, to account for potential differences in prevalence rates of nutritional deficiencies between sexes.

When all phases were included, there were no significant differences in $\delta^{13}C$ or $\delta^{15}N$ values between individuals with or without any indicator of nutritional deficiency, even when males and females were run separately. When each phase was tested separately, there were still no significant differences in $\delta^{13}C$ or $\delta^{15}N$ values between individuals with or without any indicator of nutritional deficiency in the PVP or VA. Levene tests showed significantly more variability in both $\delta^{13}C$ or $\delta^{15}N$ values among individuals in the VA without cribra femora (p=0.007 and 0.016) and significantly more variability in $\delta^{13}C$ values among females without cribra femora (p=0.038). In the LNP, there was significantly more variability in $\delta^{15}N$ values among females with CO than in females without (p=0.045). No other Levene tests for homogeneity between $\delta^{13}C$ and $\delta^{15}N$ and indicators of nutritional deficiency were statistically significant. Spearman's rho tests did not show any significant correlations between $\delta^{13}C$ or $\delta^{15}N$ and any of the indicators of nutritional deficiency in any or all of the phases.

6.1.4.2. Dental pathology

$\delta^{13}C$ and $\delta^{15}N$ values were compared with types of dental pathologies to test whether differences in the consumption of marine or terrestrial protein affected dental health. Dental pathology indicators included: calculus stage, the presence or absence of dental caries, the number of dental caries, whether an individual displayed ante-mortem tooth loss (AMTL) and the number of teeth lost ante-mortem, presence or absence of periodontal disease, presence or absence and the number of periodontal abscesses and the average attrition (wear) of teeth. Due to the anti-inflammatory benefits of marine resource consumption (particularly fish high in omega-3), it was hypothesized that an increase in $\delta^{13}C$ and $\delta^{15}N$ (indicating increased marine protein) may have resulted in a decreased prevalence in periodontal disease, abscesses and AMTL (refer to Chapter 3.1.3.2). First, the prevalence of dental pathologies was compared between age groups, as most dental pathologies are considered progressive/cumulative.

As each dental pathology was found to correlate significantly with age category (Chapter 5.4.2), individuals in the young, middle and older adult age categories were tested separately for correlations between $\delta^{13}C$ and $\delta^{15}N$ values and dental pathology within each phase. ANOVA and Spearman's rho tests were run for all dental pathology variables (AMTL, number of teeth lost AM, periodontal disease, abscesses, number of abscesses and average wear). Where ordinal variables were concerned, Kruskal-Wallis tests were run in the place of ANOVA. The only significant correlation between $\delta^{13}C$ and $\delta^{15}N$ values and any dental pathology in the PVP was among young adults, where there was a negative correlation between $\delta^{13}C$ values and calculus stage (p=0.041, r=-0.894). In the VA, there was a positive correlation between calculus stage and $\delta^{15}N$ values among middle adults (p=0.029, r=0.603). An ANOVA showed there were significantly greater $\delta^{15}N$ values among individuals with periodontal disease among older adults (p=0.046), which was the opposite of the expected result. In the LNP, there were significantly higher $\delta^{13}C$ values among middle adults with periodontal disease than those without (ANOVA p=0.008, Spearman's rho p=0.022, r=0.457). Among older adults, both $\delta^{13}C$ and $\delta^{15}N$ values were significantly higher in individuals with periodontal disease (p=0.004 and 0.014).

Next, each statistical test (ANCOVA and partial correlation tests, while controlling for age) was run three times within each phase to test for different patterns in dietary stable isotope and dental pathology correlations between sexes: one including only males, one including only females and one including both sexes. All results of statistical tests involving $\delta^{13}C$ and $\delta^{15}N$ values and dental pathology are provided in Catalogue D, Tables 4-6. When all phases were combined and age was controlled for, males exhibited a significant and positive correlation between $\delta^{13}C$ and $\delta^{15}N$ values and periodontal abscesses ($\delta^{13}C$: p=0.014, r=0.214; $\delta^{15}N$: p=0.028, r=0.192). Males with periodontal disease also exhibited significantly higher $\delta^{13}C$ than males without (p=0.021). There were no significant differences or correlations between $\delta^{13}C$ and $\delta^{15}N$ values and dental pathology in females.

When all individuals from the PVP were compared and age was controlled for, those with AMTL and/or abscesses had significantly lower $\delta^{15}N$ values (p=0.041 and 0.048, respectively) than the individuals without abscesses. There was also a negative correlation between $\delta^{13}C$ and the number of carious teeth (p=0.020, r=-0.717) and among PVP females, those with caries had significantly lower $\delta^{13}C$ values than females without caries. All four of these significant results support the hypothesis that higher consumption of marine protein may have led to a decrease in various dental pathologies. In the VA, however, males exhibited a significant correlation between the presence and number of dental caries and $\delta^{13}C$ values (p=0.025, r=0.816). $\delta^{13}C$ values were significantly higher in males with dental caries than in males without. There were no significant differences or correlations between $\delta^{13}C$ and $\delta^{15}N$ values and dental pathology in VA females. In the LNP, males exhibited a significant positive correlation between $\delta^{13}C$ and $\delta^{15}N$ values and periodontal disease ($\delta^{13}C$: p=0.009, r=0.580; $\delta^{15}N$: 0.015, r=0.551) as well as the number of teeth lost ante-mortem ($\delta^{13}C$: p=0.003, r=0.636; $\delta^{15}N$: p=0.040, r=0.474). There was also a significant correlation between the prevalence of AMTL and $\delta^{13}C$ among men (p=0.036, r=0.484). Among females, there was also a correlation between periodontal disease and $\delta^{13}C$ values (p=0.000, r=0.686), with females with periodontal disease exhibiting significantly higher $\delta^{13}C$ (p=0.000) than those without. Females also exhibited a correlation between $\delta^{13}C$ values and the number of abscesses (p=0.034 and r=0.425). When all phases were considered, males with periodontal disease exhibited higher $\delta^{13}C$ values (p=0.021). Males with abscesses exhibited both higher $\delta^{13}C$ and $\delta^{15}N$ values (p=0.017 and 0.025) and the number of abscesses correlated with both $\delta^{13}C$ and $\delta^{15}N$ values ($\delta^{13}C$: p=0.003, r=0.449; $\delta^{15}N$: p=0.014, r=0.376). Interpretations of these unexpected results will be discussed in Chapter 8.

Key findings regarding $\delta^{13}C$ and $\delta^{15}N$ and dental pathology:

- When all PVP individuals were compared, there were higher $\delta^{15}N$ values among individuals without AMTL or abscesses than those with (p=0.041 and 0.048). PVP females with caries exhibited lower $\delta^{13}C$ values (p=0.040).
- In the VA, males with dental caries showed significantly higher $\delta^{13}C$ values than those without (p=0.038). The number of carious teeth also correlated with $\delta^{13}C$ values (p=0.025. p=0.816).
- In the LNP, males with periodontal disease exhibited significantly higher $\delta^{13}C$ and $\delta^{15}N$ values than males without (p=0.015 and 0.028). Among males, the number of teeth lost ante-mortem correlated significantly with both $\delta^{13}C$ and $\delta^{15}N$ values ($\delta^{13}C$: p=0.003, r=0.636; $\delta^{15}N$: p=0.040, r=0.474). Females with periodontal disease exhibited higher $\delta^{13}C$ values and also exhibited a positive correlation between the abscesses and $\delta^{13}C$ values (p=0.034, r=0.425).

6.1.4.3. Developmental stress

Bone collagen $\delta^{13}C$ and $\delta^{15}N$ values were compared against two osteological indicators of developmental stress: dental enamel hypoplasias (DEHs, particularly linear enamel hypoplasias (LEHs) and Harris lines. $\delta^{13}C$ and $\delta^{15}N$ values were compared between individuals with and without at least one LEH and the number of teeth with LEHs per individual. Because the presence and number of teeth exhibiting LEHs differed by age category, age was controlled for using ANCOVA and partial correlations. When all phases were considered, females without LEHs exhibited significantly higher $\delta^{13}C$ and $\delta^{15}N$ values than females with at least one LEH. The number of LEHs, however, did not correlate significantly with $\delta^{13}C$ and $\delta^{15}N$ values (p=0.147 and 0.255). In none of the individual phases were there any significant differences in $\delta^{13}C$ or $\delta^{15}N$ values between individuals with or without LEHs. In the VA there were significantly higher $\delta^{13}C$ values among males with LEHs than females with LEHs (p=0.027), but there were no significant differences in

$\delta^{15}N$ values ($p=0.191$). Due to time constraints, only a small sub-set (11 individuals) of the total sample was radiographed for Harris lines (results in Chapter 5). Thus, no meaningful comparison in $\delta^{13}C$ and $\delta^{15}N$ values between individuals with and without Harris lines was possible for any phase.

6.1.4.4. Evidence of load-bearing and occupational stress markers

Next $\delta^{13}C$ and $\delta^{15}N$ values were compared by the presence or absence of indicators of occupational stress or load-bearing, to test for differences in marine protein consumption between individuals with osteological evidence of certain physical activities and manual labour: platymeria and platycnemia, osteoarthritis (OA), osteochondritis dissecans (OD), occupational/accidental trauma, squatting facets and mandibular tori. OA was broken down by affected joints including vertebrae, shoulders, hands, feet, elbows, hips, jaw, or sternocostal joints. A component variable titled 'load-bearing' was created combining the variables platymeria, platycnemia, OD and OA of load-bearing joints (hips, knees, shoulders and vertebrae) as well as occupational/accidental trauma. This component variable was also tested for differences in $\delta^{13}C$ and $\delta^{15}N$ values. As only individuals as young as juveniles (at least 5 years old) exhibited indicators of occupational stress or load-bearing, only those age categories were included in these analyses. ANCOVA and partial correlation tests were run for all variables that significantly correlated with age, to control for age (specifically OA of the shoulder and hip joints). As the load-bearing and OA variables correlated significantly with sex, sex was controlled for when those two variables were tested among all individuals of a selected phase. Where ordinal variables were concerned, Kruskal-Wallis tests were run in the place of ANOVA/ANCOVA. Again, each statistical test was run three times: one including only males, one including only females and one including both sexes, to account for potential differences in prevalence rates of pathologies between sexes. All results of statistical tests involving $\delta^{13}C$ and $\delta^{15}N$ values and load-bearing pathologies are provided in Catalogue D, Tables 8-10.

When all phases were combined, there were significantly higher $\delta^{13}C$ and $\delta^{15}N$ values among both males and females with OA of hand joints than those without (males: p=0.041 and 0.031; females: p=0.004 and 0.046). There were also higher $\delta^{13}C$ values among females with OA of the jaw (p=0.028). Males with OA of the jaw also exhibited higher $\delta^{13}C$ values than males without, however, the results were not significant (p=0.293 and 0.749). When individuals from the PVP were compared, the sample size consisted of 18 individuals: eight males, eight females and two of unknown sex. When tested separately by sex there were no significant differences in either $\delta^{13}C$ or $\delta^{15}N$ values between males with or without any indicators of occupational stress or load-bearing. Among females, there were significantly lower $\delta^{15}N$ values in those with OA of the knees (p=0.021), though there was no significant difference in $\delta^{13}C$ values (p=0.107).

When all individuals from the VA were considered, males with OA of the shoulder joint had significantly higher $\delta^{15}N$ values than males without (p=0.010), although there was no significant difference in $\delta^{13}C$ values (p=0.064). Additionally, females with OA of sternocostal joints had significantly higher $\delta^{15}N$ values than females without (p=0.020). Finally, in the LNP, males with platymeria exhibited significantly higher $\delta^{13}C$ and $\delta^{15}N$ values than males without, though the sample size only included nine individuals (p=0.025 and 0.039). Additionally, males with OA of the jaw exhibited significantly higher $\delta^{13}C$ values than males without (p=0.016). LNP females with OA of the hand joints exhibited significantly higher $\delta^{13}C$ values than females without (p=0.017). The potential link between occupational/habitual activity and diet in these cases will be further discussed in Chapter 8.

Key findings regarding $\delta^{13}C$ and $\delta^{15}N$ and evidence of load-bearing:

- When all phases were considered, there were higher $\delta^{13}C$ and $\delta^{15}N$ in individuals with OA of the hands (males: p=0.041 and 0.031; females: p=0.004 and 0.046). There were also higher $\delta^{13}C$ values among females with OA of the jaw (p=0.028).

- In the PVP, females with OA of the knee joints exhibited significantly lower $\delta^{15}N$ values than females without OA of the knee (p=0.021).
- In the VA, males with OA of one or both shoulder joints exhibited higher $\delta^{15}N$ values than males without (p=0.010), while females with OA of the sternocostal joints had higher $\delta^{15}N$ values than those without (p=0.020).
- In the LNP, males with platymeria exhibited significantly higher $\delta^{13}C$ and $\delta^{15}N$ values (p=0.025 and 0.034) than those without. Males with OA of the jaw also exhibited higher $\delta^{13}C$ values. Females with OA of the hand joints, however, higher $\delta^{13}C$ values than females without (p=0.017).

6.1.4.5. Non-specific and specific infections

The following section presents the results of statistical tests comparing $\delta^{13}C$ and $\delta^{15}N$ values between individuals with and without osteological indicators of non-specific and specific infections. Indicators of non-specific infections include periostitis, osteitis and osteomyelitis. All three were combined into a variable titled 'non-specific infections.' When all phases were combined and age was controlled for using a general linear model/ANCOVA, there was no significant difference in $\delta^{13}C$ or $\delta^{15}N$ values in either males or females with and without non-specific infections (males: p=0.450 and 0.147; females: p=0.714 and 0.738). Nor were there differences in $\delta^{13}C$ or $\delta^{15}N$ values between either males or females with and without indicators of non-specific infections when individuals were separated by phases (Catalogue D, Table 11). Specific infections observed in this collection included possible cases of tuberculosis, leprosy and meningitis. There was a total of seven individuals from all phases, sexes and age groups with such infections (see Chapter 5) whose bone collagen had been sampled. When all were included and phase and sex were controlled for, there were no significant differences in $\delta^{13}C$ or $\delta^{15}N$ values between individuals with or without specific infections (males: p=0.450 and 0.147; females: p=0.683 and 0.984).

Finally, all skeletal indicators of skeletal pathology (including nutritional deficiencies, load-bearing pathologies and specific and non-specific infections; dental pathology was excluded) were combined into one composite variable titled 'pathology'. When all phases were included, there were no significant differences in $\delta^{13}C$ or $\delta^{15}N$ values in either males or females with or without osteological evidence of pathology (males: p=0.450 and 0.147; females: p=0.714 and 0.738). In both the PVP and VA, however, males without any skeletal indicators of pathology exhibited significantly higher $\delta^{13}C$ and $\delta^{15}N$ values than males with pathology (PVP: p=0.024 and 0.019; VA: p=0.030 and 0.040), even after age was controlled for. There was not a large enough sample size to statistically compare females in the PVP, however, females with pathologies in the VA and LNP did not exhibit significantly different $\delta^{13}C$ or $\delta^{15}N$ values from females without pathologies.

6.1.5. Violent trauma

Stable isotope indicators of diet were compared between individuals with and without violent trauma to determine whether those with signs of inter-personal violence may have been of a fighting class and had differential access to nutritional resources. When individuals of all phases were combined, there were no significant differences in $\delta^{13}C$ or $\delta^{15}N$ values in either males or females with or without evidence of violent trauma (males: p=0.614 and 0.967; females: p=0.759 and 0.285). When separated by phase, neither sex showed significant differences in $\delta^{13}C$ or $\delta^{15}N$ values between those with and without evidence of interpersonal conflict/ violent trauma.

6.1.6. Burial practices and settings and $\delta^{13}C$ and $\delta^{15}N$ as indicators of diet

As laid out in Chapter 2.2., the VA saw differences in burial customs involving both the setting in which individuals were buried (the beginning of known churchyard burials), the introduction of boat graves and the inclusion of grave goods including weaponry, jewellery, textile implements, combs, daggers and agricultural tools. As one may expect, there were no grave goods definitively recovered from churchyard burials (except for two potential cases from Newark Bay which, unfortunately, lack secure context), nor were any of the cist burials within churchyards. To address whether individuals buried in churchyards may have had different diets than non-churchyard burials of the same phase due to religious dietary restrictions, $\delta^{13}C$ and $\delta^{15}N$ values were compared between VA individuals buried within and outside of churchyards. A substitution of red meat for fish would likely have increased both $\delta^{13}C$ and $\delta^{15}N$ values individuals buried in churchyards, however, the difference in fish consumption between 'pagans' and 'Christians' would have had to be substantial to result in different dietary stable isotopes values (Lerwick 2014). Among VA females, there were significantly higher $\delta^{13}C$ values and greater variability of $\delta^{13}C$ among those buried within churchyards (ANOVA p=0.001, Levene p=0.020), although there were no significant differences in $\delta^{15}N$ values (ANOVA p=0.252, Levene p=0.142). Females buried without cists also exhibited significantly higher $\delta^{13}C$ values than females in cists (p=0.021), which could be related to the fact that females outside churchyards had lower $\delta^{13}C$ values in general since there were no churchyard burials in cists. VA males exhibited no significant differences in either $\delta^{13}C$ or $\delta^{15}N$ values between those buried within and outside of churchyards (p=0.136 and 0.372). While VA males and females buried within churchyards (6 males and 13 females) did not exhibit differences in variability in either $\delta^{13}C$ or $\delta^{15}N$ values (p=0.057 and 0.570), males buried outside churchyards exhibited significantly greater variability in both $\delta^{13}C$ and $\delta^{15}N$ values (p=0.006 and 0.028) than females buried outside churchyards (19 males and 14 females; Figures 6.11 and 6.12). Males in cists did not exhibit significantly different $\delta^{13}C$ or $\delta^{15}N$ values from those without cists, however, the p value was close to significant (p=0.051), with males buried in cists exhibiting slightly lower $\delta^{13}C$ values than those without. There were no significant differences in $\delta^{13}C$ or $\delta^{15}N$ values between VA males or females buried in boat burials and those without (males: p=0.788 and 0.665; females: p=0.394 and 0.361).

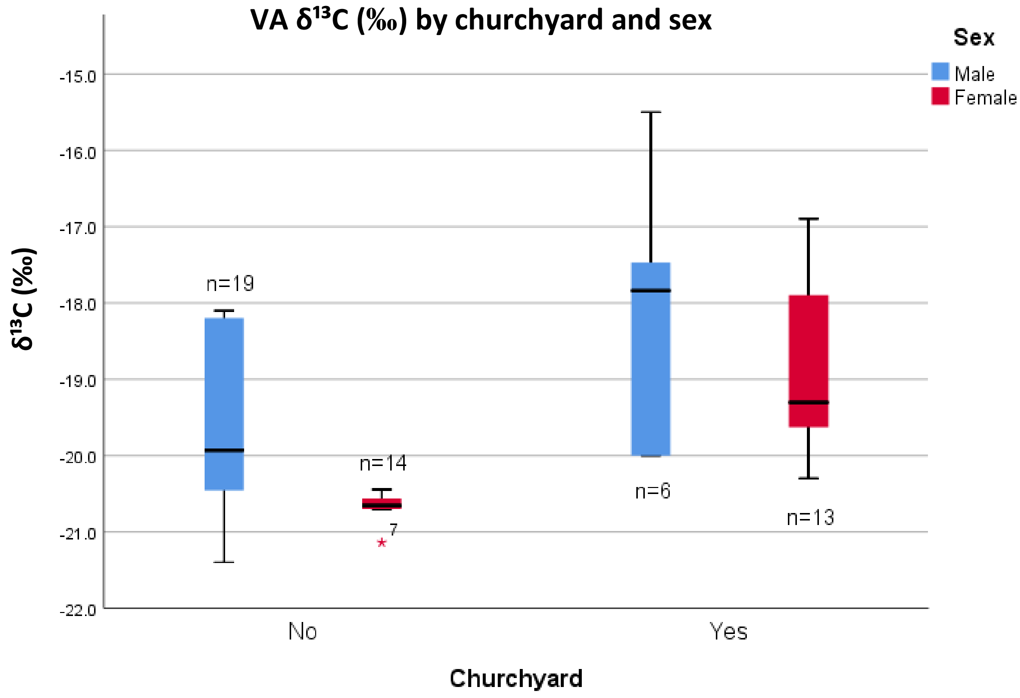

Figure 6.11. Bone collagen $\delta^{13}C$ (‰) ranges compared between VA males and females buried within a churchyard and those buried outside a churchyard.

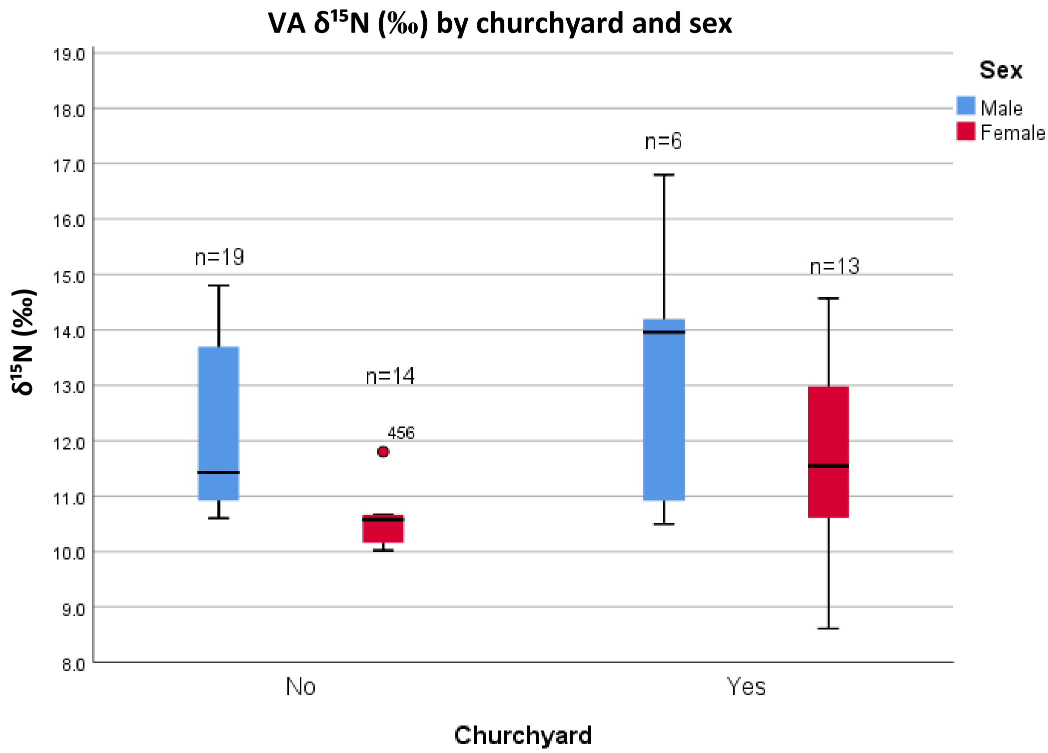

Figure 6.12. Bone collagen $\delta^{15}N$ (‰) ranges compared between VA males and females buried within a churchyard and those buried outside a churchyard.

Some types of grave goods including beads, agricultural tools and gaming pieces were found in both male and female burials. According to the relevant excavation records, however, weapons appeared exclusively in male burials and textile implements appeared exclusively in female burials. The burial of individuals with grave goods like weapons (for males) and jewellery (females) has long been seen by archaeologists as indicative of high social status or different ethnicity, as further discussed in Chapter 2. To test the validity of this hypothesis, $\delta^{13}C$ and $\delta^{15}N$ values were compared between individuals with and without grave goods. When all VA individuals were considered and age was controlled for (in case age or life stage played a role in social expectations of diet), there was no significant difference in $\delta^{13}C$ or $\delta^{15}N$ values between either males or females with and without grave goods (males: p=0.543 and 0.676; females: p=0.095 and 0.748). Grave goods were then divided by type, including weapons, jewellery, textile implements, combs, daggers, beads, gaming pieces or agricultural tools (namely sickles and/or scythes). Because of their presence in male graves (as opposed to jewellery), beads were tested separately.

When VA males and females were tested separately, there were no significant correlations or differences in $\delta^{13}C$ or $\delta^{15}N$ values depending on the presence or absence of grave goods. Where certain types of grave goods were found in both male and female graves (daggers, beads, combs, gaming pieces and agricultural tools), statistical comparison of $\delta^{13}C$ and $\delta^{15}N$ values between males and females with these grave goods were performed. There were significantly lower $\delta^{13}C$ values in females with agricultural tools than in males with agricultural tools (p=0.030); however, there were no other significant differences, correlations or variability in $\delta^{13}C$ or $\delta^{15}N$ values between individuals with the same type grave good but of the opposite sex. As some grave goods such as textile implements, jewellery or weapons were found in the graves of individuals of either sex, comparison of $\delta^{13}C$ and $\delta^{15}N$ between the two sexes with such grave goods was not possible.

6.1.7. Site, site type and subsistence practices and $\delta^{13}C$ and $\delta^{15}N$ as indicators of diet

To compare $\delta^{13}C$ and $\delta^{15}N$ values between sites with different geographical locations, functions and patterns of subsistence throughout Orkney, four different lines of evidence were employed, as detailed in Chapter 4. Firstly, zooarchaeological and archaeobotanical reports of animal and crop percentages from the burial sites were consulted. Where burial sites were not located on settlement/farmstead sites, or where excavation reports of biological remains were not available, the closest farmstead or settlement sites (of the same phase) with biological remains reports were used as a proxy for inferring nearby subsistence practices (Chapter 4.3.2 and Table 6.10., below). The following variables were created based on land quality as well as the excavated biological remains of crops and livestock: predominant cereal (barley/oat/flax), predominant livestock (cattle/sheep/pig) and predominant marine resource type (offshore/freshwater/nearshore/none). The percentage of each mammalian species present at each farmstead site was also recorded in separate variables. Based on faunal aging methods (further explained in Chapter 2), primary animal usage (whether for meat, dairy or wool/traction/other) was recorded by site (see references below). As previously mentioned, in the cases where a farmstead site is different from the burial site, the proxy farmstead site might not have been associated with the burial site (which may have had its own yet-unexcavated farmstead with different subsistence practices). The sites provided as proxies are the closest well-documented excavated farmsteads. Unfortunately, there were no comparable farmstead sites or biological assemblage reports for Skara Brae, Westness or Bu of Cairston. Finally, to estimate land quality, each burial and farmstead site and was mapped onto an ArcMap shapefile containing land classification codes (LC codes) detailing capability for agriculture and mixed farming, based on The James Hutton Institute (2020). All burial and nearby farmstead sites were then also plotted onto Ian Simpson and colleagues' (Davidson et al. 1984; Simpson 1993; Simpson et al. 1998; 2005) surveys of anthropogenic soil formation throughout the Orkney Mainland, Stronsay and Sanday.

Males and females were tested separately (where possible due to small sample sizes) and when all sexes were compared together, infants and children (0 to 5 years old) were excluded from analyses to avoid variation caused during weaning.

First, $\delta^{13}C$ and $\delta^{15}N$ values from each site within each phase were compared and age was controlled for using a general linear model. This was done to test the uniformity of $\delta^{13}C$ and $\delta^{15}N$ values across all sites of each phase throughout Orkney for inter-site variation, potentially suggestive of site specialisation. In the PVP, there was no significant difference in $\delta^{13}C$ or $\delta^{15}N$ values between sites among either males (p=0.455 and 0.975) or females (p=0.089 and 0.307). Males from Brough Road, however, exhibited greater variability in both $\delta^{13}C$ and $\delta^{15}N$ values than males from Westness (p=0.020 and 0.001; Table 6.7). VA females exhibited a significant difference in $\delta^{13}C$ values between sites, with those from Newark Bay having higher $\delta^{13}C$ values than Brough Road, Scar, or Westness (p=0.022), but there was no difference in $\delta^{15}N$ values (p=0.647). VA males exhibited no differences in either $\delta^{13}C$ or $\delta^{15}N$ values (p=0.661 and 0.741) between sites. In the LNP, males from Newark Bay exhibited significantly higher $\delta^{13}C$ and $\delta^{15}N$ values than males from the other LNP sites (p=0.000 and 0.017). While females from Newark Bay exhibited the higher $\delta^{13}C$ values than females from other LNP sites (p=0.001), females from Skaill House exhibited the highest $\delta^{15}N$ values (p=0.032). When all sites were compared and phase and age group were controlled for using a general linear model, both males and females from Newark Bay exhibited $\delta^{13}C$ values significantly higher than the other sites (p=0.005 and 0.000).

PVP

Site	**Males**					**Females**					**All**				
	$\delta^{13}C$ (‰)	±	$\delta^{15}N$ (‰)	±	No	$\delta^{13}C$ (‰)	±	$\delta^{15}N$ (‰)	±	No	$\delta^{13}C$ (‰)	±	$\delta^{15}N$ (‰)	±	No
Brough Road	-20	0.5	11.5	1.1	2					0	-20	0.5	10.9	1.3	2
Buckquoy	-20.1		10.8		1					0	-20.1		10.8		1
Newark Bay					0	-18.7	0.8	11	1.1	2	-18.7	0.8	11	1.1	2
Skaill Cist	-20.6		11.1		1					0	-20.6		11.1		1
Skara Brae					0	-20.2		10.8		1	-20.2		10.8		1
Westness	-20.7	0.2	11	0.6	4	-20.8	0.3	10.9	0.4	5	-20.8	0.2	10.9	0.4	10
ANCOVA (p)	0.445		0.975			0.089		0.307			**0.005**		0.999		
Levene (p)	**0.020**		**0.001**			0.197		0.093			**0.001**		**0.001**		

Table 6.7. PVP $\delta^{13}C$ (‰) and $\delta^{15}N$ (‰) means by site and sex. 'All' includes individuals of unknown sex. Bold p values indicate a statistical significance at α= 0.05.

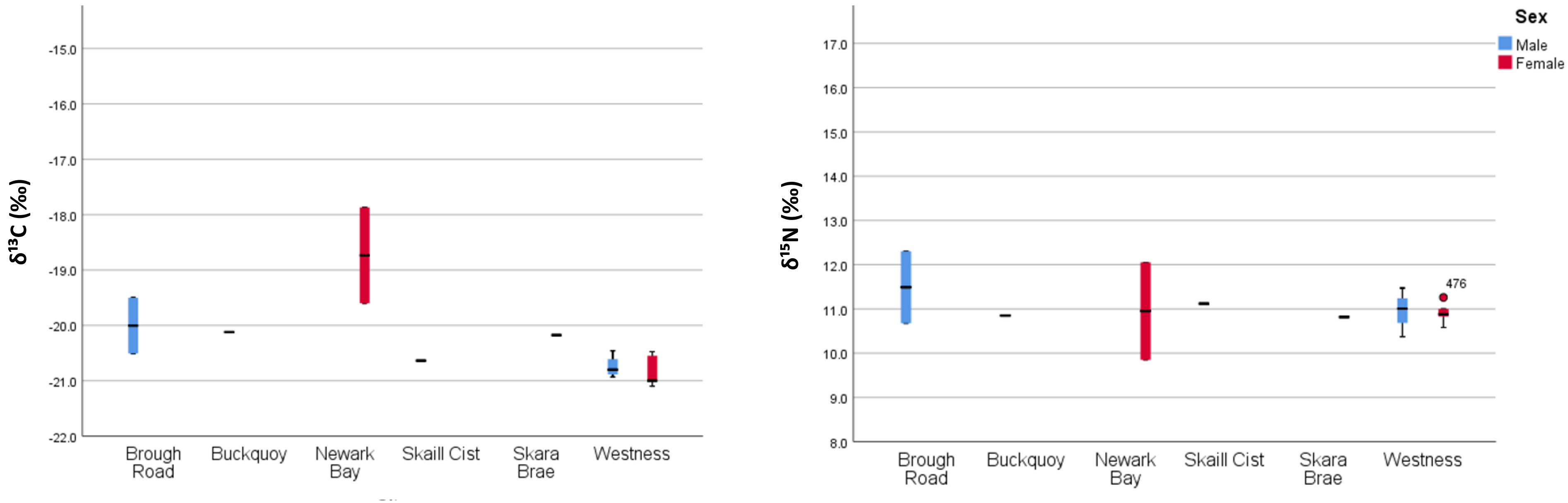

Figure 6.13. PVP $\delta^{13}C$ (‰; left) and δ15N (‰; right) ranges by site and sex.

VA															
Site	**Males**					**Females**					**All**				
	δ13C (‰)	±	δ15N (‰)	±	No	δ13C (‰)	±	δ15N (‰)	±	No	δ13C (‰)	±	δ15N (‰)	±	No
Brough Road	-19.6		11.9		1	-20.9	0.3	10.7	0.1	2	-20.5	0.7	10.9	0.6	4
Buckquoy	-20.5		10.9		1					0	-20.5		10.9		1
Newark Bay	-18.1	1.7	13.4	2.3	6	-18.8	1.1	11.8	1.8	12	-18.4	1.2	12.6	1.7	19
Scar	-20.3		10.6		1	-20.6		10		1	-20.4	0.2	10.7	0.8	3
Skara Brae					0					0	-20.1		11.2		1
Westness	-19.2	1.9	13.2	2	3	0.1		0.9		3	-19.9	1.4	12.2	1.7	6
ANCOVA (p)	0.661		0.741			0.220		0.647			**0.036**		0.534		
Levene (p)	0.300		0.430			0.089		0.234			**0.027**		0.056		

Table 6.8. VA δ^{13}C (‰) and δ^{15}N (‰) means by site and sex. 'All' includes individuals of unknown sex. Bold p values indicate a statistical significance at α= 0.05.

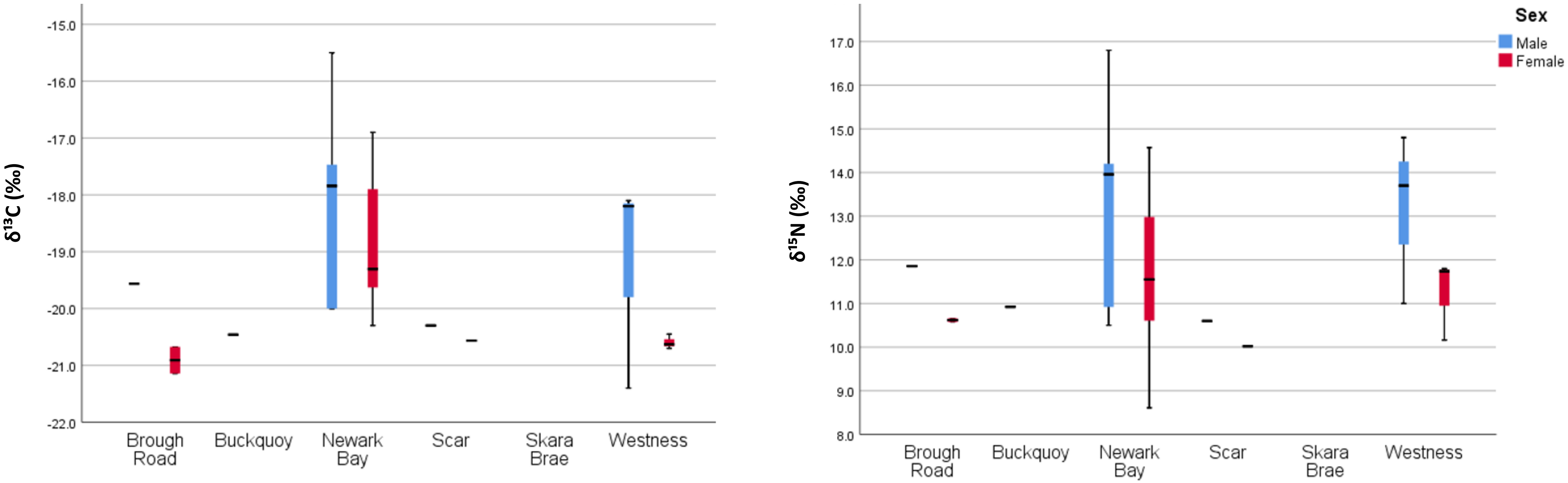

Figure 6.14. VA δ^{13}C (‰; left) and δ^{15}N (‰; right) ranges by site and sex.

LNP

Site	**Males**					**Females**					**All**				
	$\delta^{13}C$ (‰)	±	$\delta^{15}N$ (‰)	±	No	$\delta^{13}C$ (‰)	±	$\delta^{15}N$ (‰)	±	No	$\delta^{13}C$ (‰)	±	$\delta^{15}N$ (‰)	±	No
Bu of Cairston	-18.7	0.9	13.1	1.1	21	-19	0.9	12.9	1.3	29	-18.9	0.9	12.9	1.3	64
Brough of Deerness	-20.4		10.7		1					0	-20.4		10.7		1
Newark Bay	-17.2	0.9	14	1.1	8	-16.9	0.6	14.5	1	3	-17.4	1.1	13.9	1.4	12
Skaill House					0	-17.5	0.4	15.5	0.3	2	-17.5	0.4	15.5	0.3	2
ANCOVA (p)	**0.000**		**0.017**			**0.001**		**0.032**			**0.000**		**0.009**		
Levene (p)	0.434		0.548			0.432		0.364			0.336		0.440		

Table 6.9. LNP $\delta^{13}C$ (‰) and $\delta^{15}N$ (‰) means by site and sex. 'All' includes individuals of unknown sex. Bold p values indicate a statistical significance at α= 0.05.

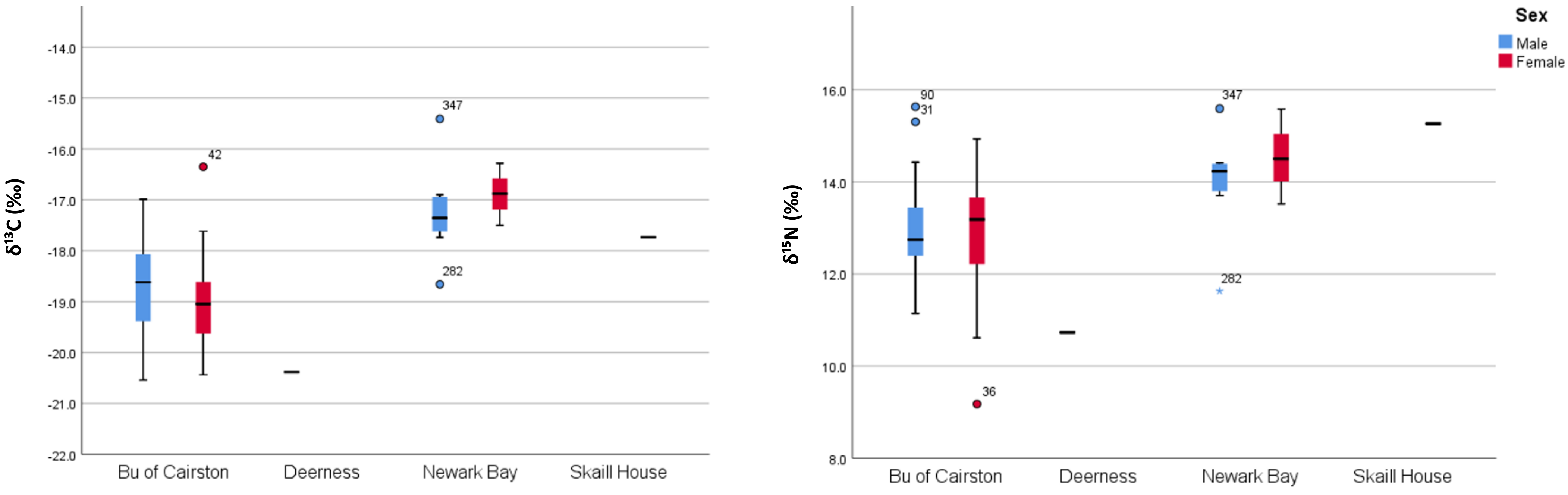

Figure 6.15. LNP $\delta^{13}C$ (‰; left) and $\delta^{15}N$ (‰; right) ranges by site and sex.

Site name classifications were then consulted (Marwick, 1923; Bailey 1971:76; Thomson 1987), a method previously used in interpreting site function as well as status differences (see site descriptions in Chapter 2). While places with the name *skaill* or *-by* may indicate high-status sites, place-names ending in *-quoy* indicated the function of the site as a farmstead. Likewise, place-names with endings like *-wall* or *-ness* would have been named for geographical features/ landmarks. Unfortunately, the origin of the place-name Scar was not able to be traced or categorized (Chapter 4). Although the introduction of Scandinavian place-names likely did not begin until at least the VA, sites with Scandinavian names of all phases were included in isotope comparison by place-name. When all phases were combined and sex and phase were controlled for, an ANCOVA test showed females from sites with *skaill* names had significantly higher $\delta^{13}C$ and $\delta^{15}N$ values than the females from sites with *-by* or land feature names (p=0.000 and 0.042). Individuals from the *-by* site had greater variability in both $\delta^{13}C$ and $\delta^{15}N$ values (p=0.022 and 0.029), though sample size may have contributed to that.

As when testing between sites, Newark Bay had significantly higher $\delta^{13}C$ values than other sites in the PVP and VA phases (p=0.021 and 0.013). In the PVP and VA, there were no significant differences in $\delta^{15}N$ values between individuals from sites with different site name types (p=0.994 and 0.531). In the LNP, however, females from the *skaill* site (Skaill House) had significantly higher $\delta^{15}N$ values (p=0.036) than females from the other LNP sites. These two females will be discussed further in Chapter 8, where their sequential dentine results will also be incorporated into the discussion.

All sites in PVP, VA and LNP Orkney had a combination of cattle, sheep/goat and pig, with the ratios at each site differing slightly (see Chapter 4). Differences in the proportion of sheep or cattle at each site may have resulted in differences in human $\delta^{13}C$ and $\delta^{15}N$ values. According to Mainland (2016), sheep were sometimes given seaweed as fodder (potentially enriching their $\delta^{13}C$ and $\delta^{15}N$ values), while cattle were not. Therefore, individuals from sites predominantly focused on rearing pigs (omnivorous) or sheep/goat may have had higher $\delta^{13}C$ and $\delta^{15}N$ values than individuals from cattle-rearing sites. When all phases were included and sex and phase were controlled for, there was no significant difference in $\delta^{13}C$ and $\delta^{15}N$ means between individuals from sites with predominantly cattle versus predominantly sheep/goat or pig (p=0.066 and 0.169). The PVP and LNP sites included in this study all had a predominance of cattle, so a comparison of $\delta^{13}C$ and $\delta^{15}N$ values between individuals from sites with different predominant species was not possible. In the VA, there was no significant difference in either $\delta^{13}C$ and $\delta^{15}N$ values from individuals from sites with predominantly cattle versus predominantly sheep/goat (p=0.123 and 0.207), however, there was greater variability in $\delta^{13}C$ in individuals from sites with predominantly cattle (p=0.047). In the PVP and LNP, there were no significant correlations between human $\delta^{13}C$ and $\delta^{15}N$ values and the proportions of cattle, sheep/goat or pig at each site. When VA individuals were compared, however, there was a positive correlation between the percentage of sheep/goat and human $\delta^{13}C$ values (p=0.005, r=0.552) and a negative correlation between the percentage of pig and human $\delta^{13}C$ values (p=0.014, r=-0.495).

Predominant animal use at each farmstead site was determined based on faunal analysis of domesticated mammalian mortality profiles at each site (see Chapter 4.3.2). Because the $\delta^{13}C$ and $\delta^{15}N$ stable isotope values of meat and dairy are indistinguishable on their own, faunal analysis is essential for the interpretation of a site's animal use. (Brown and Brown 2011, 191). Therefore, no significant differences in $\delta^{13}C$ or $\delta^{15}N$ values between individuals based solely on different predominant animal use were expected. Overall, once sex and phase were controlled for, there were no significant differences in $\delta^{13}C$ or $\delta^{15}N$ values between either males or females from sites with faunal evidence for different predominant animal use (males: p=0.265 and 0.317; females: p=0.899 and 0.488). When each phase was considered separately, there was no significant difference in either $\delta^{13}C$ or $\delta^{15}N$ values between individuals from sites with different animal product focus in the PVP (p=0.423 and 0.999), VA (p=0.170 and 0.521) or in the LNP (p=0.744 and 0.425).

Based on the archaeoichthyological evidence from each farmstead site, marine resource types were categorized as either offshore, nearshore, freshwater or none. Around the time of the 'fish event horizon (ca. AD 1000), one might expect VA and LNP sites with evidence of fishing (especially large-scale offshore or nearshore fishing) to exhibit higher $\delta^{13}C$ and $\delta^{15}N$ values than individuals from sites with little or no evidence of marine resource exploitation. When PVP individuals from sites with different predominant marine resource types (based on faunal remains) were compared, there was no difference in $\delta^{15}N$ values (p=0.853), though there were higher in $\delta^{13}C$ values (p=0.001) in individuals from the site with no fish (Newark Bay). A Levene test also showed significantly greater variability in both $\delta^{13}C$ and $\delta^{15}N$ values (p=0.045 and 0.005) from individuals from the site with no fish (Newark Bay). When tested between sites (above) Newark Bay individuals exhibited significantly higher $\delta^{13}C$ values and greater variability in both $\delta^{13}C$ and $\delta^{15}N$ than individuals from the other PVP sites. This was the largest site, however, and so is likely to exhibit the greatest variability regardless. There was no significant difference in either $\delta^{13}C$ and $\delta^{15}N$ values between individuals from sites with evidence for different marine resource exploitation in the VA (p=0.413 and 0.575). Unfortunately, there was not enough data to statistically compare $\delta^{13}C$ and $\delta^{15}N$ values between individuals from LNP sites with different predominant marine resource types.

Individual $\delta^{13}C$ and $\delta^{15}N$ values were then compared by LC code. As suggested by Barbara Crawford (1987), land in certain parts of Orkney and Scotland may have been more coveted during migration based on land quality and arability. People living on better quality soils may have invested more fertilizer and labour into their land for agricultural viability, whereas people living on poorer soils may have resorted to means other than agriculture for sustenance. Indeed, there was a positive correlation between LC code and plaggen soils when VA and LNP sites were included (p=0.000, r=0.381). If females were involved in agriculture and thus had a diet higher in agricultural goods (while males were more focused on fishing and had higher marine protein diets, as proposed by Barrett 2004), females from sites with better land quality, increased manuring and plaggen soils may have had higher $\delta^{15}N$ values than females not living in such agriculturally-focused sites. When individuals from all phases were compared by LC code (phase and age were controlled for using a general linear model), there was a significant negative correlation among females between LC code and $\delta^{13}C$ values (p=0.009, r=-0.611). When tested by phase, VA females exhibited a similar correlation between LC code and $\delta^{13}C$ values (p=0.030, r=-0.600). There were no significant differences in either $\delta^{13}C$ or $\delta^{15}N$ values between individuals from different LC codes in the PVP (p=0.844 and 0.960) or in the LNP (p=0.219 and 0.076). When all phases were included, individuals from or near farmstead sites with deep/plaggen soil deposits had significantly higher $\delta^{13}C$ values (p=0.000) than individuals from sites not associated with deep soils (again phase and sex were controlled for). There were not significantly different $\delta^{15}N$ values (p=0.087), however. While all VA sites had evidence of deep soil formation, there were significantly higher $\delta^{13}C$ (and nearly significant $\delta^{15}N$ values) in individuals from areas with deep soils in the LNP (p=0.000 and 0.058). When tested by sex, both LNP males and females from plaggen sites exhibited significantly higher $\delta^{13}C$ values than males and females not from plaggen sites (p=0.006 and 0.001), while females from plaggen sites nearly showed higher $\delta^{15}N$ values as well (p=0.052). LNP males and females from plaggen sites did not exhibit significant differences in $\delta^{13}C$ or $\delta^{15}N$ values (p=0.803 and 0.317), nor did males and females from non-plaggen LNP sites (p=0.308 and 0.631). Statistical test results comparing $\delta^{13}C$ and $\delta^{15}N$ values and indicators of subsistence practice and soil quality are provided in Catalogue D, Tables 14-16.

Site	Settlement/ Farmstead	Phase	Cattle (%)	NISP	Sh/g (%)	NISP	Pig (%)	NISP	Animal use	Predominant fish type	Sieved	Distance from coast	Predominant cereal	References
Scar	Pool	VA	35.3	3510	51.2	4886	11.3	971	Dairying	Offshore	Yes	On coast	Oat	Bond 1998, 85; 2007, 210 Nicholson 1997a; Towers et al. 2017
Newark Bay, Deerness	Skaill, Deerness	PVP	43	5608	39	5175	10	1343	Dairying	None	No	On coast	Barley	Buteux et al. 1997; Nicholson 1997b; Noddle 1997, 237
Newark Bay, Deerness	Skaill, Deerness	VA	46	2751	37	2263	11	696	Dairying	Offshore	No	On coast	Barley	Buteux et al. 1997; Nicholson 1997b; Noddle 1997, 237
Newark Bay, Deerness	Skaill, Deerness	LNP	51	136	32	81	16	43	Dairying	Offshore	No	On coast	Barley	Buteux et al. 1997; Nicholson 1997b; Noddle 1997, 237
Buckquoy	Buckquoy	PVP	52	1149	28	552	16	486	Dairy	Nearshore	No	On coast	Barley	Noddle 1976, 202
Buckquoy	Buckquoy	VA	51	1396	29	868	13	466	Dairy	Nearshore	No	On coast	Barley	Noddle 1976, 202
Brough Road	Birsay Bay	PVP	40.3	147	30.5	100	29.2	114	Meat	Offshore	Yes	On coast	Barley	Morris et al. 1989; Rackham 1989, 243
Brough Road	Birsay Bay	VA	40.4	15	27	44	32.6	45	Meat	Offshore	Yes	On coast	Barley	Morris et al. 1989; Rackham 1989, 244
Skaill House and Cist	Snusgar	VA	48.4	13	37.7	16	13.9	13	Meat	Offshore	Yes	500m	Oat	Griffiths et al. 2019; Mainland et al. 2019, 184; Nicholson 2019
Skaill House and Cist	Snusgar	LNP	45.2	22	40.5	24	14.3	13	Meat	Offshore	Yes	500m	Oat	Griffiths et al. 2019; Mainland et al. 2019, 185; Nicholson 2019
Pierowall	Quoygrew	VA	28.5	1181	23.7	981	3.2	131	Meat	Offshore	Yes	On coast	Barley	Barrett and Harland 2012; Harland 2012, 142

Table 6.10. Burial sites with associated settlement/farmstead sites and biological remains profiles with references.

Westness and Newark Bay are the two largest multi-phase PVP, VA and LNP cemeteries excavated so far in Orkney. Westness and Newark Bay are both within a short distance of a Skaill (*skali*) site and both have easy access to the shore for fishing. Newark Bay is located on the eastern side of the Orkney Mainland, while Westness is located on the southwestern coast of Rousay. Although there are no faunal reports for Westness or its neighboring farmstead Skaill, Rousay, the two sites were compared for evidence of different subsistence practices based on human isotope analysis. Once sex and phase were controlled for using a general linear model, there were significantly lower $\delta^{13}C$ values from individuals buried at Westness than individuals buried from Newark Bay (p=0.001).

When individuals (juvenile and older) from these two sites were compared by phase, Newark Bay individuals from the PVP and LNP showed significantly higher $\delta^{13}C$ values than contemporary individuals from Westness (p=0.000 and 0.014). There were no significant differences in $\delta^{13}C$ or $\delta^{15}N$ values in the VA (p=0.122 and 0.964). With phase was controlled for, females from Newark Bay had significantly higher $\delta^{13}C$ values than females from Westness (p=0.001) and significantly greater variability in $\delta^{13}C$ values (p=0.001) but not significantly different or more variable $\delta^{15}N$ values (p=0.522 and 0.059, respectively). Males showed no significant difference in either $\delta^{13}C$ or $\delta^{15}N$ values (p=0.162 and 0.642), nor was there a difference in variability (p=0.734 and 0.662).

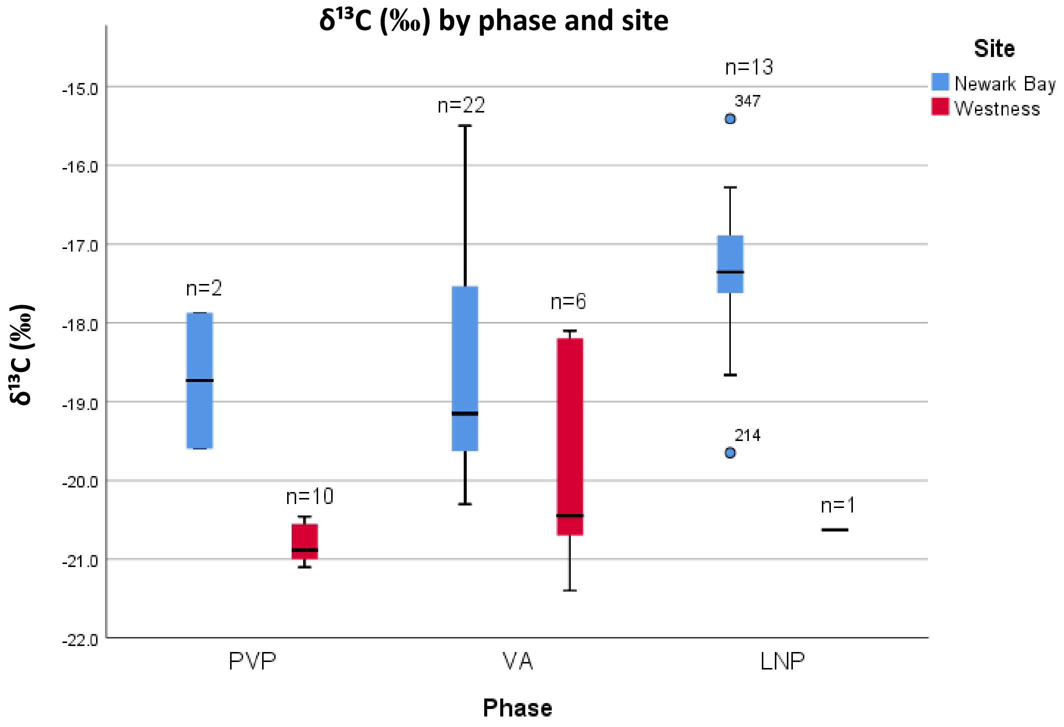

Figure 6.16. δ^{13}C (‰) ranges from individuals from Newark Bay and Westness cemeteries by phase.

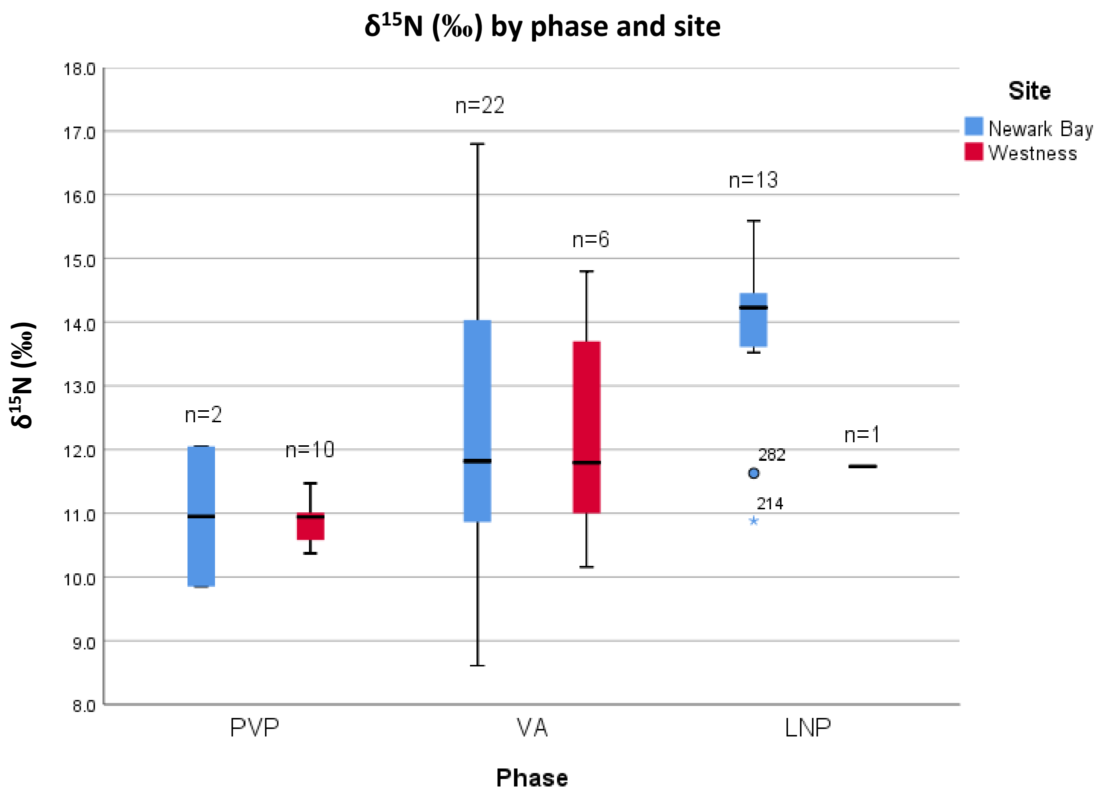

Figure 6.17. δ^{15}N (‰) ranges from individuals from Newark Bay and Westness cemeteries by phase.

When Newark Bay individuals were analysed, there were significant differences in $\delta^{13}C$ or $\delta^{15}N$ values between the three phases (p=0.018 and 0.030), with higher $\delta^{13}C$ and $\delta^{15}N$ values in the LNP than the VA and PVP. Both $\delta^{13}C$ and $\delta^{15}N$ values also correlated positively with phase ($\delta^{13}C$: p=0.040, r=0.360 and $\delta^{15}N$: p=0.031, r=0.376). A Levene test showed no significant difference in variability of $\delta^{13}C$ or $\delta^{15}N$ values between phases (p=0.353 and 0.135), despite the differences apparent in Figures 6.16. and 6.17., above. When sexes were tested separately, no significant difference in either $\delta^{13}C$ or $\delta^{15}N$ values were observed in males between phases (p=0.241 and 0.521), but significantly higher $\delta^{13}C$ and $\delta^{15}N$ values were found in females in the LNP than the VA (p=0.043 and 0.049). Unfortunately, there were not enough PVP individuals for a comparison between the sexes. There was no significant difference in $\delta^{13}C$ or $\delta^{15}N$ values, however, between males and females in the VA (p=0.290 and 0.125) or the LNP (p=0.560 and 0.498). When all three phases were combined, females from Newark Bay had significantly lower $\delta^{15}N$ values than males (p=0.035), though there was no difference in $\delta^{13}C$ values between sexes (p=0.108). A Levene test showed significant differences in the variability of $\delta^{13}C$ or $\delta^{15}N$ values (p=0.386 and 0.849).

When only Westness individuals were considered, a Levene test showed significantly more variability in both $\delta^{13}C$ and $\delta^{15}N$ values in the VA than the PVP (p=0.000 and 0.000). Neither $\delta^{13}C$ nor $\delta^{15}N$ values, however, differed significantly between phases once sex was controlled for (p=0.205 and 0.145). When all phases were considered, there was no significant difference in $\delta^{13}C$ or $\delta^{15}N$ values between males and females (p=0.166 and 0.141). Nor were there differences in $\delta^{13}C$ or $\delta^{15}N$ values in the PVP (p=0.666 and 0.830) or the VA (p=0.409 and 0.206). There were not enough LNP individuals to compare between sexes. Neither sex when tested separately exhibited significant change in $\delta^{13}C$ or $\delta^{15}N$ values between phases either (males: p=0.159 and 0.075; females: p=0.539 and 0.459). Differences in stable isotope indicators of diet between the two sites will be further discussed in Chapter 8.

6.2. Sequential dentine $\delta^{13}C$ and $\delta^{15}N$ results

Dietary profiles of 28 individuals were reconstructed through $\delta^{13}C$ and $\delta^{15}N$ isotopes from sequential dentine micro-samples. As discussed in Chapter 3, this method can provide evidence of short-term shifts in diet not discernable from bone collagen. The goals of this analysis were four-fold. Firstly, although not the primary focus of this study, patterns in first molar sequential dentine are often used for interpreting weaning processes. Although limited in sample size, this study presents the results of sequential dentine samples taken from seven first molars dating to the PVP (n=3), VA (n=3) and LNP (n=1). Secondly, as previous studies have found a significant difference in the $\delta^{13}C$ and $\delta^{15}N$ values of males and females in the VA and LNP (discussed further below), this study sought to determine at what age individuals of different sexes began eating different proportions of marine or terrestrial resources. Although the bone collagen data included in this study did not find any significant differences in male and female diet (section 6.1.2), this study aimed to determine if diets between males and females varied at a particular point in development. Thirdly, this study sought to reconstruct individuals' diets from childhood through young adulthood to determine whether there is evidence of preferential resource distribution and consumption for individuals of specific demographic groups (i.e., did males of fighting age consume greater amounts of terrestrial or marine protein than women of child-birthing age) (Burt 2015; Katzenberg and Waters-Reist 2019, 469; Sealy et al. 1995). Finally, short-term periods of physiological stress may have resulted in fluctuations in diets that correspond with the timing of DEHs in teeth or the presence of osteological indicators of nutritional deficiency.

A total of 31 teeth from 28 individuals were sequentially sampled for dentine $\delta^{13}C$ and $\delta^{15}N$ values, as detailed in Chapter 3. Approximately 10-15 horizontal slices were taken from each tooth. Within the constraints of the thesis, an average of 5 sections per tooth were run for $\delta^{13}C$ and $\delta^{15}N$ isotopes. Full tables of results are provided by individual in Catalogue B-3. Figures 6.18. and 6.19. illustrate $\delta^{13}C$ and $\delta^{15}N$ profiles through tooth development, by phase. This includes first molars

(M1s), second molars (M2s) and third molars (M3s). All trendlines are set to reflect a moving two-point average, as each point (sample) represents the $\delta^{13}C$ and $\delta^{15}N$ values of an estimated developmental age range. Per methods developed by Teresa Fernandez- Crespo et al. (2020), dentine sections from each individual were averaged within the age ranges presented in Table 6.12. Tables 6.12 and 6.13 present the mean dentine $\delta^{13}C$ and $\delta^{15}N$ values for each age group by sex and phase, as well as the results of ANOVA and Levene tests of variances for a direct comparison of the $\delta^{13}C$ and $\delta^{15}N$ means of each age group by phase.

Individual	*Phase*	*Sex*	*Tooth*	*Min $\delta^{13}C$ (‰)*	*Max $\delta^{13}C$ (‰)*	*Diff. (‰)*	*Min $\delta^{15}N$ (‰)*	*Max $\delta^{15}N$ (‰)*	*Range (‰)*	*No. Sections*
BU059	**LNP**	**U**	M1	-20.7	-20.4	0.3	11.8	13.3	1.5	5
BU059	**LNP**	**U**	M3	-20.6	-19.4	1.1	12.2	13.8	1.5	5
BU081	**LNP**	**M**	M3	-20.1	-18.4	1.7	10.5	12	1.5	5
BU189	**LNP**	**F**	M3	-19.3	-18.2	1.1	11.9	14.3	2.5	5
BU214	**LNP**	**F**	M3	-19.7	-18.6	1.1	9.3	13.6	4.3	5
BU370	**LNP**	**M**	M3	-19.5	-18.6	0.8	13.5	14.4	0.9	5
Buck M12	**PVP**	**M**	M1	-21.1	-20.1	1	9.6	11.3	1.7	17
BY78CU	**VA**	**F**	M3	-20.9	-19.8	1.1	9.6	11.8	2.2	5
BY78DJ	**VA**	**U**	M1	-20.1	-18.8	1.3	10.9	11.2	0.3	5
BY78DT	**VA**	**M**	M2	-21.4	-19	1.1	10.5	13	2.5	4
BY78DT	**VA**	**M**	M3	-20.7	-19.1	1.6	10.6	12.9	2.3	5
BY78IO	**PVP**	**M**	M2	-20.8	-19	1.8	9.6	11.5	1.8	5
BY78IO	**PVP**	**M**	M3	-20.2	-19	1.2	10.6	11.4	0.8	5
NB004	**LNP**	**U**	M1	-20.6	-19.4	1.2	11.8	14.2	2.4	5
NB007	**Undated**	**F**	M2	-20.3	-19.2	1.2	10.2	11.9	1.7	5
NB010F	**Undated**	**F**	M3	-19.1	-18.2	0.8	12.1	14.3	2.2	5
NB69(8)	**LNP**	**F**	M3	-17.7	-14.7	3.1	16.8	18.8	2	9
NB71(13)B	**Undated**	**F**	M2	-19.9	-17.2	2.7	10.8	15.6	4.8	4
NBSK?ST12	**Undated**	**M**	M2	-20.2	-19.6	0.6	10.3	12.1	1.8	5
SB2	**PVP**	**M**	M1	-21.8	-19	2.8	9	14.6	5.6	7
Scar135	**VA**	**U**	M1	-21.5	-19.8	1.7	9.2	12.4	3.2	15
Skaill Cist	**PVP**	**M**	M1	-21.1	-20.1	1	10.3	15.6	5.3	5
Skaill Cist	**PVP**	**M**	M2	-21.3	-20.5	0.8	10.1	12.4	2.3	3
Skaill Cist	**PVP**	**M**	M3	-20.9	-20.2	0.7	12.8	13	0.2	2
Skaill House1	**LNP**	**F**	M2	-16.5	-14.6	2	16.8	18.9	2.1	14
Skaill House3	**LNP**	**F**	M3	-20.4	-19.2	1.2	10.8	12.4	1.7	8
West10	**PVP**	**M**	M3	-21.2	-20.3	0.8	10.3	10.6	0.3	2
West12	**VA**	**M**	M3	-20	-18.1	1.9	10.1	15	4.8	5
West24	**PVP**	**F**	M3	-20.9	-19.8	1.1	10	11.6	1.6	5
West25	**PVP**	**U**	dm1	-21.3	-19.3	2	11.2	11.8	0.7	4
West28A	**PVP**	**F**	M3	-21.1	-20.1	1	10.7	12.2	1.5	9
West7	**PVP**	**F**	M3	-21.4	-19	2.4	9.7	11.5	1.8	6

Table 6.11. Ranges in $\delta^{13}C$ (‰) and $\delta^{15}N$ (‰) values by individual, along with the number of sections analysed.

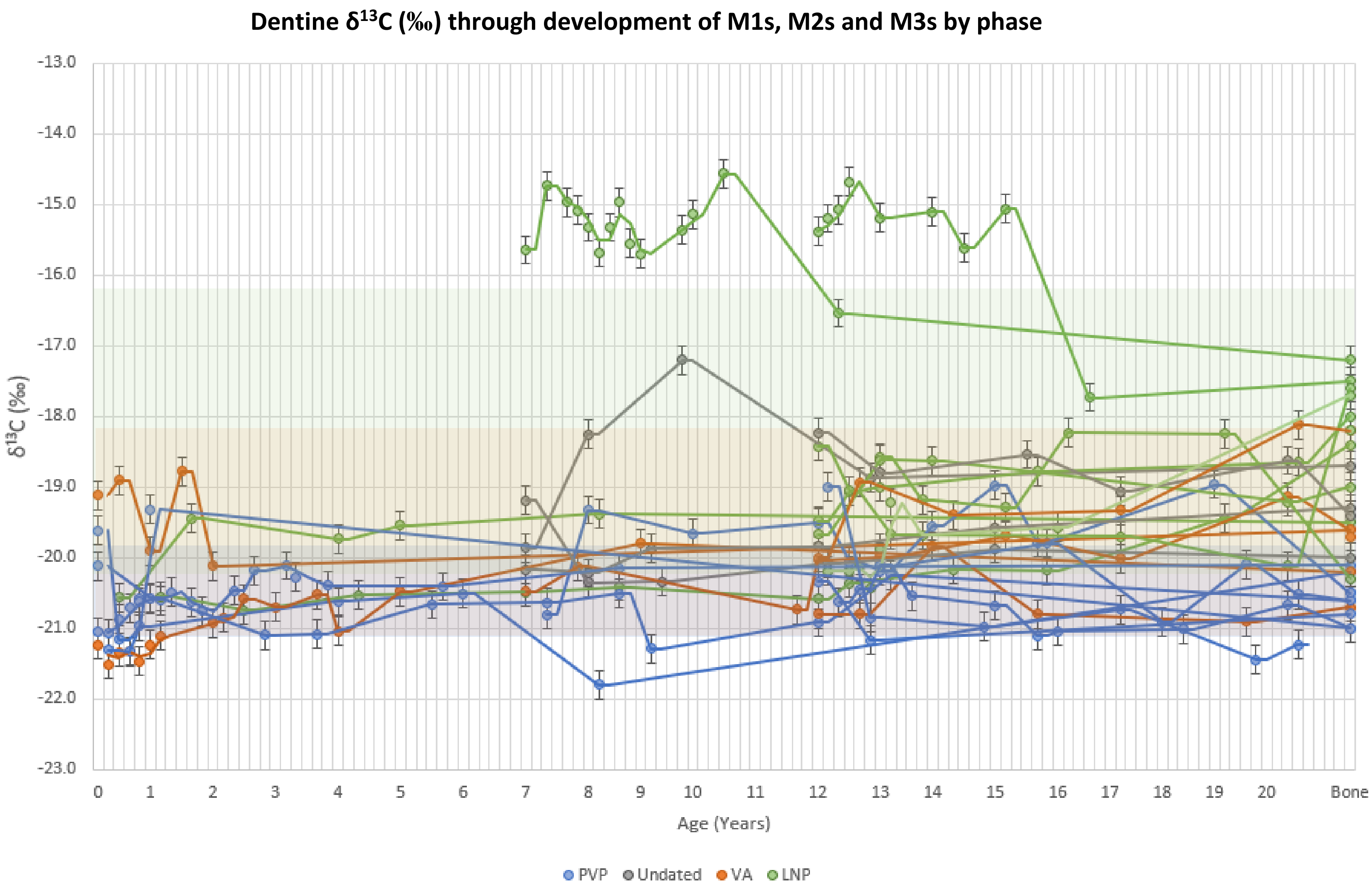

Figure 6.18. Dentine δ^{13}C (‰) of PVP, VA and LNP individuals throughout development, by phase. The blue, orange and green shaded boxes represent the bone collagen range (mean ± 2SD) for the PVP, VA and LNP, respectively.

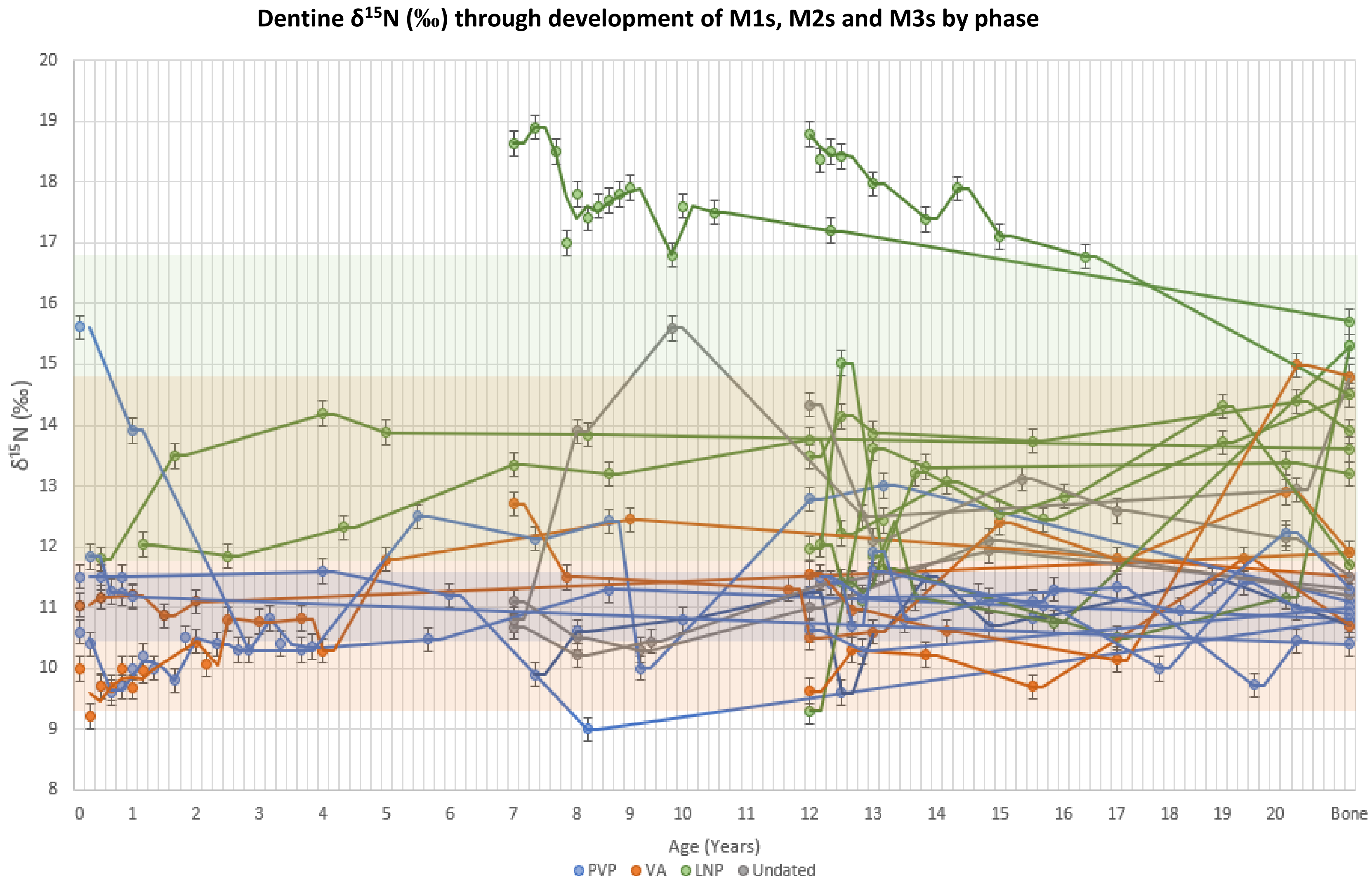

Figure 6.19. Dentine δ15N (‰) of PVP, VA and LNP individuals throughout development, by phase. The blue, orange and green shaded boxes represent the bone collagen range (mean ± 2SD) for the PVP, VA and LNP, respectively.

		Males					Females					All				
Phase	Age range	$\delta^{13}C$ (‰)	1 SD	$\delta^{15}N$ (‰)	1 SD	N	$\delta^{13}C$ (‰)	1 SD	$\delta^{15}N$ (‰)	1 SD	N	$\delta^{13}C$ (‰)	1 SD	$\delta^{15}N$ (‰)	1 SD	N
PVP	0-2.9 y.o.	-20.5	0.3	11.9	1.6	3	NA		NA		0	-20.5	0.2	11.8	1.4	4
	3-4.9 y.o.	-20.7	0.4	10.8	0.7	3	NA		NA		0	-20.7	0.4	10.8	0.7	3
	5-6.9 y.o.	-20.5	0.1	11.4	1.0	3	NA		NA		0	-20.5	0.1	11.4	1.0	3
	7-9.9 y.o.	-20.5	0.6	10.6	1.1	4	NA		NA		0	-20.7	0.8	10.6	1.1	4
	10-12.9 y.o.	-20.3	1.5	11.3	1.3	3	-20.2	0.4	11.2	0.1	2	-20.4	0.5	11.3	0.9	5
	13-16.9 y.o.	-19.9	0.4	12.0	1.5	2	-20.5	0.5	11.2	0.1	3	-20.3	0.5	11.5	0.8	5
	17-20.5 y.o.	-19.0	NA	11.4	NA	1	-20.8	0.3	11.0	0.6	3	-20.4	1.0	11.1	0.5	4
VA	0-2.9 y.o.	NA		NA		0	NA		NA		0	-20.3	1.3	10.6	0.8	2
	3-4.9 y.o.	NA		NA		0	NA		NA		0	-20.8	NA	10.6	NA	1
	5-6.9 y.o.	NA		NA		0	NA		NA		0	-20.5	NA	11.8	NA	1
	7-9.9 y.o.	-20.3	0.3	12.1	NA	1	NA		NA		0	-20.1	0.4	12.3	0.2	2
	10-12.9 y.o.	-19.9	0.6	11.1	0.3	2	-20.8	NA	10.0	NA	1	-20.2	0.7	10.7	0.7	3
	13-16.9 y.o.	-19.6	0.3	11.1	0.6	2	-20.3	NA	10.0	NA	1	-19.8	0.5	10.7	0.8	3
	17-20.5 y.o.	-19.1	0.6	12.5	0.1	2	-20.9	NA	11.8	NA	1	-19.7	1.1	12.3	0.4	3
LNP	0-2.9 y.o.	NA		NA		0	NA		NA		0	-20.3	0.5	12.3	0.6	2
	3-4.9 y.o.	NA		NA		0	NA		NA		0	-20.1	0.6	13.3	1.3	2
	5-6.9 y.o.	NA		NA		0	NA		NA		0	-19.5	NA	13.9	NA	1
	7-9.9 y.o.	NA		NA		0	-15.3	NA	17.8	NA	1	-18.4	2.7	15.0	2.5	3
	10-12.9 y.o.	-19.0	0.4	13.7	0.2	2	-17.6	2.7	14.2	4.5	4	-18.4	2.2	13.9	3.2	7
	13-16.9 y.o.	-19.3	0.6	12.7	1.6	2	-18.2	1.7	13.8	2.6	4	-18.8	1.5	13.3	2.0	7
	17-20.5 y.o.	-19.3	0.9	12.6	2.5	2	-18.7	0.7	13.9	0.6	2	-19.1	0.7	13.3	1.5	5
VA and LNP	0-2.9 y.o.	NA		NA		0	NA		NA		0	-20.3	0.8	11.4	1.2	4
	3-4.9 y.o.	NA		NA		0	NA		NA		0	-20.3	0.5	12.4	1.8	3
	5-6.9 y.o.	NA		NA		0	NA		NA		0	-20.0	0.7	12.9	1.5	2
	7-9.9 y.o.	-20.3	NA	12.1	NA	1	-15.3	NA	17.8	NA	1	-19.0	2.1	13.9	2.3	5
	10-12.9 y.o.	-19.5	0.7	12.4	1.5	4	-18.2	2.8	13.3	4.3	5	-19.0	2.1	12.9	3.0	10
	13-16.9 y.o.	-19.4	0.4	11.9	1.4	4	-18.6	1.7	13.0	2.8	5	-19.1	1.3	12.5	2.1	10
	17-20.5 y.o.	-19.2	0.6	12.6	1.5	4	-19.4	1.3	13.2	1.3	3	-19.3	0.8	12.9	1.3	8

Table 6.12. Mean $\delta^{13}C$ (‰) and $\delta^{15}N$ values (‰) by phase, age group and sex. 'All sexes' category includes individuals of undetermined sex.

	Males					*Females*					*All Sexes*				
	ANOVA		Levene			ANOVA		Levene			ANOVA		Levene		N
Age range	$\delta^{13}C$ (p)	$\delta^{15}N$ (p)	$\delta^{13}C$ (p)	$\delta^{15}N$ (p)	N	$\delta^{13}C$ (p)	$\delta^{15}N$ (p)	$\delta^{13}C$ (p)	$\delta^{15}N$ (p)	N	$\delta^{13}C$ (p)	$\delta^{15}N$ (p)	$\delta^{13}C$ (p)	$\delta^{15}N$ (p)	
0-2.9 y.o.	NA	NA	NA	NA	3	NA	NA	NA	NA	0	0.875	0.356	**0.001**	0.384	8
3-4.9 y.o.	NA	NA	NA	NA	3	NA	NA	NA	NA	0	0.488	0.125	0.539	0.113	6
5-6.9 y.o.	NA	NA	NA	NA	3	NA	NA	NA	NA	0	**0.041**	0.303	NA	NA	5
7-9.9 y.o.	0.682	0.322	NA	NA	5	NA	NA	NA	NA	1	0.261	**0.036**	**0.040**	0.069	9
10-12.9 y.o.	0.120	0.085	0.369	0.060	7	0.416	0.643	**0.000**	**0.008**	8	0.148	0.169	**0.029**	0.168	16
13-16.9 y.o.	0.444	0.522	**0.000**	**0.000**	6	0.141	0.246	0.322	0.156	9	0.094	0.073	0.513	0.428	16
17-20.5 y.o.	0.946	0.859	**0.000**	**0.000**	5	0.118	**0.012**	**0.005**	0.655	7	0.152	**0.032**	0.709	0.283	12

Table 6.13. ANOVA and Levene test of homogeneity results (p values) comparing $\delta^{13}C$ (‰) and $\delta^{15}N$ (‰) values from dentine collagen of males and females of different age categories between phases. Bold p values indicate a statistical significance at α= 0.05. N represents the number of individuals in each age category. 'All sexes' category includes individuals of unknown sex.

6.2.1. Infant and childhood trends in dentine $\delta^{13}C$ and $\delta^{15}N$ values

Sequential dentine $\delta^{13}C$ and $\delta^{15}N$ values from around birth up to 3 years old were plotted from seven individuals to compare trends in weaning between phases. This age group showed significantly greater variability in $\delta^{13}C$ values in the VA than in the other two phases (p=0.001 and 0.040). The phase with the greatest variability in $\delta^{13}C$ among infants 0-2.9 years old was the VA (1SD± 1.3‰, with the least variability of 1SD± 0.2‰ in the PVP). Interestingly, only two individuals (both date to the PVP) exhibit fairly clear weaning signals, with a drop in $\delta^{15}N$ around the age of two years old, though one begins much earlier (Figure 6.20., below). Better dentine preservation would have allowed for additional samples from the LNP individuals, which may or may not have displayed a decrease in $\delta^{15}N$ values around the same age. While these two PVP individuals exhibit a difference of between 4 and 6‰ in dentine $\delta^{15}N$ values, the VA and LNP individuals showed a difference of 1-2‰ between birth and three years old. There were no significant differences in average $\delta^{13}C$ and $\delta^{15}N$ values in age group 0-2.9 years between phase, nor were there differences in variability of either $\delta^{13}C$ or $\delta^{15}N$ values within this age group between phases. There was, however, significantly greater variability of $\delta^{15}N$ values of individuals 3-4.9 years old in the VA than in the PVP (p=0.007). Individuals ages 5-6.9 years old exhibited the greatest variability in the VA, though no LNP individuals of this age were sampled.

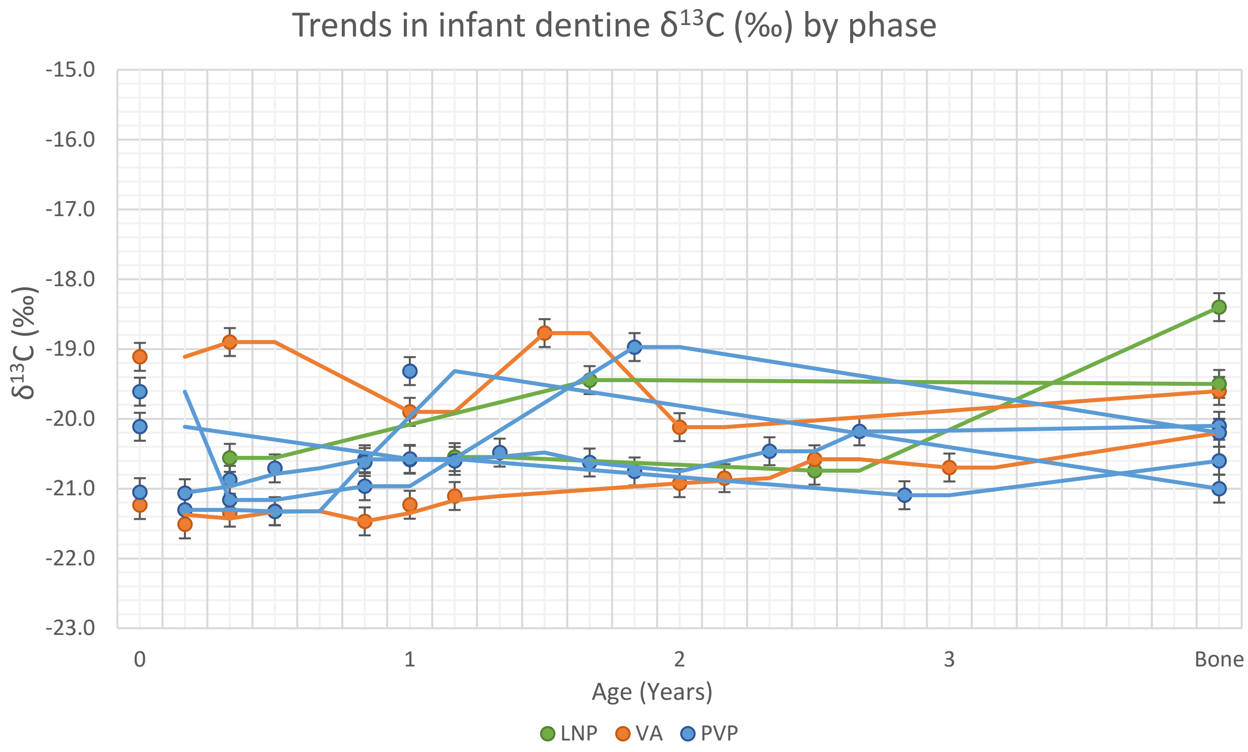

Figure 6.20. Sequential dentine $\delta^{13}C$ (‰) in individuals from around birth to 3 years old, along with bone collagen $\delta^{13}C$ (‰) at time of death.

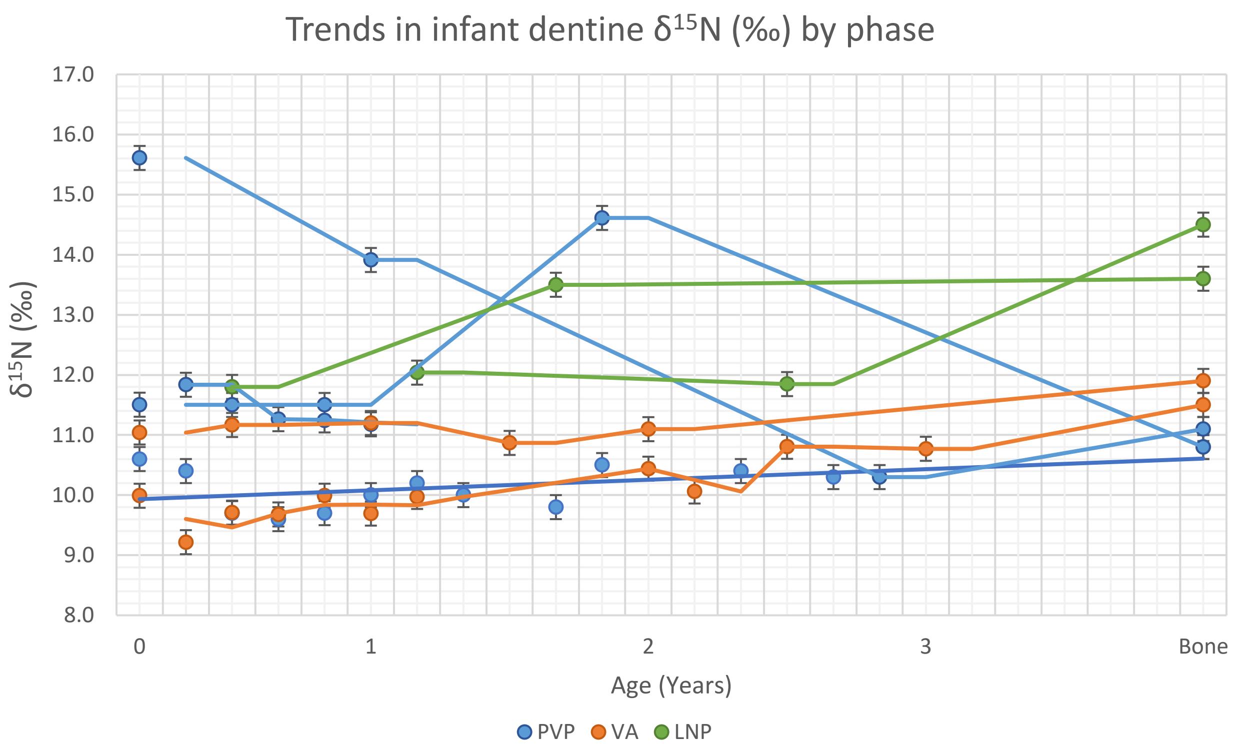

Figure 6.21. Sequential dentine $\delta^{15}N$ (‰) in individuals from around birth to 3 years old, along with bone collagen $\delta^{15}N$ (‰) at time of death.

6.2.2. Trends in $\delta^{13}C$ and $\delta^{15}N$ through adolescence

The only demographic group that exhibited significantly different $\delta^{15}N$ values between phases was females between the ages of 17 and 20.5 years old (Table 6.14), who exhibited significantly higher $\delta^{15}N$ values in the LNP than in the PVP or VA (p=0.012). When individuals of all sexes were combined, there were significantly higher $\delta^{15}N$ among individuals in age groups 7-9.9 years and 50+ years in the LNP than in the other two phases (p=0.033 and 0.022). Based on Barrett and Richards (2004) and Richards et al. (2006) findings that $\delta^{13}C$ and $\delta^{15}N$ values were significantly higher in males than females during the VA and LNP, the present study sought to specify at what age patterns in diet may have begun to diverge between the two sexes. To test the hypothesis that differences in diet may have stemmed from sex-based divisions of labour or perhaps with the onset of puberty and reproductive age, sampling of second and third molars for $\delta^{13}C$ and $\delta^{15}N$ values focused on the ages of 10+ (around the age of menarche; Lewis et al. 2015; 2020). Second and third molars (M2s and M3s) from PVP, VA and LNP individuals were compared between sexes to reveal potential differences in patterns of $\delta^{13}C$ and $\delta^{15}N$ values between males and females during adolescence and young adulthood. Among M2 and M3 samples, variability in both $\delta^{13}C$ and $\delta^{15}N$ values increased from the PVP through the VA and LNP. Males and females in the PVP (9 individuals) ranged between -21.8‰ and -19.0‰ in $\delta^{13}C$ and between 9.6‰ and 12.2‰ in $\delta^{15}N$, with an outlying value of 15.6‰ (>2SD from the mean) from the young adult male from Skaill Cist. All of the PVP individuals exhibited bone collagen $\delta^{13}C$ and $\delta^{15}N$ values within 2.0‰ of their dentine values from early adolescence through adulthood (Figures 6.22. and 6.23); which is more than half the estimate of a full trophic level (3.4‰, per Hussey et al. 2013). PVP females between the ages of 17 and 20.5 exhibited significantly lower dentine $\delta^{13}C$ values (-20.8‰) than dentine samples from the only male (-19.0‰) of the same age group (p=0.036).

Due to the small sample size and to compare our dataset more closely with Barrett and Richards' (2004) study, the VA and LNP individuals were then combined into one phase category (Figures

6.24. and 6.25). Only in the PVP was there a significant difference between $\delta^{13}C$ between sexes, with significantly lower values among females ages 17-20.5 than males of the same age (p=0.036). There was no difference between $\delta^{15}N$ values (p=0.577). In neither the VA or the LNP did males and females exhibit significantly different $\delta^{13}C$ or $\delta^{15}N$ values in any of the age groups. Results for statistical tests involving all age groups are provided in Table 6.14. In the LNP, females ages 10-12.9 years old exhibited significantly greater variability in both $\delta^{13}C$ and $\delta^{15}N$ values than males of the same ages (females: $\delta^{13}C$= -17.6‰ ± 2.7‰, $\delta^{15}N$= 14.2‰ ± 4.5‰; males: $\delta^{13}C$= -19.0‰ ± 0.4‰, $\delta^{15}N$=13.7‰ ± 0.2‰, p=0.000). LNP females ages 17-20.5, however, exhibited significantly less variability in both $\delta^{13}C$ and $\delta^{15}N$ than males of the same age (females: $\delta^{13}C$= -18.7‰ ± 0.7‰, $\delta^{15}N$= 13.9‰ ± 0.6‰; males: $\delta^{13}C$= -19.3‰ ± 0.9‰, $\delta^{15}N$=12.6‰ ± 2.5‰, p=0.000). Interpretations on the changing variability of $\delta^{13}C$ and $\delta^{15}N$ values for both sexes will be considered in Chapter 8.

Of the six VA and LNP females (all young or middle adults), four exhibited adult bone $\delta^{13}C$ and $\delta^{15}N$ values lower than their adolescent dentine values (Skaill House 1, NB69(8) and BU189). Only one of the females (Skaill House 3) exhibited an increase in $\delta^{13}C$ and $\delta^{15}N$ values (by nearly 2.0‰ in $\delta^{13}C$ and nearly 5‰ in $\delta^{15}N$). The other female (BU214, a middle adult) exhibited consistent bone and dentine $\delta^{13}C$ and $\delta^{15}N$ values. Five of the six VA and LNP females exhibited short-term (approximately between 6 and 12 months) increases in $\delta^{13}C$ and $\delta^{15}N$ throughout adolescence, with four of the six exhibiting an increase of nearly 1.0‰ in $\delta^{13}C$ between the ages of 12 and 14. These short-term shifts in $\delta^{13}C$ were reflected in similar simultaneous increases in $\delta^{15}N$ of between 0.5‰ and 1.0‰. None of the VA or LNP males exhibited similar short-term rises in both $\delta^{13}C$ and $\delta^{15}N$ throughout adolescence. One of the females exhibited an increase in $\delta^{15}N$ of approximately 4.0‰ within a year (between the ages of 12 and 13) with a slight decrease in $\delta^{13}C$ of approximately 1.0‰ over the same period. This was the most abrupt and significant shift in $\delta^{15}N$ values from any individuals during adolescence and will be discussed further in Chapter 8. Furthermore, the two individuals with the highest $\delta^{13}C$ and $\delta^{15}N$ values in the VA and LNP phases were LNP females (NB96(8) and Skaill House 1). While only one tooth was sampled from each of these two females, they showed consistently higher δ^{13}C and δ^{15}N values than the rest of the LNP individuals. Their bone collagen δ^{13}C and δ^{15}N values were among the highest in the phase but much lower than their dentine values. The lower bone values suggest their diets became more similar to the other VA and LNP individuals in adulthood. Two of the VA and LNP males' (Westness 12 and BU081) δ^{15}N profiles exhibited significant enrichment at or after the age of 20, indicating a difference between adolescent and adulthood diets. The other two males (BY78DT and BU370) kept relatively consistent δ^{13}C and δ^{15}N values throughout adolescence and into adulthood.

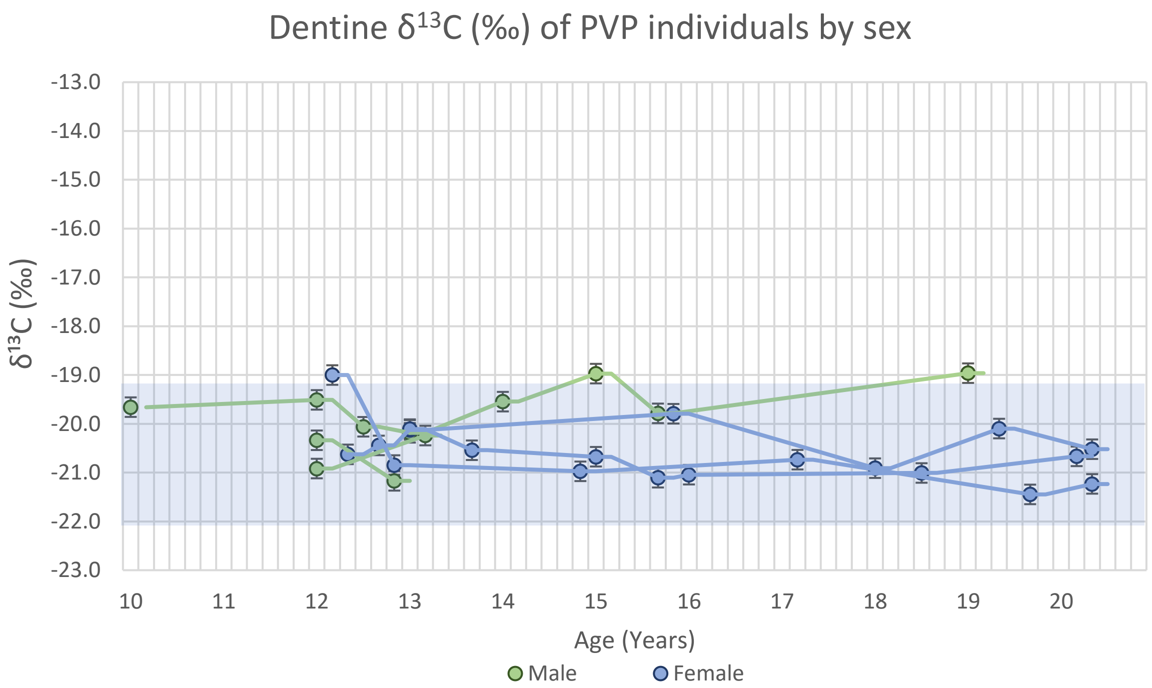

Figure 6.22. Profiles of δ^{13}C (‰) values from M1, M2 and M3 dentine of PVP males and females from the ages of 10+. The blue box delineates the PVP bone collagen δ^{13}C (‰) mean ± 2SD (-21.9‰ to -18.9‰).

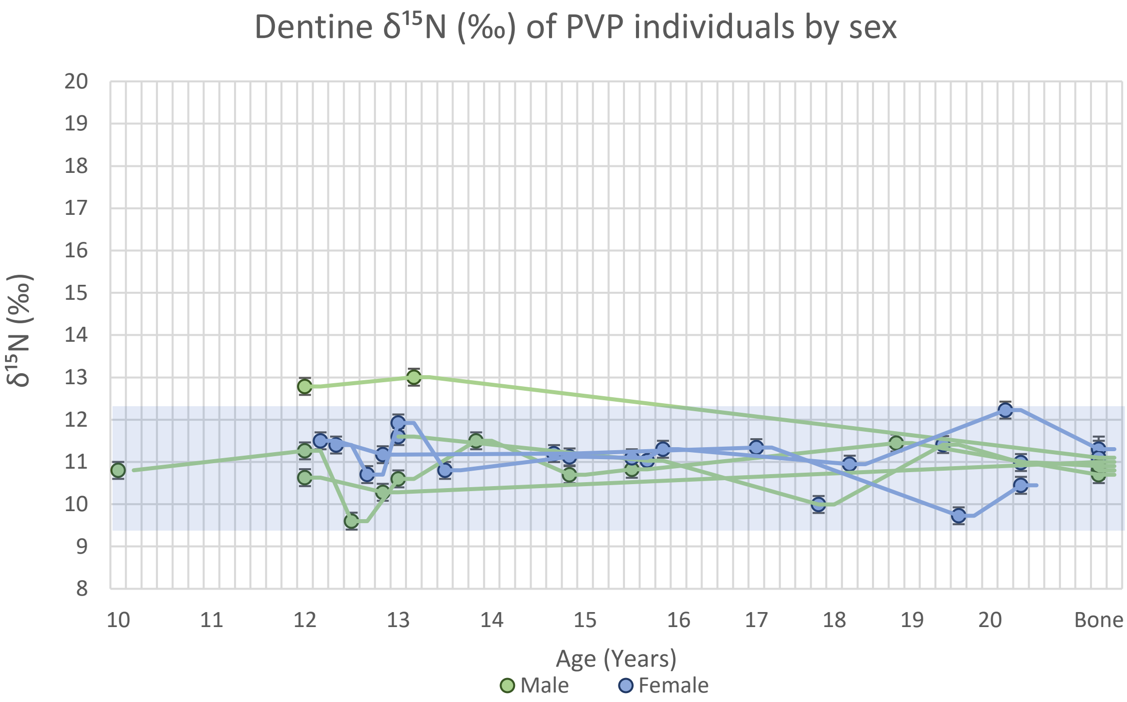

Figure 6.23. Profiles of δ^{15}N (‰) values from M1, M2 and M3 dentine of PVP males and females from the ages of 10+. The blue box delineates the PVP bone collagen δ^{15}N (‰) mean ± 2SD (9.7‰ – 12.1‰).

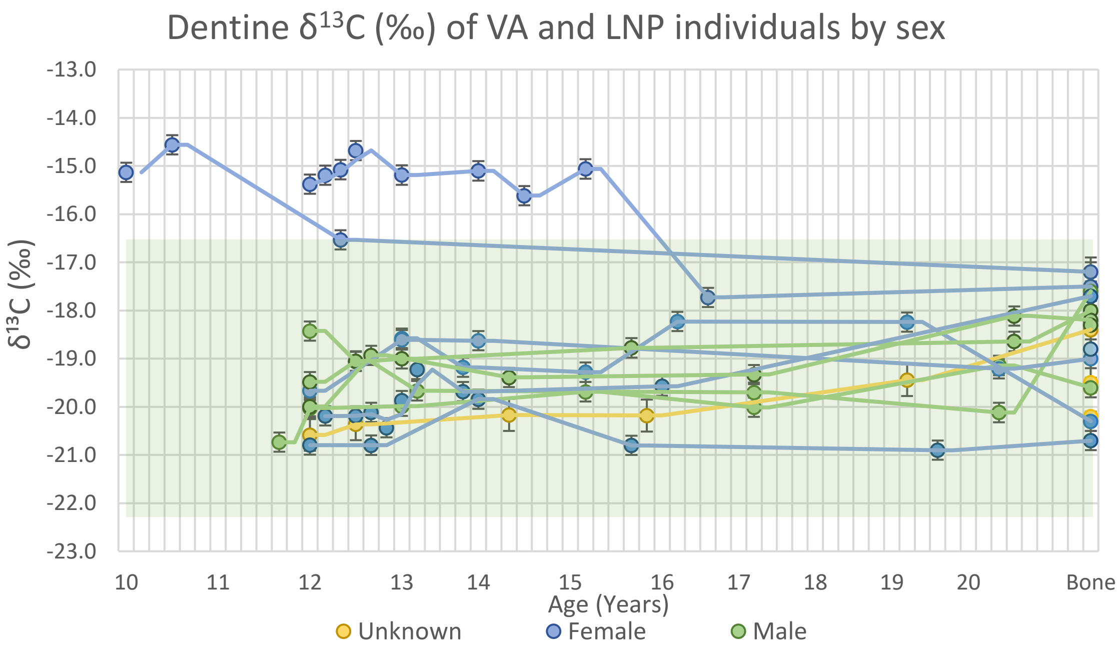

Figure 6.24. Profiles of δ^{13}C (‰) values from M1, M2 and M3 dentine of VA and LNP males and females. The green box delineates the VA and LNP bone collagen δ^{13}C mean (‰) ± 2SD (-22.4‰ to -16.4‰).

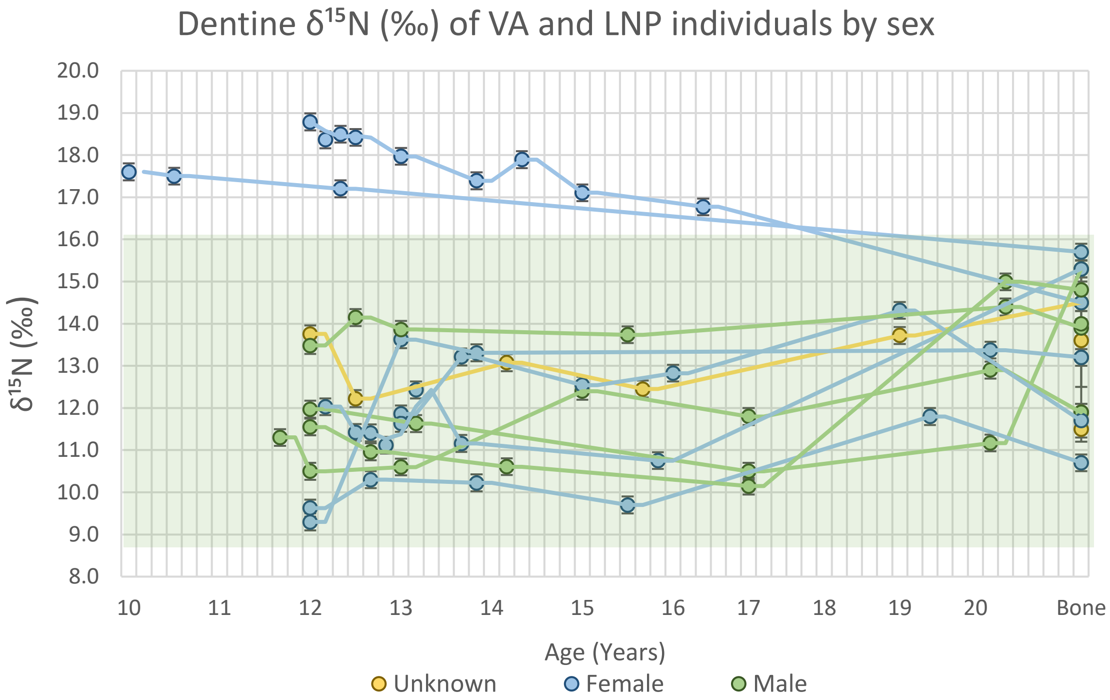

Figure 6.25. Profiles of $\delta^{15}N$ (‰) values from M1, M2 and M3 dentine of VA and LNP males and females. The green box delineates the VA and LNP bone collagen $\delta^{15}N$ mean (‰) ±2SD (8.7‰ – 16.0‰).

	PVP					VA					LNP				
	ANOVA		Levene		N	ANOVA		Levene		N	ANOVA		Levene		N
Age range	$\delta^{13}C$ (p)	$\delta^{15}N$ (p)	$\delta^{13}C$ (p)	$\delta^{15}N$ (p)		$\delta^{13}C$ (p)	$\delta^{15}N$ (p)	$\delta^{13}C$ (p)	$\delta^{15}N$ (p)		$\delta^{13}C$ (p)	$\delta^{15}N$ (p)	$\delta^{13}C$ (p)	$\delta^{15}N$ (p)	
0-2.9 years	NA	NA	NA	NA		NA	NA	NA	NA		NA	NA	NA	NA	
3-4.9 years	NA	NA	NA	NA		NA	NA	NA	NA		NA	NA	NA	NA	
5-6.9 years	NA	NA	NA	NA		NA	NA	NA	NA		NA	NA	NA	NA	
7-9.9 years	NA	NA	NA	NA		NA	NA	NA	NA		NA	NA	NA	NA	
10-12.9 years	0.676	0.925	0.365	0.070	5	0.792	0.675	**0.000**	**0.000**	4	0.530	0.883	**0.000**	**0.009**	6
13-16.9 years	0.271	0.428	0.658	**0.000**	5	0.902	0.873	**0.000**	**0.000**	4	0.446	0.634	0.291	0.546	6
17-20.5 years	**0.036**	0.577	NA	NA	4	0.583	0.333	**0.000**	**0.000**	4	0.561	0.570	**0.000**	**0.000**	5

	VA and LNP					All Phases				
	ANOVA		Levene		N	ANOVA		Levene		N
Age range	$\delta^{13}C$ (p)	$\delta^{15}N$ (p)	$\delta^{13}C$ (p)	$\delta^{15}N$ (p)		$\delta^{13}C$ (p)	$\delta^{15}N$ (p)	$\delta^{13}C$ (p)	$\delta^{15}N$ (p)	
0-2.9 years	NA	NA	NA	NA		NA	NA	NA	NA	
3-4.9 years	NA	NA	NA	NA		NA	NA	NA	NA	
5-6.9 years	NA	NA	NA	NA		NA	NA	NA	NA	
7-9.9 years	NA	NA	NA	NA		**0.002**	**0.006**	NA	NA	6
10-12.9 years	0.369	0.600	**0.036**	**0.039**	10	0.288	0.593	**0.009**	**0.025**	14
13-16.9 years	0.342	0.466	0.300	0.457	10	0.711	0.682	0.070	0.360	14
17-20.5 years	0.900	0.660	0.457	0.894	8	0.119	0.778	0.084	0.662	11

Table 6.14. Results of statistical tests (p values) comparing males and female dentine $\delta^{13}C$ and $\delta^{15}N$ values by age range and phase. Bold p values indicate a statistical significance at α= 0.05.

6.3. $\delta^{13}C$ and $\delta^{15}N$ stable isotope conclusions

A total of 152 individuals were sampled for bone collagen $\delta^{13}C$ and $\delta^{15}N$ and 28 were sampled for sequential dentine $\delta^{13}C$ and $\delta^{15}N$. When results from previous isotope studies were compiled, the dataset included bone collagen samples from 292 individuals from twelve sites throughout Orkney.

6.3.1. Bone collagen results

First, the results of bone collagen $\delta^{13}C$ and $\delta^{15}N$ were analysed. There were significant increases in $\delta^{13}C$ and $\delta^{15}N$ values from the PVP through the LNP observed in both males and females-primarily among young, middle and older adults, but not in juveniles and adolescents. The VA exhibited the greatest variability in both $\delta^{13}C$ and $\delta^{15}N$, with the least variability in the PVP. In none of the phases was there a significant difference in either $\delta^{13}C$ or $\delta^{15}N$ values between sexes, though there were some differences between age groups. Young adults in the VA had the highest $\delta^{15}N$ values while middle adults had the lowest. While there were no significant differences in either $\delta^{13}C$ or $\delta^{15}N$ values between individuals with and without osteological indicators of nutritional deficiency in any phase, there were correlations between dental pathologies and $\delta^{13}C$ or $\delta^{15}N$ values in each phase. In the PVP, $\delta^{13}C$ values were higher among individuals with AMTL or abscesses. In the VA, both $\delta^{13}C$ and $\delta^{15}N$ values were higher in individuals who had lost at least one tooth ante-mortem. VA males with periodontal disease also exhibited higher $\delta^{13}C$ or $\delta^{15}N$ values. When compared by indicators of developmental stress, females with LEHs exhibited higher $\delta^{13}C$ and $\delta^{15}N$ values than females without LEHs.

Next, $\delta^{13}C$ and $\delta^{15}N$ values were compared between individuals with and without osteological indicators of physical stress/manual labour to determine whether individuals with occupation-related pathologies may have consumed different levels of marine protein than individuals without evidence of physical stress, potentially due to differences in occupation or social status.

When all phases were considered, there were higher $\delta^{13}C$ and $\delta^{15}N$ in both males and females with OA in one or both hands. In the VA, males with OA of one or both shoulder joints exhibited higher $\delta^{15}N$ values than males without, while females with OA of at least one sternocostal joint exhibited higher $\delta^{15}N$ values than females without. In the LNP, males with platymeria had higher $\delta^{13}C$ and $\delta^{15}N$ values and males with OA of the jaw had higher $\delta^{13}C$ values than males without. LNP females with OA of the hands had significantly higher $\delta^{13}C$ values, but not $\delta^{15}N$ values. Differences in prevalence rates of OA and other indicators of load-bearing are provided in Chapter 5 and discussed further in Chapter 8. To determine whether individuals with evidence of violence were consuming different diets, potentially due to differences in social status or role in society, $\delta^{13}C$ and $\delta^{15}N$ values were compared between individuals with and without violent trauma. There were no significant differences in males or females with and without violent trauma in any phase.

Next, $\delta^{13}C$ and $\delta^{15}N$ values were compared by burial settings and grave goods to test whether diet may have differed between individuals of different religious or cultural affiliations. This included comparing individuals buried within and outside of churchyards, with and without grave goods, as well as with and without boat burials or cists. As there are no proven churchyards or burials with grave goods in PVP Orkney, this comparison was limited to VA individuals. Females buried within churchyards exhibited higher and greater variability in $\delta^{13}C$ values than females buried outside churchyards. Despite the possible link between Scandinavian identity and boat burials, there was no difference in $\delta^{13}C$ or $\delta^{15}N$ values between individuals with or without boat burials. Differences in $\delta^{13}C$ and $\delta^{15}N$ values were tested between males and females with and without grave goods, as well as by type of grave good to determine whether those with grave goods (or certain types of grave goods) were consuming a different diet, potentially due to differences in social status or ethnicity. There were no differences in either $\delta^{13}C$ or $\delta^{15}N$ values between either males or females with or without grave goods in the VA. When $\delta^{13}C$ and $\delta^{15}N$ values of males and females were compared by type of grave good, there were significantly lower $\delta^{13}C$ values among females with agricultural tools than males with agricultural tools.

Finally, to determine whether $\delta^{13}C$ and $\delta^{15}N$ values were different between sites and if so, whether they may have been affected by site location, function (as inferred by place-name type), or differences/changes in subsistence practices, several site and subsistence-related variables were statistically tested against $\delta^{13}C$ and $\delta^{15}N$ values: location (east vs west), the proportions of mammals at the site, predominant animal use and predominant cereal and fish types. When individual sites were compared within each phase, there were no significant differences in males or females between sites in the PVP. In the VA, females from Newark Bay exhibited higher $\delta^{13}C$ values than females from Westness, Brough Road or Scar. In the LNP, both males and females from Newark Bay exhibited higher $\delta^{13}C$ values than males and females from the Brough of Deerness, Bu of Cairston, Westness, or Skaill House. While females from Newark Bay exhibited higher $\delta^{13}C$ values, females from Skaill House exhibited significantly higher $\delta^{15}N$ values. When $\delta^{13}C$ and $\delta^{15}N$ values were compared by place name type (including all phases but controlling for age and phase using a general linear model), females from the *skaill* site (Skaill House) exhibited significantly higher $\delta^{13}C$ and $\delta^{15}N$ values, followed by females from *-by* sites (Newark Bay and Bu of Cairston). Females from the site named for a land feature (Westness) had the lowest $\delta^{13}C$ and $\delta^{15}N$ values. Among VA individuals there was a positive correlation between $\delta^{13}C$ values and the percentage of sheep/goat found at the site and a negative correlation between $\delta^{13}C$ values and the proportion of pigs. As expected, there was no difference in $\delta^{13}C$ or $\delta^{15}N$ values between sites with faunal evidence for a focus on raising animals for dairying or meat production. In the PVP, one site exhibited evidence of offshore fishing, one of nearshore fishing and one of no or negligible amounts of fishing. Although one might expect higher $\delta^{13}C$ and $\delta^{15}N$ values among individuals from sites with ichthyological evidence of marine resource exploitation, there were higher $\delta^{13}C$ values and greater variability in both $\delta^{13}C$ and $\delta^{15}N$ values among individuals from the site without fishing (Newark Bay). There were no significant differences in either δ^{13}C or δ^{15}N values among males or females in the VA depending on whether the site they were from had evidence of offshore, nearshore or no fishing. Analysis was not possible between types of fishing and δ^{13}C and δ^{15}N values in the LNP because all sites with archaeoichthyological reports exhibited evidence of offshore fishing by this phase. When compared by land quality codes (LC codes) and evidence of plaggen soil formation, VA females from better quality soils exhibited higher δ^{13}C values and individuals from sites with plaggen soils in the VA and LNP had higher δ^{13}C values. The correlation between sites with better quality soil and sites with plaggen soil formation, along with the significantly higher δ^{13}C values among individuals from more arable sites will be further discussed in Chapter 8.

6.3.2. Dentine δ^{13}C and δ^{15}N

Sequential dentine micro-samples were taken of teeth from PVP, VA and LNP individuals to reconstruct patterns in diet throughout infancy/early childhood and adolescence/young adulthood. While first, second and third molars were selected due to accessibility and preservation, this study focused primarily on diet profiles between the ages of birth to 3 years old and 10 and 20.5 years old. While there were no significant differences in dentine δ^{13}C and δ^{15}N means of birth to 3-year-olds between phases, there was the greatest variability in δ^{13}C values in the VA. Trendlines from birth to 3 years old were reconstructed for eight individuals. Interestingly, only two individuals (both dating to the PVP) exhibited a clear decrease in δ^{15}N values that are typically observed during weaning (to be further discussed in Chapter 8). It is possible, however, that breastfeeding was short-term enough to not have produced discernable differences in M1 δ^{13}C and δ^{15}N values.

When dentine section δ^{13}C and δ^{15}N values were averaged within age ranges and compared by phase, individuals in the age range 7-9.9 years and in the age range 17-20.5 years exhibited significantly higher $\delta^{15}N$ values in the LNP than the other two phases. In the PVP, females in the 17-20.5 age range exhibited lower $\delta^{13}C$ values than the only male. In the VA and LNP, there were no age ranges in which $\delta^{13}C$ or $\delta^{15}N$ values differed significantly by sex. While LNP females ages 10-12.9 exhibited greater variability in both $\delta^{13}C$ and $\delta^{15}N$ values than males of the same age, females 17-20.5 exhibited less variability in both $\delta^{13}C$ and $\delta^{15}N$ values than males of the same age. The majority of VA and LNP females exhibited short-term increases in $\delta^{13}C$ and $\delta^{15}N$ throughout adolescence, while these increases were not observable in any of the males. Changes in the mean $\delta^{13}C$ and $\delta^{15}N$ through adolescence, the variability of $\delta^{13}C$ and $\delta^{15}N$ values in females and how they may correspond to changes in life stages will be discussed in Chapter 8. Despite previous findings of significantly higher bone collagen $\delta^{13}C$ and $\delta^{15}N$ values among males in the VA and LNP, the consistently highest dentine VA and LNP $\delta^{13}C$ and $\delta^{15}N$ values were of two females, one from Newark Bay (NB69(8)) and one from Skaill House (Skaill House 1). While all but one of the males and females in the PVP exhibit dentine $\delta^{13}C$ and $\delta^{15}N$ means within 1.0‰ of their respective bone collagen values, VA and LNP males and females exhibited a slightly greater disparity between mean dentine values and bone collagen values of approximately 1.5‰.

Chapter 7. Mobility: Strontium and Oxygen Isotopes

A total of 68 teeth (57 individuals) from nine Pre-Viking (PVP), Viking Age (VA) and Late Norse Phase (LNP) sites in Orkney were sampled for strontium ($^{87}Sr/^{86}Sr$) and oxygen ($\delta^{18}O_C$) isotopes. Enamel samples were predominantly taken from M3s, which would correspond to between 11 and 14 years of age (per methodology laid out in Chapter 3). Tooth type is specified below, in Table 7.1.

Name	Tooth	Age	Sex	Phase	$^{87}Sr/^{86}Sr$	2SD	[Sr] (ppm)*	1/[Sr] x 10^3	$\delta^{18}O_c$ VPDB (‰)	$\delta^{18}O_c$ SMOW (‰)	$\delta^{18}O_p$ SMOW (‰)
BUC009	M2	YA	F	LNP	0.709582	0.000011	236	4.2	-3.2	27.6	18.8
BUC009	M3	YA	F	LNP	0.709463	0.000008	276	3.6	-3.2	27.6	18.8
BUC015	M1	Ad	M	LNP	0.709828	0.000012	207	4.8	-4.0	26.8	17.9
BUC015	M2	Ad	M	LNP	0.709712	0.000009	218	4.6	-5.3	25.4	16.5
BUC015	M3	Ad	M	LNP	0.709797	0.000017	257	3.9	-4.5	26.2	17.4
BUC018	M3	YA	F	LNP	0.709807	0.000011	215	4.6	-4.9	25.9	17.0
BUC026	M3	YA	F	LNP	0.709352	0.000009	354	2.8	-2.3	28.5	19.7
BUC037	M3	Ad	F	LNP	0.709776	0.000013	376	2.7	-1.1	29.8	21.0
BUC050	M3	Ad	U	LNP	0.709434	0.000015	319	3.1	-3.8	27.0	18.1
BUC059	M1	J	U	LNP	0.710253	0.000011	162	6.2	-3.6	27.2	18.4
BUC059	M3	J	U	LNP	0.709851	0.000020	243	4.1	-4.5	26.3	17.5
BUC081	M3	OA	M	LNP	0.710913	0.000009	167	6.0	-4.1	26.7	17.9
BUC087	M3	Ad	F	LNP	0.709837	0.000011	343	2.9	-4.3	26.5	17.7
BUC098	M3	YA	F	LNP	0.709892	0.000010	241	4.1	-2.0	28.9	20.1
BUC189	M3	MA	F	LNP	0.709829	0.000013	213	4.7	-2.9	28.0	19.2
BUC214	M3	MA	F	LNP	0.709730	0.000010	235	4.2	-4.2	26.6	17.7
BUC237	M3	OA	M	LNP	0.709509	0.000011	359	2.8	-4.4	26.3	17.5
BUC257	M1	J	U	LNP	0.709406	0.000015	373	2.7	-3.4	27.5	18.6
BUC326	M1	YA	M	LNP	0.709689	0.000008	241	4.1	-3.7	27.1	18.3
BUC326	M2	YA	M	LNP	0.709864	0.000013	297	3.4	-3.6	27.2	18.4
BUC345	M3	MA	M	LNP	0.709512	0.000011	295	3.4	-3.2	27.6	18.8

BUC370	M3	YA	M	LNP	0.709594	0.000013	200	5.0	-3.6	27.2	18.4
BUC433	M3	OA	U	LNP	0.709658	0.000013	276	3.6	-3.0	27.8	19.0
BUCKQM12	M1	YA	M	PVP	0.709857	0.000011	237	4.2	-3.4	27.4	18.6
BY78AS	M2	MA	M	PVP	0.711076	0.000013	140	7.2	-4.1	26.7	17.9
BY78AS	M3	MA	M	PVP	0.711448	0.000007	163	6.1	-4.2	26.6	17.7
BY78CD	M2	YA	U		0.709621	0.000015	154	6.5	-4.1	26.7	17.8
BY78CU	M3	YA	F	VA	0.710311	0.000011	150	6.7	-3.8	27.0	18.2
BY78DJ	M1	YA	U	VA	0.709348	0.000011	158	6.3	-2.8	28.0	19.2
BY78DT	M1	OA	M	VA	0.709422	0.000012	231	4.3	-2.5	28.3	19.6
BY78IO	M2	MA	M	PVP	0.709676	0.000012	240	4.2	-1.6	29.3	20.5
BY78IO	M3	MA	M	PVP	0.709661	0.000010	259	3.9	-3.5	27.3	18.5
NB004	M1	J	U	LNP	0.709357	0.000012	250	4.0	-3.4	27.4	18.6
NB007	M2	MA	F		0.709499	0.000011	393	2.5	-3.0	27.8	19.0
NB010f	M3	YA	F		0.709341	0.000009	211	4.7	-4.1	26.7	17.9
NB11	M3	MA	M		0.709606	0.000016			-4.8	26.0	17.1
NB68(12)	M3	YA	M	LNP	0.709262	0.000009	352	2.8	-3.8	27.0	18.1
NB69(8)	M3	MA	F	LNP	0.709630	0.000014	293	3.4	-4.2	26.6	17.7
NB70(29)	M3	MA	F		0.709490	0.00001	234	4.3	-2.4	28.5	19.7
NB70(37)	P2	A	M	VA	0.709362	0.000008	247	4.1	-3.4	27.4	18.6
NB71(12)	M1	Ad	M	VA	0.709365	0.000016	292	3.4	-3.0	27.8	19.0
NB71(12)	M2	Ad	M	VA	0.709445	0.000013	304	3.3	-2.8	28.0	19.2
NB71(12)	M3	Ad	M	VA	0.709306	0.000015	333	3.0	-3.0	27.8	19.0
NB71(13)B	M2	YA	F		0.710112	0.000009	314	3.2	-4.4	26.4	17.6
NBCC3A	M2	MA	F		0.709659	0.000011	292	3.4	-4.1	26.7	17.8
NBD3	M3	MA	M		0.709577	0.000009	250	4.0	-4.4	26.4	17.5
NBMJ	M3	U	U		0.709843	0.000010	187	5.4	-5.0	25.7	16.9
NBNB1	M3	OA	M		0.709452	0.000015	329	3.0	-5.0	25.7	16.9
NBNB2	dm1	J	U		0.709564	0.000010	187	5.3			
NBNB2	M1	J	U		0.709436	0.000015	247	4.0	-3.3	27.5	18.7
NBSK?ST12	M2	Ad	M		0.710196	0.000014	185	5.4	-3.7	27.1	18.3
NBSK?ST14	M2	OA	M		0.709952	0.000014	222	4.5	-1.8	29.1	20.3
NBSK?ST14	M3	OA	M				214	4.7	-3.4	27.4	18.6

NBSK?ST17	M1	U	U		0.709394	0.000010	223	4.5			
SB2	M1	MA	M	PVP	0.709844	0.000001	206				
SCAR135	M1	J	U	VA	0.709157	0.000013	268	3.7	-5.4	25.4	16.5
SkaillCist	M1	YA	M	PVP	0.709586	0.000009	154	6.5	-4.6	26.2	17.3
SkaillCist	M2	YA	M	PVP	0.709157	0.000015	176	5.7	-4.0	26.8	18.0
SkaillCist	M3	YA	M	PVP	0.710190	0.000008	279	3.6	-4.4	26.4	17.5
SKH1	M2	MA	F	LNP	0.709528	0.000016	217	4.6	-4.7	26.1	17.3
SKH3	M3	MA	F	LNP	0.709837	0.000008	265	3.8	-3.2	27.7	18.9
WEST10	M3	YA	M	PVP	0.709487	0.000011	240	4.2	-3.6	27.2	18.4
WEST12*	P1	MA	M	VA	0.71197	0.00004					15.4
WEST12	M3	MA	M	VA	0.711627	0.000012	165	6.1	-5.5	25.2	16.3
WEST24	M3	MA	F	PVP	0.709910	0.000012	313	3.2	-2.4	28.5	19.7
WEST25	dm1	J	U	PVP	0.709919	0.000009	197	5.1	-4.7	26.1	17.2
WEST25*	M1	J	U	PVP	0.70987	0.00004					
WEST28A	M3	YA	F	PVP	0.709416	0.000013	251	4.0			
WEST28A*	M3	YA	F	PVP	0.70942	0.00004					17.8
WEST34	Incisor	OA	M	VA	0.709845	0.000009	491	2.0			
WEST7	M3	OA	F	PVP	0.709741	0.000012	208	4.8	-4.2	26.5	17.7
WEST5*	P2	MA	F	VA	0.70729	0.00004					17.2
WEST11*	M2	OA	M	VA	0.71015	0.00004					15.5
WEST32*	M2	OA	F	PVP	0.70977	0.00004					17.8

Table 7.1. Tooth enamel $^{87}Sr/^{86}Sr$ and O (‰) isotopes from PVP, VA and LNP individuals analysed in this study. [Sr]/ppm was normalized to 40% [Ca] (Snoeck et al. 2019). The analytical error for converting $\delta^{18}O_c$ to $\delta^{18}O_p$ was ± 0.56‰ (2SD; Chenery et al. 2012). Under 'Age at Death', J = Juvenile, A= Adolescent, YA= Young Adult, MA= Middle Adult, Ad= Adult, OA= Older Adult, U= Unknown. Under 'Sex', M= Male, F= Female, U= Unknown. Isotope data for individuals with asterisks are from Montgomery et al. 2014.

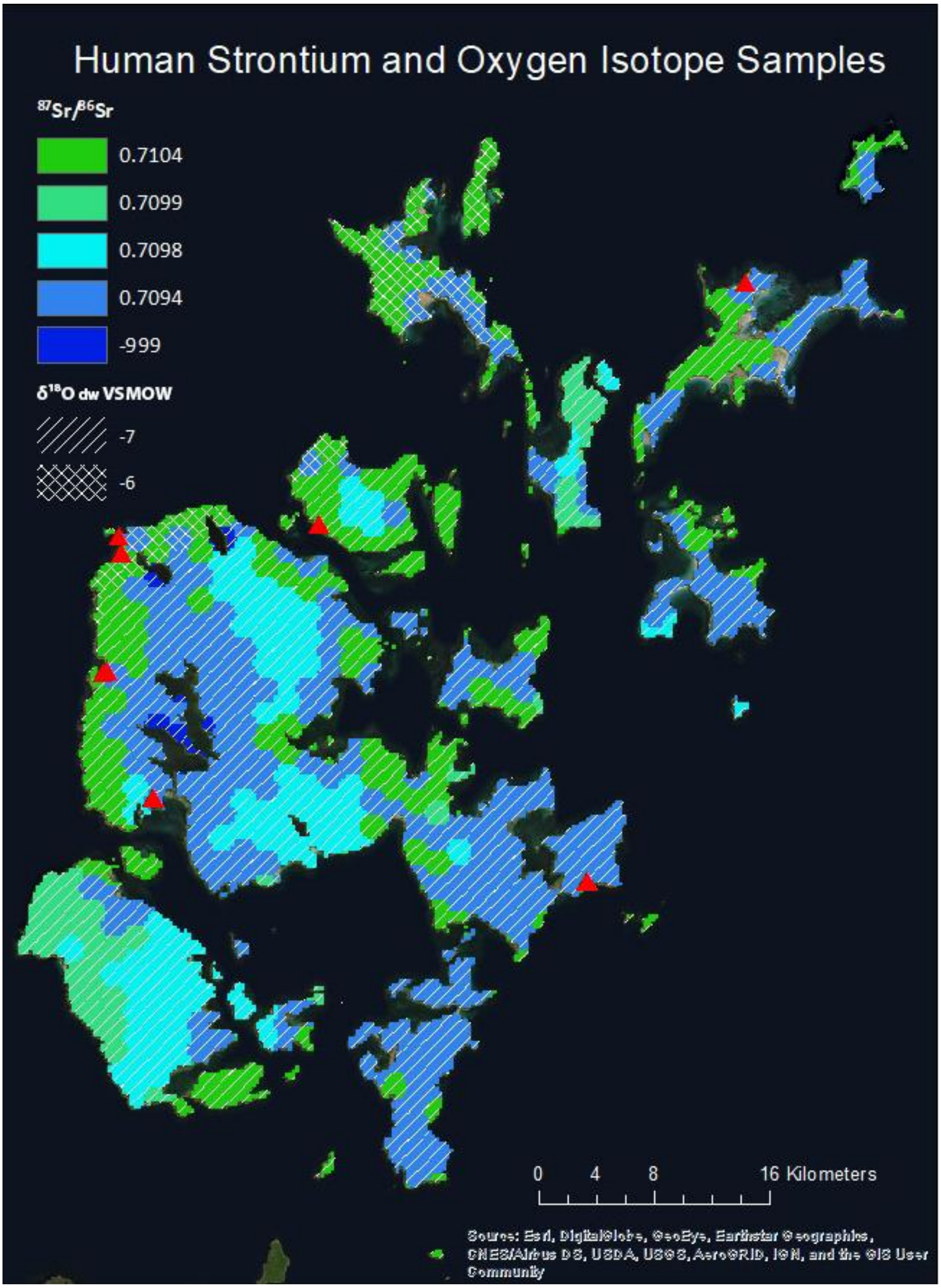

Figure 7.1. $^{87}Sr/^{86}Sr$ and $\delta^{18}O_{dw}$ V-SMOW (‰) isoscapes (Darling et al. 2003; Evans et al. 2010); with human enamel samples plotted as red triangles (this study; Snoeck et al. 2019) with additional Westness data from Montgomery et al. 2014.

7.1. Strontium isotopes

To establish a baseline of bioavailable strontium at different locations across Orkney, 27 plant samples were collected. Sample locations and strontium isotopes are provided in Table 7.2. and Figure 7.1. An ANOVA showed a significant difference in strontium isotopes between samples taken from within and without 500m from the coast (p=0.002). Therefore, all samples taken within 500m of the coast were designated as 'coastal', while samples taken from over 500m from the coast were listed as 'inland'. According to a Spearman's rho test, there was a significant positive correlation between strontium isotopes and distance from coast (r=0.623, p=0.000), meaning strontium isotopes increased as the distance from the coast increased. Strontium isotopes in the plant samples ranged from 0.70922-0.711581, with a mean of 0.70976 ± 0.00127 (2SD), broadly comparable with results from Montgomery et al. 2014 and Evans et al. 2010 who recorded a local range of between 0.7092 and 0.7100. Montgomery et al. 2014 refer to this range as the "strontium of doom," due to the ubiquity of such isotopes from individuals from coastal environments due to the "sea-spray" effect, as modern seawater is 0.7092. Due to the geology of Orkney and the plant strontium isotopes, it is very unlikely that any local human would have strontium measurements below 0.7092, so those individuals were considered non-local. The mean for human strontium isotopes was 0.70974 ± 0.0009 (2SD). Unfortunately, the majority of enamel samples (58) from this study resulted in strontium isotopes between 0.7092 and 0.7100, making them difficult to interpret. Regardless, when the human strontium isotopes were plotted using the plant strontium isotopes (±1SD) as the 'local' range (or between 0.7092 and 0.7101), three individuals had strontium isotopes below this range (Skaill Cist (M2), Scar 135 and Westness 5) and eight had strontium isotopes above (BY78AS, BY78CU, BUC081, NB 71(013)b, NB SK?ST12, Skaill Cist (M3), Westness 11 and Westness 12; Figures 7.3. and 7.4). Five individuals (BY78CU, Scar 135, Westness 5, Westness 11 and Westness 12) dated to the VA, while BY78AS and Skaill cist dated to the PVP and BUC081 dated to the LNP. BY78AS, BUC081, NB SK?ST12, Skaill Cist, Westness 11 and Westness 12 were younger to older adult males, while BU78CU, NB71(013)b and Westness 5 were young to middle adult females. Scar 135 was a juvenile between 10 and 11 years old. It should be mentioned that of the individuals identified as non-local based on their strontium isotopes, all of them except Westness 5 could have possibly been from elsewhere in Britain or Ireland (between 0.7078 and 0.7165, according to Evans et al. 2012).

Sample	Site	X Eastings	Y Northings	Sr	2SD	Distance from coast	Location
AJPL01	Bay of Skaill	323500	1019000	0.709744	0.000005	080m	Coastal
AJPL03	Bay of Skaill	323600	1019400	0.709358	0.000008	170m	Coastal
AJPL15	Cuween Cairn	336400	1012700	0.710955	0.000008	570m	Inland
AJPL17	Cuween Cairn	336400	1012700	0.711045	0.000007	600m	Inland
AJPL12	Kirkwall	336200	1013100	0.711581	0.000006	350m	Coastal
AJPL25	Kirkwall	336200	1012900	0.710935	0.000009	500m	Inland
AJPL14	Loch of Harray	330290	1012850	0.710615	0.000008	3400m	Inland
AJPL04	Scar	367900	1045800	0.709328	0.000010	060m	Coastal
AJPL23	Scar	367900	1045800	0.709263	0.000008	070m	Coastal
AJPL24	Scar	367900	1045800	0.709374	0.000008	070m	Coastal
AJPL27	Scar	367900	1045800	0.709339	0.000008	070m	Coastal
AJPL02	Scar	367900	1045700	0.709259	0.000007	130m	Coastal
AJPL11	Scar	367850	1045650	0.709239	0.000008	140m	Coastal
AJPL22	Scar	367900	1045700	0.709259	0.000007	150m	Coastal
AJPL05	Scar	368700	1045300	0.709393	0.000008	170m	Coastal
AJPL06	Scar	368700	1045300	0.709222	0.000009	170m	Coastal
AJPL19	Scar	368700	1045300	0.709344	0.000007	170m	Coastal
AJPL16	Scar	368700	1045300	0.709296	0.000008	175m	Coastal
AJPL07	Scar	368200	1045500	0.709346	0.000007	500m	Inland
AJPL08	Scar	368200	1045500	0.709349	0.000007	500m	Inland
AJPL20	Scar	368200	1045500	0.709310	0.000009	500m	Inland
AJPL21	Scar	368200	1045500	0.709220	0.000006	500m	Inland
AJPL26	Scar	368300	1045500	0.709748	0.000007	550m	Inland
AJPL09	Scar	368300	1045500	0.709374	0.000009	570m	Inland

AJPL10	Scar	368300	1045500	0.709867	0.000007	600m	Inland
AJPL18	Skaill House	323419	1018614	0.709403	0.000009	200m	Coastal
AJPL13	Skaill House	323419	1018614	0.709503	0.000009	230m	Coastal
MPL1	Westness	338259	1029029	0.71007	0.0004	260m	Coastal
MPL7	Westness	338582	1029093	0.71045	0.0004	600m	Inland
MPL6	Westness	338837	1029183	0.70949	0.0004	850m	Inland
MPL3	Westness	338431	1030724	0.70990	0.0004	1300m	Inland
MPL5	Westness	339452	1029483	0.70975	0.0004	1500m	Inland
MPL2	Westness	338480	1020049	0.71048	0.0004	1950m	Inland
MPL4	Westness	340070	1029680	0.70959	0.0004	2200m	Inland

Table 7.2. Plant $^{87}Sr/^{86}Sr$ results from this study (all AJPL samples; Snoeck et al. 2020) as well as from Montgomery et al. 2014 (all MPL samples).

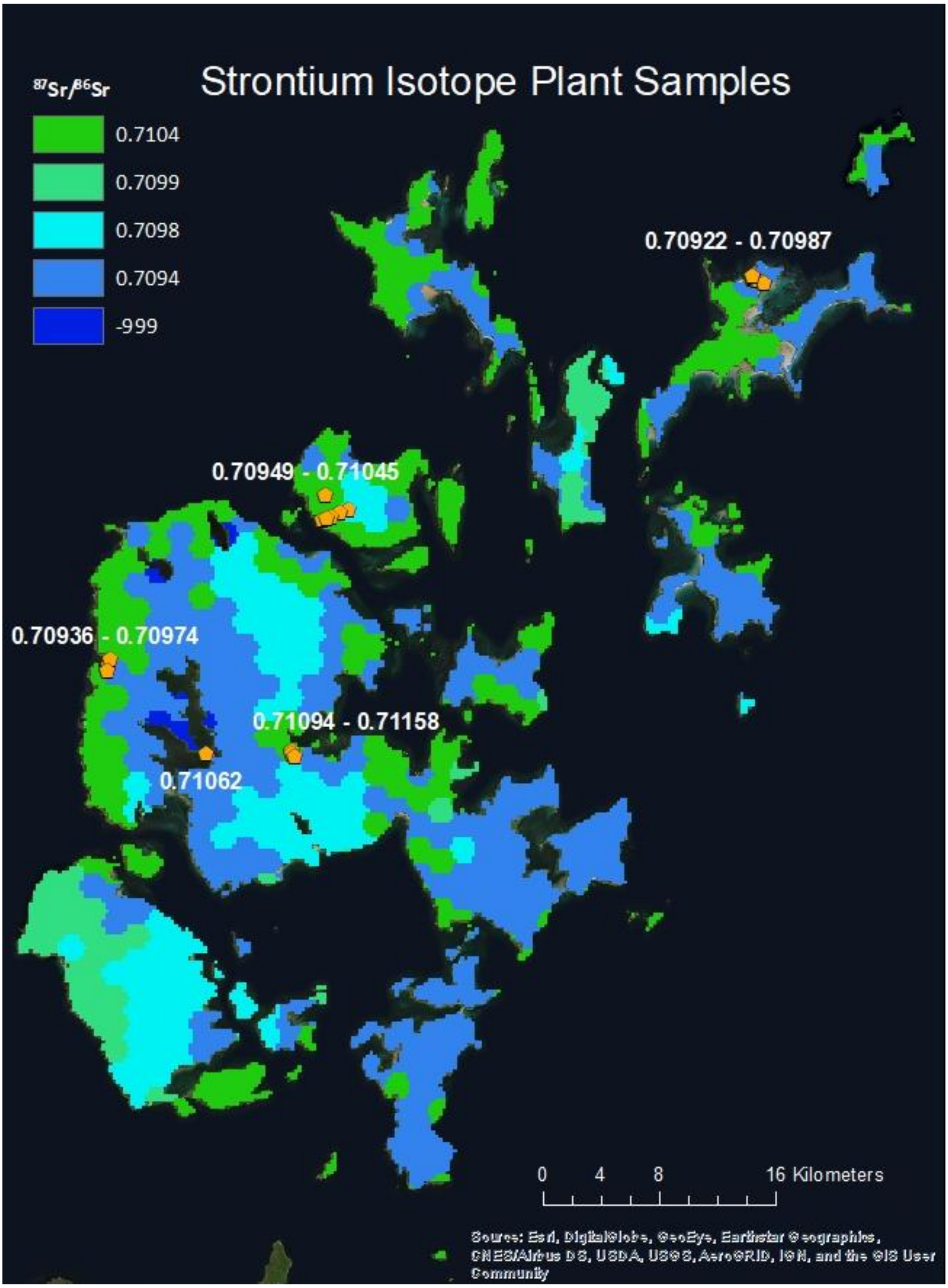

Figure 7.2. Strontium baseline isoscape constructed predominantly from plants (Evans et al. 2010; BGS 2020) with plotted plant samples (orange pentagons) and measured strontium isotope ranges (this study; Westness data from Montgomery et al. 2014).

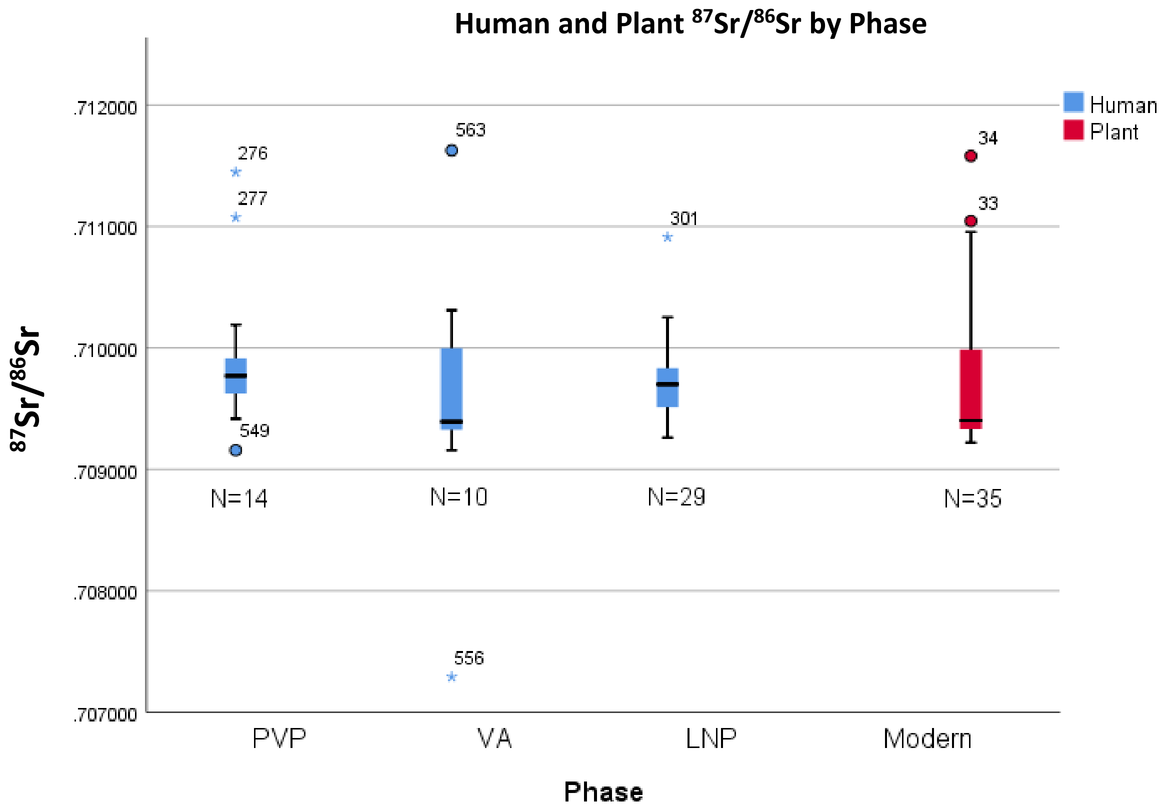

Figure 7.3. Human and plant $^{87}Sr/^{86}Sr$ isotope ranges by phase. Human samples included those collected during this study as well as three Westness individuals by Montgomery et al. 2014. All plant samples were modern (this study; Evans et al. 2010; Montgomery et al. 2014). N= number of samples. Label numbers refer to database entry numbers.

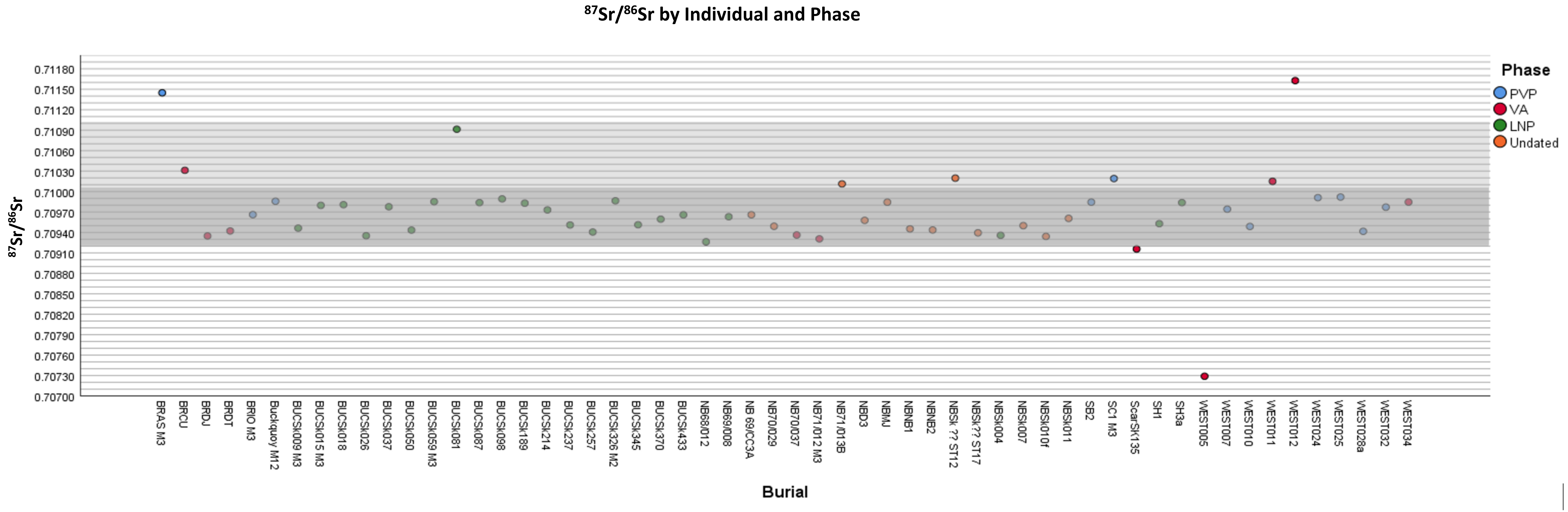

Figure 7.4. $^{87}Sr/^{86}Sr$ isotopes by individual burial and phase (human data from this study; Montgomery et al. 2014). The light grey box delineates the 'local' strontium range, as defined by the plant samples, 0.709760 ± 0.00127 (2SD), while the dark grey box delineates the local range as defined by the plant samples within 1SD (0.709466 ± 0.00063). The dotted green line illustrates the isotope for seawater, 0.7092 (Montgomery et al. 2014). Site names are abbreviated thusly: BY78= Brough Road, BUC = Bu of Cairston, NB= Newark Bay, SB= Skara Brae, SC= Skaill Cist, SH= Skaill House, WEST= Westness. Westness 5, 11 and 32 are from Montgomery et al. (2014).

Strontium concentrations were also measured for each enamel sample using multi-collector-inductively coupled plasma mass spectrometry (MC-ICP-MS) and normalized to 40% calcium (Snoeck et al. 2019). Strontium concentrations can be affected by underlying geology, proximity to seawater and the use of seaweed as animal fodder; higher concentrations have been found in coastal populations (Evans et al. 2012, 756; Montgomery et al. 2010; 2014,63; Neil 2017, 386). Unfortunately, it was not possible to test the correlation between distance from sea and strontium concentration as part of this study as the precise distance between each burial (or burial site) from the sea was not provided in excavation reports. While Montgomery et al. 2014 and Evans et al. 2012 reported a wide range of strontium concentrations (mostly between 84 and 417 ppm) throughout Britain and Ireland, their results were achieved using thermal ionization mass spectrometry (TIMS). Unfortunately, a lack of verified methods for comparing strontium concentrations from ICP-MS and TIMS prevents the direct comparison of values between the two methods (Snoeck et al. 2016; Weis et al. 2006). Therefore, only strontium concentrations measured as part of this study were included in analyses.

Mean strontium concentrations from tooth enamel in this study were 251 ppm, with a range between 140 and 491 ppm (Figure 7.5). There was a significant and negative correlation between strontium isotope ratios and concentrations ($r=-0.378$, $p=0.002$). Although boat grave 34 from Westness exhibited strontium isotopes within the local range, it stood out as an outlier in terms of concentration, with 491 ppm. Once this outlier was removed, there was a significant negative correlation between strontium isotopes and concentrations ($r= -0.433$, $p=0.000$).

As previously mentioned, strontium concentrations can be affected by proximity to the coast (e.g., sea-spray on terrestrial crops; Walser et al. 2020). The correlation between strontium concentration and carbonate $\delta^{13}C$ values (indicative of all diet, not only protein) were tested within each phase. In the PVP and VA, there was no significant correlation (PVP: $p=0.643$, VA: $p=0.427$), while in the LNP, there was a significant positive correlation between carbonate $\delta^{13}C$ and strontium concentration (r=0.509, p=0.007). When all phases were combined, there was a significant positive correlation between strontium concentration and carbonate $\delta^{13}C$ (r=0.392, p=0.001).

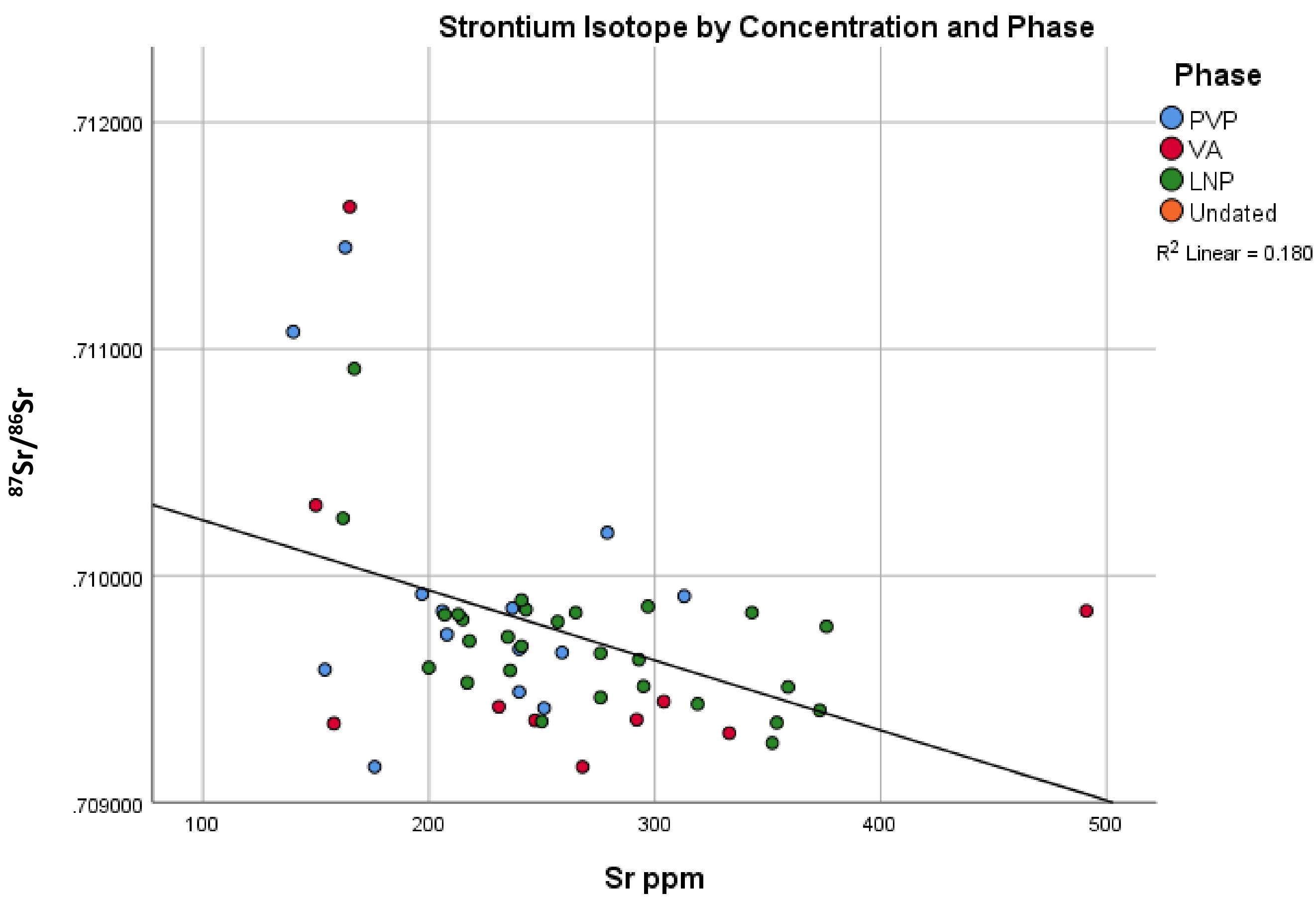

Figure 7.5. $^{87}Sr/^{86}Sr$ and strontium concentrations by phase.

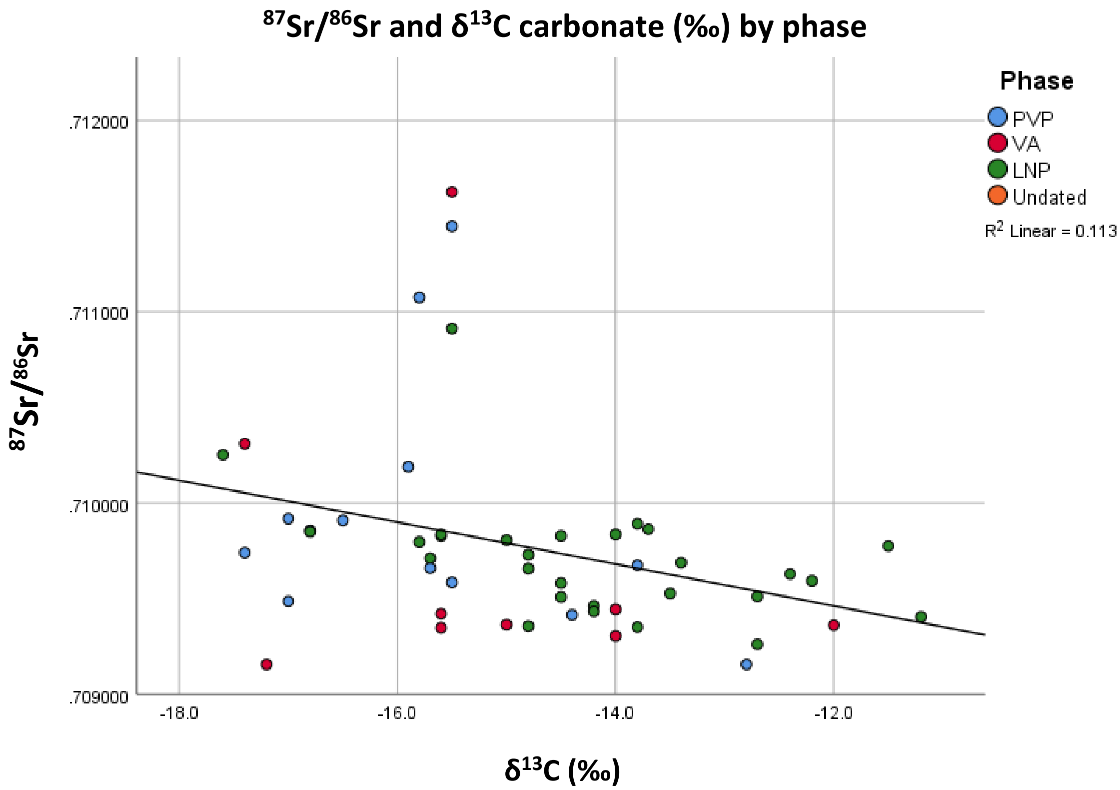

Figure 7.6. $^{87}Sr/^{86}Sr$ plotted against carbonate δ^{13}C (‰), with linear regression line.

7.2. Oxygen isotopes

A total of 61 teeth (51 individuals) provided oxygen isotope ($\delta^{18}O_{C\ (VPDB)}$) results. In addition, two Westness individuals (graves 5 and 11) with $\delta^{18}O_p$ measured by Montgomery et al. (2014) were included in this analysis. To compare the human $\delta^{18}O_C$ results with the baseline established by Evans et al. 2010 and Montgomery and Evans 2006, $\delta^{18}O_{C\ (VPDB)}$ isotopes were converted to $\delta^{18}O_{C\ (SMOW)}$ (Coplen 1988; Pollard 2012; 89), then from $\delta^{18}O_{C\ (SMOW)}$ to $\delta^{18}O_{p\ (SMOW)}$ using the equation by Chenery et al. 2012. Raw data and conversions are in Table 7.1, above. Equations used were as follows:

1) $\delta^{18}O_{C\ (SMOW)} = (1.03091 \times \delta^{18}O_{C\ (VPDB)}) + 30.910‰$ (Coplen 1988).

2) $\delta^{18}O_{P\ (SMOW)}$ (± 0.56‰, 2SD) = $(1.0322 \times \delta^{18}O_{C\ (SMOW)}) - 9.6849$ (Chenery et al. 2012).

Evans et al. (2012) and Montgomery et al. (2014, 62) cite the mean $\delta^{18}O_p$ for Britain as 17.7‰ ± 1.4‰ (2SD, which encompassed 95% of locals within a range of 16.3‰ to 19.1‰) based on a total of 615 archaeological tooth enamel samples. When including Montgomery and colleagues' (2014) $\delta^{18}O_p$ results and using the former range as the local range for Britain, there were a total of nine individuals who fell outside of these bounds (after accounting for the analytical margin of error)- four males and five females comprising BY78IO, BUC026, BUC037, BUC098, NB 70(29), NBSK?ST14, Westness 11, Westness 12 and Westness 24. All these individuals except Westness 11 and Westness 12 exhibited strontium isotope values within the local range (±2SD). Two molars (M2 and M3) were sampled from two of these individuals: BY78IO and NBSK?ST14. In both individuals, the M2s exhibited (calculated) $\delta^{18}O_p$ values inconsistent with the range for Britain (20.5‰ ± 0.56‰ and 20.3‰ ± 0.56‰, respectively). Enamel $\delta^{18}O_p$ from both individuals' M3s, however, fell within the normal range of the British Isles (18.6‰ ± 0.56‰ and 18.8‰ ± 0.56‰, respectively). While the M2 sampled from Westness 12 as part of this study exhibited a $\delta^{18}O_p$ value within the local range (16.3‰), the P1 sampled from Westness 12 as part of Montgomery et al. 2014's study provided a $\delta^{18}O_p$ value of 15.4‰, below the local range. Individuals whose $\delta^{18}O_p$ values were within the local range (once the margin of error for converting $\delta^{18}O_c$ to $\delta^{18}O_p$ (0.56‰) was accounted for) were considered local.

While NBSK?ST14 (from Newark Bay) is not yet dated, BY78IO (from Brough Road) and Westness 24 date to the PVP (BP 1705 ± 80 or cal. AD 445-614, within 95% probability; estimated % marine diet was used to adjust for the marine reservoir effect using OxCal v.4.3). Westness 11 dates to the VA and BU037 and BU098 from Bu of Cairston date to the LNP. Of the individuals that fell outside of the local range, only two (Westness 11 and Westness 12) had $\delta^{18}O_p$ values too low to be considered local (15.5‰ and 15.4‰, respectively). The others all exhibited $\delta^{18}O_p$ values too high to be local. What this means regarding the possible origins for these non-locals will be discussed in Chapter 8.

Next, the local mean for Orkney of 18.2‰ ± 1.0‰ (2SD, which provides a range of 17.2‰ to 19.2‰ for 95% of the population, as provided by Evans et al. 2012) was used to separate local Orcadians from individuals who may have been from other parts of Britain. There was a total of 11 individuals that fell outside of the local range as currently understood (Figure 7.7). This included three individuals who fell within the local range for Britain, but not for Orkney itself. Of these 11 individuals, two were from the PVP (male burial BY78IO and female burial Westness 24). Three non-Orcadians (two males and one individual of unknown sex) dated to the VA (Scar 135, Westness 11 and 12) and four dated to the LNP (three females and one male including BUC015, BUC026, BUC037 and BUC098). Two individuals who did not fall within the Orcadian $\delta^{18}O_p$ local range have not yet been dated (NB70/29 and NBSK?ST14). Interestingly, at least one non-local female dated to the PVP but none dated to the VA. One of the undated females (NB 70/29) may date to the VA, but radiocarbon dating is needed to confirm that. A chart of $\delta^{18}O_p$ isotopes by sex and phase is provided in Figure 7.8., followed by a chart showing all individuals in this study and how they plot according to both strontium and oxygen local isotopes (Figure 7.9). Based on both strontium and oxygen isotopes, a total of 19 individuals (21 teeth) were identified as originating outside of the Orkney Isles. Nine of these individuals exhibited $\delta^{18}O_p$ outside of the range for Britain (16.3‰-19.1‰) and twelve individuals not falling within the strontium isotope range for Orkney (0.7092-0.7101). Although this study will define the 'local' Sr isotope range as within 1SD of the local plant values (between 0.7092 and 0.7101), variability in $\delta^{18}O_p$ caused by food/drink processing including brewing, boiling or stewing limit our ability to interpret $\delta^{18}O_p$ with the same resolution (Royer et al. 2017; Tuross et al. 2017). 'Local' $\delta^{18}O_p$ values will be from here on refer to isotopes between 16.3‰ and 19.1‰, per Evans et al. (2012) and Montgomery et al. (2014).

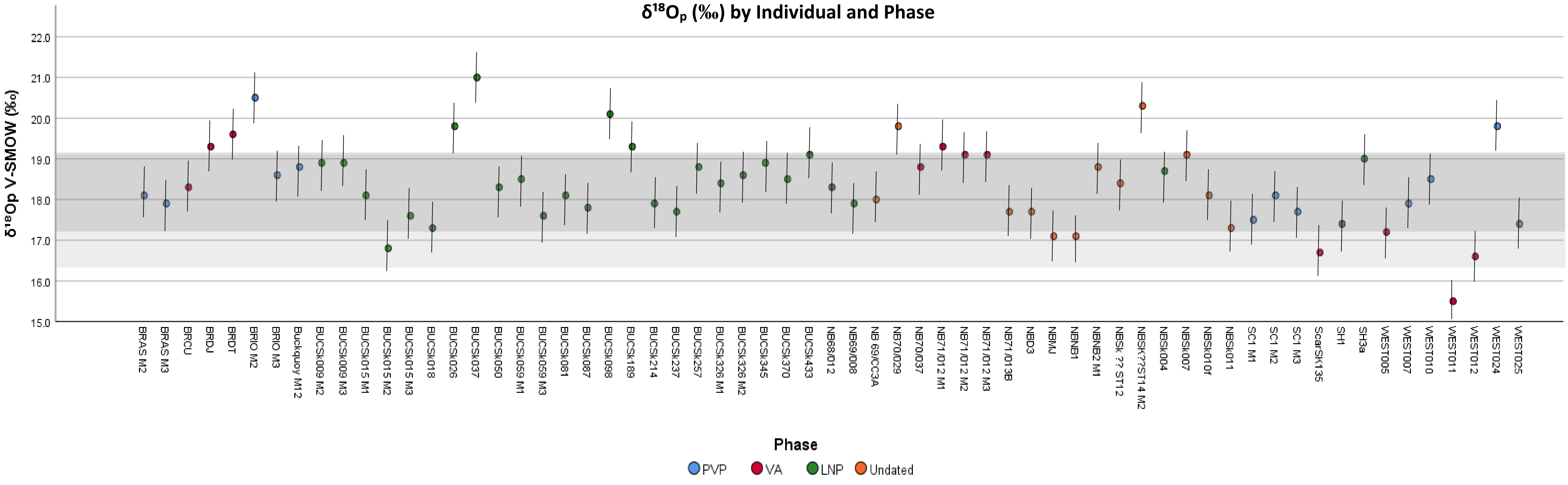

Figure 7.7. Enamel δ18Op (‰) by individual and phase. The light grey box delineates the established local range for Britain (16.3‰-19.1‰ [2SD]; Evans et al. 2012; Montgomery et al. 2014), while the inset darker grey box delineates the established local range for areas of higher precipitation, the Scottish Isles in particular (17.2‰-19.2‰, 2SD; Evans et al. 2012). The error bars represent the margin of error for converting $\delta^{18}O_c$ to $\delta^{18}O_p$ (0.56‰). Human data are from this study and Montgomery et al. 2014.

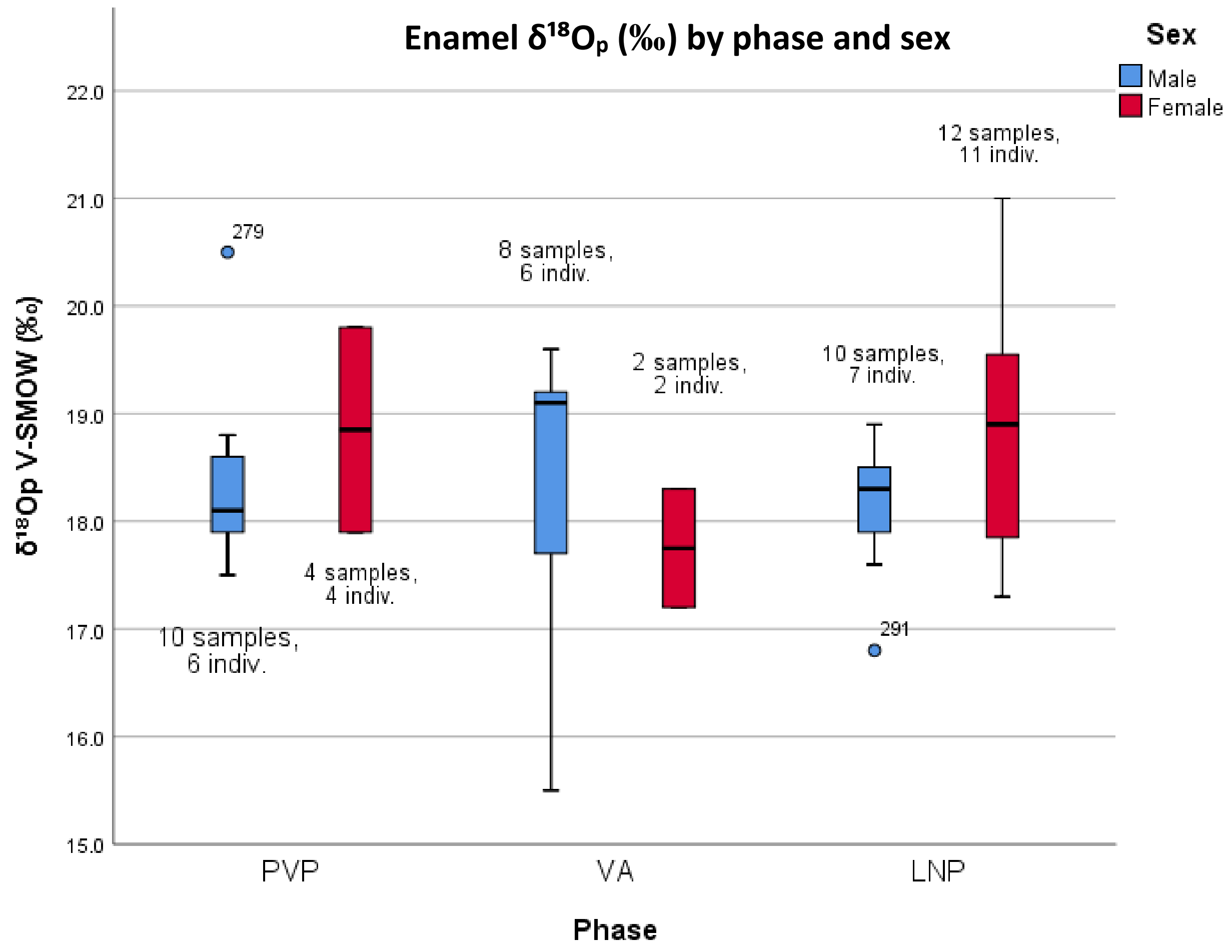

Figure 7.8. Enamel $\delta^{18}O_p$ (‰) ranges by phase and sex (this study; Montgomery et al. 2014). Case numbers 279 and 291 (outliers) correspond with burials BY78IO and BU015, respectively.

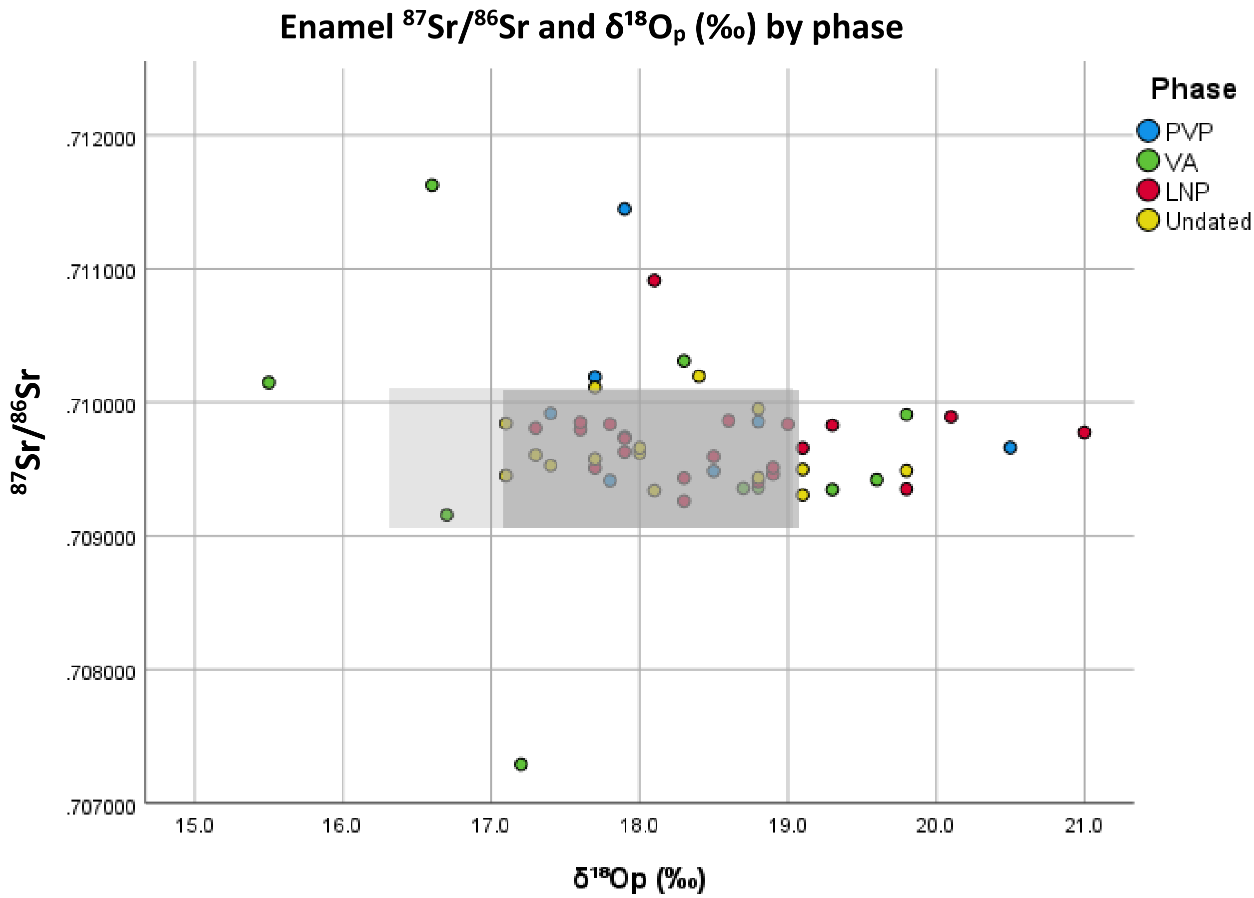

Figure 7.9. Enamel $^{87}Sr/^{86}Sr$ and $\delta^{18}O_p$ (‰) by phase (this study; Montgomery et al. 2014). The light grey box delineates the local Orkney range for Sr (between 0.7092 and 0.7101, 1SD) and the local British range for $\delta^{18}O_p$ (between 16.3‰ and 19.1‰), while the darker grey box delineates the 'local' Orkney range for Sr as well as for $\delta^{18}O_p$ (17.2‰ to -19.2‰). Individual $\delta^{18}O_p$ (‰) values within 0.56‰ (error margin) of the local range were considered local.

7.3. Diet, health and mobility

Next, diet and osteological indicators of health between 'locals' and 'non-locals' (non-Orcadians), as determined by strontium and oxygen isotopes, were compared to test whether 'non-locals' (potentially from Scandinavia or elsewhere in Britain) exhibited different life experiences, as evidenced by osteological indicators of health, including prevalence rates of nutritional deficiencies, infectious diseases, trauma, occupational stress markers and dietary isotopes.

7.3.1. Osteological indicators of health and isotopic indicators of mobility

As discussed in Chapter 2, the VA brought substantial changes in agriculture, settlement and subsistence practices. Had the impetus for these large-scale changes been the immigration of culturally distinctive practices, one might expect to see changes in the prevalence, distribution or severity of osteological indicators of health, diet and physical labour in certain individuals, perhaps initially in the non-local individuals. To test this, the prevalence of osteological markers of nutritional deficiency, infection, dental pathology and trauma were compared between local and non-local (non-Orcadian) individuals. Non-normally distributed nominal data were tested using Chi^2, while scale data was tested using ANOVA and ordinal data was tested using Kruskal-Wallis tests (Table 7.3). Unfortunately, the number of individuals with 'mobility' isotopes was too small to compare (statistically) females and males separately in the PVP. When all individuals juvenile and older were included, however, there were significantly greater prevalence rates of mandibular tori (p=0.023) and nearly greater prevalence rates of platymeria (p=0.053) among locals versus non-locals. In the VA, local males continued to show a greater prevalence of mandibular tori (p=0.046) and a higher prevalence of occupational/accidental trauma (p=0.025). Among all VA individuals (juvenile and older) non-locals exhibited greater average stages of calculus (p=0.035). In the LNP, the sample size was limited to seven males and ten females. Comparison of mandibular tori between local and non-local males or females was not possible due to the lack of individuals with tori. Non-local males exhibited a higher prevalence of OA of the shoulder (p=0.008) and specific infections (p=0.008), while local LNP males exhibited higher a prevalence rate of non-specific infections (p=0.008). Among LNP females, LEHs were more prevalent among non-local females (p=0.016). When all phases were combined, local males overall exhibited a higher prevalence rate of non-specific infection (p=0.046). Non-local females in all phases exhibited a higher prevalence of LEHs (p=0.014) as well as periostitis (p=0.035). Interpretations of the prevalence in both indicators and why they might differ between locals and locals will be addressed in Chapter 8.

	PVP		*VA*				*LNP*						*All phases*					
Pathology	All Sexes		Males		All Sexes		Males		Females		All Sexes		Males		Females		All Sexes	
	Chi² p	N	Chi² P	N	Chi² p	N	Chi² p	N	Chi² p	N	Chi² p	N	Chi² p	N	Chi² p	N	Chi² p	N
Stature	0.495	8	0.646	3	0.421	6	NA	4	NA		NA		0.618	12	0.314	11	0.592	24
CO	0.257	9	1.000	4	0.809	7	NA	5	0.439	6	0.461	11	0.494	18	0.770	15	0.414	36
CO Stage	0.676	7	0.480	3	1.000	5	0.617	5	0.346	4	0.294	9	0.281	15	0.917	12	0.419	30
PH	0.453	9	0.248	4	0.764	9	NA	4	0.809	7	0.649	14	0.402	17	0.707	17	0.613	41
Cribra femora	0.090	8	NA	3	0.439	6	0.659	7	0.290	7	0.308	14	0.383	16	0.330	16	0.208	33
Scurvy	NA	11	0.248	4	1.000	10	0.495	7	0.880	10	0.950	21	0.435	23	0.856	22	0.537	54
Rickets	0.428	11	NA	4	NA	10	0.659	7	NA	10	0.619	21	0.280	23	NA	22	0.329	54
Nutritional deficiency	0.658	11	NA	4	0.197	10	NA	7	0.260	10	0.586	21	0.636	23	0.211	22	0.876	54
Calc scale	0.232	10	0.182	5	**0.035**	**11**	0.186	7	0.557	10	0.745	21	0.184	23	0.150	21	**0.043**	**53**
Caries	0.301	10	0.171	5	0.064	11	0.624	6	0.301	10	0.348	20	0.563	22	0.240	22	0.822	53
No. caries	0.329	9	0.272	5	0.114	11	0.704	5	0.389	10	0.396	20	0.621	20	0.563	22	0.772	52
AMTL	0.303	11	0.361	5	0.197	10	0.212	7	0.880	10	0.605	18	0.484	22	0.058	21	0.061	48
Periodontal disease	0.201	11	0.361	5	0.778	10	0.212	7	0.301	10	0.946	19	0.416	22	0.776	21	0.624	49
Abscesses	0.428	11	0.248	4	0.343	9	0.088	7	0.301	10	0.736	21	0.266	23	0.240	22	0.181	53
No. Abscess	0.479	11	0.495	5	0.477	10	0.117	6	0.389	10	0.962	21	0.231	23	0.179	22	0.111	54
Avg Wear	0.801	10	1.000	4	0.555	11	0.408	7	0.789	10	0.294	21	0.483	22	0.639	22		
LEH	0.635	9	1.000	4	0.197	10	0.659	7	**0.016**	**10**	0.172	21	0.829	19	**0.014**	**22**	0.157	50
No. of LEHs	0.170	9	0.698	4	0.218	10	0.721	6	0.096	10	**0.042**	**20**	0.580	18	0.057	22	**0.041**	**49**
Loadbearing	0.428	11	NA	5	0.621	11	0.659	7	0.635	9	0.648	20	0.439	24	0.378	21	0.407	54
OA	0.428	11	0.361	5	0.376	11	0.495	7	0.490	10	0.916	21	1.000	24	0.512	22	0.949	55
Platymeria	0.053	7	0.248	4	0.659	7	NA	4	0.386	3	0.495	7	0.707	14	0.197	10	0.386	24
Platycnemia	NA	7	NA	4	NA	4	NA	2	NA	6	NA	2	NA	8	0.212	7	0.205	15
OD	NA	10	NA	5	0.168	8	NA	6	NA	6	NA	13	0.523	18	NA	116	0.510	37
OA Verts	0.490	10	0.248	4	0.270	7	0.171	5	0.386	3	0.858	9	0.091	17	0.679	12	0.264	32
OA Shoulder	0.091	10	0.361	5	0.659	7	**0.008**	**7**	NA	4	**0.001**	**12**	0.436	20	0.279	13	0.777	36

OA Hands	0.408	8	NA	5	NA	7	0.439	6	NA	5	0.217	12	0.513	16	0.371	12	0.429	31
OA Knees	0.257	9	NA	5	NA	9	NA	6	NA	8	NA	16	0.506	17	0.687	16	0.653	37
OA Feet	0.673	8	NA	4	0.439	6	0.361	5	NA	3	0.880	10	0.597	14	0.465	8	0.780	26
OA Elbows	0.428	11	0.505	4	0.273	6	0.439	6	0.624	6	0.448	15	0.179	19	0.360	15	0.145	39
OA Hips	0.343	9	0.136	5	0.465	8	0.273	6	1.000	6	0.292	15	0.502	18	0.667	15	0.658	38
OA Jaw	NA	11	NA	3	NA	8	NA	7	NA	9	NA	19	NA	20	NA	21	NA	48
OA STC	0.091	10	0.505	4	1.000	6	0.624	6	NA	3	0.708	9	0.070	18	0.310	12	0.581	32
Squatting facets	NA	6	NA	3	NA	4	NA	1	NA	1	NA	2	0.439	6	0.809	7	0.764	13
Mandibular torus	0.023	9	**0.046**	**4**	0.147	7	NA	5	NA	6	NA	11	0.086	17	1.000	12	0.214	31
Periostitis	0.477	11	0.361	5	0.122	11	0.350	7	0.098	10	0.292	21	0.204	24	**0.035**	**22**	0.270	55
Spec infection	0.898	11	NA	5	NA	11	**0.008**	**7**	NA	10	**0.035**	**21**	0.190	24	0.262	22	0.645	55
Non-specific infection	0.477	11	0.709	5	0.137	11	**0.008**	**7**	0.490	10	0.916	21	**0.046**	**24**	0.141	22	0.592	55
Pathology	0.165	11	NA	5	0.251	11	NA	7	0.880	10	0.950	21	0.149	24	0.907	22	0.722	56
Violent Trauma	NA	11	0.171	5	0.154	11	NA	6	0.301	10	0.456	20	0.214	23	0.387	22	0.663	55
Occupational/ Accidental Injuries	0.898	11	**0.025**	**5**	**0.006**	**11**	0.350	7	NA	10	0.364	21	0.074	24	0.531	22	0.401	56

Table 7.3. Results (p values) of Chi^2, ANOVA, Spearman's rho tests comparing the prevalence of osteological markers of health and nutrition between local and non-local individuals by sex and phase. Bold p values indicate a statistical significance at α= 0.05. N= number of recordable individuals; LEH= linear enamel hypoplasia; OA= osteoarthritis.

7.3.2. Bone collagen δ^{13}C and δ^{15}N and mobility

As discussed in Chapter 2, dietary differences can be strongly culturally and economically driven. To determine whether an increase in marine resource consumption in the VA was related to an influx of immigrants with a more seafood-reliant dietary tradition, bone collagen δ^{13}C and δ^{15}N isotopes were compared between local and non-local individuals. When local and non-local (non-Orcadian) individuals were divided by phase then statistically tested for significant differences in diet based on bone collagen δ^{13}C and δ^{15}N (Table 7.4., below), LNP local females exhibited nearly higher δ^{15}N values than non-local LNP females (p=0.055, means of 11.4‰ and 14.0‰, respectively), with no significant difference in δ^{13}C values. Unfortunately, the limited number of samples did not provide enough data to compare PVP and VA local and non-local females.

	Males					***Females***					***All***				
Phase	ANOVA		Levene		N	ANOVA		Levene		N	ANOVA		Levene		N
	δ^{13}C	δ^{15}N	δ^{13}C	δ^{15}N		δ^{13}C	δ^{15}N	δ^{13}C	δ^{15}N		δ^{13}C	δ^{15}N	δ^{13}C	δ^{15}N	
PVP	0.655	0.533	0.522	0.126	5	NA	NA	NA	NA	3	0.143	0.261	0.297	0.072	8
VA	0.703	0.445	**0.000**	**0.000**	4	NA	NA	NA	NA	1	0.627	0.747	0.625	0.947	10
LNP	0.522	0.127	NA	NA	7	0.364	0.055	0.995	0.233	10	0.598	0.223	0.318	**0.005**	20
All	0.391	0.806	0.627	0.495	22	0.451	0.262	0.993	0.315	20	0.335	0.436	0.903	0.247	52

Table 7.4. ANOVA and Levene test results (p values) for local versus non-local bone collagen δ^{13}C and δ^{15}N. Bold p values indicate a statistical significance at α= 0.05.

As a strontium isotope of 0.7092 can be indicative of proximity to the coast (due to sea-spray), strontium isotopes and concentrations were compared with bone δ^{13}C and δ^{15}N isotopes to test if marine protein consumption correlated with proximity to the coast. A Spearman's rho showed no significant correlation between either strontium isotopes and bone δ^{13}C and δ^{15}N values (p=0.670 and 0.876, respectively) or strontium concentrations and bone δ^{13}C and δ^{15}N values (p=0.091 and 0.184). A correlation between strontium isotopes and concentrations and bone δ^{13}C and δ^{15}N values was not necessarily expected, since bone δ^{13}C and δ^{15}N values are derived from protein intake, while digested strontium isotopes and concentrations are primarily derived from plants rather than protein (Johnson et al. 2019, 1367).

In the PVP, there are no significant differences in bone $\delta^{13}C$ and $\delta^{15}N$ isotopes between sexes when only local individuals were compared (p=0.328 and 0.743), nor was there a difference in bone $\delta^{13}C$ and $\delta^{15}N$ values between sexes when only non-locals were compared (p=0.339 and 0.677). In the VA, locals did not show a significant difference in bone $\delta^{13}C$ and $\delta^{15}N$ values between sexes (p=0.319 and 0.681), however, non-local males exhibited significantly higher bone $\delta^{13}C$ values than non-local females (p=0.000). There were higher $\delta^{15}N$ values (but not significantly) between sexes of non-locals (p=0.062). In the LNP, locals showed no difference in either bone $\delta^{13}C$ and $\delta^{15}N$ values between sexes (p=0.541 and 0.642) and neither did non-locals (p=0.277 and 0.266).

In no phase were there significant differences in bone $\delta^{13}C$ and $\delta^{15}N$ values between local and non-local males or females (PVP: p=0.655 and 0.533, VA: P=0.703 and 0.445, LNP: p=0.522 and 0.127). There was, however, greater variability in $\delta^{13}C$ and $\delta^{15}N$ values in local VA males than in non-local VA males (p=0.000 and 0.000) (Levene's test results in Table 7.4).

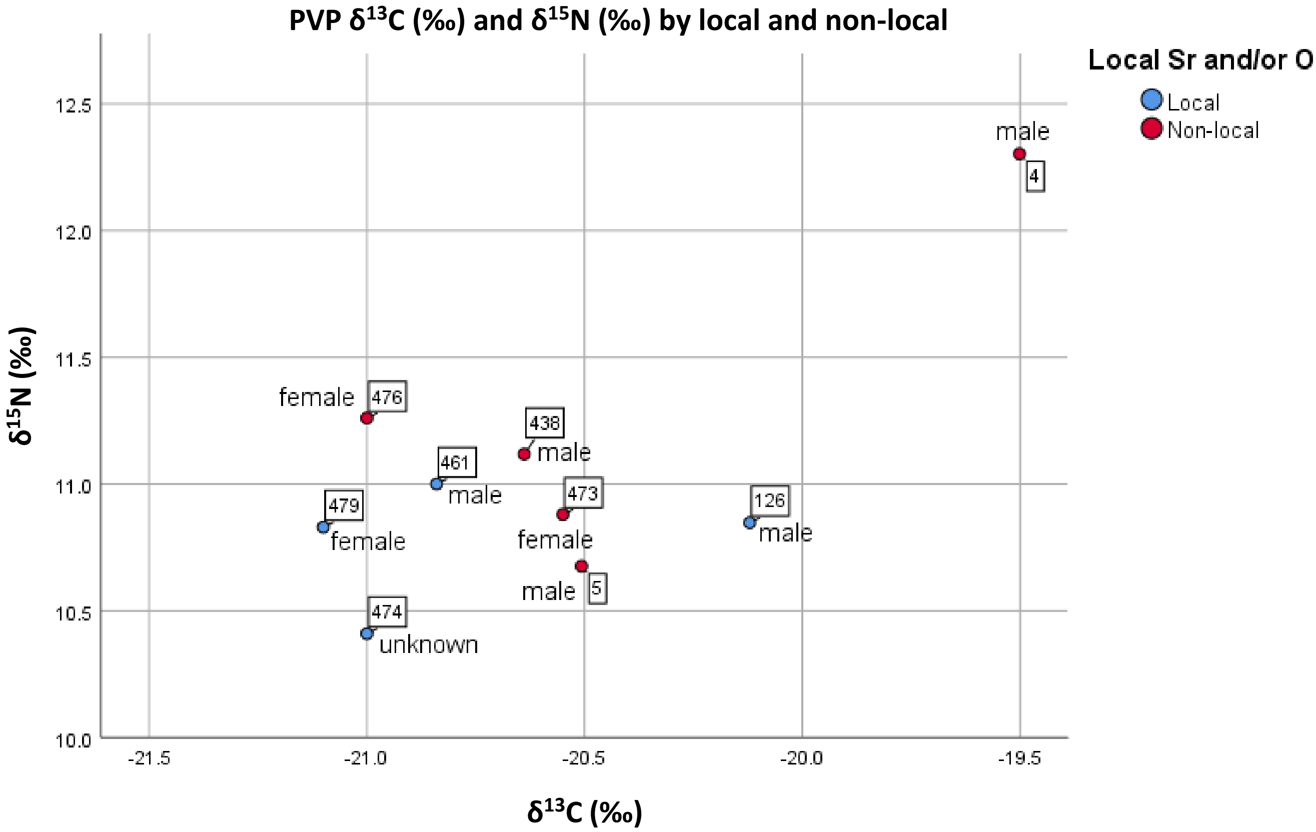

Figure 7.10. PVP $\delta^{13}C$ (‰) and $\delta^{15}N$ (‰) by local and non-local males and females.

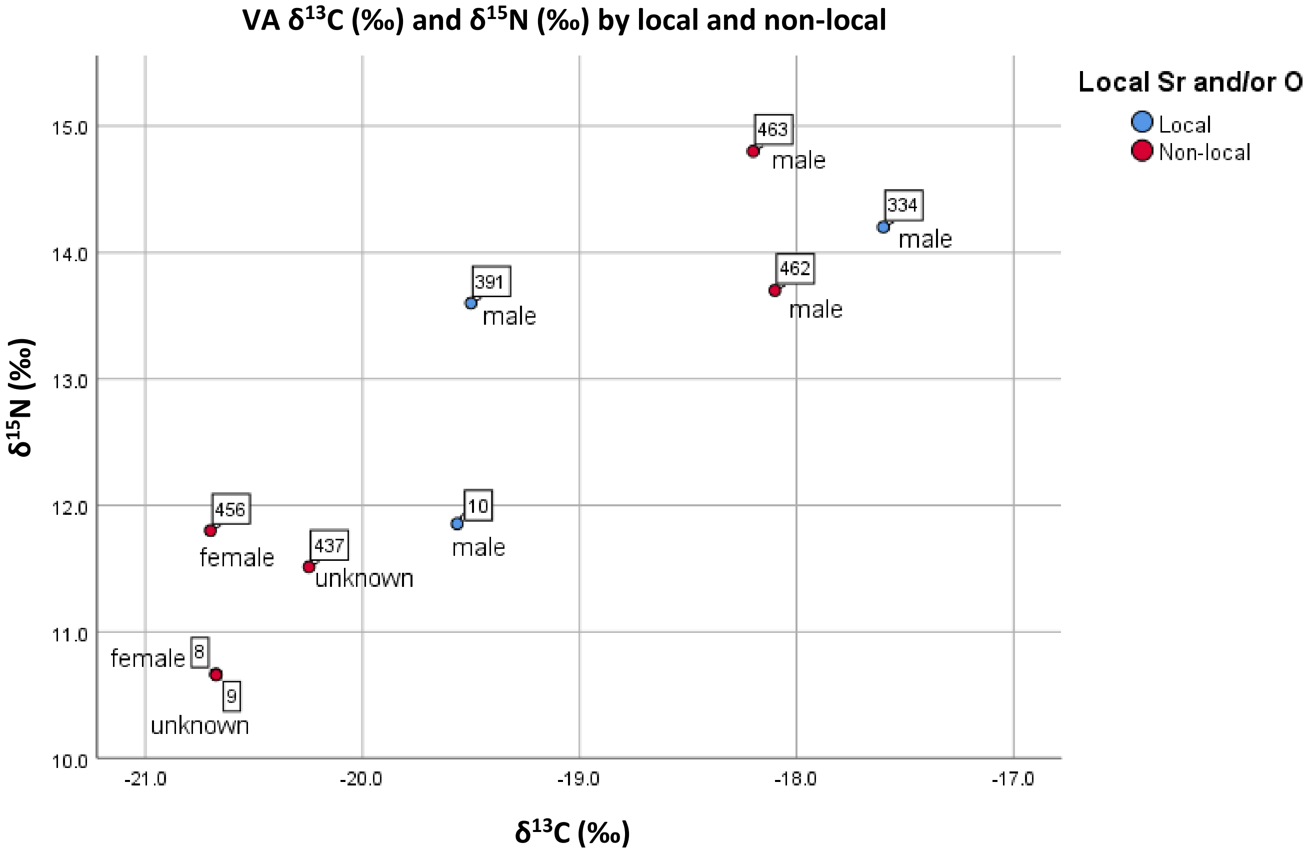

Figure 7.11. VA $\delta^{13}C$ (‰) and $\delta^{15}N$ (‰) by local and non-local males and females.

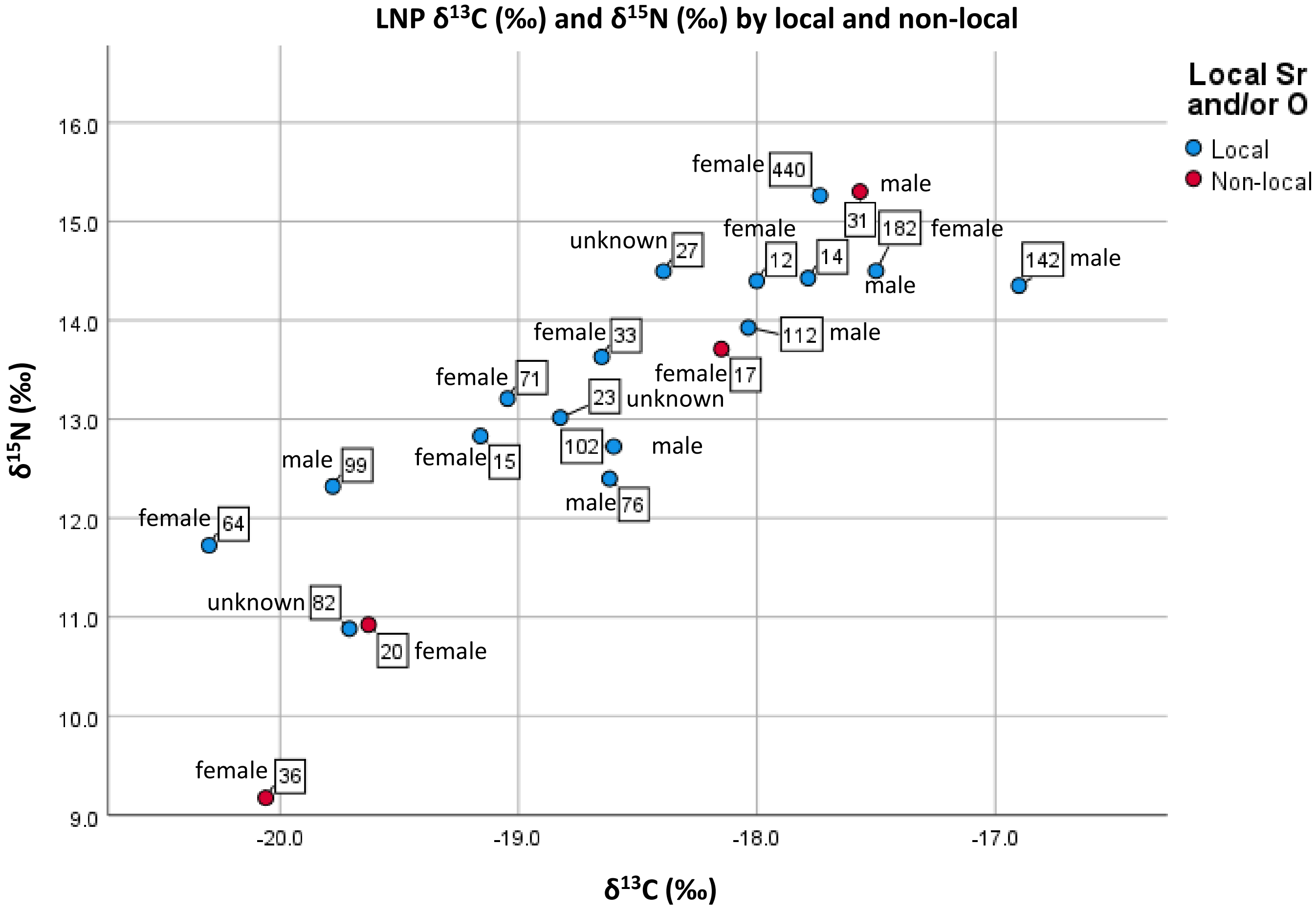

Figure 7.12. LNP $\delta^{13}C$ (‰) and $\delta^{15}N$ (‰) by local and non-local males and females.

7.3.3. Dentine $\delta^{13}C$ and $\delta^{15}N$ and mobility

Trends in dentine $\delta^{13}C$ and $\delta^{15}N$ were next compared between local and non-local individuals to test whether differences in dietary trends between sexes may have originally begun as a non-local tradition and if there were differences in weaning signals and childhood diet between locals and non-locals. As detailed in Chapter 6.2, dentine $\delta^{13}C$ and $\delta^{15}N$ values from each individual were averaged within each of seven age groups. ANOVA tests were then run by age group, between locals and non-locals (and males and females, when possible) in each phase. Dentine samples were taken from the first molars of eight individuals, representing diet from around birth to three years old. Included were four individuals from the PVP, two from the VA and two from the LNP. Most individuals exhibited strontium and oxygen isotopes within the local Orkney range, while two individuals (Skaill Cist from the PVP and

Scar 135 from the VA) were considered 'non-local' based on their strontium and/or oxygen isotopes. When phase was controlled for using a general linear model, there were no significant differences in mean $\delta^{13}C$ or $\delta^{15}N$ values of the 0-2.9-year-old age group between locals and non-locals (p=0.118 and 0.826). When tested within the PVP and VA/LNP, this test confirmed there were no significant differences between locals and non-locals in either phase (PVP: p=0.783 and 0.252; VA: p=0.260 and 0.176). When all individuals were included (and again, phase was controlled for) there was no significant correlation between $\delta^{13}C$ or $\delta^{15}N$ values of the age group 0-2.9 years and the ages at death (p=0.224 and 0.778). Unfortunately, there were no known females in this age group so a comparison between sexes was not possible. Among the PVP individuals, a slight increase in $\delta^{13}C$ values was observable between birth and two years in all the local individuals, while the non-local individual exhibited a more dramatic decrease in $\delta^{15}N$ values (nearly a 5.0‰ decline from around birth to three years old). While only three points were visible in the trendline of the non-local (Skaill Cist), six samples were taken within this age range but had to be combined (due to dentine preservation) to weigh enough for measurement using the mass spectrometer (≥0.300mg). Among the VA and LNP individuals, the non-local's trendline was consistently lower than that of the local individuals, though mean $\delta^{13}C$ and $\delta^{15}N$ values over this age were not significantly different (p=0.260 and 0.176). Comparison of these trendlines with previous studies on weaning signals and childhood diet and possible interpretations will be presented in Chapter 8.

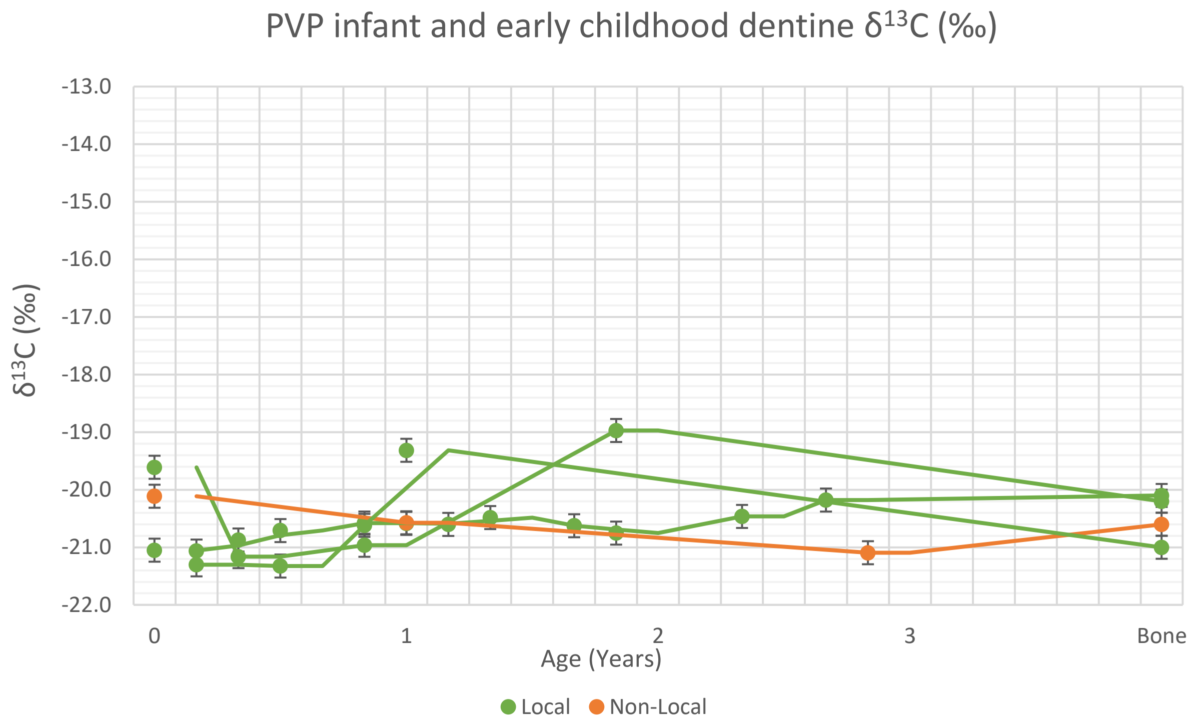

Figure 7.13. PVP infant and early childhood $\delta^{13}C$ (‰) of four individuals from around birth to three years old.

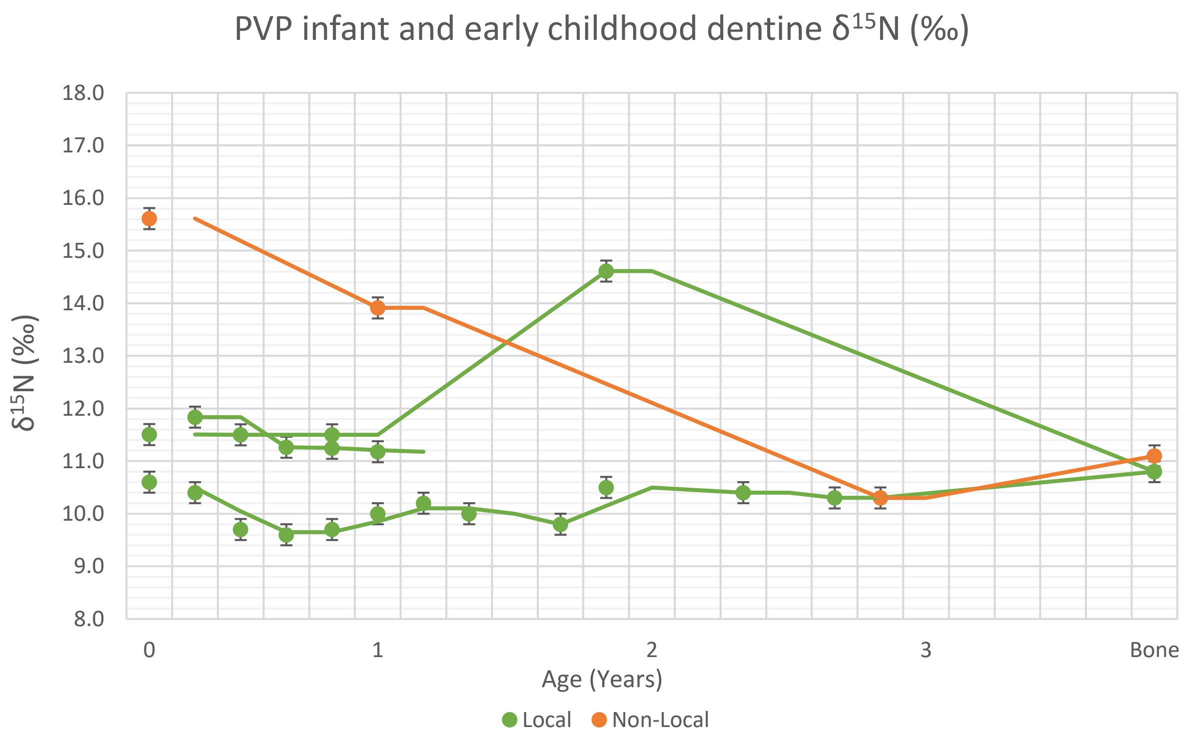

Figure 7.14. PVP infant and early childhood $\delta^{15}N$ (‰) of four individuals from around birth to three years old.

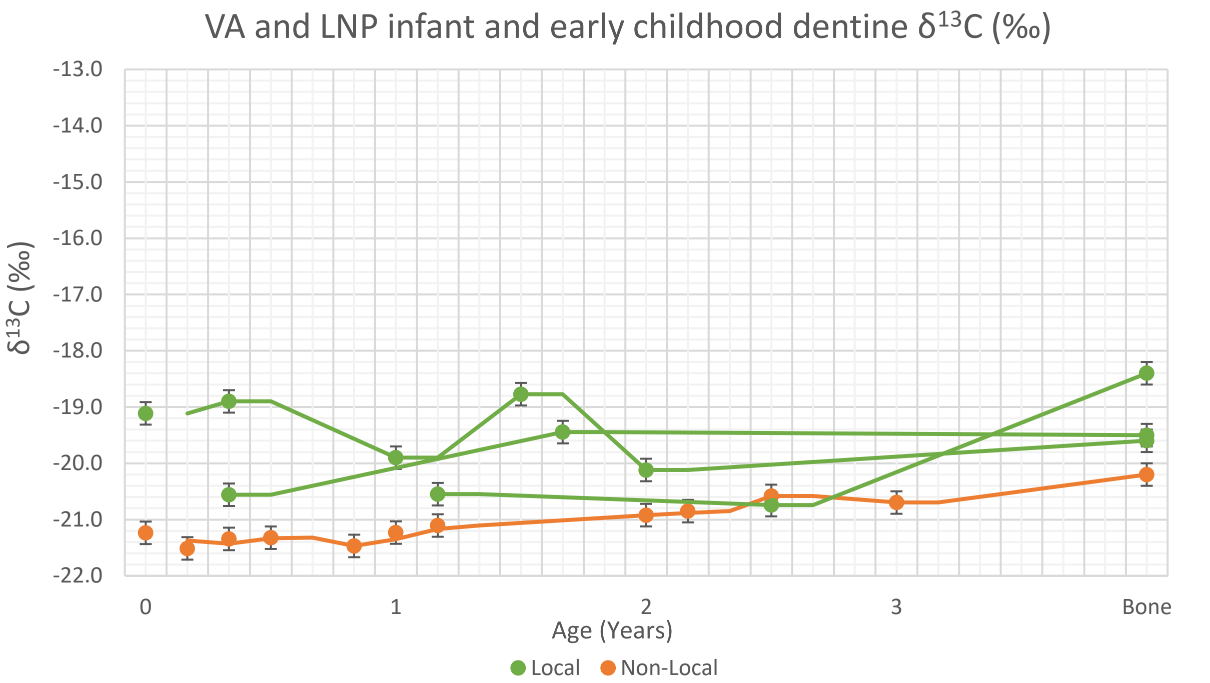

Figure 7.15. VA and LNP infant and early childhood δ^{13}C (‰) of four individuals from around birth to three years old.

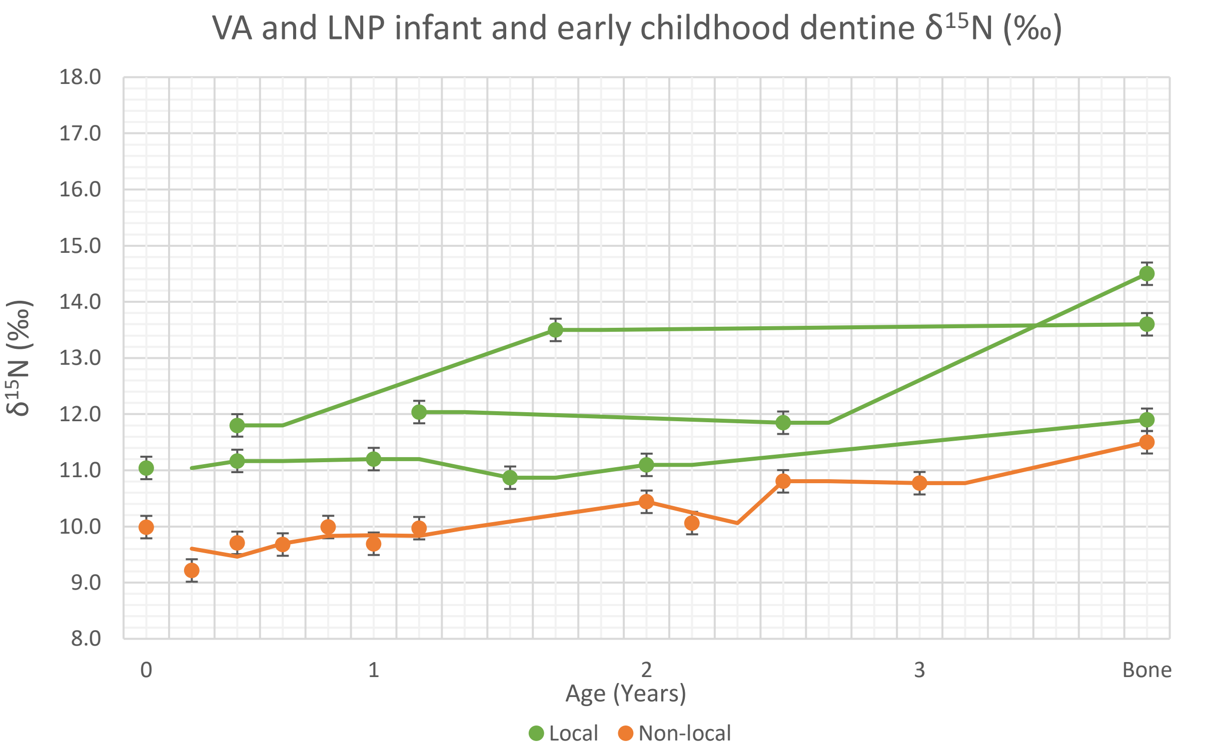

Figure 7.16. VA and LNP infant and early childhood δ^{15}N (‰) of four individuals from around birth to three years old.

In the PVP, non-local individuals aged 13-16.9 years exhibited higher $\delta^{15}N$ values than locals of the same age group (p=0.039); however, the sample size was limited to two non-locals and three local individuals. Both local and non-local individuals exhibited dentine $\delta^{13}C$ means within 1.0‰ of their bone collagen values in the PVP and all but one individual (Skaill Cist) exhibited dentine $\delta^{15}N$ means within 1.0‰ of their bone collagen values, suggesting little to no difference in diet between adolescence/early adulthood and diet later in adulthood (in approximately the last 10 years of life, depending on bone turnover rate). Although sample size did not allow for statistical comparison of every age group within each sex and phase, the results of all possible statistical comparisons are provided in Table 7.5., below. The maximum VA inter-point undulation in $\delta^{15}N$ was 4.9‰, from a non-local male (Westness 12), while the maximum LNP inter-point undulation in $\delta^{13}C$ was 2.6‰ from a local female. Most individuals (6 out of 11) in the VA and LNP exhibited a difference of ≥ 1.5‰ between their adolescent/young adult dentine means and bone collagen $\delta^{13}C$ and $\delta^{15}N$. The greater difference in the VA and LNP between adolescent dentine means and bone collagen values suggests diet continued to change after the age of 17.5-20.

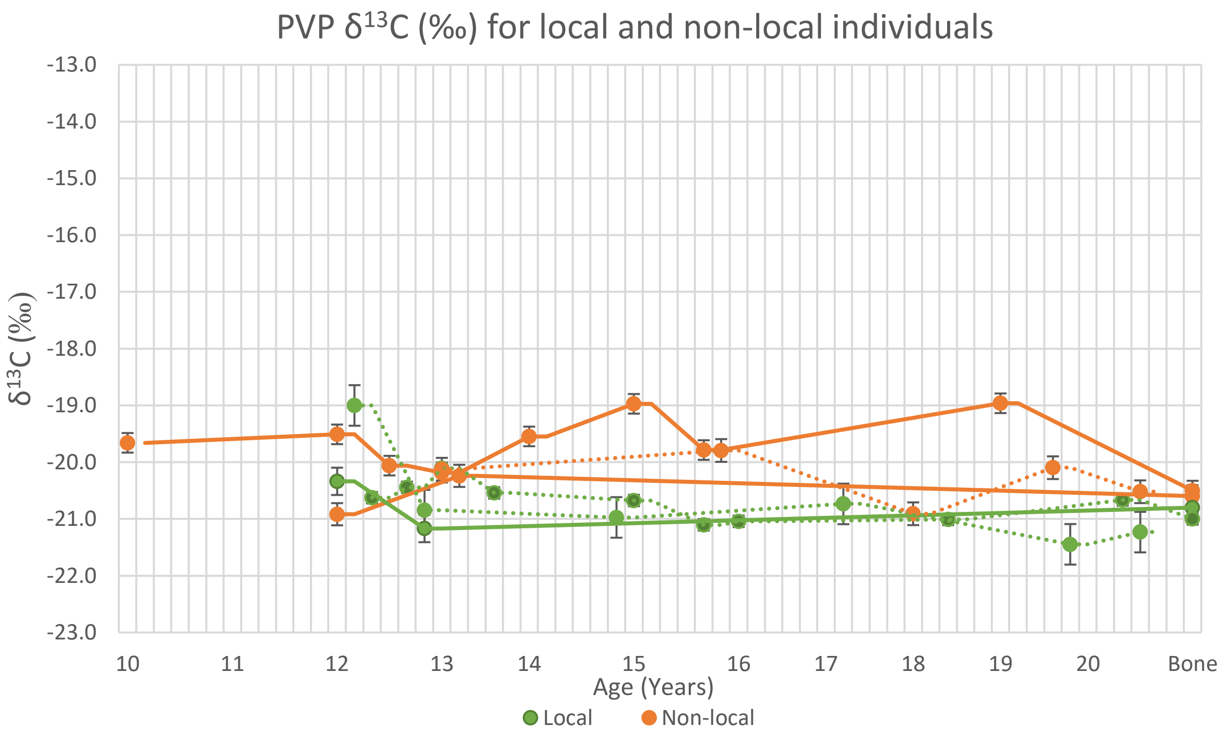

Figure 7.17. PVP dentine δ13C (‰) for local and non-local individuals. Solid trendlines indicate male and dashed trendlines indicate female.

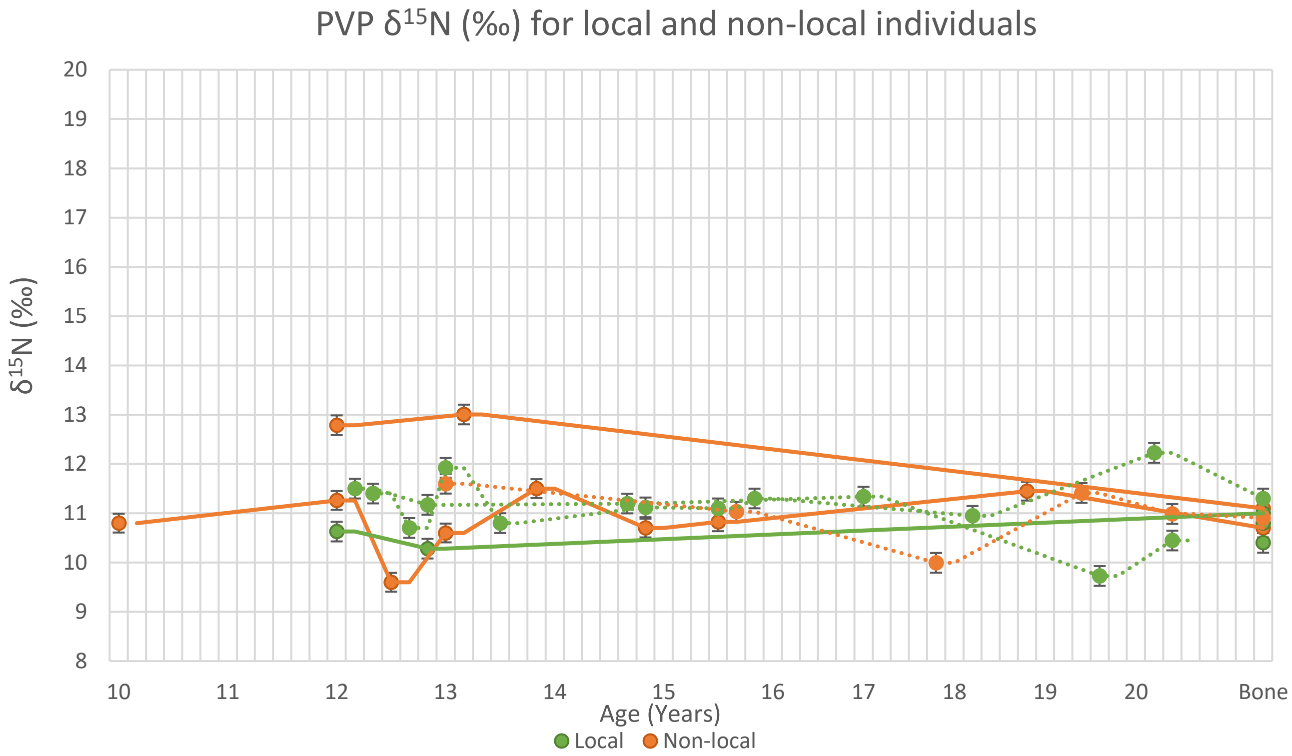

Figure 7.18. PVP dentine $\delta^{15}N$ (‰) for local and non-local individuals. Solid trendlines indicate male and dashed trendlines indicate female.

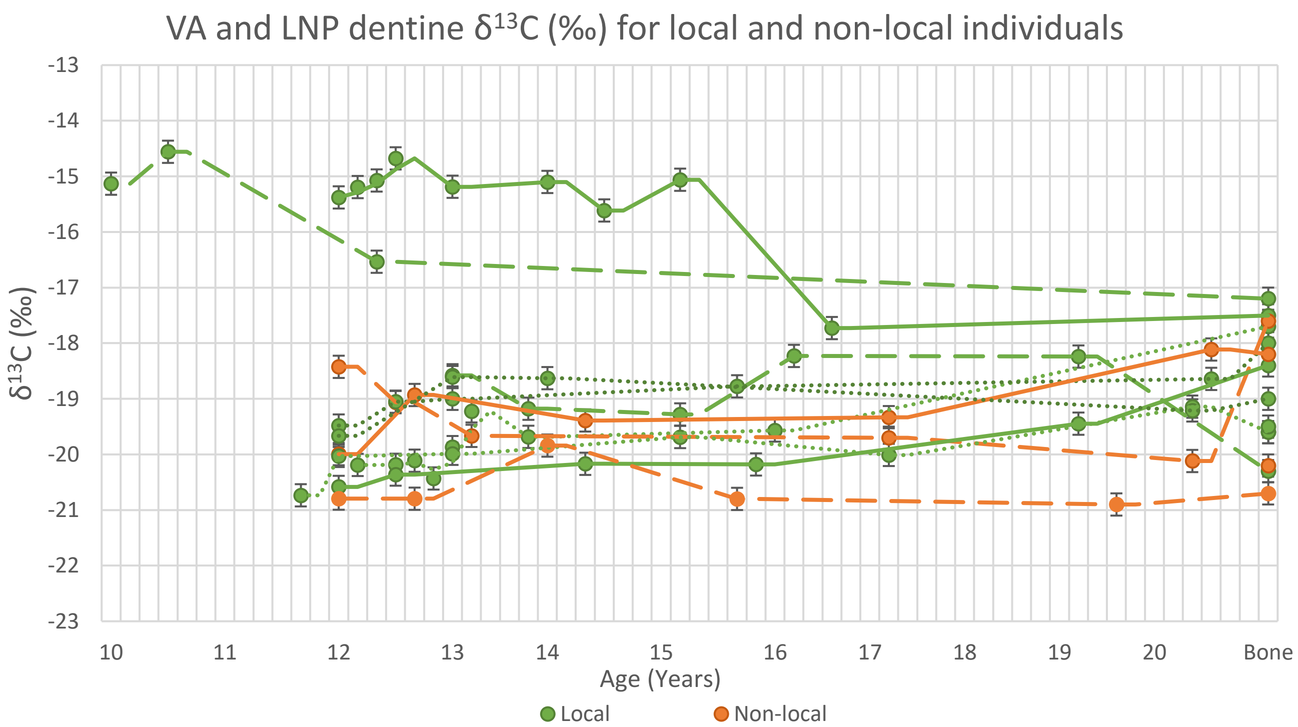

Figure 7.19. VA and LNP dentine $\delta^{13}C$ (‰) values for local and non-local individuals, 10 years+. Solid trendlines indicate male, dashed trendlines indicate female and dotted trendlines indicate unknown sex.

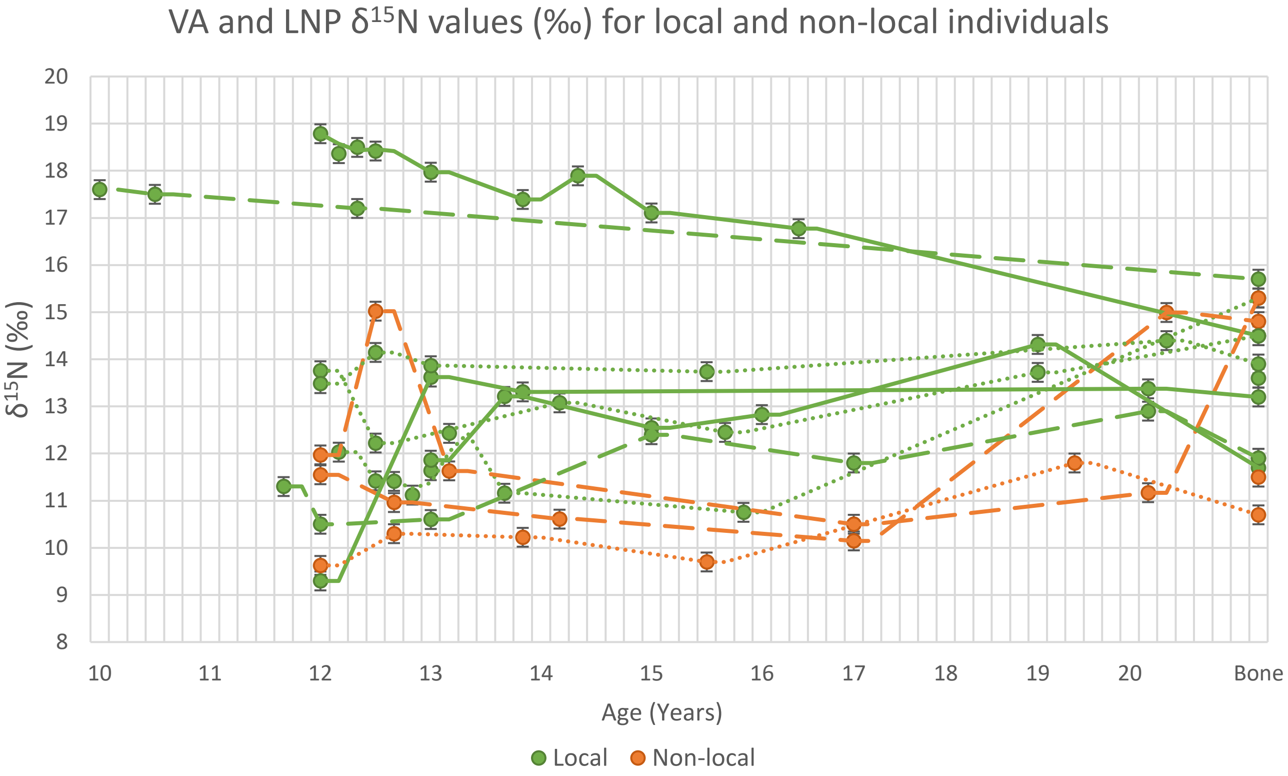

Figure 7.20. VA and LNP dentine $\delta^{15}N$ values (‰) for local and non-local individuals, 10 years+. Solid trendlines indicate male, dashed trendlines indicate female and dotted trendlines indicate unknown sex.

	PVP					**VA and LNP**					**All Phases**				
	ANOVA		**Levene**			**ANOVA**		**Levene**			**ANOVA**		**Levene**		**N**
Age range	$\delta^{13}C$ (p)	$\delta^{15}N$ (p)	$\delta^{13}C$ (p)	$\delta^{15}N$ (p)	N	$\delta^{13}C$ (p)	$\delta^{15}N$ (p)	$\delta^{13}C$ (p)	$\delta^{15}N$ (p)	N	$\delta^{13}C$ (p)	$\delta^{15}N$ (p)	$\delta^{13}C$ (p)	$\delta^{15}N$ (p)	
0-2.9 years	0.783	0.252	NA	NA	4	0.260	0.176	NA	NA	4	0.118	0.826	0.458	0.470	8
3-4.9 years	0.291	0.575	NA	NA	3	0.534	0.354	NA	NA	3	0.126	0.459	0.485	0.331	6
5-6.9 years	0.262	0.224	NA	NA	3	NA	NA	NA	NA	2	0.379	0.849	0.106	0.143	5
7-9.9 years	0.612	0.542	**0.000**	**0.000**	4	0.434	0.493	0.105	0.168	5	0.642	0.758	0.219	0.155	12
10-12.9 years	0.901	0.464	0.136	**0.008**	5	0.225	0.372	0.110	0.184	12	0.302	0.437	0.066	**0.041**	19
13-16.9 years	**0.039**	0.567	0.602	0.073	5	0.100	0.106	0.404	0.550	11	0.207	0.133	0.059	0.350	18
17-20.5 years	0.253	0.944	**0.000**	**0.000**	4	0.121	0.159	0.335	0.694	9	0.670	0.257	0.540	0.501	13

Table 7.5. Results of ANOVA and Levene tests (p values) for comparing local and non-local diets by age group and phase. Bold p values indicate a statistical significance at α= 0.05.

7.4. Mobility isotope conclusions

To determine which individuals were of local (Orcadian) origin and which were non-local, enamel strontium and oxygen samples were taken from 68 teeth. In addition, strontium data from three previously sampled Westness individuals (graves 5, 11 and 32) were incorporated into the present dataset for statistical analysis (Montgomery et al. 2014). A total of 27 plant samples were collected from throughout Orkney. These plant samples combined with the previously measured eight plant samples (Evans et al. 2012; Montgomery et al. 2014) were used to provide a baseline of expected strontium isotopes throughout Orkney. The plant material measured as part of this study corresponded approximately with the 'local' range previously set forth of between 0.7092 and 0.7101 (*ibid.*). Four individuals (BY78AS from the PVP and Westness 5, Westness 12 and Scar 135 from the VA) fell outside of this local range. Notably, one of the four non-locals (Westness 5) was a female.

Sixty-one teeth (51 individuals) provided $\delta^{18}O_C$ results. These results were converted from VPDB to VSMOW (per Coplen 1988) and then to the approximated equivalent in phosphate (per Chenery et al. 2012). Based on the established baseline range by Evans et al. (2012) and Montgomery et al. (2014) of 17.2‰-19.8‰ for the Orkney Isles, 17 individuals were categorized as not being from Orkney. Furthermore, the range for Britain established by Chenery et al. 2010 and in Evans et al. (2012) was used to determine that seven of the 17 individuals were likely not to have originated in Britain. A discussion on the possible origins of these non-locals is provided in Chapter 8.

Incorporating the enamel strontium isotope and concentration and oxygen isotope results as indicators of mobility, the prevalence of osteological indicators of health and nutrition, bone collagen and patterns in dentine $\delta^{13}C$ and $\delta^{15}N$ values were compared between local and non-local individuals. Comparison of prevalence rates of nutritional deficiencies, diseases and markers of physical labour between local and non-local individuals was done to determine whether non-locals and locals partook in different physical activities/occupations or were susceptible to different pathological conditions. Additionally, skeletal evidence for load-bearing was compared to determine whether there was evidence for occupational differences between the two groups. Indeed, there was a significantly higher prevalence of OA of the verts among non-locals in the VA than locals. In addition, there was a higher prevalence of cribra femora among non-local males than local males in the LNP.

Eight individuals were sampled for sequential dentine from a first molar to compare $\delta^{13}C$ and $\delta^{15}N$ values from infancy and early childhood (birth to about three years of age) and then from adolescence to early adulthood (10 to 20.5 years old). When $\delta^{13}C$ and $\delta^{15}N$ values in infancy were compared between locals and non-locals, the VA non-local exhibited consistently lower $\delta^{13}C$ and $\delta^{15}N$ values. The small sample size limits possible interpretations, however. Both adult locals and non-locals in the PVP exhibited dentine means within 1.0‰ of their respective bone collagen values, suggesting similar diets continued through adulthood. In the VA and LNP, non-locals aged 17-20.5 exhibited higher $\delta^{15}N$ values than their local counterparts. Interestingly, there was a greater disparity between bone collagen and mean dentine $\delta^{13}C$ and $\delta^{15}N$ in the VA and LNP than there was in the PVP, which indicates a greater difference between adolescent and adulthood diet after around AD 800. Although sample sizes were small, these trends in dentine profiles through infancy and adolescence/young adulthood could imply differences in the accessibility of resources between locals and non-locals, as well as support ideas of cultural impact on diet. This will be further discussed in Chapter 8.

Chapter 8. Summary and Discussion

8.1. Health and human development through the Pictish/Norse transition and into the Late Norse Phase

Osteological evidence presents a window into how the human body has been affected by occupational, economic and subsistence transitions through changes in the prevalence of nutritional and pathological markers on the skeleton and teeth. Dietary stable isotope analysis provides a complementary view of changes in diet that may have accompanied these occupational or economic transitions. As discussed in Chapter 2, the Viking Age has been portrayed as a period of cultural and economic transitions not only in Orkney but across the North Atlantic region. Bioarchaeological evidence for agriculture and husbandry practices suggest a pre-Viking Orcadian economy as constituting many dispersed and self-sustaining farmsteads scattered across the archipelago. There is evidence for an emerging hierarchical network of specialised sites that worked together to distribute a growing range of products, produce agricultural surplus and supply goods to high-status sites beginning in the Viking Age. The production of a surplus for an emerging market-based economy was supported by improvements and expansions in agriculture (such as plaggen soil formation and land-clearance to expand arable farming), the introduction of oats and flax (to enable overwintering of animals and diversify occupations), an increased focus on dairying at certain sites and the large-scale exploitation of marine resources. While previous studies of dietary stable isotopes of the Orkney population have supported a significant increase in marine resource exploitation in the tenth century, how else were health, nutrition and diet affected by these substantial economic changes?

If the model for the beginnings of a large-scale transition to a market-based economy with a growing (largely immigrant) population and increasingly specialised sites to provide goods to high-status sites is to be represented osteologically and/or isotopically, what could we expect to see? Regarding demographic profiles, one might expect a rise in the ratio of males to females in the Viking Age, with raiding predominantly being undertaken by young and middle adult males. Because of the disparity in pre-Viking stature means between Orcadians and Scandinavians, we might expect to see an increase in male Orcadian stature means in the Viking Age and Late Norse phase with Scandinavian settlement. We might also expect greater stature means among males with Scandinavian grave goods (if in fact, grave goods were symbolic of Scandinavian ancestry). The movement from self-sustaining farmsteads toward a series of specialised sites charged with the production of goods for high-status or consumer sites would likely lead to diversity in the location and type of load-bearing indicators between sites and/or regions. Despite specialisation of the labour force, the redistribution of products may have led to a more homogeneous diet across the different sites.

This chapter first considers what types of patterns in health and diet were observed between phases using osteological and isotope analysis. Next, it examines how diet and health varied between different sites with archaeological evidence for different subsistence practices and economic foci. Finally, the roles religion, ethnicity and geographic origin (as inferred by burial practice and isotope analysis) may have played in diet and health on an individual level are discussed and three case studies are presented which expand upon the variability of life experiences in the PVP and VA.

8.1.1. Changes in subsistence and lifeways

8.1.1.1. The Pre-Viking Phase

The Pre-Viking phase (henceforth referred to as the PVP) refers in this study to between AD 500 and AD 750. PVP burial sites in this study included Brough Road (n=3), Buckquoy (n=1), Newark Bay (n=4), Skaill Cist (n=1), Skara Brae (n=2) and Westness (n=13). While Brough Road, Buckquoy, Skaill Cist, Skara Brae and Westness are on the western side of the Orkney Mainland, Newark Bay is the only PVP site in this study on the eastern side of the Mainland. None of these sites offer definitive evidence for the presence of a church in this phase, though there is evidence for Christianity at the contemporary sites of Papa Westray and Papa Stronsay on more northern Orkney islands, as well as Holm and Kirkwall (Crawford 2005; Lamb 1995). None of the PVP individuals from these sites have evidence of grave goods, as this does not seem to have been the custom in Late Iron Age Scotland, though practices included the use of cairns, cists and plain earth burials. As interpreted from zooarchaeological and archaeobotanical reports, all the farmsteads near and/or associated with PVP burial sites had a predominance of cattle and barley, though other domesticated mammal and crop species were also found. Cattle kill-off patterns at Newark Bay and Brough Road both showed an economic focus on dairying or a combination of meat and dairying, while it appears cattle at Buckquoy were reared more for meat production. Besides dairying vs. meat procurement, the primary difference in evidence of subsistence between these PVP sites is the nature of the fish remains. Of the four sites with archaeoichthyological evidence, Westness and Brough Road had evidence of offshore fishing and Buckquoy provided evidence of predominantly near-shore fishing in the PVP. The ichthyological remains from Newark Bay (in the PVP) were negligible and suggest very little reliance on marine resources in this phase. There were no correlations between subsistence variables (predominant animal, animal use, etc.) among PVP sites.

8.1.1.2. The Viking Age

The Viking Age (henceforth referred to as the VA) in Orkney dates to between AD 750 and AD 1100. VA burial sites in this study included Brough Road (n=5), Buckquoy (n=1), the Broch of Gurness (n=1), Skara Brae (n=1), Scar (n=3), Pierowall (n=15), the Brough of Deerness (n=3), Newark Bay (n=23) and Westness (n=13). Bioarchaeological assemblages from sites in the VA reflect more diverse and specialised subsistence practices, as seen in excavation reports from nearby farmsteads (discussed in Chapters 2 and 3). An emerging hierarchy of peripheral and specialised producer sites providing goods for high-status consumer sites in the VA is evidenced by Scandinavian place-names (Graham-Campbell 1998; Griffiths 2015, 227; Marwick 1952; Thomson 1995), as well as zooarchaeological evidence for increased dairying at certain sites, differences in the predominant domestic animal and crop (barley/oats) between sites and importantly, increased offshore marine resource exploitation (Barrett et al. 2000b; 2004; Bond 1998). Overall, archaeobotanical evidence suggests the increased focus on oats (thought to be of Scandinavian influence) allowed for the overwintering of more animals (rather than herd culling) and an increase in agricultural production that was required for the payment of skat (Barrett et al. 2000b; Bond 1998). In addition to a growing emphasis on surplus agricultural production, the increase in dairying and the catching and processing of fish provided forms of practical and adaptable wealth that could supplement cereal as skat (Critch et al. 2019). The *Orkneyinga Saga* attests to the importance of Birsay Bay as a political centre in the VA. With the western face of the Orkney Mainland being the most critical for controlling trade to and from Norway, Shetland, the Hebrides and Ireland, Birsay Bay became the seat of the earl and the first bishopric in the twelfth century (S.J. Gibbons, pers. comm., 2020). Besides the archaeological evidence for shifts in subsistence practices and site function came the emergence of overtly Scandinavian-style richly furnished burials at the sites of Brough Road, Buckquoy, Broch of Gurness, Scar, Pierowall and Westness. A comparison of health and diet between VA individuals buried in different styles is discussed in section 8.3.2.

8.1.1.3. The Late Norse Phase

The Late Norse phase (or LNP) refers to the period of later Norse settlement in Orkney, between AD 1100 and AD 1299. The LNP burial sites included in this study were the Brough of Deerness (n=4), Newark Bay (n=15), Bu of Cairston (n=114) and Skaill House (n=10). The latest radiocarbon date for any Orkney burials with grave goods in the early eleventh century (Scar 134, dated to AD 1009 $\pm$ 60), signaling a shift in burial practice towards simple, earthen burials within churchyards. This date coincides with the conversion of Norway (and thus Orkney) to Christianity. It is in this phase that the fish event horizon (FEH) is most clearly visible, though this study found evidence for increased marine resource consumption beginning in the VA (discussed in Chapter 6). While Christian fasting practices may have encouraged increased fish consumption, there was already a growing shift towards fish consumption that may have been economically, culturally and environmentally driven. Besides a growing focus on marine resource exploitation, archaeobotanical and written evidence support a model of surplus agricultural production for export through agricultural intensification and an expansion of cultivated land (discussed in Chapter 2; Bond 1998; 2012). While there is evidence for some of these developments beginning in the VA, the formation of plaggen soils and the Scandinavian designation of place-names (which seem to be based predominantly on site function) had been established by the early LNP (Simpson 1993). Norse settlement and the institution of Norse elite as earls and nobility solidified a hierarchical social structure and system of site specialisation and distribution that shifted the economy away from subsistence farming and towards the production of surplus for skat and export (Barrett et al. 2000b; Barrett and Richards 2004; Critch 2019). The transition to more specialised farmsteads with specific crop and livestock foci may have led to more site-based differences in the prevalence of osteological indicators of load-bearing that resulted from subsistence activities.

8.1.2. Osteological evidence of nutrition and diet: a summary by phase

Primary osteological indicators of nutritional deficiency, dental pathology, developmental stress, occupational/ load-bearing stress, specific and non-specific infections and trauma were compared through time, from the PVP to the VA and LNP.

8.1.2.1. Age expectancy

Overall, life expectancy from the PVP through the LNP remained relatively constant, at around 30-35 years of age. Although Dr. Theya Molleson estimated the average life expectancy to be between 35 and 60 years at Newark Bay (Molleson 2005, 113), this study found that individuals who survived infancy had an average life expectancy of 35 years in the PVP, 32.2 years in the VA and 29.1 years in the LNP. When all individuals were considered, 26.5% of the population (121 out of 457 individuals) was under the age of five at death. Newark Bay, the largest multi-phase cemetery, exhibited a high proportion of infants and children, which constituted 31.6% (78 out of 247 individuals) of the population. Molleson’s study on Newark Bay found that the high infant (between birth and one year old) mortality rate is likely to result from poor nutrition, especially during the winter months (Molleson

2010, 51). Infants born over the winter months stood a slimmer chance of survival than those born in the warmer spring or summer months. Unfortunately, only two infants have so far been radiocarbon dated, which hinders our ability to track patterns in infant nutrition and mortality through time. Osteological analysis of the St. Ninian's Isle cemetery in Shetland found a comparatively high proportion of infants in the VA (Roberts 2017). It is possible economic hardship in the VA played a part in the number of infant deaths (*ibid)*, though additional dating of the Newark Bay infants is needed.

8.1.2.2. Nutritional deficiency

Cribra orbitalia (CO) and porotic hyperostosis (PH) are the most commonly used osteological indicators of nutritional deficiency, along with (to a much lesser extent) cribra femora. They can indicate iron deficiency anaemia or scurvy (depending on the distribution of lesions, as described in Chapter 3). When all phases were included, this study observed a CPR of 66.7% of infants and 71.4% of children exhibiting at least one indicator of nutritional deficiency. The high proportion of infants with signs of nutritional deficiency supports the idea that the primary cause of infant death was poor nutrition, as with the malnourished infants observed at the St. Ninian's Isle VA cemetery. In adults of all phases, the prevalence of at least one indicator of nutritional deficiency was 50.5%, with the highest rate in the VA (62.5%) and the lowest in the LNP (42.5%; the rate in the PVP was 45.8%). A significant increase in the prevalence rates of cribra orbitalia (CO) and porotic hyperostosis (PH) was exhibited among males from the PVP to the LNP, with CO rising from 37.5% in the PVP to 88.2% in the LNP and PH rising from 0% in the PVP to 33% in the LNP. In none of the phases was there a difference in the prevalence rates of CO or PH between sexes, though there was a higher prevalence of diagnosable scurvy among males in the VA. The possible correlation between migration and long-distance travel with the development of scurvy and other nutritional deficiencies is discussed in section 8.2.1.2.

The Ph.D. thesis by Allison Cairns (2015) reported CO prevalence rates of between 30% and 67.9% for medieval sites (eleventh to seventeenth century) from Germany, Sweden, Norway and the UK (St. Helen-on-the-walls; Cairns 2015, 201). This indicates that while a substantial portion of the Orkney population suffered from nutritional deficiencies in the VA and LNP, nutrition in other parts of Britain and the North Atlantic declined as well. Interestingly, the Orcadian females did not show similar increases in CO and PH prevalence rates by phase, suggesting males were more greatly affected by reduced access to resources rich in vitamin C or iron. Cairns's comparative analysis showed the opposite, with females exhibiting higher CO rates than males at most medieval sites (*ibid)*.

8.1.2.2. Dental pathology

Dental attrition and calculus stages, as well as the prevalence of dental caries, ante-mortem tooth loss (AMTL), periodontal disease and abscesses were recorded as dental indicators of diet and compared by phase. Once age was accounted for, there were no differences in attrition levels which would suggest a change in food consistency or preparation between phases. Nor were there differences in calculus levels in either males or females from the PVP to the VA or LNP, which would have suggested a change in the proportion of protein consumed through time. Despite archaeobotanical evidence for increased cereal production in the LNP, neither the percentage of individuals with dental caries (CPR) nor the percentage of teeth affected by caries (TPR) varied by phase. The types of teeth affected, however, did. While only maxillary molars and premolars were affected by caries in the PVP, the VA and LNP presented mandibular and maxillary carious incisors, canines, premolars and molars. Although attrition rates did not vary by phase, changes in the distribution of dental caries could have been due to changes in occupational use of teeth or masticatory processes rather than an increase in cariogenic foods like carbohydrates. There were no differences in the prevalence rates of AMTL or abscesses in males or females by phase, though prevalence rates varied by site (discussed in 8.1.4, below). While there was no difference in the prevalence of periodontal disease between sexes in the PVP or the LNP, VA females exhibited a higher prevalence than VA males. Only females exhibited an increase in the prevalence of periodontal disease from 28.6% in the PVP to 87.5% in the VA, before a decline to 14.3% in the LNP. In the PVP (unlike the other two phases), females exhibited greater levels of attrition than males (average scores of 1.4 and 1.3, respectively), which could suggest differences in occupational use of teeth in this phase, though differences in diet could also be partially responsible (discussed further in 8.1.3.1).

In contrast to this study, Roberts and Cox reported a decrease in caries from Iron Age to the early medieval period in Britain, before a substantial increase in both CPRs and TPRs of caries in the later medieval age (LNP; 2003, 190 and 258). This was also expected in the Orkney population, with a rise in fish consumption in the VA (non-cariogenic) before the intensification and increased production of agriculture in the LNP. It is possible, however, that a large proportion of Orcadian agricultural produce in the LNP was exported rather than consumed locally. According to Roberts and Cox's *Health and Disease in Britain*, rates of periodontal disease varied widely by site throughout early and late medieval Britain, with sites like Dundee and Merton Priory, London having prevalence rates as low as 5.9% and 6.5%, respectively while 100% of the 40 individuals from the Dominican friary in Guildford exhibiting periodontal disease (2003, 260).

8.1.2.3. Occupational stress/ load-bearing indicators

Archaeological evidence for increased agricultural intensification and production discussed in Chapter 2 led to the theorizing of an increased prevalence in osteological markers of occupational stress or load-bearing through time. Osteological indicators of occupational stress included platymeria and platycnemia, osteoarthritis (particularly of weight-bearing joints), osteochondritis dissecans and non-violent or physical stress-related trauma (as discussed in Chapter 3). In addition, two non-metric traits arguably impacted by physical activity were included- squatting facets and mandibular tori (Boulle 2001; Sellevold 1980). Platymeria (the antero-posterior flattening of the femur) and platycnemia (the lateral flattening of the tibia) indices were calculated from measured femora and tibiae using the formulae provided in section 3.1.2. There was no difference in the prevalence of either platymeria or platycnemia by phase, either among males or females. Although only one of many osteological indicators of physical stress, this suggests there was no substantial change in the practice of lifting heavy objects or squatting. In the PVP there was a significantly greater prevalence of platymeria among young adults (25-35 years old) than middle and older adults. The lack of difference between age groups in the other two phases could suggest that it was the young adults doing the greatest amount of lifting and squatting in the PVP. The prevalence of platymeria declined significantly from the PVP to the VA for middle adults, but not for younger or older adults.

Osteoarthritis (OA) was recorded by joint surface and the prevalence rates by joint surface, phase and sex are provided in section 5.4.4.2. When females were compared by phase, there was a decline in the prevalence of OA of vertebral joints and foot joints from the PVP to the LNP. Males showed no differences in the prevalence rates of OA at any joint surface between phases. As OA is a degenerative disease (meaning it progresses with age), it is important to take age into account when calculating prevalence rates. When age groups were tested separately, there was a decrease in the prevalence of OA among young adults (25-35 years old) from the PVP to the VA, specifically OA of hip joints. Among middle adults (35-45) there was not an observable decrease in the prevalence of OA until the LNP and the joint surface that benefitted most (statistically) were vertebral joints. In none of the phases was there a significant difference in the prevalence of OA at any specific joint between sexes. The decrease in the prevalence of load-bearing indicators in two joints from the PVP to the LNP suggests a lessening of physically strenuous activity. Interestingly, the two age groups experienced differences in OA at two different joint surfaces. This could be used to suggest that manual labour was assigned based on age group as well as by gender.

While the majority of occupational stress markers and indicators of load-bearing do not display differences in prevalence rates between males and females, there was a higher proportion of males than females with evidence of non-violent trauma. Likewise, while females exhibited a decreased prevalence of squatting facets from the PVP through the LNP, males did not. Although males and females showed no differences in the prevalence rates of platymeria, platycnemia, osteoarthritis or osteochondritis dissecans, there were more instances of non-violent trauma among males than females. Non-violent trauma included instances of vertebral compression/stress fractures, os acromiale and os vesalianum. There was also a decrease in the prevalence of squatting facets among females from the PVP to LNP. A decrease in the prevalence of platymeria among middle adults and a decline in the prevalence of OA (especially of the hip joints) among young adults from the PVP to the LNP suggests a lessening of physically strenuous manual labour that affected different age groups differently. An age-based workforce structure would not have been unheard of. At the site of Portmahomack, differences in dietary stable isotopes between age groups led Shirley Curtis-Summers to suggest a similar age-based division of labour (Curtis-Summers et al. 2014). More on isotope patterns in this study will be discussed in section 8.1.3.

Physical hardship seems to have been widespread in the PVP throughout the Northern and Western Isles, as well as in Caithness. Similar instances of osteological markers of physical labour and load-bearing have been noted at sites like Cille Phaedair, (where a young woman exhibited osteoarthritis and other signs of heavy lifting; Mulville et al. 2003, 25; Parker Pearson 2004, 118), Dun Vulan (Chamberlain 1999, 288), An Coran (Badcock and Downes 2000) and Galson in the Hebrides (Neighbour et al. 2000, 572). At Cnip, on the Isle of Lewis, all four PVP adults exhibited unilateral platymeria and spinal degeneration (Dunwell et al. 1995). Although there was a decrease in the osteological indicators of load-bearing and physical stress from the PVP to the VA and LNP at sites throughout Orkney, LNP individuals from the monastic site of Portmahomack exhibited increased prevalence of degenerative joint disease and markers of load-bearing between the PVP and LNP (Spall 2018). Cecily Spall has interpreted these diachronic changes as evidence that although the monastery survived earlier Viking attacks, life continued to be much harder through the LNP (*ibid.,* Carver 2008; Carver et al. 2016). While examples of human remains from this period in Caithness and Sutherland are few, the VA adolescent male from Balnakeil also exhibited osteological signs of physical "over-use of developing limbs" (Batey and Paterson 2012, 637). Likewise, Thomas Bryce's 1927 description of the human remains recovered from the VA cemetery at Ackergill (like Arthur Edwards' 1927 description of the VA skeleton from Reay) included descriptions of "excessive torsion of the tibia [and femur]" and evidence of habitual squatting in most of the individuals (Bryce 1927, 306-7).

8.1.2.4. Specific and non-specific infections

There was no significant difference in the prevalence of specific or non-specific infections between phases, in either males or females. Despite written evidence of Orkney being wealthy and powerful, there is little archaeological evidence of urbanization during the LNP. While Birsay Bay was likely the location of one of the first Scandinavian power centres and Kirkwall became the first Orcadian town in the LNP, archaeological evidence suggests an overall continuity of settlement practice of dispersed farmsteads and small villages which persists largely to this day. The lack of urban centres in Orkney suggests there may not have been a significant change in hygiene or population density in the VA or LNP, as there were in other market-based economic hubs in the Early Medieval period. While direct osteological evidence for a continuously low population density is limited, the stable rates of specific and non-specific infection throughout these phases support that model. Osteological analysis of VA human remains from York, for example, demonstrate a marked increase in sinusitis and bronchitis, due to smoke from hearths in confined living spaces and tuberculosis from sharing living space with livestock (Roberts and Cox 2003, 177-184). The prevalence of specific and non-specific infections among different sites and between site type and subsistence practices will be discussed below.

8.1.2.5. Violent trauma

Despite written records claiming violent raiding and domination of the Pictish people by Scandinavians in the eighth through the tenth centuries, few individuals with osteological evidence of violent trauma were identified dating to this period. There has been substantial debate as to the nature of Pictish/ Norse relations during this transitional time, with some experts like Brian Smith (2001; 2003) arguing for increased levels of interpersonal violence between native Orcadians and Scandinavian incomers. Others, such as Anna Ritchie and Cecil Curle have claimed that the continuation of Pictish-style artefacts in Viking Age contexts (as found at Buckquoy and the Brough of Birsay) suggests the survival of Pictish culture and a more peaceful hybridization of ethnicities (Curle 1982, 95; Ritchie 1974; 1985, 200; Towrie 2020). To test whether there was osteological evidence of a violent period of raiding or increased violence due to inter-cultural conflict in Orkney, evidence of violent trauma was compared between phases. Evidence of violent trauma included peri or ante-mortem skull and mandibular fractures, parry fractures and sharp and projectile force trauma (explained in Chapter 3.1.4.; Galloway and Wedel 2013). Unexpectedly, there was a slight but insignificant increase in the prevalence of violent trauma between phases among both males and females. There was also no significant difference in the prevalence of violent trauma between males and females in any of the phases. It is important to note that only 17 out of the 36 individuals exhibiting violent trauma have been securely dated. The remaining 19 undated individuals with evidence of violent trauma (including Sk011 from Newark Bay) have the potential to alter these trends substantially and further elucidate the level of conflict from the PVP through the LNP.

As concluded by Adrian Maldonado, "…it is remarkable how little evidence there is of violent deaths or even major bodily trauma in the Scottish burial record before the nineth century" (Maldonado 2013, 11). Interestingly though, the trend of relatively low rates of violent trauma observed in PVP Scotland continued through the VA in Orkney, contrasting not only with written evidence of Viking activity throughout the North Atlantic but also with rates of inter-personal violence observed in other Scottish populations, especially at ecclesiastical sites like Portmahomack (Carver 2008; Carver et al. 2016; Curtis-Summers et al. 2014; Spall 2018), at St. Ninian's Isle, Shetland (Roberts 2017) and St. Andrews, Fife (Maldonado 2013, 11).

8.1.3. Isotope evidence of dietary change through time

A total of 165 individuals were sampled for bone collagen $\delta^{13}C$ and $\delta^{15}N$ isotopes. Out of those 165, 54 individuals were sampled for tooth enamel (strontium, oxygen and carbon isotopes) and 27 out of those 54 individuals were sequentially micro-sampled for dentine (carbon and nitrogen isotopes). The bone collagen $\delta^{13}C$ and $\delta^{15}N$ values represent an average of dietary protein over several years, while the dentine micro-samples provide a high-resolution chronology of diet from birth to approximately 21 years of age (depending on the tooth sampled, see section 3.2.3 for more detail).

While bone collagen and dentine samples only represent the $\delta^{13}C$ and $\delta^{15}N$ from dietary protein (thus unlikely to impact strontium isotopes or concentrations in the same way; Montgomery et al. 2007), the carbonate $\delta^{13}C$ in enamel represents all dietary components (Walser et al. 2020). A recent study in Iceland by Walser and colleagues (2020) found a correlation between strontium isotopes, strontium concentration and carbonate $\delta^{13}C$, indicating those living closer to the seat had a diet more reliant on marine resources in diet with proximity to the sea (Walser et al. 2020, 156). This study, however, showed that while this was not the case in the PVP or the VA, there was a correlation between strontium concentration and carbonate $\delta^{13}C$ in the LNP. This suggests that while marine resources were not largely consumed by anyone in the PVP (even those living near the coast), increased marine resource consumption in the LNP most affected those living near the coast. In addition to the samples taken as part of this study, previously published bone collagen $\delta^{13}C$ and $\delta^{15}N$ results from 147 individuals were incorporated into the dataset (Barrett et al. 2000a; 2004b; 2001; Richards et al. 2006). The combination of datasets resulted in seven duplicates, which were used to test for significant differences between laboratories and methodologies, for which none were found.

8.1.3.1. Bone collagen

Overall, human bone collagen $\delta^{13}C$ and $\delta^{15}N$ values from both males and females demonstrate a significant increase from the PVP to the LNP, with the greatest variation occurring during the Viking Age, followed by the LNP (Figures 8.1. through 8.3). Based on $\delta^{13}C$ values, a mean of 7.1% (±10%) of diet in the PVP consisted of marine protein. This increased to 18.9% (±10%) in the VA and 25.8% (±10%) in the LNP. This increase from the PVP to the VA suggests a significant increase in marine consumption began in the early VA, before continuing into the LNP. While the VA incorporates the early dates for the fish event horizon (FEH, ca. AD 1000), it is possible the increase in marine resource consumption in the VA pre-dates the FEH, though the favourable climate ca. AD 1000 may have helped to accelerate the already-growing trend in fishing (Barrett et al. 2000b). Below is a table with ranges and means for each phase (Table 8.1).

	Males					Females					All				
	δ^{13}C (‰)	1SD	δ^{15}N (‰)	1SD	N	δ^{13}C (‰)	1SD	δ^{15}N (‰)	1SD	N	δ^{13}C (‰)	1SD	δ^{15}N (‰)	1SD	N
PVP	-20.5	0.5	11.1	0.6	8	-20.2	1.1	10.9	0.6	8	-20.4	0.8	10.9	0.6	18
VA	-18.9	1.7	12.8	2.1	12	-19.5	1.3	11.5	1.6	18	-19.3	1.4	12.0	1.8	37
LNP	-18.4	1.1	13.2	1.2	30	-18.7	1.1	13.2	1.4	34	-18.7	1.1	13.1	1.5	87

Table 8.1. Means and standard deviations of bone collagen δ^{13}C (‰) and δ^{15}N (‰) by phase for males and females. 'All' includes individuals of unknown sex.

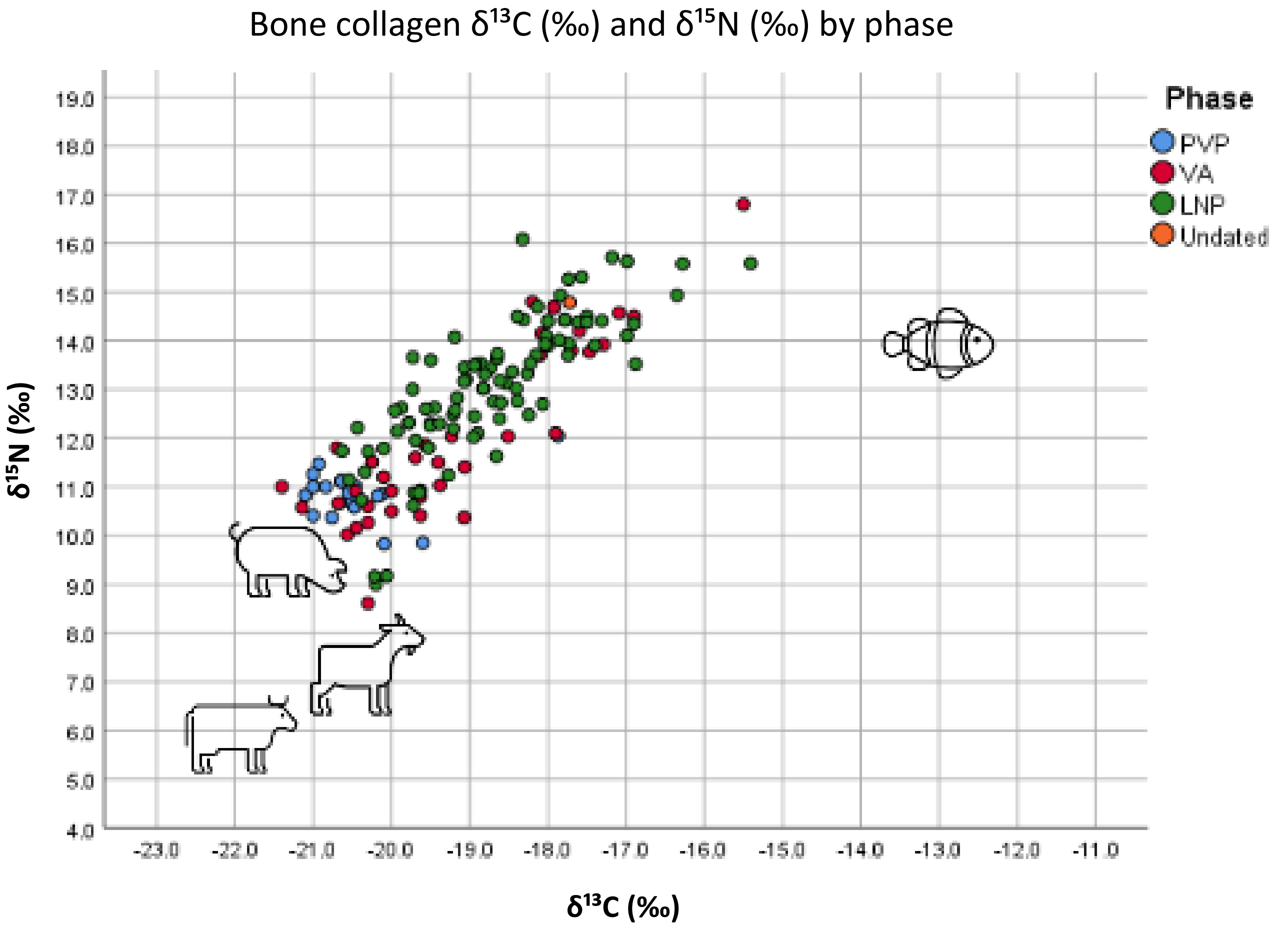

Figure 8.1. Bone collagen δ^{13}C (‰) and δ^{15}N (‰) by phase, alongside representations of the mean pig (terrestrial omnivore), sheep/goat (terrestrial herbivore), cattle (terrestrial herbivore) and marine fish values.

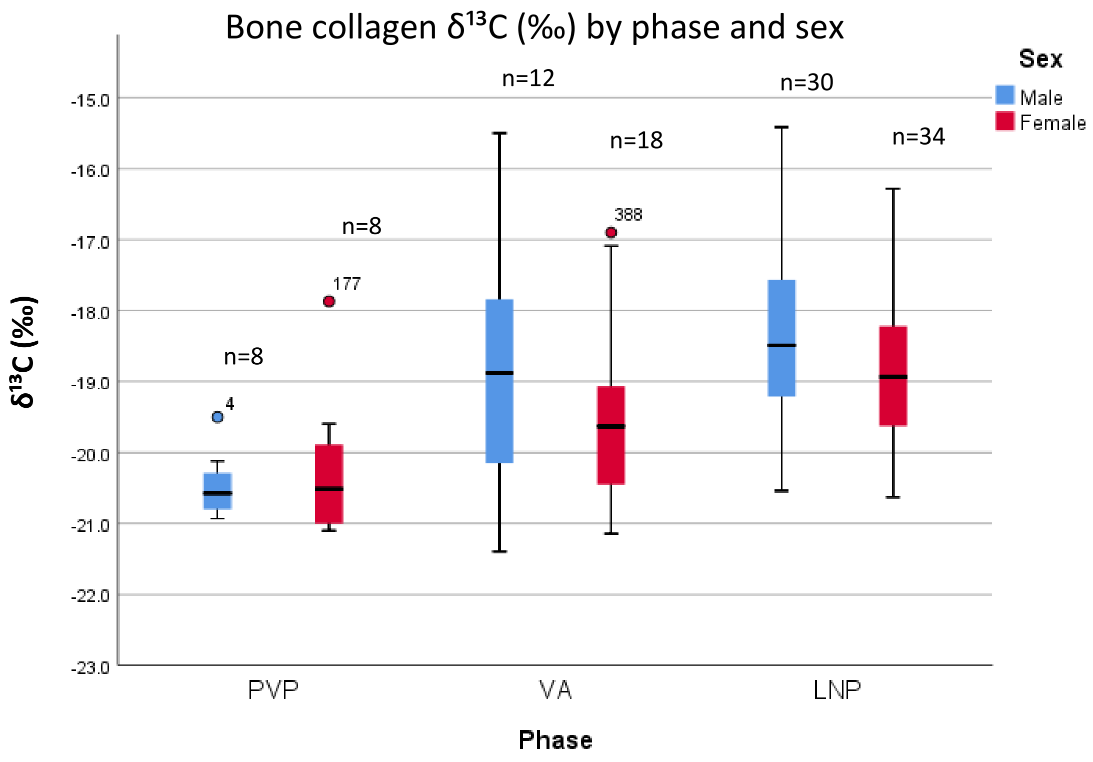

Figure 8.2. Bone collagen δ^{13}C (‰) ranges for males and females by phase. Numbers of samples and means provided in Table 8.1., above.

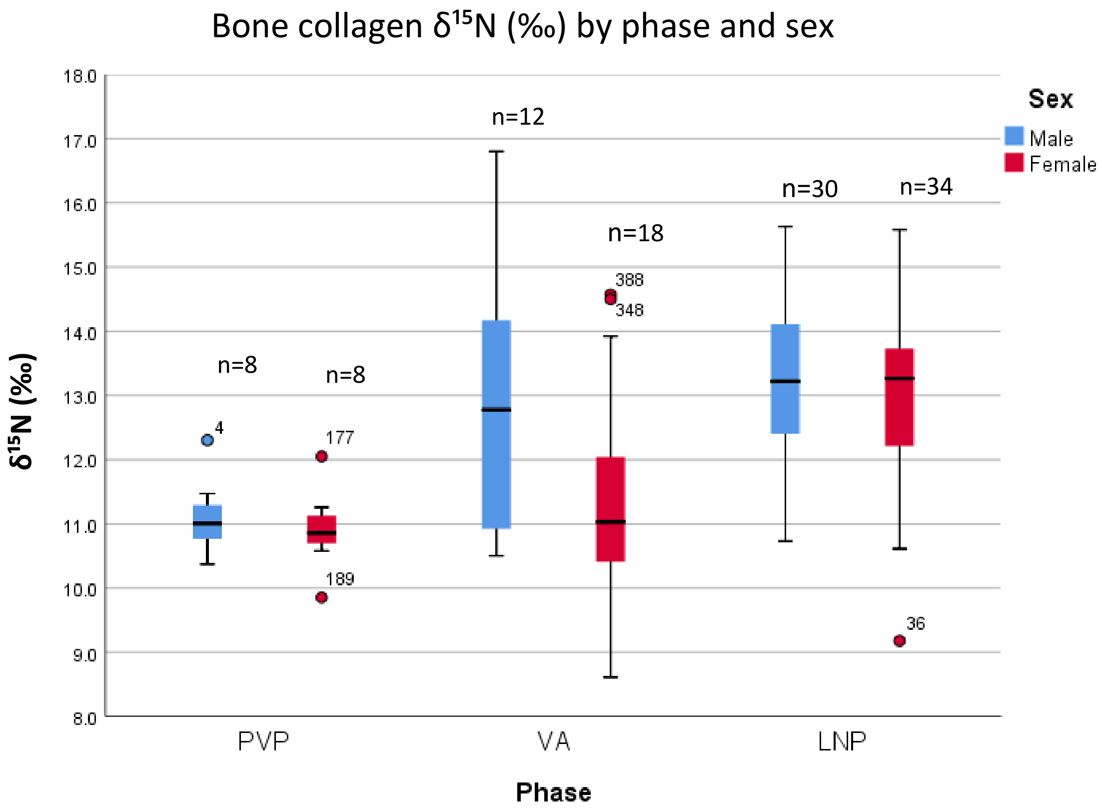

Figure 8.3. Bone collagen δ^{15}N (‰) ranges of males and females by phase. Numbers of samples and means provided in Table 8.1., above.

Compared with the bone collagen stable isotope data from Portmahomack (Figure 8.5., below), Orcadian PVP individuals were slightly higher (on average) in $\delta^{13}C$ and much more variable in $\delta^{15}N$, similar to Norwegian values (Naumann et al. 2014). This could be because of Orkney's location as a point of trade between Norway and Scotland or Ireland and their access to Norway-traded stockfish. Although Portmahomack was an ecclesiastical site in the PVP, there were slightly lower $\delta^{13}C$ and $\delta^{15}N$ means than in Orkney. The $\delta^{15}N$ means (but not $\delta^{13}C$ means) at Portmahomack then surpassed Orkney in the LNP, perhaps with re-founding of the monastery in the 13th century after it had been raided and destroyed (Curtis-Summers et al. 2014).

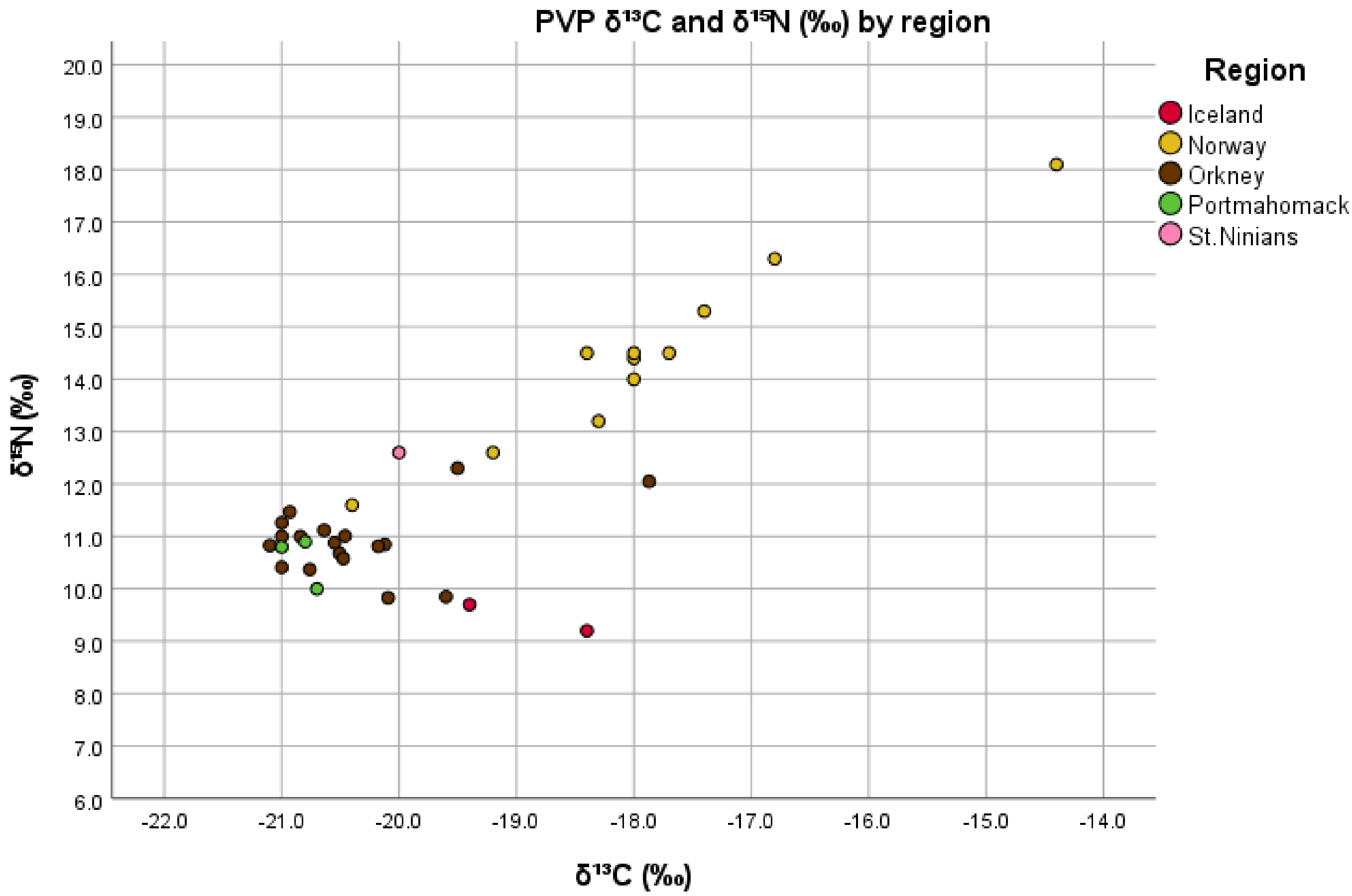

Figure 8.4. PVP $\delta^{13}C$ (‰) and $\delta^{15}N$ (‰) by region (this study; Ascough et al. 2012; Barrowman 2017; Curtis-Summers et al. 2014).

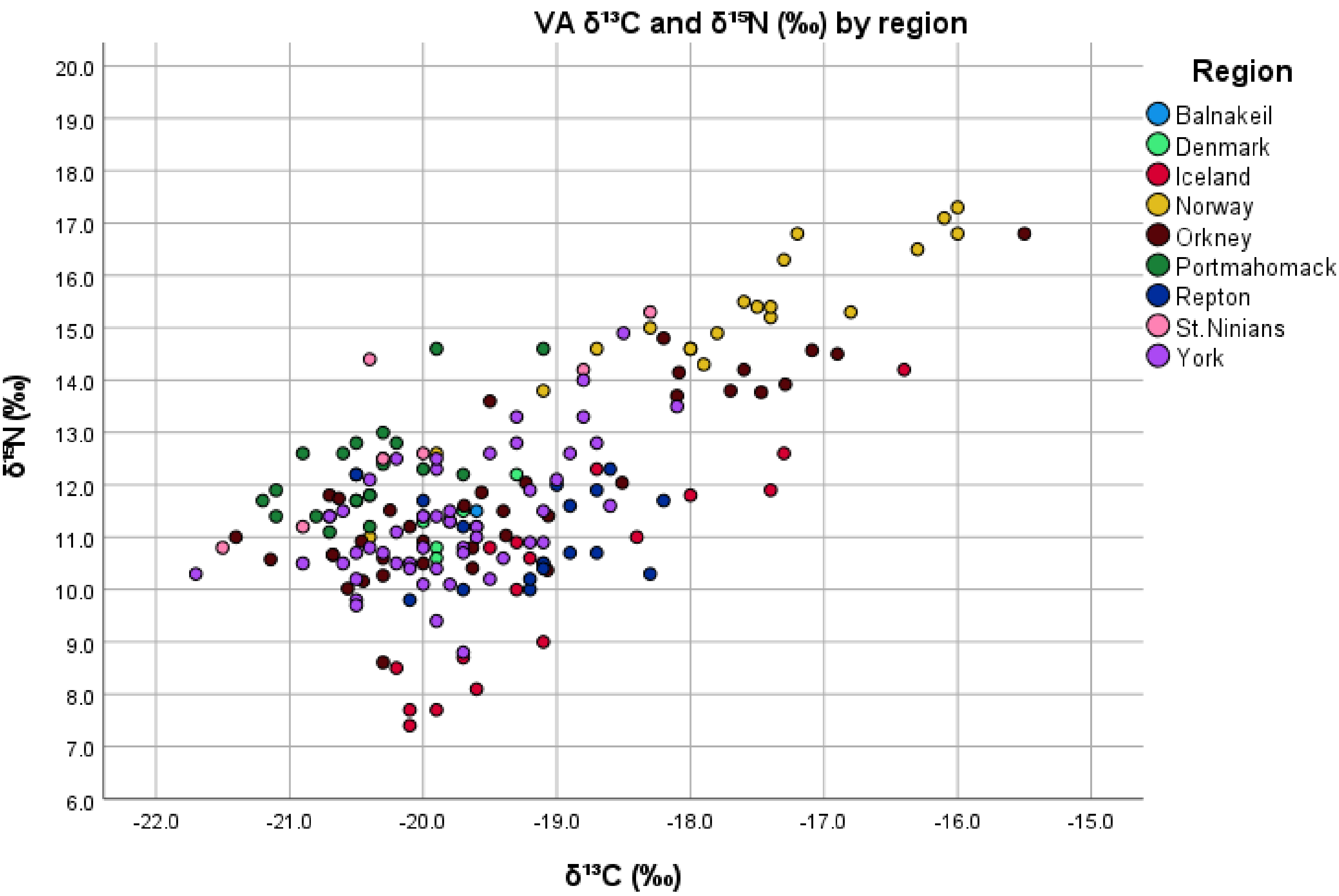

Figure 8.5. VA $\delta^{13}C$ and $\delta^{15}N$ values (‰) by region (this study; Arneborg et al. 1999; Ascough et al. 2012; Barrett and Richards 2004; Barrowman 2017; Buckberry et al. 2014; Curtis-Summers et al. 2014; Johansen et al. 1986; Mays et al. 2007; Müldner and Richards 2007; Naumann et al. 2014; Price et al. 2015; Sayle et al. 2014; Zori and Byock 2014).

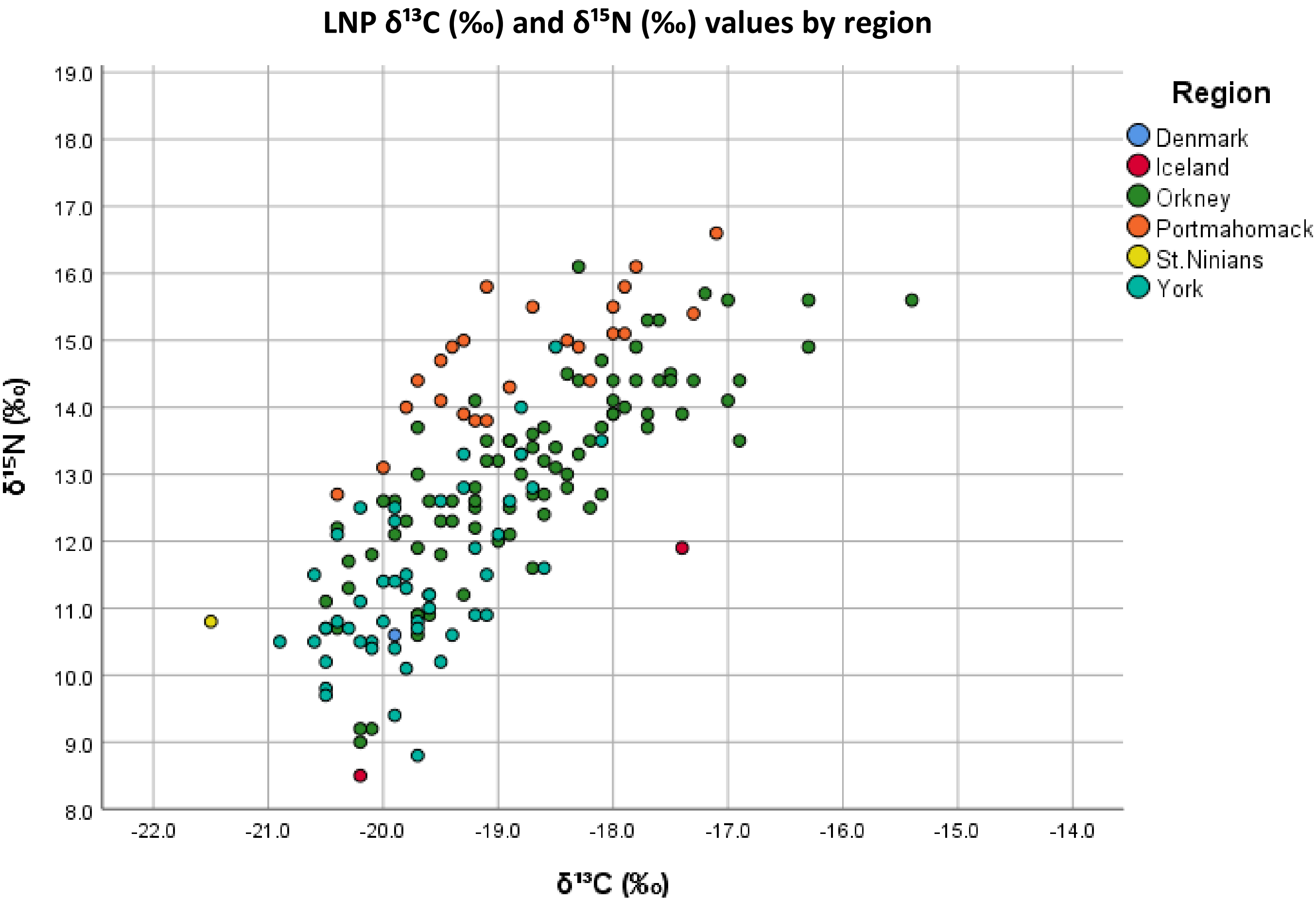

Figure 8.6. LNP δ¹³C (‰) and δ¹⁵N (‰) values by region (this study; Arneborg et al. 1999; Ascough et al. 2012; Barrowman 2017; Buckberry et al. 2014; Curtis-Summers et al. 2014; Johansen et al. 1986; Mays et al. 2007; Müldner and Richards 2007; Naumann et al. 2014; Price 2014; Sayle et al. 2014; Zori and Byock 2014).

8.1.3.2. Sequential dentine micro-sampling

In addition to bone collagen, a series of individuals were sampled for sequential dentine $\delta^{13}C$ and $\delta^{15}N$. As molars do not remodel through life, mapping sequential dentine $\delta^{13}C$ and $\delta^{15}N$ provides a life history of diet during the early years of an individual's development, from birth up to approximately 21 years. Sequential dentine analysis of the first molar (as detailed in Chapter 3) provides evidence for the timing of weaning and diet during early childhood. The second and third molars provide evidence for diet trends throughout adolescence and early adulthood, with the second molars reaching completion around the age of 14 and third molars reaching completion around the age of 21. Sampling of first molars (M1s) was done to explore how weaning patterns may have changed by phase or varied between local and non-local individuals. This section will focus on patterns by phase. Weaning is typically marked by a significant decrease in $\delta^{15}N$ values somewhere between six months and 2 or 3 years old, as infants transition from breastmilk to solid food (Beaumont et al. 2015; Burt 2015; King et al. 2017). Interestingly, the only individuals with these clear decreases in $\delta^{15}N$ are two males in the PVP (Skaill Cist and Skara Brae; Figures 8.7. and 8.8). The stability in $\delta^{15}N$ values in the other individuals (particularly in the VA) could be caused by a transition from breastmilk onto weaning foods high in marine protein. Nicole Burt's study on weaning infant diets from Fishergate House, York, demonstrated similar patterns, with evidence of higher amounts of fish and pig in their diets than expected (Burt 2015; Scott and Halcrow 2017, 8). Burt interpreted the high $\delta^{13}C$ and $\delta^{15}N$ values in infancy to mean that mothers were feeding their babies expensive and nutritious foods during weaning to avoid the dangers of malnutrition (Burt 2015, 283). This could be the case in Orkney as well, where the high prevalence of children with osteological signs of malnutrition and the high proportion of infant and child remains could signal a lack of options for available nutritious resources at the time. As most of the individuals with sampled M1s were subadults and were not able to be accurately sexed, a comparison in weaning between males and females was not possible.

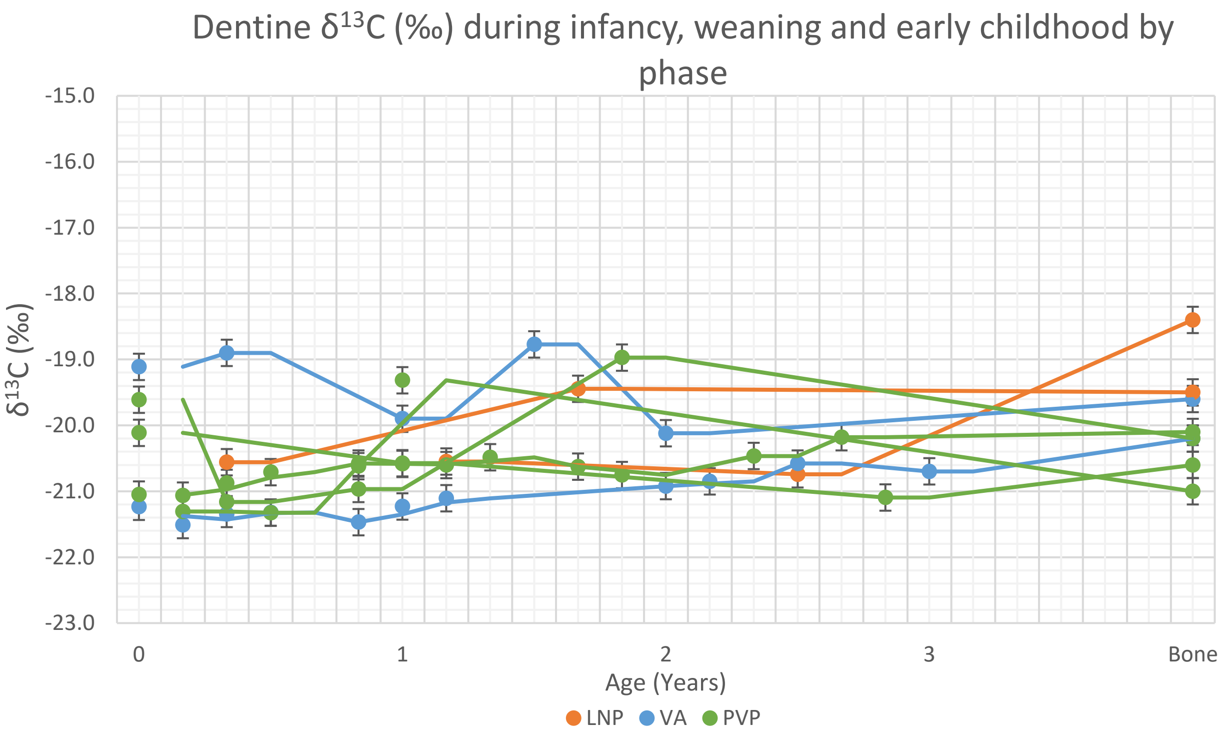

Figure 8.7. Dentine $\delta^{13}C$ (‰) during infancy, weaning and early childhood by phase.

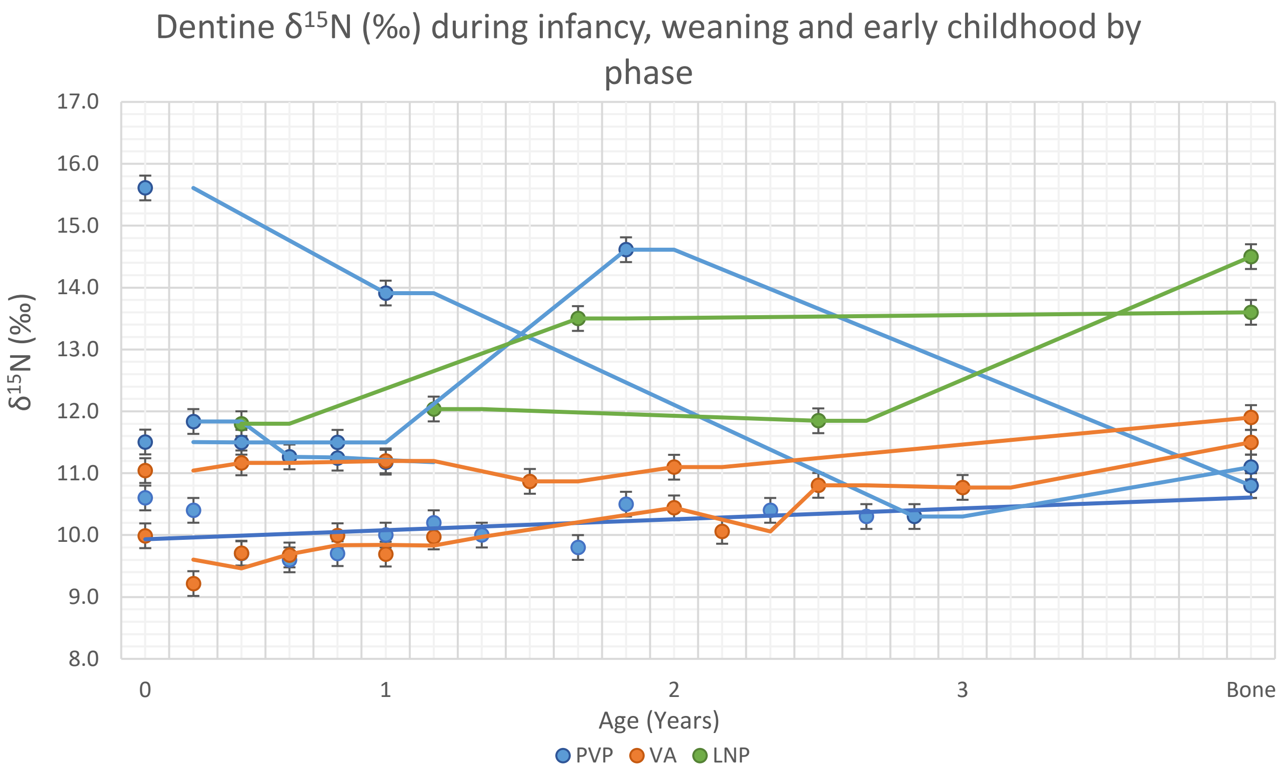

Figure 8.8. Dentine $\delta^{15}N$ (‰) during infancy, weaning and early childhood by phase.

To investigate differences in patterns in diet between males and females through adolescence and early adulthood and how these patterns may have changed through time (possibly due to cultural ideas of adulthood and maturity), a total of 23 second and third molars from 19 individuals were sequentially sampled for dentine $\delta^{13}C$ and $\delta^{15}N$. Males and females were compared within each phase (Figures 8.9.-8.14). In the PVP, the females all exhibited relatively steady dentine $\delta^{13}C$ through adolescence, while males exhibited greater fluctuation in dentine $\delta^{13}C$ values. PVP females aged 17-20.5 had lower $\delta^{13}C$ means than males in the same age group, however, there was no difference in $\delta^{15}N$ means. Both males and females exhibited temporary peaks in $\delta^{15}N$ lasting between 6 months and two years. While these individuals all exhibited bone collagen $\delta^{13}C$ and $\delta^{15}N$ values within a narrow 0.7‰ and 0.5‰ range of each other, their dentine values indicate diets could have varied by up to 3.5‰ in $\delta^{13}C$ at any given point in development. Although the VA male and female sample size was small, males exhibited slightly higher values and greater variation in both $\delta^{13}C$ and $\delta^{15}N$. This would seem to support the notion of a diet higher in δ^{15}N among males than females as early as adolescence (ages 11-12 years).

None of the age groups showed significant differences between males and females in the VA, however. On average, males in the VA exhibited a greater variation in δ^{15}N through adolescence than males in the PVP and despite the small sample size there did appear to be a more distinct difference in trendlines between the female (lower) and the males (higher). Interestingly, these patterns were reversed in the LNP, where the two highest δ^{13}C and δ^{15}N trendlines were those of females. While more VA samples are needed, the VA appears to exhibit a consistently clearer distinction between male and female diets through adolescence, with slightly higher marine protein consumption in males.

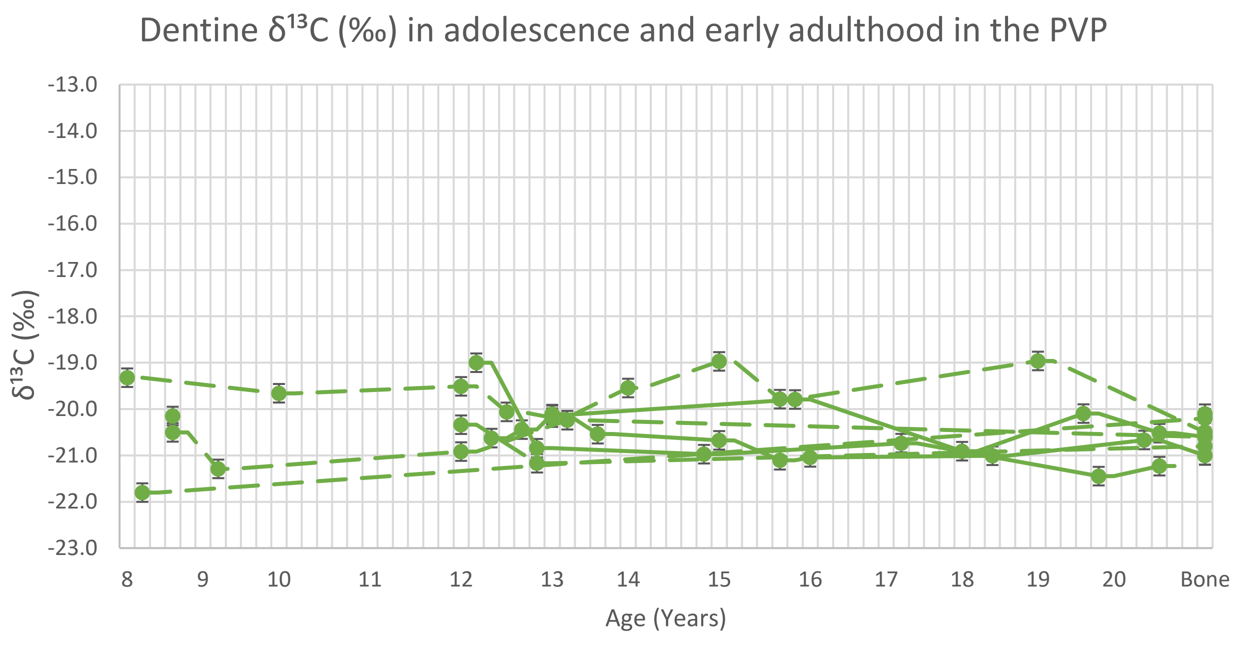

Figure 8.9. Dentine δ^{13}C (‰) in adolescence and early adulthood in the PVP. Males are represented by dashed lines and females are represented by solid lines.

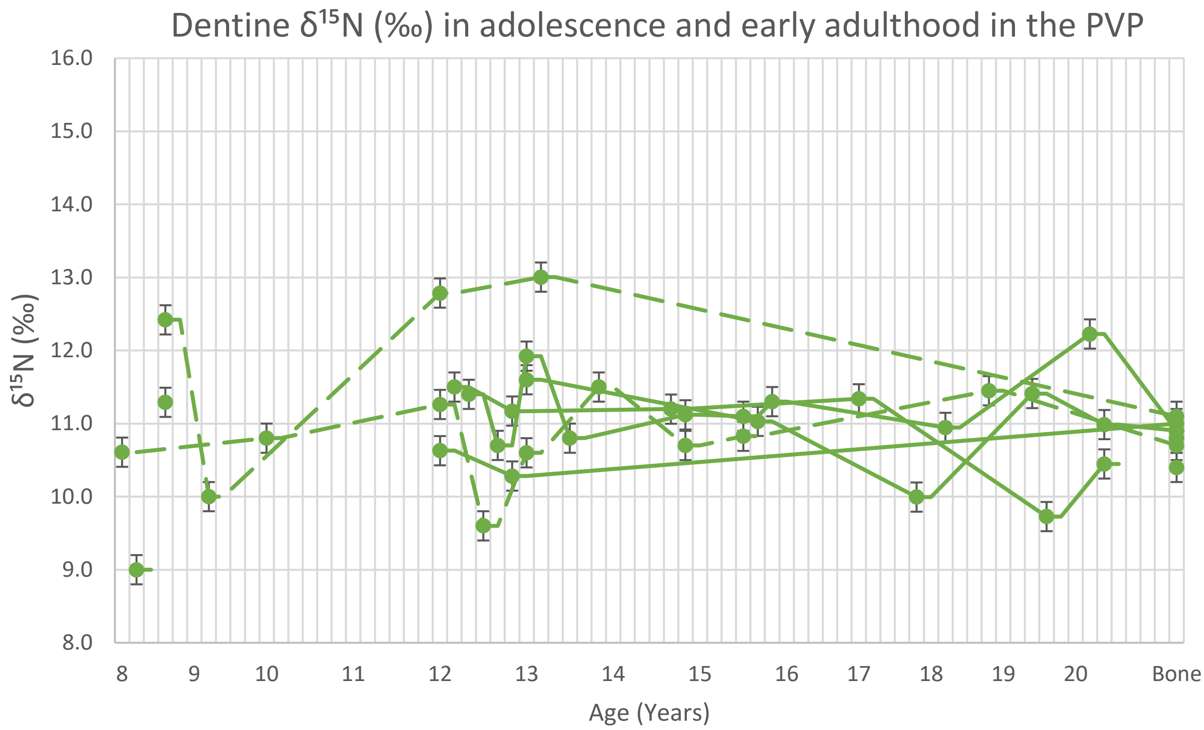

Figure 8.10. Dentine δ[15]N (‰) in adolescence and early adulthood in the PVP. Males are represented by dashed lines and females are represented by solid lines.

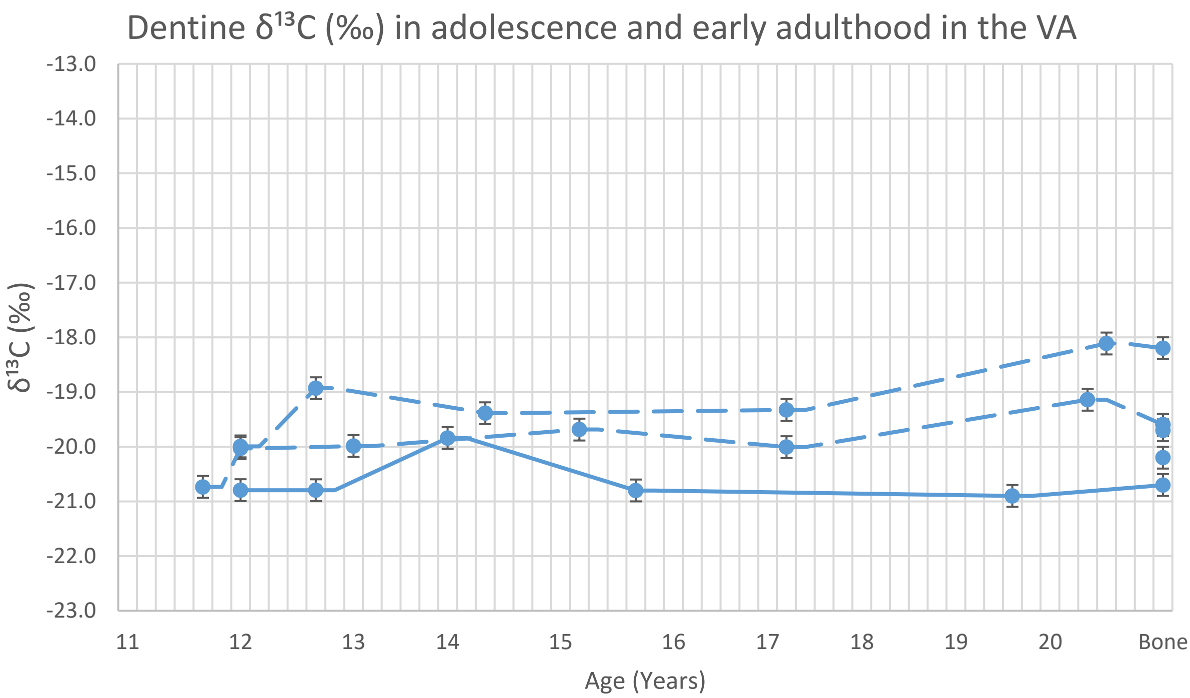

Figure 8.11. Dentine δ[13]C (‰) in adolescence and early adulthood in the VA. Males are represented by dashed lines and females are represented by solid lines.

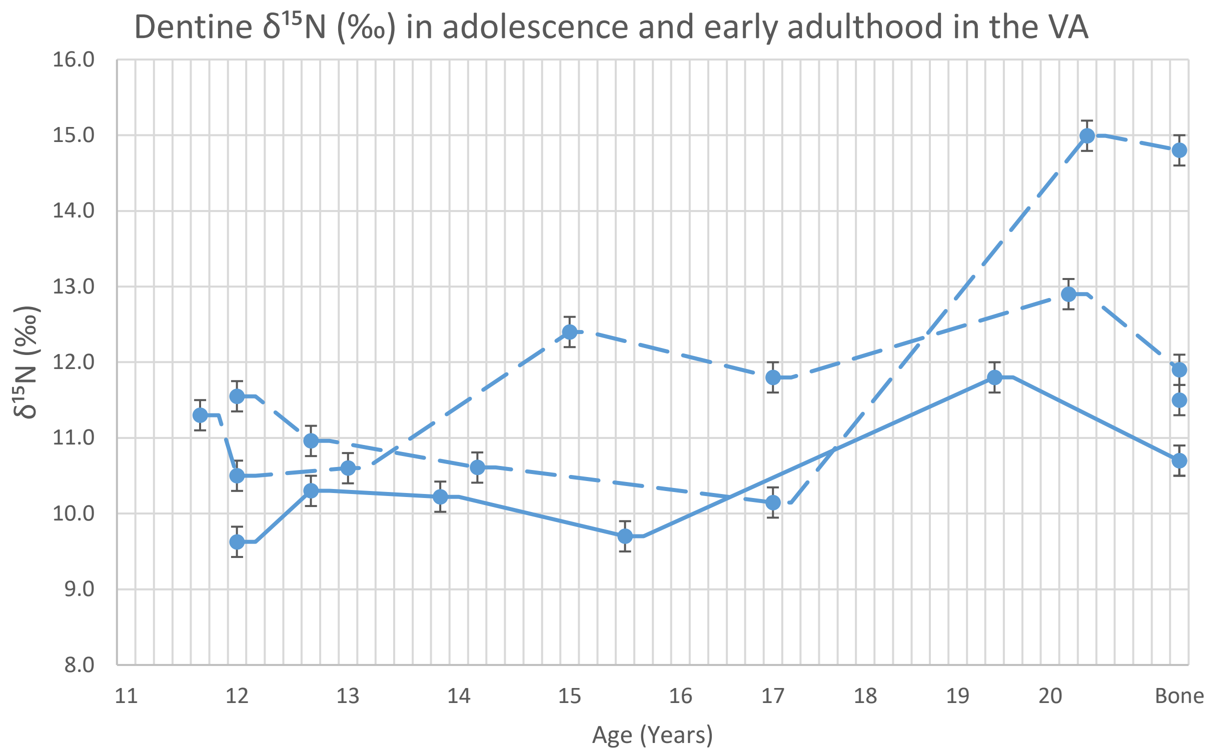

Figure 8.12. Dentine δ^{15}N (‰) in adolescence and early adulthood in the VA. Males are represented by dashed lines and females are represented by solid lines.

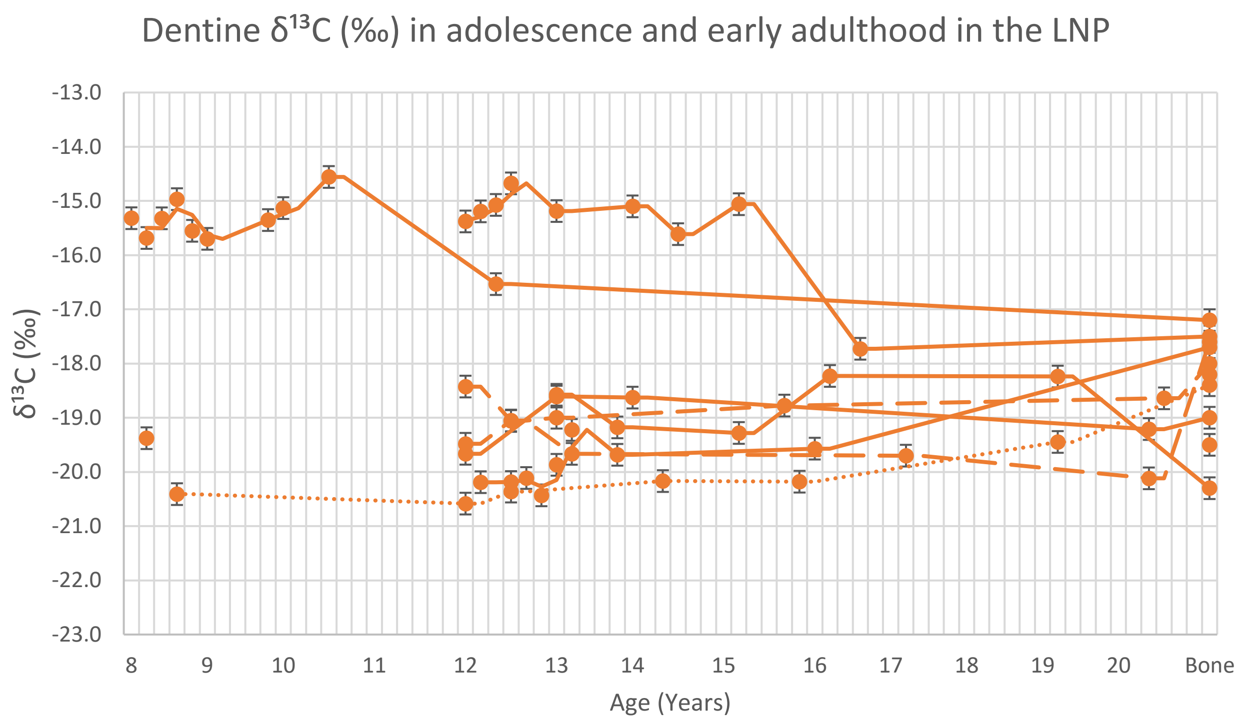

Figure 8.13. Dentine δ^{13}C (‰) in adolescence and early adulthood in the LNP. Males are represented by dashed lines and females are represented by solid lines.

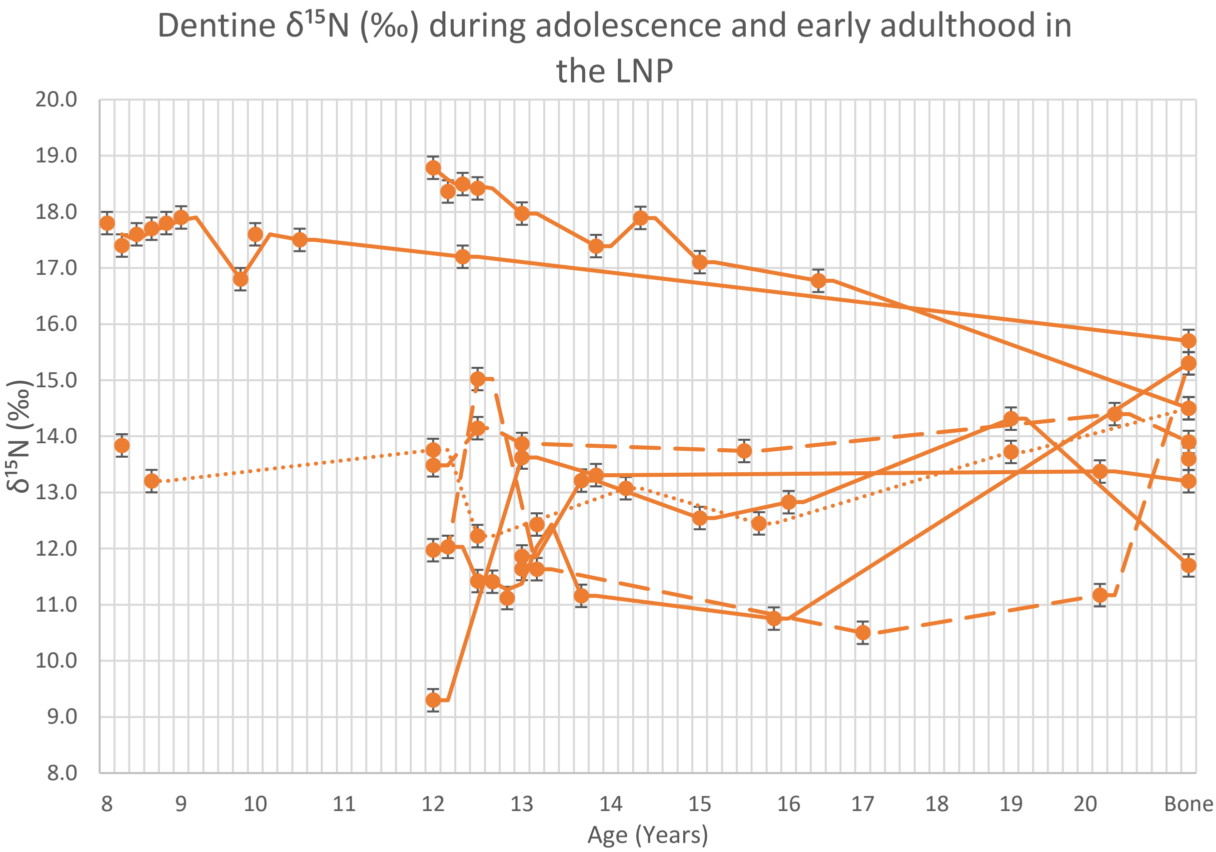

Figure 8.14. Dentine δ¹⁵N (‰) in adolescence and early adulthood in the LNP. Males are represented by dashed lines and females are represented by solid line.

8.1.4. Health and diet by site, site function and subsistence

After a broad comparison of osteological indicators of health and stable isotope evidence of diet through time and by demographic group, these indicators were then compared between sites within each phase and set within the context of what is broadly known of the period to explore whether site location (eastern or western side of the archipelago), type or function (as primarily interpreted from place-names) or subsistence had an observable effect on health and diet. A profile of subsistence at each site (or nearby farmstead) in the PVP, VA and LNP was constructed from site bioarchaeological reports. Where records of subsistence were not available (or applicable) for a particular burial site, published archaeobotanical and zooarchaeological reports from nearby (potentially associated) farmsteads were consulted. Profiles of subsistence were constructed based on the predominant crop (oat, barley or flax), the predominant domesticated mammal (cattle, sheep/goat or pig) and proportions for each, predominant fish type (offshore, near-shore or none) and predominant animal use (meat, dairying or traction). Evidence for plaggen soil and soil quality (LC code) was also accounted for.

A comparison of dental and skeletal pathologies between sites in the PVP revealed a higher prevalence of periodontal disease and abscesses among both males and females at Newark Bay than at other sites. Females from Westness, however, had a greater prevalence of nutritional deficiency indicators than the other females. When osteological indicators of load-bearing were compared between sites, Newark Bay had the highest proportion of females in this phase with OA of any joint surface, though females from Westness had a significantly higher prevalence of OA of vertebral joints, specifically. Reasons for these differences in load-bearing indicators could be because of differences in subsistence strategies between sites, cultural or religious differences, or all of the above (discussed in section 8.3). Arguments for each factor will be discussed in this and later sections of this chapter. Overall, females from sites with better quality soils (both Newark Bay and Westness as opposed to Brough Road and Skara Brae) exhibited a higher prevalence of OA of vertebral joints and osteochondritis dissecans (OD). Males from sites with poorer quality soils (Skaill Cist, Brough Road and Buckquoy) and males from sites with evidence of near-shore fishing (Buckquoy) exhibited a higher prevalence of OA of knee joints than males from Newark Bay or Westness.

As previously mentioned, excavation reports from Skaill, Deerness (nearby Newark Bay) showed only a negligible number of fish remains dating to the PVP, while analysis of Westness's ichthyological assemblage showed evidence of offshore fishing. Omega-3, commonly derived from fish, is an anti-inflammatory agent that may very well have contributed to the lower prevalence of periodontal disease at Westness compared with Newark Bay. Despite archaeoichthyological evidence of greater marine resource exploitation at Westness, there were significantly greater $\delta^{13}C$ values and greater variability in both $\delta^{13}C$ and $\delta^{15}N$ values among females at Newark Bay (with no significant difference in $\delta^{15}N$ values between the two sites). A comparison of PVP males from Newark Bay and Westness was not possible due to the small sample size. Although fresh fish is a considerable source of iron, fat, protein and even vitamins C and D (Gadsby and Steele 2004; Jones 2019), females at Westness suffered a greater incidence of nutritional deficiency than other females in the PVP. It is possible that, although Westness exploited near-shore marine resources, females (for some reason) were not consuming them or perhaps they were being exported to nearby sites. The higher prevalence of females with mandibular tori at Westness suggests that a higher proportion of the female population was native. Therefore, abstaining from fish consumption could have had cultural/ ethnic roots. It is also possible that the lack of standardised sieving during excavation of Skaill, Deerness resulted in an under-representation of fish remains at the site, skewing our perceptions of marine exploitation in this phase of occupation at Newark Bay. The greatest variability in both $\delta^{13}C$ and $\delta^{15}N$ values among PVP males was at Brough Road. Brough Road, along Birsay Bay, was a centre of political control in the PVP and into the VA (Morris 1989; 1985, 217; Ritchie 1985, 193). Along the shore of perhaps the most important trade route through Orkney, it makes sense that the males from this site exhibited the highest variability in diet for this phase, as they may have had access to the greatest variety of foods.

Though there were no significant differences in the prevalence rates of any osteological stress markers or load-bearing indicators between males and females in this phase to support the idea of a sex-based division of labour, the different prevalence rates of specific indicators (i.e., OA of vertebral joints and OD) between sites suggest different (possibly subsistence-related) inveterate physical activity between Newark Bay and the western sites of Westness, Brough Road, Skaill Cist, Skara Brae and Buckquoy. The higher prevalence rate of nutritional deficiency indicators among females at Westness, along with the differences in δ^{13}C values also contributes to the theory of distinct patterns or strategies in subsistence between sites in this phase. The variability in male δ^{13}C and δ^{15}N values at Brough Road supports the established picture of Brough Road as being a hub of trade and travel even at this early date.

The VA and LNP saw a rise in marine resource exploitation, as well as in dairying and cereal production. On the one hand, marine resource consumption (an excellent source of omega-3 and good fats) acts as an anti-inflammatory, reducing symptoms of osteoarthritis, periodontal disease and other inflammatory reactions. Sites from across the North Atlantic (Orkney included), however, exhibited an increasing focus on dairying and cereal production, which provided the means of skat payment and export. While fish consumption is health-friendly, consumption of cereals that are high in carbohydrates causes dental caries, periodontal disease, abscesses and AMTL (Chapple et al. 2017; Hujoel 2009; Hujoel and Lingström 2017). VA males and females from the western sites of Brough Road, Broch of Gurness, Buckquoy and Pierowall had the highest rates of periodontal disease, AMTL and abscesses- considerably higher rates than observed in individuals from the eastern sites of Newark

Bay and the Brough of Deerness. Females from sites with better quality soil (including Broch of Gurness) showed a greater prevalence of AMTL and abscesses, though this pattern was not observed in males. It is possible that females from sites with better soils (possibly a greater focus on agriculture) had a diet higher in carbohydrates than females from other sites. Additionally, VA males from the western plaggen sites of Brough Road, Buckquoy and Pierowall exhibited higher prevalence rates of diagnosable scurvy (and PH) than males from Newark Bay, Scar and the Brough of Deerness.

As fresh cream is higher in carbohydrates than meat, an increased reliance on cheeses and cream/milk as a source of protein could also have resulted in a slight increase in dental caries, periodontal disease and abscesses. It is also possible that sites specialising in dairying traded their goods for flour or cereal from other sites, which (while not necessarily detectable in the archaeological record) could have provided a considerable source of carbohydrates. Although there is evidence for dairying at Brough Road and the Bay of Skaill in the VA and LNP, the sites most focused on dairying (based on the cattle kill-off evidence) in the VA and LNP are the eastern sites of Scar and Skaill (Deerness), the large multi-phase farmstead associated with Newark Bay and the Brough of Deerness. Incidentally, LNP males and females from the eastern sites (Newark Bay and the Brough of Deerness) had higher prevalence rates of periodontal disease than those from the western sites of Skaill House and Bu of Cairston. Females from eastern sites also exhibited a greater prevalence and number of abscesses. There was no significant difference in the prevalence of dental caries among either females or males from the different sites, however.

When evidence of load-bearing was compared, males from eastern sites exhibited higher prevalence rates of load-bearing, platymeria, OD, occupational/accidental trauma and OA of vertebrae, knee joints and sternocostal joints. Females from eastern sites exhibited greater prevalence rates of platymeria, OA of vertebral joints, OA of hand joints and OA of the jaw (TMJ). The females from sites with better quality soils exhibited a higher prevalence of OA of elbow joints and osteochondritis dissecans (OD), suggesting they were putting in more physical manual labour than females on poorer quality soils.

8.2. Migration and mobility in PVP, VA and LNP Orkney

8.2.1. Osteological evidence of a population transition- raiders and settlers

8.2.1.1. Demography and stature

The osteological evidence is limited in providing clues to migration. Reconstruction of demographic patterns, however, show no significant differences in the population structure- the ratio of males to females, or the average age at death- between the PVP, VA and LNP. In all three phases, middle adults had the highest death rate, with a life expectancy of between 29 and 35 years of age, which was typical of Late Iron Age and early Medieval populations (Molleson 2005; Roberts and Cox 2003). Previous studies have proposed a model in which there were at least two waves of Scandinavian migration: the first a wave of predominantly male individuals raiding and potentially conducting reconnaissance for future settlement and the second wave comprising men, women and children with the purpose of long-term settlement (Graham-Campbell and Batey 1998, 2; Morris 1985, 213; and the *Orkneyinga* account of the presence of raiding bases in Orkney before the arrival of Harald Fine-hair supports this). Although the initial raiding was likely to have been done primarily by young and middle adult males, the proportion of young and/or middle adult males did not rise significantly from the PVP to the VA. The demographic evidence based on osteological analysis (as presented in section 5.2) does not show differences in the male to female ratio between phases. Furthermore, the estimated age at death did not vary significantly among males or females between the phases. The demographic evidence, therefore, suggests a relatively stable population structure. An osteological study by Shane McLeod

(2011) on human remains from England found that while there was no mention of women and children accompanying the Norse army that attacked Wessex in the 890s, the remains of Norse women have been found from the earliest known campaigns in the 860s. McLeod found that even early stages of raiding likely included females and so did not substantially change the male to female ratios of the affected populations (*ibid.*, 353). While it appears the proposed model of Scandinavian migration cannot be supported based solely on the demographic evidence, additional methods for addressing this theory include strontium and oxygen isotope evidence which will be discussed in section 8.2.2., below.

Stature means estimated from long bone length formulae showed no significant differences in height between Orcadian males or females between the three phases. Various studies on Iron Age and VA Scandinavian remains have calculated mean statures for males and females, providing the data for an inter-regional comparison (Bennike 1985; Sellevold et al. 1984). When comparing Orkney stature estimates for the same date ranges, the Scandinavian males and females both exhibited significantly greater stature than their Orcadian counterparts in the PVP but not in the VA or LNP. Although not significantly different, Orcadian male stature increased by a mean of 4.3cm from the PVP to the VA, while female stature only increased by approximately 1.7cm (Table 8.2). This suggests male stature was more affected by immigration than female stature.

The increased uniformity of stature means between the two regions in the VA could reflect improvements in nutrition and health in Orkney and/or decline of health in Scandinavia. It is also possible that while stature did not increase significantly in Orkney, there was an influx of Scandinavians with a genetic predisposition to greater stature (Ruff 2018). With the VA came the inclusion of Scandinavian-style furnished burials throughout Orkney. Interestingly, VA males with grave goods had significantly greater stature on average than VA males without grave goods. This suggests that either males with Scandinavian grave goods were of a higher social status and had access to better nutritional resources and health care, or that the furnished males were potentially of Scandinavian ancestry with a genetic predisposition to greater stature. The relationship between ethnicity and ancestry regarding Scandinavians in Orkney will be explored further with the discussion of the isotope results.

According to Orkney stature data collated in this study as well as in previous studies, (see caption for additional references) and Scandinavian data from Bennike (1985), Ruff (2018) and Sellevold (1984), Scandinavian males and females in the PVP had significantly greater stature means (p=0.000 and 0.000) than Pre-Viking Orkney populations (approximately 3cm taller; Table 8.2., Figure 8.15. and 8.16). In the VA and LNP, neither Scandinavian males nor females had significantly different stature estimations than their Orcadian counterparts (VA: p=0.658 and 0.196, LNP: p=0.385 and 0.149). While there is a steady decrease in Scandinavian male stature from the PVP (LIA) through the LNP, Orkney males and females exhibit the greatest stature means in the VA. Both Orcadian male and female stature means surpassed Scandinavian means in the VA, before declining in the LNP. Interestingly, despite the lack of statistical difference in stature means between VA Scandinavians and Orcadians, VA males buried with Scandinavian grave goods in Orkney exhibited significantly greater stature than VA males without grave goods.

	Orkney						**Scandinavia**					
Phase	Male (cm)	N	Female (cm)	N	All (cm)	N	Male (cm)	N	Female (cm)	N	All (cm)	N
PVP	168.4	8	158.9	6	165.3	15	174.9	77	161.9	81	168.2	158
VA	172.7	11	160.6	13	166.5	26	172.3	87	159.3	64	166.8	151
LNP	170.9	15	158.8	13	165.3	30	171.5	209	159.7	190	165.9	399

Table 8.2. Stature means for Orkney and Scandinavian individuals by phase and sex. Scandinavian data from Bennike 1985; Hanson 1992; Ruff 2018 and Sellevold et al. 1984.

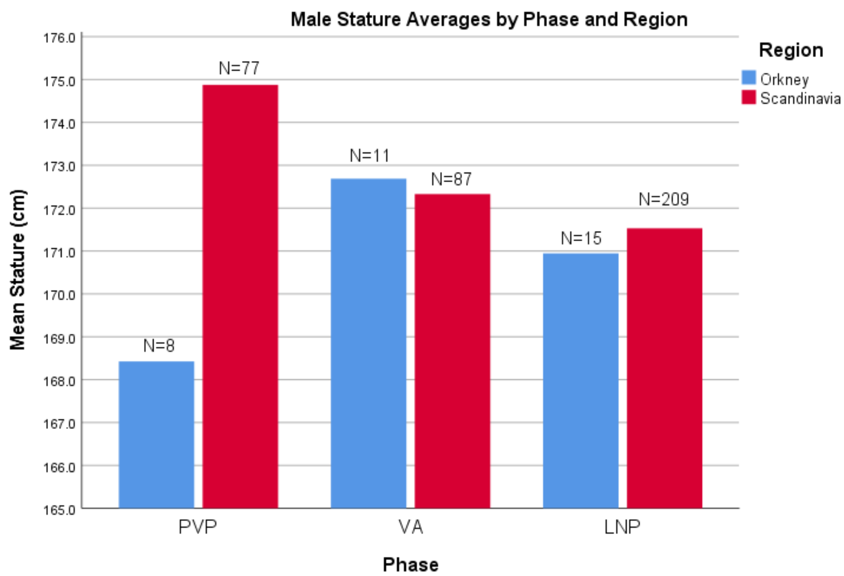

Figure 8.15. Stature means (cm) for Scandinavian and Orcadian males by phase (this study; Bennike 1985; Hanson 1992; James 1999; Molleson n.d.; 2005; Ruff 2018; Sellevold 1999; Sellevold et al. 1984).

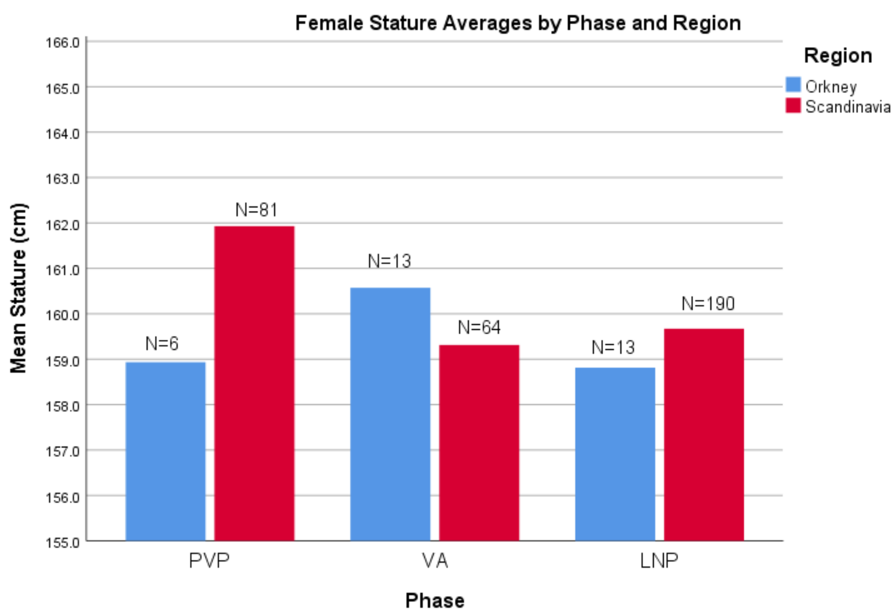

Figure 8.16. Male and Female stature means (cm) for Scandinavia and Orkney by phase (this study; Bennike 1985; Hanson 1992; James 1999, 767; Molleson n.d.; 2005; Ruff 2018; Sellevold 1999 and Sellevold et al. 1984, 226).

8.2.1.2. Non-metrics and pathology

While osteological evidence of individual migration is scant and strontium and oxygen isotopes provide a more robust determination of local or non-local origin, a few osteological results were worth noting. Firstly, as discussed in section 3.1.3.4.5., mandibular tori are (at least partially) heritable non-metric traits observed more frequently in the northern Icelandic and Greenland populations than in Scandinavian populations (Capasso et al. 1999, 18; Hauser and DeStefano 1989). According to Berit Sellevold (1980; Sellevold et al. 1984, 204), only 8 out of 183 (4.4%) VA individuals from Denmark exhibited mandibular tori and a study on modern Norwegians reported a prevalence of 7.2% (Haugen 1992, 69). To further Sellevold's argument that mandibular tori were driven more by genes than masticatory stress, she tested for a correlation between mandibular tori and dental attrition. Like her findings (1980, 572), this study found no significant correlation between the two (p=0.223). It was also previously suggested by Theya Molleson (2005) that this trait could potentially be used to distinguish local from non-local individuals in Orkney. To her credit, the present study found that while six of the seven individuals from Westness with local strontium and oxygen values had observable mandibular tori, none of the three non-locals did. There was a significant decline in the prevalence of mandibular tori among males from the PVP (70.6%) to the VA (31.3%) and LNP (14.3%), however, this trend was not reflected in females. This could suggest a continuity of native Orcadian females during an influx of males from a different (possibly Scandinavian) gene pool. Furthermore, while the middle adults exhibited a significant decrease in the prevalence of mandibular tori from the PVP to the VA, only young adults decreased in prevalence between the VA and LNP. The prevalence of mandibular tori, however, must not be over-interpreted and further investigation of migration should rely on aDNA and isotope analysis.

Although Viking sea routes likely stayed close to land to use dead reckoning wherever possible (Crawford 1987, 14; Goodrich 2010; Marcus 1955, 601; Power 2002) there is written evidence (such as the story in the *Saga of Thorstein the White*) that the Vikings sometimes lost their way and did occasionally suffer from scurvy or *skyrbjugr* (De Luca and Norum 2011; Guth 2002, 72). While scurvy alone is not indicative of migration, it was many times the result of long-distance maritime travel. The increased prevalence of diagnosable scurvy among young adults from the PVP to the VA supports the idea of increased long-distance seafaring, possibly by Vikings and Scandinavian settlers. It is important to note that the voyage from Norway to Orkney may have only taken a few days, and it is likely those with signs of scurvy must have been travelling frequently or over longer distances to be chronically suffering from a chronic lack of vitamin C.

There was a higher prevalence of both diagnosable cases of scurvy and individual indicators (CO and PH) among VA males with boat graves and in males with grave goods (particularly weapons) than in males without. When VA sites were compared, Westness exhibited the highest (significantly) prevalence of scurvy. Westness, a western site named for its land feature (-ness), is the site of some of the earliest Scandinavian-style burials in Orkney, dating to as early as AD 760 ±50 (grave 5). Being on the northwest side of Orkney, along a trade route from Shetland to the Hebrides (Crawford 1987), Westness (along with the Brough of Birsay) may have been one of the first points of landing in Orkney by Scandinavians. While scurvy increased from the PVP to the VA at western sites, the prevalence rates did not change at the eastern site of Newark. If scurvy was more common among migrants, increased rates observed in both VA males and females suggest young adults of both sexes are migrating. Strontium and oxygen isotopes have the potential to shed further light on the prevalence of nutritional deficiencies among migrant and native individuals.

8.2.2. Isotope evidence for mobility

8.2.2.1. Strontium and oxygen isotopes

A series of enamel samples were taken from 57 individuals for strontium and oxygen isotopes as part of this study and produced a mean strontium measurement of 0.70974 ± 0.0009 (2SD). Based on the 27 plant samples collected as part of this study, as well as published measurements from previous studies (Evans et al. 2010; Montgomery et al. 2014), a strontium baseline of between 0.7092 and 0.7101 was used to define 'local' Orcadian individuals. Ten individuals fell outside of this range- three (Skaill Cist (M2), Scar 135 and Westness 5) had at least one molar with strontium isotopes below 0.7092 and eight (BY78AS, BY78CU, Skaill Cist (M3), BUC081, NB Sk?ST12, NB 71/013b, Westness 11 and Westness 12) had at least one molar with strontium isotopes above 0.7101 (Table 8.3). Six individuals from Westness (graves 5, 11, 12, 28, 28a and 32) were measured by Montgomery and colleagues (2014, 59), of which three fell outside of the strontium baseline (Westness 5 was below and Westness 11 and 12 were above). When oxygen isotopes from the 57 individuals measured in this study were plotted against the oxygen baseline established for Britain ($\delta^{18}O_p$ between 16.3‰ and 19.1‰, per Evans et al. 2010; Montgomery and Evans 2006), an additional six individuals measured above the 'local' range (NB70/029, NBSK?ST14, BY78IO, BUC026, BUC037 and BU098) and one (Westness 12) was below. It is important to note that three of the individuals with non-local signals dated to the PVP: BY78AS, BY78IO, Skaill Cist. For nine individuals, multiple teeth were sampled for strontium and oxygen. Four of those individuals exhibited strontium and oxygen isotopes within the local range for all sampled teeth. Interestingly, enamel strontium and/or oxygen isotopes from multiple molars of five individuals exhibited a combination of non-local and local isotopes (Table 8.3). Two of the individuals (BY78IO and NBSK?ST14) likely moved to Orkney in early adolescence, between formation of the M2s and M3s (between ages 5.5-14). As the M2 from BU059 was not sufficiently well preserved for sampling, the timing of migration to Orkney can only be narrowed down to between late childhood or early adolescence. Skaill Cist, however, exhibits M1 strontium isotopes consistent with Orkney, but M2 and M3 strontium isotopes that are non-local. This suggests that the Skaill cist individual's infancy was spent in Orkney (or somewhere with 'local' strontium isotopes) and/or that their mother's isotopes passed down through breastmilk were consistent with Orkney (Hamre and Daux 2016, 418). The Skaill Cist individual will be discussed further in section 8.4.1.

While it is not possible to determine conclusively that an individual is from a specific region (e.g., Scandinavia), it is possible to narrow down the range of possible origins. To this end, strontium and oxygen baselines from Scandinavia were compared with the non-locals identified in this study. Price and Naumann's study on identifying a local signal for Norway found $^{87}Sr/^{86}Sr$ ratios to be highly variable between sites (2014, 97). Nevertheless, they proposed a range of bioavailable $^{87}Sr/^{86}Sr$ (based on flora) in Norway between 0.709 and 0.721, although a range between 0.7075 and 0.7317 was observed in human tooth enamel samples (*ibid., 89*). In coastal areas, the sea-spray effect makes it difficult to tease apart Scandinavian and Orcadian individuals based on strontium alone. Strontium isotopes in Northern Norway, however, differ significantly from averages across Orkney, making differentiation between Orkney and Northern Norway possible. Oxygen ($\delta^{18}O_p$) in Norway is lower than in Orkney, with a range of between 15.6‰ and 16.9‰ and "with little variation across Scandinavia" (Price et al. 2018, 33), while the $\delta^{18}O_p$ range in Orkney is between 17.2‰ and 19.2‰ (2SD; Chenery et al. 2010). Based on the Norwegian strontium and oxygen isotope baselines, Westness 12 may have been from Norway. Westness 11 might also be of Norwegian origin, with a $\delta^{18}O_p$ value of 15.5‰ (since it falls within the Norwegian range after accounting for an analytical error of ± 0.56‰, 2SD). The other non-local individuals have oxygen isotopes too high or strontium isotopes too low to be from Norway.

Site	Burial	Phase	Sex	Age (years)	Tooth	$^{87}Sr/^{86}Sr$	[Sr] (ppm)	1/[Sr]	δ18Oc VPDB (‰)	δ18Op VSMOW (‰)
Brough Road	AS	PVP	Male	35-49	M2	0.711076	140	0.0072	-4.1	18.1
					M3	0.711448	163	0.0061	-4.2	17.9
Brough Road	CU	VA	Female	18-34	M3	0.710311	150	0.0067	-3.8	18.3
Brough Road	IO	PVP	Male	35-49	M2	0.709676	240	0.0042	-1.6	20.5
					M3	0.709661	259	0.0039	-3.5	18.6
Bu of Cairston	SK026	LNP	Female	18-34	M3	0.709352	354	0.0028	-2.3	19.8
Bu of Cairston	SK037	LNP	Female	18+	M3	0.709776	376	0.0027	-1.1	21.0
Bu of Cairston	SK059	LNP	Unkn	5-10	M1	0.710253	162	0.0062	-3.6	18.5
					M3	0.709851	243	0.0041	-4.5	17.6
Bu of Cairston	SK081	LNP	Male	50+	M3	0.710913	167	0.0060	-4.1	18.1
Bu of Cairston	SK098	LNP	Female	18-34	M3	0.709892	241	0.0041	-2.0	20.1
Newark Bay	71/13B	ND	Female	18-34	M3	0.710112	314	0.0032	-4.4	17.7
Newark Bay	SK?ST12	ND	Male	18+	M2	0.710196	185	0.0054	-3.7	18.4
Newark Bay	SK?ST14	ND	Male	50+	M2	0.709952	222	0.0045	-1.8	20.3
					M3		214	0.0047	-3.4	18.8
Scar	135	VA	Unkn	10-11	M1	0.709157	268	0.0037	-5.4	16.7
Skaill Cist	1	PVP	Male	18-34	M1	0.709586	154	0.0065	-4.6	17.5
					M2	0.709157	176	0.0057	-4.0	18.1
					M3	0.710190	279	0.0036	-4.4	17.7
Westness*	12	VA	Male	35-45	P1	0.71197				15.4
					M2	0.711627	165	0.0061	-5.5	16.6
Westness*	5	VA	Female	35-45	P2	0.70729				17.2
Westness*	11	VA	Male	45-50	M2	0.71015				15.5

Table 8.3. Individuals with non-local strontium and oxygen isotopes from at least one tooth (this study; Montgomery et al. 2014). Light blue boxes highlight the local tooth and isotopes.

Of the other non-local individuals, BY78AS, BY78CU, BU059, BU081, NB71(13)B and NBSK?ST12 have strontium isotopes too high to be from Orkney but within the range for Shetland, parts of Ireland, or Norway. BY78IO, BU026, BU037, BU098 and NBSK?ST14 all have oxygen isotopes too high to be from Britain, between 19.8‰ and 21.0‰ (Evans et al. 2012). These oxygen isotopes would be consistent with areas with higher rainfall, including Ireland or parts of Denmark (Fricke et al. 1995).

Using strontium and oxygen isotopes in differentiating migrants from natives is, however, slightly problematic (as explained in Chapter 3). First, to the sea-spray effect results in overlapping strontium isotopes may have led to a mischaracterization of non-locals as locals. Also, as strontium and oxygen are not hereditary but are based on diet (unlike DNA), they would not differentiate between first-generation immigrants and the offspring of native Orcadians.

8.2.2.2. Isotopes, aDNA and ethnicity

Ashot Margaryan and colleagues' 2019 study on Viking migration throughout the North Atlantic sequenced the genomes of seven Orcadian individuals included in this study: BY78CU, BY78DT, BY78IO, Buckquoy M(12), Buckquoy B(7), NB68(12) and NB71(13), as well as an unlabelled individual from Newark Bay. The two individuals with at least 50% Scandinavian ancestry were both from Newark Bay, including LNP individual 68(12) and the individual of unknown burial number (*ibid*); both were buried in a Christian graveyard and had no grave goods. Although of Norwegian ancestry, individual 68(12) exhibited strontium and oxygen isotopes within the local Orcadian range ($Sr^{87/}Sr^{86}$ 0.709262, $\delta^{18}O_p$ 18.3‰). This individual could have been the descendent of a Scandinavian immigrant, rather than being an immigrant themselves.

Of the six VA individuals buried with Scandinavian grave goods or in a boat burial that were sampled for strontium and oxygen isotopes, the only two with possible Scandinavian origins include Westness 11 and 12 (two middle adult males). A similar pattern of association with Scandinavian ethnicity was also found in Margaryan and colleagues' study. Although individuals BY78DT and Buckquoy B7 were buried with Scandinavian or "Viking" grave goods, they had over 85% UK ancestry (Margaryan et al. 2020, 10). Although Westness 5 (a middle adult female) was buried with Scandinavian grave goods, the low strontium isotopes indicate she must have been from a region with an underlying geology of Basalts or marine carbonates, such as Iceland or the Faroes (Montgomery et al. 2014, 63-64).

While Margaryan and colleagues (2019) determined that individuals BY78CU and NB 71(13) lacked Scandinavian ancestry, their strontium isotopes being 0.710311 and 0.710112, respectively. While these strontium ratios are unlikely to have originated in Orkney based on this study's plant results, ratios as high as 0.7105 have been observed in cattle from Mine Howe (Towers 2013, 124). Additionally, BY78DT and BY78IO were found to have predominantly UK ancestry but exhibited oxygen isotopes ($\delta^{18}O_p$ 19.6‰ and 20.5‰, respectively) inconsistent with having been raised in Britain. This study found there was no correlation between the designation of 'local' and 'non-local' (based on strontium and oxygen isotopes) and the presence or absence of grave goods in either male or female graves, displaying an association with Scandinavian ethnicity through the incorporation of Scandinavian grave goods was not limited to those from Scandinavia.

8.3. Health, diet, origin and ideology

This section explores differences between the prevalence of pathological indicators and stable isotope evidence of diet between individuals with local/no-local strontium and oxygen isotopes, as well as between individuals with grave goods or Scandinavian burial types. The former indicating geographic origin and the latter indicating ethnicity, it may be possible to identify which (if any) differences in health and diet are likely to be culturally based.

8.3.1. Health, pathology and dietary indicators: locals versus non-locals

Comparisons were limited by the number of individuals that have been sampled for enamel strontium and oxygen isotopes. In the PVP, three of the eleven individuals exhibited strontium and oxygen isotopes outside of the local range for Orkney. Unfortunately, the PVP sample size was too small to separate comparisons by male and female.

8.3.1.1. Osteological indicators of health and diet

When all PVP individuals (ages 5+) were included (n=11), a greater prevalence of local individuals exhibited mandibular tori. This supports previous findings (discussed in 8.2.1.2) that mandibular tori were more common among Orkney natives and Icelanders than among other (particularly Scandinavian) populations. There was also a higher prevalence of platymeria among locals than non-locals, which suggests a difference in the type of inveterate physical labour undertaken between native Orcadians and incomers in the PVP. In the VA, five of the ten individuals sampled for strontium and oxygen measured outside of the local range for Orkney. The local males continued to exhibit a greater prevalence of mandibular tori than non-local males. In addition, local males exhibited a higher prevalence of occupational/accidental trauma. As in the PVP, this could be because of differences in physical activity or occupation between native Orcadians and raiders or traders coming to Orkney in this phase. When individuals of both sexes (ages 5+ years) were compared, non-locals exhibited significantly greater levels of dental calculus and a higher prevalence of caries than locals. This was unexpected, as it was assumed that native individuals with a more terrestrial-based (carbohydrate-rich) diet would have had a higher prevalence of caries. The difference in calculus levels was also unexpected. Assuming most VA immigrants were Scandinavian, there is evidence Scandinavians practiced good hygiene. Individuals recovered from Norse burials (including the female from the Oseberg ship burial) exhibited clear evidence of using a pick or other implement to clean their teeth (Holck 2006; Ruffoni 2011, 31).

Finally, local and non-local males and females dating to the LNP were compared (n=22). Among males, non-locals had a higher prevalence of OA of shoulders, though the sample size only included seven males. OA of shoulders could have resulted from amount of rowing necessary for traversing long distances. The only LNP male (BU081) with a specific infection was a non-local who had a potential case of tuberculosis. When comparing females (n=10), there was a higher prevalence of LEHs among non-locals, suggesting greater physical or emotional stress during development (ages birth to 21 years old). When females from all phases were considered (n=22), there was still a higher prevalence of LEHs among non-locals, while local females exhibited a higher prevalence of platymeria.

8.3.1.2. Isotope differences between locals and non-locals

Unfortunately, because of the small sample size, a comparison of $\delta^{13}C$ and $\delta^{15}N$ values between local and non-local females was not possible for the PVP or the VA. There was no difference between local and non-local females in the LNP. In none of the phases was there a difference in local and non-local diet among males, though local males exhibited greater variability in both $\delta^{13}C$ and $\delta^{15}N$ values. This was contrary to the hypothesis that non-local males, those travelling for trade or raiding, would have had greater variety in diets. When sequential dentine trendlines were compared between locals and non-locals in each phase, PVP non-locals exhibited greater fluctuations in $\delta^{13}C$ values during adolescence than locals. When VA individuals with grave goods were compared between those with local and non-local strontium and oxygen isotopes, there were no differences in either $\delta^{13}C$ or $\delta^{15}N$ values. When males with grave goods were tested separately, however, there were higher $\delta^{13}C$ values among the locals than the non-locals. It is possible that while local males were consuming mainly marine fish, non-locals could have been consuming more freshwater fish from the lochs, like trout. For non-locals of high status (those with grave goods at least), freshwater fish may have been a more prized commodity while they viewed marine fish as lower status food (Barrett 1995; 2003b, 90).

8.3.2. Diet, health and grave goods

While much of the Orkney population consider themselves of Scandinavian ancestry, even up to modern times (Berry and Firth 1986), archaeological evidence for Scandinavian ethnicity is limited to artefacts and in this case, burial practices. For this study, individuals buried with Scandinavian grave goods or in a boat burial were afforded Scandinavian "ethnicity", regardless of whether their strontium and oxygen isotopes were within the local Orcadian range. As Scandinavian grave goods in Orkney were limited to within the VA, it is the VA on which this section focuses. VA grave goods (as explained in more detail in Chapters 2 and 5) comprised weaponry (so far found only among males), jewellery and textile working implements (so far found only among females) as well as gaming pieces, combs, daggers, beads and agricultural tools (found in graves of both sexes).

A comparison of osteological indicators of health and diet in VA males revealed several differences between those with and without grave goods, offering insight into how ethnicity, occupation and social status may have been represented through incorporating these items. The grave goods most commonly found in male graves were weaponry (either a sword, arrows, shield boss, or a combination of weapons) and daggers (multipurpose knives). ANOVA tests showed VA males with any form of grave goods were significantly taller than VA males without grave goods, which either suggests a difference in the gene pool or a disparity in nutrition between members of different social status (see section 3.1.2). There was also a greater prevalence of diagnosable scurvy (as well as the indicator porotic hyperostosis), OA of at least one shoulder joint, squatting facets and oral abscesses among males with grave goods. When separated by type of grave good, males with weaponry were taller than VA males without, had a higher prevalence rate of scurvy (and porotic hyperostosis), OA of at least one shoulder joint, OA of at least one elbow joint, squatting facets and oral abscesses than males without weaponry. While the presence of weaponry did not correlate with the presence of combs, males with combs also exhibited a higher prevalence of scurvy than those without. Interestingly, while males with grave goods exhibited such differences in health, there was no difference in their $\delta^{13}C$ or $\delta^{15}N$ values which suggests the proportion of marine protein in their diets were similar ($\delta^{13}C$ mean of -18.9‰ ± 1.7‰ and $\delta^{15}N$

mean of 12.8‰ ± 2.1‰). VA males who had scurvy and were buried with grave goods (n=4) may have been Vikings. This group includes Scar 134, Westness 11, Westness 12 and BY78DT. While Scar 134 did not have a tooth for strontium and oxygen sampling, Westness 11 and Westness 12 had non-local strontium and oxygen isotopes consistent with being from Norway. Although BY78DT had strontium and oxygen isotopes within the local Orkney range, his strontium isotope ratio was also consistent with having possibly been from Norway (as strontium isotopes overlap along much of the coastline). Males buried with agricultural tools had a higher prevalence and number of dental caries, suggesting males with social roles more strongly associated with agriculture had a diet more heavily reliant on carbohydrates like cereals. Interestingly, females buried with and without agricultural tools showed no difference in the prevalence or number of caries.

Females with grave goods had a higher prevalence rate of LEHs, as well as a greater number of LEHs. Interestingly, the only female buried with gaming pieces (Westness 36) was significant in her lack of periodontal disease or indicators of load-bearing. The lack of load-bearing indicators and good oral hygiene, along with the presence of gaming pieces, beads and steatite bowl would suggest she was of high social status. While her bone collagen $\delta^{13}C$ (-20.6‰) and $\delta^{15}N$ (11.7‰) values were not significantly different from other females in the VA, her diet only comprised approximately 4% marine protein. This could support James Barrett's assertion that the consumption of fish was not considered high status (Barrett et al. 2000b), at least not among females in the VA.

8.3.3. Christianity, diet and health

While *papar* place-names throughout the isles indicates there was at least some level of pre-Scandinavian Christianity in Orkney, the earliest churches found date to the tenth century (within the VA; Graham-Campbell and Batey 1998, 253). By the LNP, all cemeteries were associated with a churchyard. With only a few archaeological indicators of Christianity, most interpretations of Christian burial in Orkney are based on the presence of churchyards, the absence of grave goods and east/west alignment of the body. Unfortunately, early antiquarian excavations (or poor recording) at some sites limit our ability to systematically test for the prevalence of osteological indicators of health and stable isotope indicators of diet by the position of the body. As the presence of grave goods has been covered in section 8.3.2. as indicative of Scandinavian ethnicity, that leaves the presence of churchyards. Without burials at known churches in the PVP and with the shift to only churchyards by the LNP (with Christianisation of Norway and thus Orkney), comparisons between churchyard and non-churchyard burials were limited to the VA. Among males, there was a higher prevalence rate and number of oral abscesses among those buried in churchyards. All six of the VA males with osteological evidence of scurvy and all five of the males with squatting facets were found to have been buried outside of churchyards and with grave goods. This included Westness 11, Westness 12 and Scar 134 (previously mentioned as potential Vikings in section 8.3.2). Among the VA females, there were no differences in the prevalence rates of any osteological markers of diet or health between those buried within and outside of churchyards. This was interesting because while males within and outside of churchyards showed no difference in $\delta^{13}C$ or $\delta^{15}N$ values, females buried in churchyards exhibited higher $\delta^{13}C$ values than females buried outside churchyards (-18.8‰ compared with -20.7‰). Females buried in churchyards also had a slightly higher (though insignificant) $\delta^{15}N$ mean than those buried outside of churchyards. Both the high-status VA female (Westness 36) and a non-local female with grave goods (Westness 5) had the two highest $\delta^{15}N$ values of VA females not buried in churchyards (11.7‰ and 11.8‰, with $\delta^{13}C$ values of -20.7‰ and -20.6‰, respectively), though both individuals' $\delta^{13}C$ and $\delta^{15}N$ values reflected a predominantly terrestrial diet.

Ceilidh Lerwick's thesis (2014) on identity and ethnicity among Norse and natives in early medieval Scotland found a significantly higher prevalence of OA of hip joints among Christian individuals, particularly among females. Lerwick suggested this was evidence that Christian females may have had heavier workloads than the Christian males (2014, 384). This study, however, found no differences between VA individuals (neither males nor females) from within and without churchyards, nor was there a difference between VA females and males buried in churchyards. Unlike Lerwick's study, this study found no evidence of differences in workloads or occupational stress between individuals buried within and without known churchyards, apart from a higher prevalence of squatting facets among males buried outside churchyards (p=0.008).

8.4. Case studies and skeletal biographies

This section focuses on three individuals for whom osteological and isotopic analyses were undertaken. It aims to piece together the information gleaned from a variety of techniques using the human remains to create a personal profile of individuals who lived through this period. These profiles exhibit the range of life experiences in the PVP and VA and force our perspective from the large-scale to the individuals' lives.

8.4.1. Skaill Cist

The individual in the Skaill cist was a young adult male, dating to between AD 569-772 (within 95% probability; estimated proportion marine diet was used to adjust for the marine reservoir effect using OxCal v.4.3) and aged between 18 and 25 years old at the time of death. Long bone measurements provided an estimated height of 162cm (this study; James 1999, 773). Despite his young age at death, he exhibited multiple indicators of load-bearing including OA of hip joints, a healed fracture of the third sacral vertebra and degenerative changes to the left knee. The presence of porotic lesions on the visceral side of multiple ribs could indicate he had tuberculosis. He is one of only two individuals in this study known to have been buried in a prone position; the other was a VA female from Pierowall. His burial face down has been used to suggest an "indignity inflicted…after death," perhaps reflecting his lower social standing in society due to physical disability (Lorimer 1999 in James 1999, 773). It is possible the trauma (and subsequent disability) early in life limited his responsibilities and roles in society (this study; *ibid)*.

His bone collagen $\delta^{13}C$ (-20.6‰) and $\delta^{15}N$ (11.1‰) results were within the mean range for PVP males and reflect a diet of predominantly terrestrial protein, with an estimated minimal marine contribution of only 4% (±10‰). Because of his unusual burial, a first, second and third molar was sequentially micro-sampled for dentine $\delta^{13}C$ and $\delta^{15}N$ to investigate how his diet may have fluctuated from birth through early adulthood. Unfortunately, the tooth dentine was poorly preserved and only ten micro-samples from all three molars provided $\delta^{13}C$ and $\delta^{15}N$ results. The three samples taken from between the ages of birth and three years old show a slight decrease in $\delta^{13}C$ by approximately 1.0‰ and a greater decrease in $\delta^{15}N$ by over 5.0‰. The Skaill cist individual began life at approximately 4.0‰ higher than the next highest PVP individual $\delta^{15}N$ value (15.6‰ compared with 11.5‰) but decreased drastically until the age of around 3 years old (Figures 8.17. and 8.18., below). This could suggest a prolonged weaning period. While his $\delta^{13}C$ and $\delta^{15}N$ values correlate more or less through development, his $\delta^{15}N$ values continued to fluctuate widely through adolescence. This demonstrates the limitations in interpreting isotope analysis based solely on bone collagen values, which only provides a mean of $\delta^{13}C$ and $\delta^{15}N$ values over the last few years (explained in Chapter 3).

Enamel strontium and oxygen isotopes were sampled to investigate his geographic origins. As mentioned in section 8.2.2.1., the M1 isotopes (more indicative of the mother's origin) fell within the local Orkney range. The M2 and M3 strontium isotopes, however, were too low, then too high

(0.709157 and 0.710190, respectively) to be from Orkney. Despite Skaill Cist male's early date, it may be possible that he was born of a mother in Orkney and sent to foster in Norway during their adolescence before returning and being buried in Orkney. Similar stories of fostering/ hostage-taking were recorded in the sagas (*Egil's Saga*, *Gisla saga* and *Laxdaæla Saga* among others; Palmstierna et al. 2016, 2). It is possible that even at this early date Norse were coming to political arrangements with the Pictish natives through bonds like fostering. Although the M1 strontium fell within the local Orkney range, the strontium isotopes for all three molars are consistent with being from Norway. It is therefore possible that the Skaill Cist male was a recent Norse immigrant; and that being a migrant and having a physical disability potentially resulted in his unusual burial.

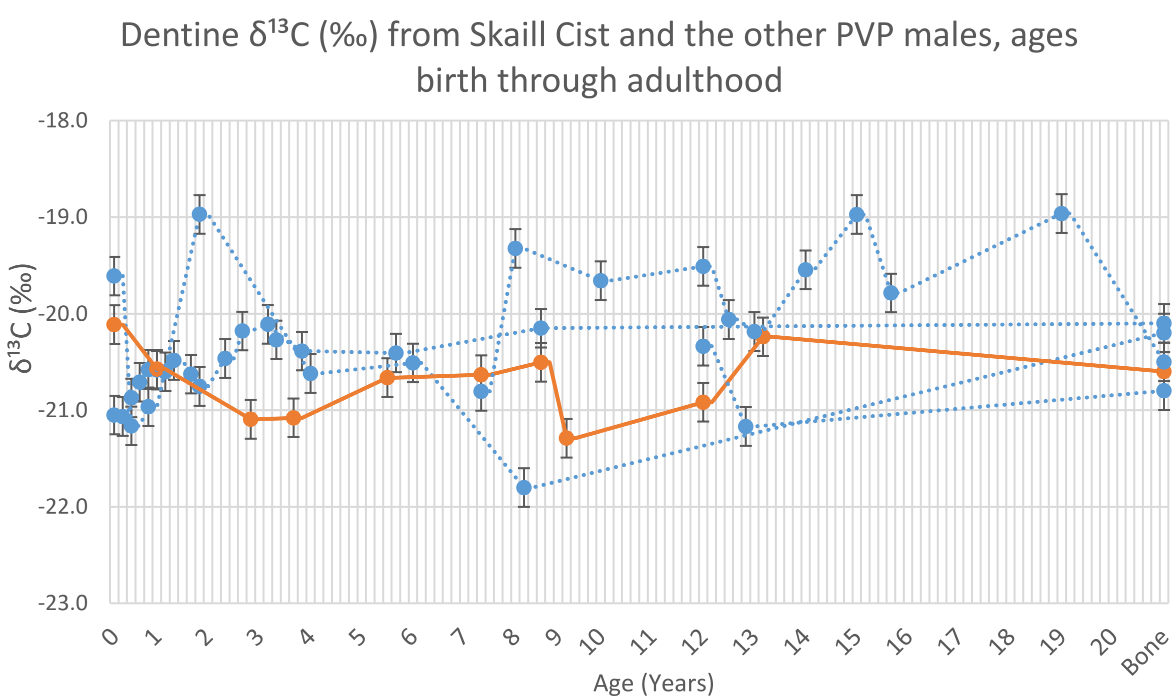

Figure 8.17. Dentine $\delta^{13}C$ (‰) from the Skaill cist male (in orange) from birth through adulthood, plotted with the other PVP males (blue dashed line).

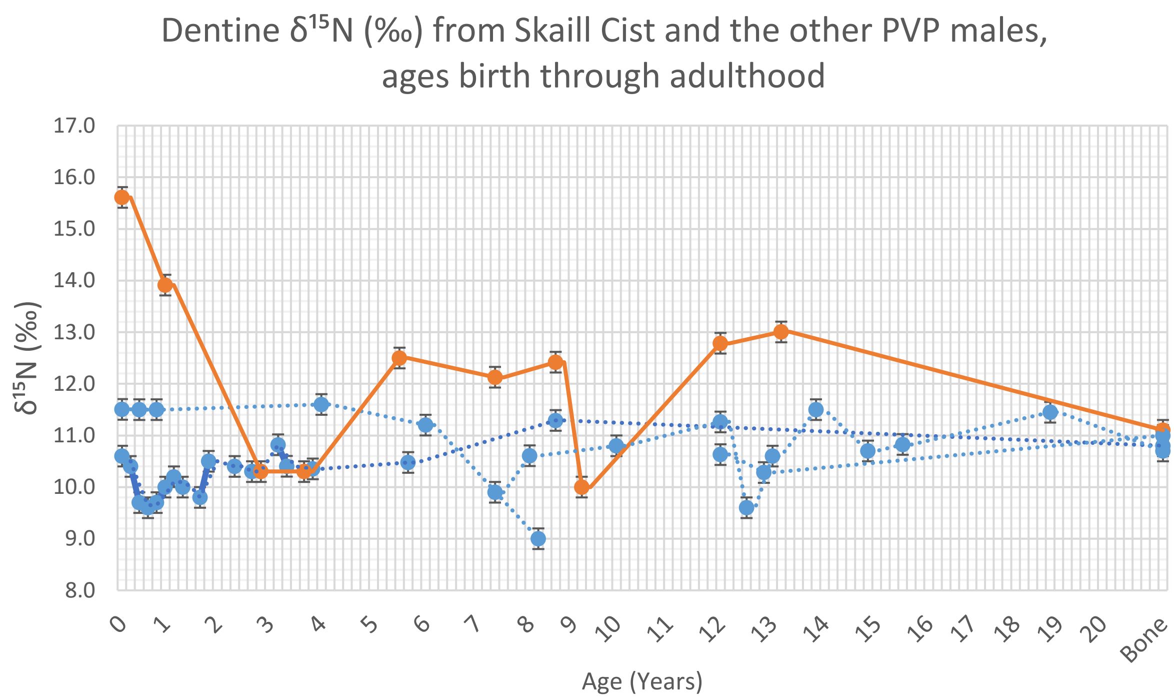

Figure 8.18. Dentine δ^{15}N (‰) from the Skaill cist male (in orange) from birth through adulthood, plotted with the other PVP males (blue dashed line).

8.4.2. Westness 5

Westness grave 5 was a non-local middle adult female dating to the early VA (AD 760 ± 50), between the ages of 35 and 45 years old (this study; Sellevold 1999, 7). She was one of two females buried with an agricultural tool (sickle) at the site, along with a brooch, comb and spindle whorls. Strontium and oxygen isotopes measured by Montgomery and colleagues (2014, 57) indicate that this individual was not local to Orkney but had immigrated after the age of thirteen. Interestingly, although being buried with Scandinavian grave goods, her strontium isotopes (0.70729) are inconsistent with someone who grew up in Scandinavia, but more likely western Scotland (Iceland or the Faroes are more remote possibilities; Montgomery et al. 2014, 64). Could she have been taken from her homeland as an adolescent or young adult for the bride of a Scandinavian male? The adoption of Scandinavian personal items suggests an adoption of Scandinavian ethnicity and recent aDNA studies have shown evidence that women were brought from Ireland and Iceland in the VA (Goodacre et al. 2005; O'Sullivan 2018). The date of this female burial (late eighth century) indicates that females were already part of the migrating population in the early VA and suggests that Scandinavian males were potentially already bringing wives and families to settle in Orkney in the VA. Another possibility, though improbable, is that she was a part of raiding in this phase (McLeod 2011).

She stood at an estimated 152cm, the second shortest recorded woman in VA Orkney where the mean was 160.6 ± 6cm. While she did not exhibit CO or PH, she did exhibit cribra femora, an indicator of anaemia. While the inclusion of grave goods may infer she was of high social status, she exhibited osteoarthritis of the hip, sternocostal and vertebral joints, suggesting she may have taken part in manual labour. She also exhibited signs of non-specific infection (periostitis and osteomyelitis) in one femur, both tibiae and her right fibula, lesions which were still active at the time of death (this study; Sellevold 1999, 29). The chronic infection in both legs would likely have inhibited her mobility and harmed her quality of life.

Analysis of her teeth revealed linear enamel hypoplasias (LEHs) of two maxillary medial incisors, which would indicate some sort of physiological stress event at around two years of age. A tooth lost post-mortem (likely a maxillary lateral incisor) exhibited at least three LEHs, all corresponding to between the ages of 2 and 4 (Primeau et al. 2015, 386; Reid and Deen 2000, 138). Physiological stress around this age could have been a result of weaning, as many individuals from all three phases exhibit LEHs between the ages of 2 and 4 years old. It is possible that the stress that caused the LEHs could have also ultimately contributed to her short adult stature. Her teeth also exhibited medium to heavy calculus deposits, predominantly on the labial surface of the mandibular incisors and the buccal surface of the maxillary molars. The presence of calculus deposits and the moderate-to-severe attrition level may very well have concealed additional LEHs. In addition to calculus deposits, grave 5 exhibited two teeth with dental caries, indicating a diet relatively high in carbohydrates. To incorporate the stable isotope evidence, her $\delta^{13}C$ (-20.7‰) and $\delta^{15}N$ (11.8‰) values indicate her diet included little marine protein, only approximately 3.3%, based on her bone collagen (this study). Despite living on or near the coast, her diet likely comprised terrestrial protein and carbohydrate-rich foods like grains. Her high status as interpreted by the presence of grave goods and her diet low in marine resources would fit with James Barrett's assertion that fish consumption was indicative of lower status in the VA (Barrett 2003b, 90). The inclusion of a sickle in her grave could have represented her perceived social roles and status in life, which would be consistent with the presence of osteological indicators of load-bearing and consumption of carbohydrates. The unequal wear of her mandibular molars sloping buccally suggests the attrition could be due to occupational use. In addition to a lesion on her frontal bone described by Sellevold (1999, 29) as a 'pseudo-trepanation', a possible peri-mortem perforation was observed by the author at bregma (the point of conjunction between the two parietal and occipital bones). The lesion included internal bevelling and radiating fracture lines, though the edges of the bone appeared smooth. The lesion is notable because it represents one of only a handful of incidences of violent trauma in VA Orkney and a female migrant, no less.

8.4.3. Scar 135

Scar 135 was a VA juvenile between the ages of 10 and 11, of indeterminate sex. Being one of the three individuals buried in the Scar boat burial, Scar 135 was the only subadult and was not associated directly with any of the recovered grave goods. Coastal erosion had badly damaged the burial, however, and it is possible any grave goods once associated with this individual were either moved or washed away completely (Owen and Dalland 1999). Although 135 was buried with an adult male and middle adult female, it is unclear whether they were biologically related, as DNA analysis has not been undertaken. Of the present dentition, only four observable teeth were definitively from 135 and none had LEHs. Despite the lack of dental evidence for physiological stress, a radiograph of 135's distal tibia revealed a Harris Line, indicating at least one period of stress during development. Skeletal preservation was poor, with surface damage and fragmentation of most elements.

Enamel from a first molar from Scar 135 was sampled for strontium and oxygen isotopes and sequential dentine was sequentially sampled for carbon and nitrogen isotopes. The strontium isotopes (0.709157) and oxygen isotopes (16.7‰ $\delta^{18}O_p$) indicate they were not native to Orkney. Despite being interred in a Scandinavian-style boat burial, Scar 135 exhibited low strontium and oxygen isotopes that are characteristic of parts of eastern mainland Scotland or England (Figure 8.19.; per British Geological Survey 2018 Biosphere isotope domains database).

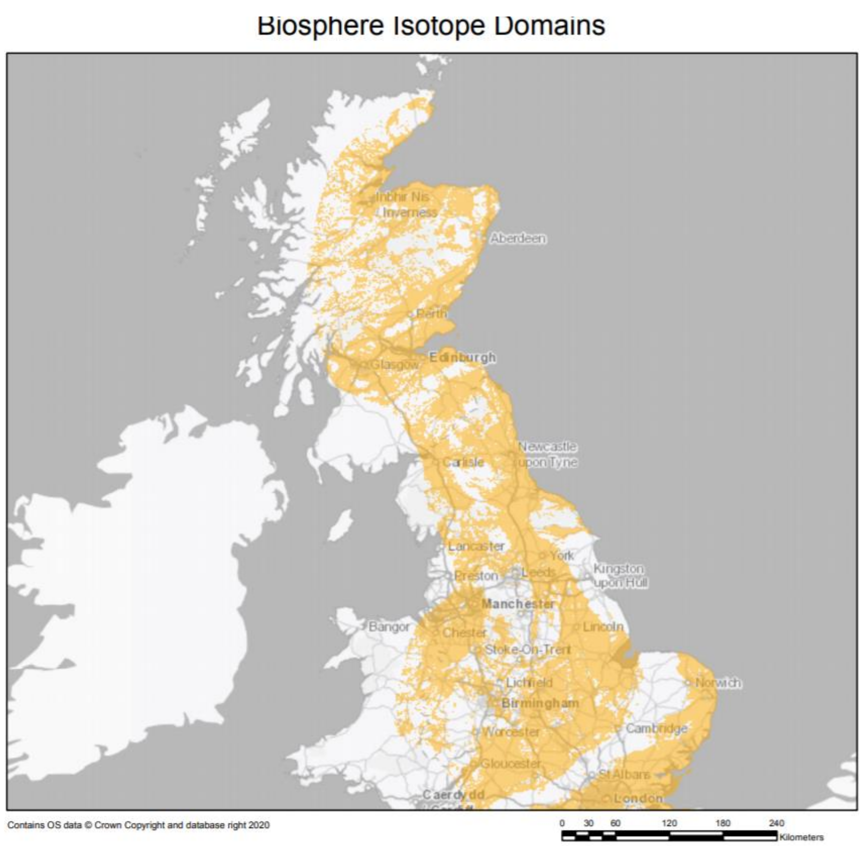

Figure 8.19. Biosphere isotope domains relevant to Scar 135 (limited to within Great Britain), with strontium (0.709157) and oxygen isotopes (16.7‰ $\delta^{18}O_p$) queried (BGS 2018; Contains British Geological Survey materials © UKRI [2020]).

Bone collagen $\delta^{13}C$ (-20.2‰) and $\delta^{15}N$ (12.4‰) values indicate Scar 135 had a diet comprising 8.4% marine protein, slightly higher than the adult female and adult male buried in the same grave (4.8‰ and 7.8%, respectively). The same molar that was sampled for enamel strontium and oxygen was also sequentially sampled for dentine $\delta^{13}C$ and $\delta^{15}N$. Below (Figures 8.20. and 8.21) are the trendlines for the M1 from Scar 135, plotted with the other M1s from the VA (blue) and the LNP (green). The $\delta^{13}C$ and $\delta^{15}N$ values correlate strongly and increase slightly between the ages of 2 and 5 years old, however, the mean dentine $\delta^{13}C$ and $\delta^{15}N$ values (-20.9‰ and 10.4‰, respectively) from Scar 135 were lower than the $\delta^{13}C$ and $\delta^{15}N$ from all the other sampled M1s, regardless of phase. The only M1 with a lower $\delta^{15}N$ mean was Buckquoy M12, dating to the PVP (10.4‰). The consistently low $\delta^{13}C$ and $\delta^{15}N$ values throughout infancy suggest Scar 135 was not breastfed (at least not for a substantial amount of time) and did not undergo a period of weaning onto a diet high in marine protein. Rather, the terrestrial dietary isotope values suggest Scar 135 was sustained on cow or goat's milk, or gruel made from cereal. Despite being so young, Scar 135 exhibited mild calculus and had at least one carious tooth, supporting the theory that they may have subsisted on animal milk and cereal-based food. The presence of mild CO in both orbits and indicators of non-specific infection suggest they suffered from malnutrition and this may have contributed to their premature death. Possibly an immigrant from a very young age, or the child of an immigrant mother, their rich boat burial suggests being of high status despite their chronic malnutrition. The child's burial with an adult male and older female suggests they may have been the child's relatives or primary care givers. That evidence, along with the lack of weaning signal in the dentine trendline, suggests it is possible and the child's mother may not have provided them with the nutrition they so much needed early in life. However, as previously mentioned, it is possible that nursing early in life (i.e., until around 6 months old) did not result in apparent increases in sequential dentine $\delta^{13}C$ or $\delta^{15}N$ values. Unfortunately, we may never know their story or what brought them to be buried in a Viking boat grave on a sandy beach in Orkney.

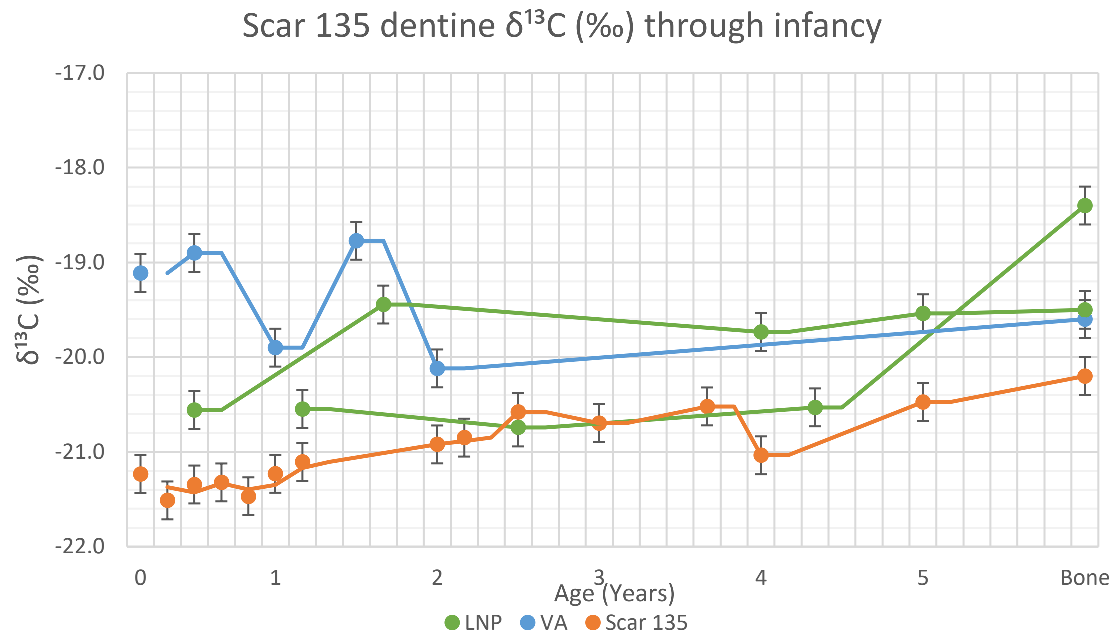

Figure 8.20. Dentine $\delta^{13}C$ (‰) trendline from Scar 135 (orange) through infancy, in contrast with other M1s from the VA (blue) and LNP (green).

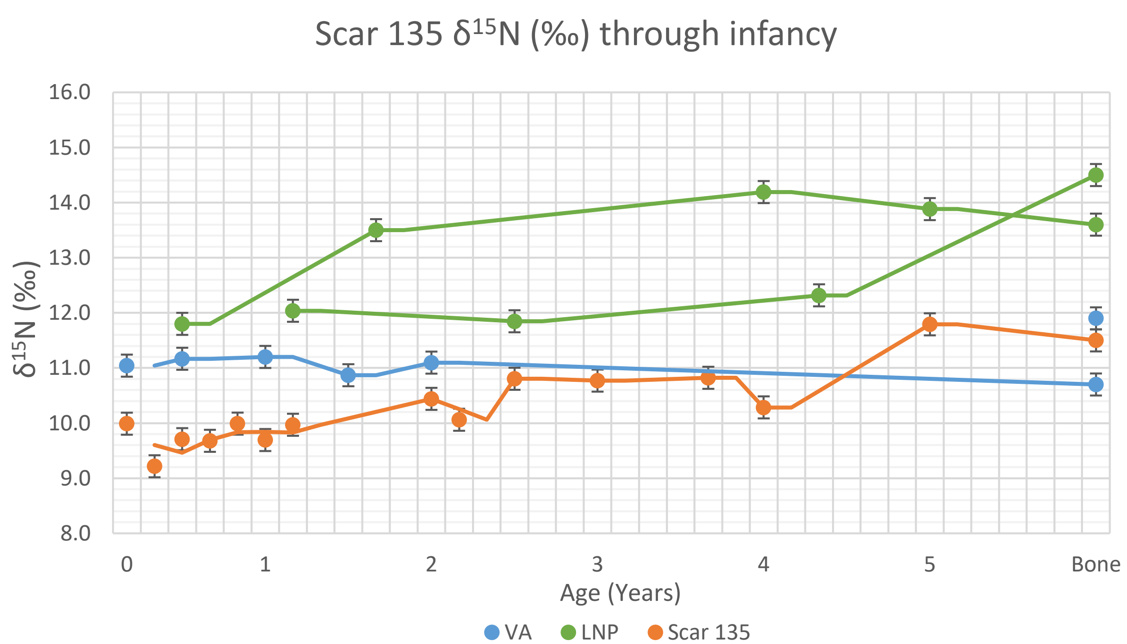

Figure 8.21. Dentine $\delta^{15}N$ (‰) trendline from Scar 135 (orange) through infancy, in contrast with other M1s from the VA (blue) and LNP (green).

8.5. Scandinavian settlement and its impact on Orkney: economic, sociocultural and religious change

8.5.1. Climatic trends and changes in diet and health

This section examines the evidence for changes in diet and health as the result of a climate-related change in the environment, in addition to the cultural and religious changes throughout Orkney and the North Atlantic. Fluctuations in climate can have a decisive impact on the success of agricultural and pastoral communities, especially those in already marginal environments like the Orkney Isles. According to Davidson and Jones' chapter on the environment of Orkney, "the Orkney climate, especially the elements of wind and dampness, places severe stress on agriculture…. An unusually wet summer… can cause serious hardship" (Davidson and Jones 1985*,* 19). However simple it might be to assume environmental stability over the last 1500 years, this has not been the case. Based on the Greenland ice core, the North Atlantic experienced significant deviation from mean temperatures between ca. AD 950 and 1250, in what has been termed the Medieval Warm Period (MWP) or Medieval Climate Optimum (Dugmore et al. 2007, 169). Figure 8.22. shows a model of Northern Hemisphere temperature variations during the MWP reconstructed by Mann et al. 2009, with the VA outlined in blue.

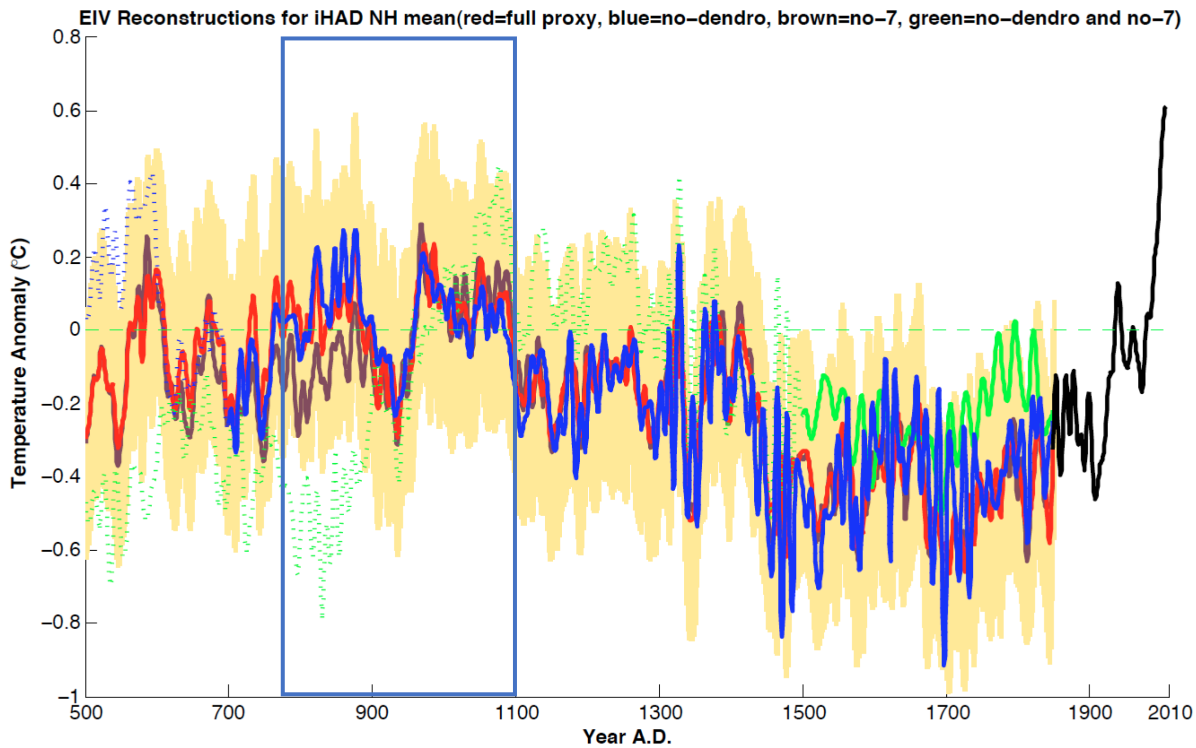

Figure 8.22. Reconstruction of variations in temperature in the Northern Hemisphere during the Medieval Warm Period, as modelled by Mann et al. 2009, Figure S8; reproduced with the author's permission.

Michael Mobilia's 2009 dissertation used δ[18]O values from Viking Age limpet shells to demonstrate a shift towards a warmer, more temperate climate in Scotland between AD 800 and 1300, which suggests an environmental component to dietary change (Mobilia 2009, iii). "The initial Viking period expansion seems to have taken place during a warming period now called the "…little climatic optimum (LCO) which is usually estimated to have had mean temperatures approximately 1˚Celcius higher than present means…" (McGovern et al. 1988, 248). Specific fluctuations occurring during the Viking Age have been identified in AD 975, 980, 1025, 1040 and 1180 (Dugmore et al. 2007, 169). This is relevant because as McGovern and colleagues' model reflects, temperature effects in Shetland, Iceland and Greenland would have been favourable to cereal agriculture in the first couple of centuries of Viking expansion (McGovern et al. 1988, 249). James Barrett has also suggested that the mild temperatures brought by the MWP could have encouraged "agricultural expansion" (Barrett 2004, 2419).

Based on the dating available, male diet in Orkney shows evidence of an increase in marine protein beginning between AD 800-850 (Figures 8.23. and 8.24., below). This would coincide with the warmer temperatures of the LCO reported by Mobilia (2009), nearly 200 years before the FEH. The earliest males with more marine-based diets in the VA were Westness 11 and Westness 12: two non-locals, possibly from Norway. The trend towards increased marine protein consumption (among males at least) in Orkney appears to have begun with non-local traders or raiders, two Viking suspects. Of the stable isotope data gathered from previous studies throughout the North Atlantic, there was a negative correlation between $\delta^{13}C$ and $\delta^{15}N$ values and distance from Bergen (chosen as a Norwegian starting point because of its known role in VA trading; Baug et al. 2018; Keller 2010). This could suggest Norse influence precipitated the trend in more fish-reliant diets. The increased variability observed in the Orkney VA also closely resembles trends in Norway. Although the Orkney Isles are separated by the North Sea from Norway, the two regions share a similar climate due to the warm currents of the North Atlantic Drift (Coles and Housley 2004, xi-xii). The question is then why do male diets seem to transition earlier than female diets? There are a couple of possible explanations. Female diet, however, began a shift towards more marine protein at around the time James Barrett estimates the beginnings of the FEH (Figures 8.25. and 8.26). The five earliest females with higher $\delta^{13}C$ and $\delta^{15}N$ just after AD 1000 were all from Newark Bay, though their geographic origins are unknown. In addition to the isotope evidence for a Norse-driven shift towards more marine-based diets, the archaeological evidence credits the Norse for bringing flax to Orkney (Bond 1998; Bond and Hunter 1987), the adoption of the horizontal mill (Batey 1992; 1993), an increased focus on dairying and growing the cultivation of oats, which led to the overwintering of more livestock and less culling of the herd (Bond 1998; 2003).

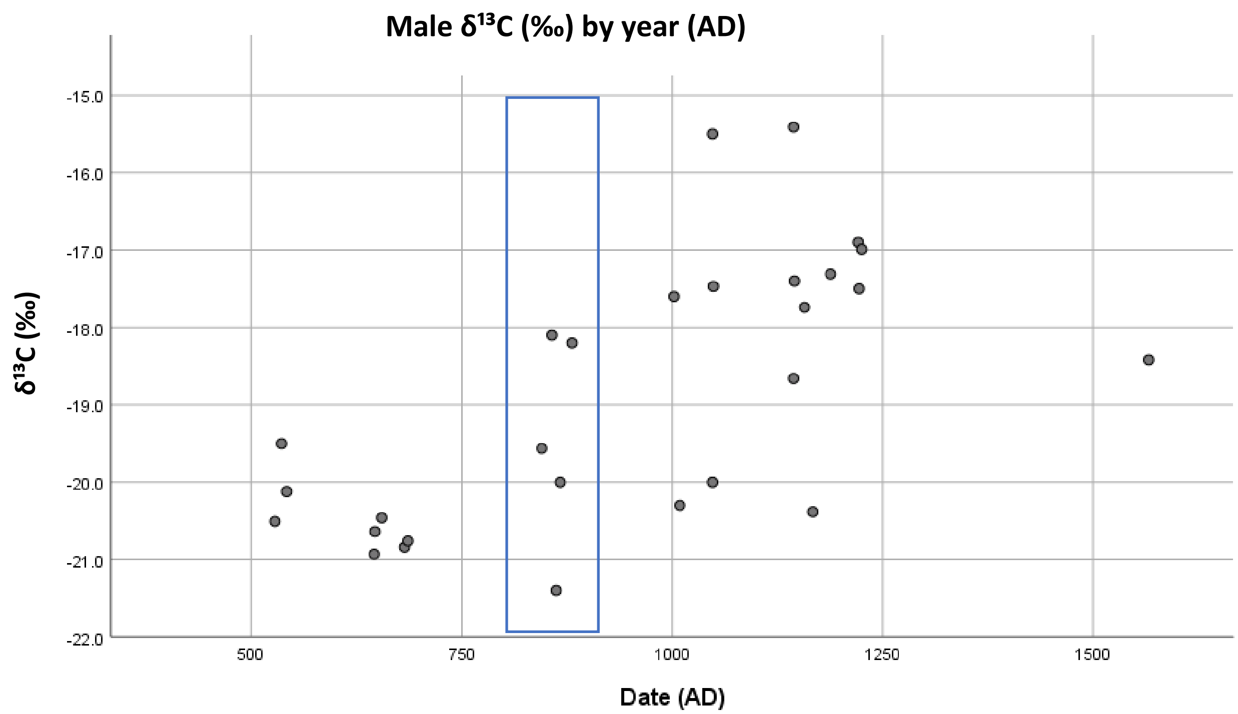

Figure 8.23. Male bone collagen δ^{13}C (‰) by year (AD) (Barrett et al. 2000b).

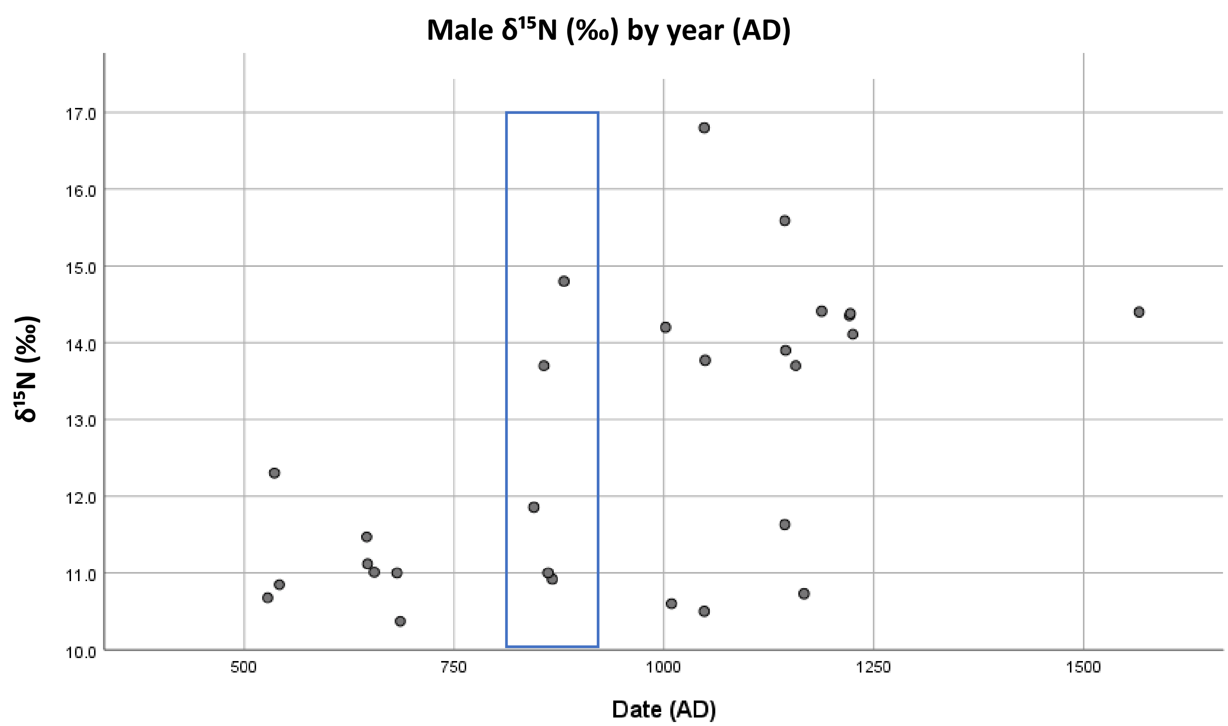

Figure 8.24. Male bone collagen δ^{15}N (‰) by year (AD) (Barrett et al. 2000b).

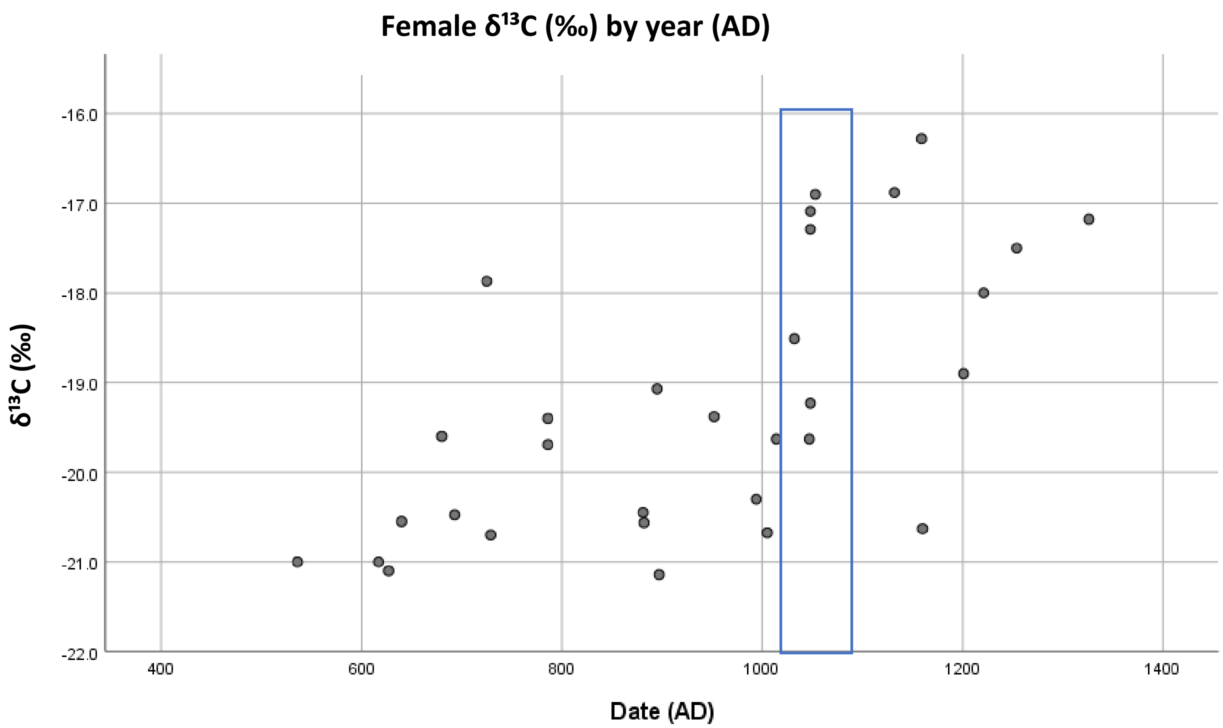

Figure 8.25. Female bone collagen $\delta^{13}C$ (‰) by year (AD) (Barrett et al. 2000b).

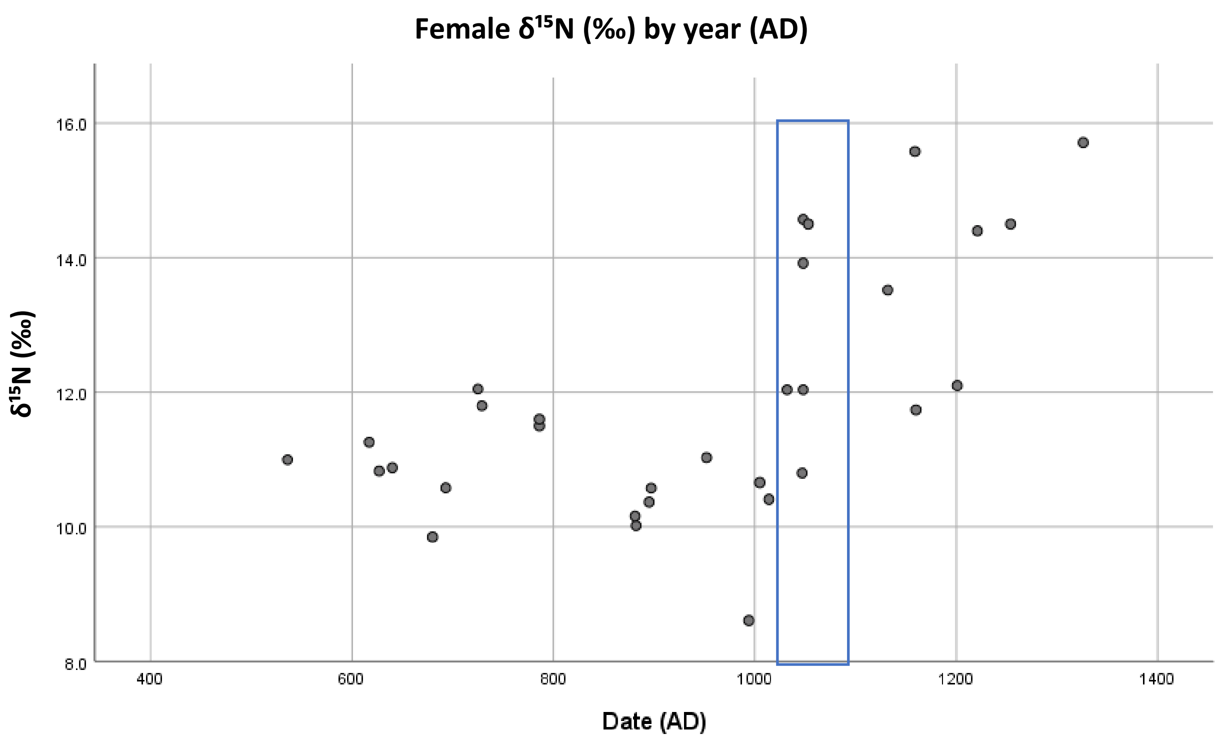

Figure 8.26. Female bone collagen $\delta^{15}N$ (‰) by year (AD) (Barrett et al. 2000b).

8.5.2. East and west

A contrast in the nature of PVP, VA and LNP sites on the western versus the eastern side of the archipelago has been made in the past by archaeologists like James Barrett (2003a) and Simon Buteux (1997). While all but one of the richly-furnished Scandinavian-style burials (Scar) have been found on the western side, evidence for the earliest chapels comes from two sites on the eastern side: Newark Bay and the Brough of Deerness (Barrett 2003a, 209; Graham-Campbell and Batey 1998). Reconstructed trade routes by Barbara Crawford (1987) and more recently by C. Richard Bates and colleagues (2020) have suggested Norse travellers in the VA came around the northwest side of the archipelago from Norway and Shetland, making their way through Scapa Flow and south to reach the Hebrides and Ireland. The latter study uncovered a Norse waterway through Mainland Orkney that would have been navigable by shallow Norse vessels, running from Birsay through the Lochs of Boardhouse, Harray and Stenness and into the Bay of Ireland (Richard Bates et al. 2020, 13) (Figures 8.27 and 8.28). The establishment of high-status sites at prominent geographical locations on the coastline and along trade routes (such as at the point of Buckquoy and along Birsay Bay) is attested in the *Orkneyinga Saga* and has been pointed out by Christopher Morris (1989) and David Griffiths in their studies of Skaill and Birsay Bays (Griffiths et al. 2019). It could be that these points became the primary points of Scandinavian settlement, around which previously self-sustaining farmsteads became (voluntarily or involuntarily) producer sites. Based on the distribution of Scandinavian-style graves, regional density of individuals identified as non-local and the corresponding prevalence of scurvy in the VA, it is proposed here that Scandinavian settlement began along the west of the Orkney mainland, around sites with Norse land-feature names. While the Brough of Deerness lies on the eastern side of the mainland, its defensive location on a promontory along the coast has led James Barrett and Adam Slater to suggest it may have been an early centre of power and religion, similar to Birsay Bay (Barrett and Slater 2008, 5). Important sites like these were likely built as 'watch-towers' to oversee trade and migration, as well as serve as ecclesiastical and political power centres (*ibid., 4*). Unfortunately, the limited number of burials from the Brough of Deerness limits possibilities for interpretation of health and diet at the site and how the conditions at the site may have compared to those at sites along Birsay Bay. Patterns in diet and health between the eastern and western sites are evaluated in more depth in this section.

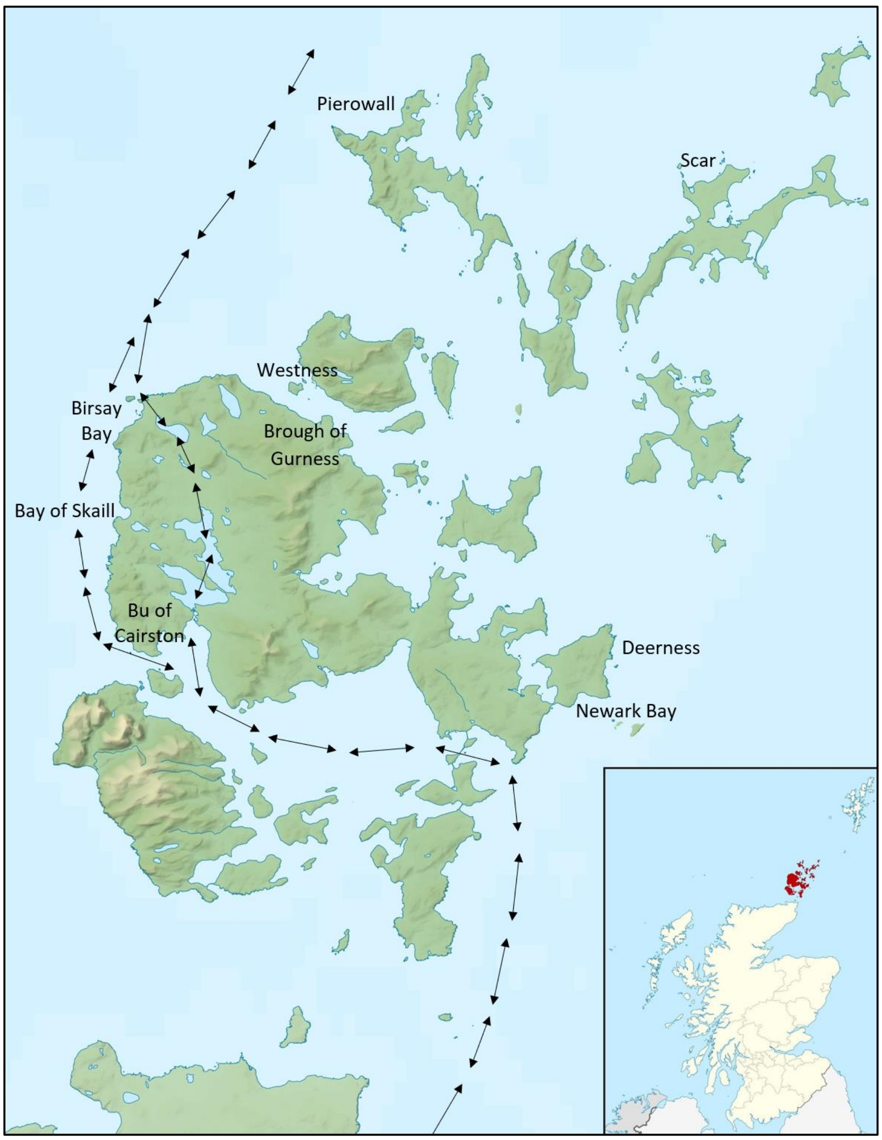

Figure 8.27. Possible VA trade routes from Norway or Shetland through Orkney to mainland Scotland, Hebrides and Irish Sea (map created based on Crawford 1987, 23 and Richard Bates et al. 2020).

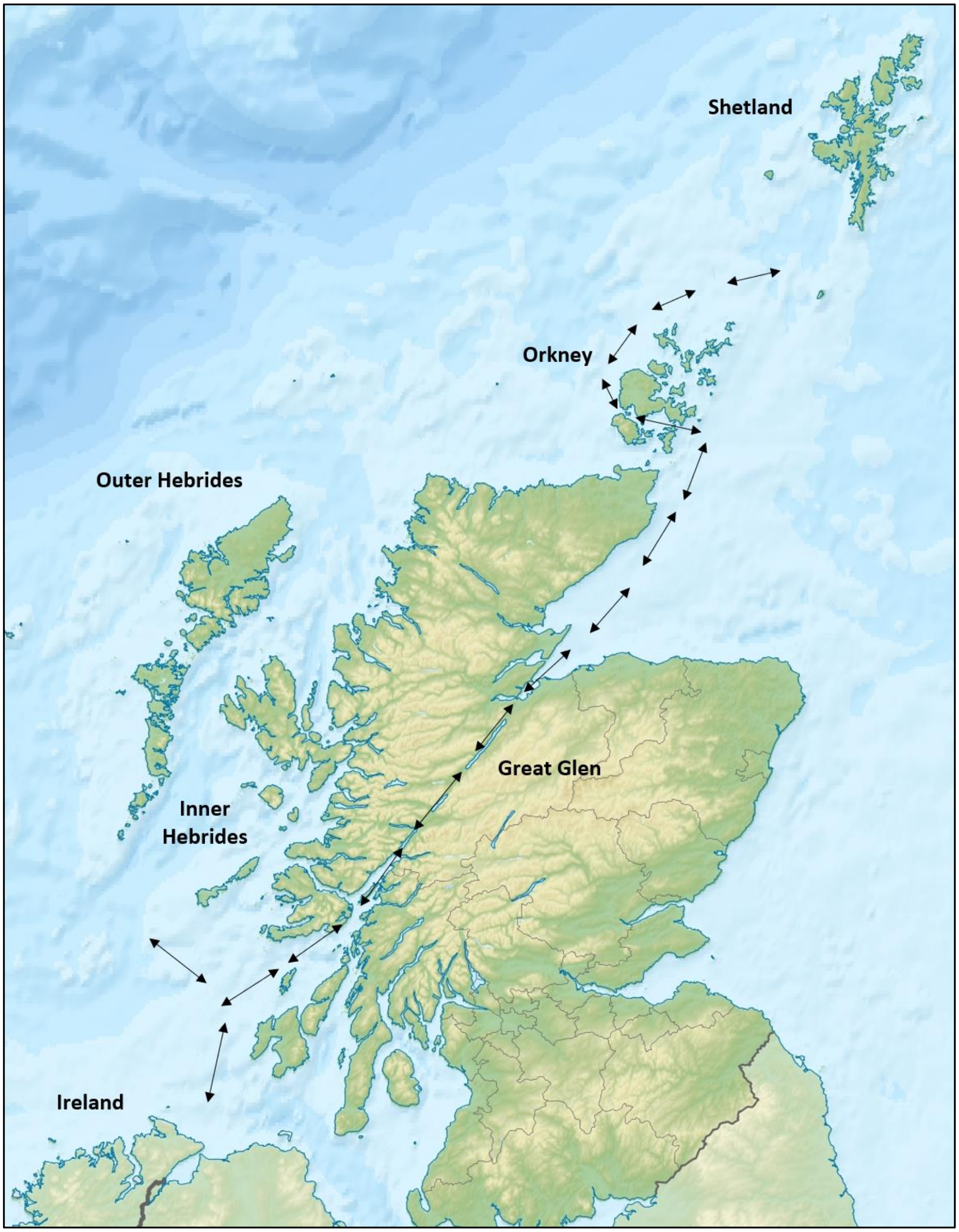

Figure 8.28. Possible VA trade route from Norway or Shetland through Orkney and the Great Glen to the Hebrides and Ireland (map created based on Crawford 1987, 23).

8.5.2.1. Health and nutritional deficiencies

As osteological markers of nutrition, dental pathologies and indicators of load-bearing were analysed, what emerged was a distinction between prevalence rates at sites on the western and eastern sides of the archipelago. Patterns in nutritional deficiency suggest a differential impact of socioeconomic and cultural change in the eastern portion of the archipelago than the west. In the PVP, there were only two significant differences between indicators of health in the east and west: a higher prevalence of CO among females at western sites and a higher prevalence of abscesses among males from eastern sites. The difference in rates of CO among females could suggest the provision of more nutritious resources for male consumption at western sites, but the two indicators alone are difficult to interpret. In the VA, however, more differences between health at eastern and western sites emerged. Among females, there were higher crude and true prevalence rates of LEHs at western sites.

Among males, there were higher prevalence rates of:

- PH at western sites
- Scurvy (almost significantly, p= 0.057) at western sites
- OA of shoulder joints at western sites
- Squatting facets at western sites
- Violent trauma at western sites
- Abscesses at eastern sites
- OA of hand joints at eastern sites

There was a positive correlation between VA males with PH, scurvy and OA of at least one shoulder joint. The higher prevalence of PH (and scurvy) in males from western sites indicate these were males with less regular access to fresh foods with vitamin C. The higher prevalence of PH and scurvy, in combination with the higher prevalence of OA of shoulder joints could suggest these were men who regularly rowed boats and were active in long-distance travel. Not only was evidence of scurvy found only in VA individuals buried outside churchyards, but there was a substantially higher rate of scurvy among VA males with boat graves or grave goods (particularly weapons). This supports the idea that Vikings or traders with Scandinavian ethnicity primarily settled at sites along the trade route, predominantly along the western coast. With the prominent location of important sites like those around Birsay Bay along trade routes down the western side of the Orkney Mainland, it would make sense if it were these sites that were first to be occupied by migrants- Scandinavian or not- and that these migrants would exhibit higher rates of nutritional deficiency than the local population because of their limited access to resources while traveling over long distances. The greater variation observed in sequential dentine $\delta^{13}C$ and $\delta^{15}N$ among non-local VA individuals also suggests instability in diet. If immigrants primarily settled in the west of Orkney, that would explain the greater presence of Scandinavian-style burials in the west, at the sites of Pierowall, Brough Road, Westness and Buckquoy. When sites were tested separately, the prevalence of scurvy rose from the PVP to the VA at western sites but not at the eastern site of Newark Bay.

When separated by age group, an increase in CO and indicators of scurvy was seen specifically in young adults from the PVP through the LNP. This would support the theory that young adults were the primary age group among migrants in the VA, young and strong enough to suffer through nutritional deficiencies in their long-distance travel. The increase in both males and females, along with non-local strontium and oxygen isotopes, suggests young adults of both sexes were involved in migration, although possibly from different origins.

Differences in health between the two regions continued to develop in the LNP, affecting both males and females. LNP males from eastern sites exhibited significantly higher prevalence rates of periodontal disease, OD, OA of vertebral, knee and sternocostal joints, as well as squatting facets and occupational/accidental trauma. This is substantial evidence for greater levels of physical labour among males at eastern sites in the LNP. Could these differences in prevalence be in part the result of differences in subsistence practices? Interestingly, the development of the plaggen soils is more prevalent on the western coast as well, which could be the result of different levels of excavation, a result of differences in soil quality, or reflect differences in Scandinavian settlement (as most areas with plaggen soils had Scandinavian place-names; Simpson 1993). Despite sites on the east and the west predominantly growing barley and raising cattle, better soils on the western coast could have prompted more agricultural development, spurred on by Scandinavian settlement.

8.5.2.2. Stable isotope evidence of an east/west division

Regarding dietary stable isotope differences in individuals from eastern versus western sites, there were higher $\delta^{13}C$ values in females from eastern sites throughout the PVP, VA and LNP. Males from eastern sites also exhibited higher $\delta^{13}C$ values than males from western sites, but only in the LNP. It appears that the isotopic evidence supports the theory of there being considerable differences in diet and subsistence at eastern sites than at western sites, especially in the LNP. The greater exploitation (and consumption) of marine resources at western sites (as evidenced by the archaeoichthyological evidence) would have increased the $\delta^{15}N$ and $\delta^{13}C$ values of individuals living in the west and perhaps leveled with increased $\delta^{15}N$ values at the eastern sites that was caused by manuring. When PVP, VA and LNP cattle $\delta^{13}C$ and $\delta^{15}N$ values were compared between eastern and western sites, there were higher $\delta^{13}C$ values in cattle from eastern sites than western sites ($p=0.000$), suggesting the differences in beef $\delta^{13}C$ values could have at least contributed to differences in human $\delta^{13}C$ values.

There was a notable difference in the timing of the adoption of a more marine-based diet between males and females. Males from western sites exhibited a significant but gradual increase in $\delta^{13}C$ and $\delta^{15}N$ values from the PVP to the LNP, with no substantial difference between either the PVP and VA or the VA and LNP. Females from both eastern and western sites exhibited no difference in $\delta^{13}C$ and $\delta^{15}N$ values from the PVP to the VA but then a significant increase from the VA to the LNP. This increase coincides with both the MWP and the conversion of Orkney to Christianity (currently accepted as AD 995; Barrett 2003a; Barrett et al. 2000b, 13). If the increase in $\delta^{13}C$ and $\delta^{15}N$ values among western males was related to their exposure to Scandinavian influence (as opposed to their eastern counterparts who showed no change in $\delta^{13}C$ and $\delta^{15}N$ values over time), we might expect to see a difference in values between VA males with and without grave goods. While unfortunately there is none, there are, however, higher $\delta^{13}C$ values among western non-local males than local males. This suggests differences in diet may have been due to access to foreign goods.

Chapter 9. Conclusions

This chapter provides a synopsis of the findings, scope and progress of this study, as well as a discussion of the inherent limitations and recommendations for future work.

9.1. Scope and progress

There is ample written and archaeological evidence for large-scale socioeconomic changes in the VA and LNP, not only on Orkney but across the North Atlantic region. Although human remains continue to be found from time to time (for example as the Orkney shoreline erodes), this study sought to amalgamate data from the entire assemblage of human remains thus far recovered from the pre-Viking (PVP, AD 500-750), Viking Age (VA, AD 750-1100) and Late Norse Phase (LNP, AD 1100-1300) Orkney. Detailed, yet site-specific osteological analyses have previously provided invaluable insights into the population structure and pathology of some of the key sites from these phases: Newark Bay, Buckquoy, Westness, Skaill Cist and House and Bu of Cairston (James 1999; Lorimer 1970; Molleson n.d., 2005; Sellevold 1999; Stevens et al. 2005), yet a systematic analysis of the entire assemblage and how indicators of health and diet varied by site, phase, age and sex had not been attempted until now. Foundational isotope studies for Orkney including those by James Barrett (1999; 2000a; 200b, 2004), Mike Richards (2006) and Janet Montgomery paved the way for the large-scale comparison of isotopic indicators of diet and mobility. Archaeological studies of settlement sites including Skaill (Deerness), Bay of Skaill, Birsay Bay, Pool and Quoygrew have reported bioarchaeological evidence of increasing marine resource exploitation and consumption, expansion of agriculture and diversification of crops and a greater focus on dairy and crop surplus as forms of portable wealth (Alldritt 2012; Barrett 2012c; Barrett et al. 2000b; Bond 1998; 2003; Critch 2019; Morris 1989; etc.). To integrate previous and present osteological work in an all-encompassing analysis of pathology, nutrition and diet from the PVP through the LNP, the complete body of material needed to be methodologically standardized. While it would not have been possible without previous osteological and isotopic research, this study is the largest osteological study of PVP, VA and LNP Orkney to date and incorporates carbon, nitrogen, strontium and oxygen isotopes intending to answer (or at least contribute to) long-standing archaeological questions, including those regarding Pictish/Scandinavian relations.

Economic, cultural and religious transformations swept Orkney in the VA and LNP. Intensification of agriculture (increased manuring and labour per land unit of land) in the VA, as well as expansion of cultivated land and the movement towards the regular production of cereal surpluses (mainly for export and payment of skat), have been proposed by palynologists and soil chemical analysts (Bond 1998; Simpson 1993), as well as in evidence including a speech given by the King of Norway in 1182 (Barrett et al. 2000b, 20; Chapter 2). These economic developments would have required additional manual labour. While it is possible that the brunt of this manual labour was being carried out by traction animals, if humans had an increased physical workload this would have resulted in increases in osteological indicators of load-bearing including platymeria, OA, OD and occupational/accidental trauma. Meanwhile, written evidence of Scandinavian raiding and later settlement in the VA and LNP, respectively, led to hypotheses that there would be an overall increase in stature (due to genetic admixture), a shift towards more marine-based diets because of Scandinavian dietary preferences and an increase in violent trauma with Viking-exacerbated increases in inter-personal conflict in the VA.

9.2. Lines of investigation

By combining osteological and isotope analysis from these twelve sites, it was the principal aim of this study was to explore trends in health, diet and mobility throughout the Pictish/Norse transition and investigate whether some or all of the trends detected could be associated with the archaeological evidence of cultural, religious and/or socioeconomic changes attributed to these phases. While these factors are inextricably related in everyday life, they leave different strands of evidence in the archaeological record. For example, differences in subsistence and manual labour cause differences in the skeletal manifestations of physical stress and load-bearing, while differences in cultural or religious affiliation can be inferred from different burial practices (i.e., the inclusion of grave goods or burial within a churchyard). Research questions centered on investigating how the populations of Orkney were affected by a socioeconomic progression towards a market-based economy that included increasing site specialisation, a newly-formed Scandinavian ruling elite and substantial shifts in subsistence including increased agricultural production, dairying and deep-sea marine exploitation. The following osteological and isotope indicators were compared across phases, age groups, sexes, sites, site type, subsistence profiles, cultural indicators (grave goods), religious indicators (churchyard vs. non-churchyard) and geographic origin (strontium and oxygen isotopes):

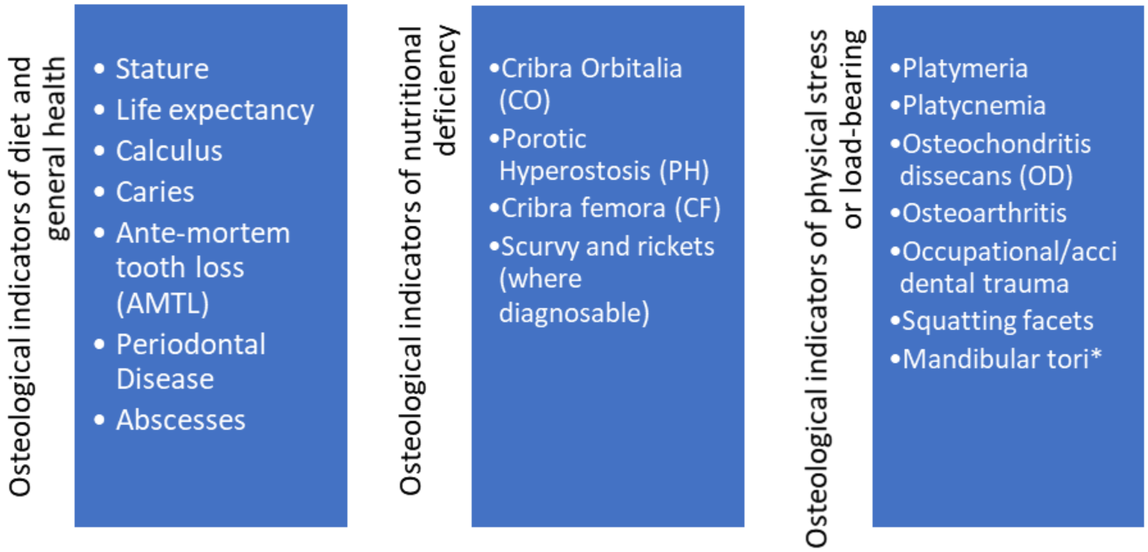

Figure 9.1.Osteological indicators analysed as part of this study.

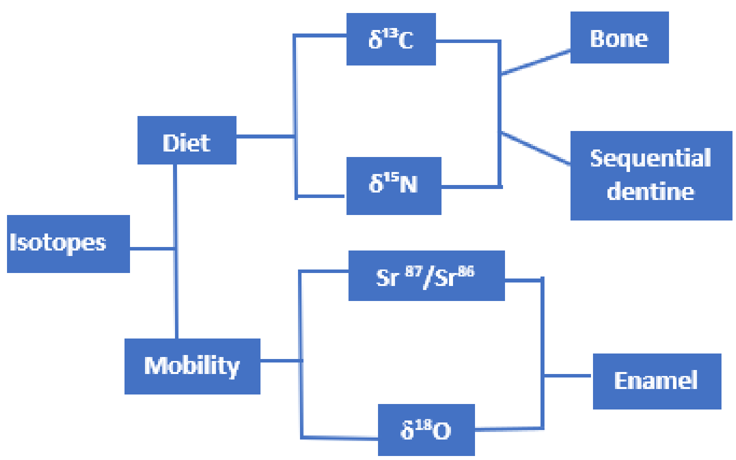

Figure 9.2. Isotopes indicative of diet (carbon and nitrogen) were tested from bone collagen and dentine, while mobility isotopes (strontium and oxygen) were tested from enamel.

9.3. A synopsis of findings

9.3.1. Comparisons by phase

First, osteological markers of health and nutrition and dietary stable isotopes ($\delta^{13}C$ and $\delta^{15}N$) were compared between phases, sexes and age categories to identify whether there were changes in the prevalence rates (or values) through time, regardless of the underlying cause.

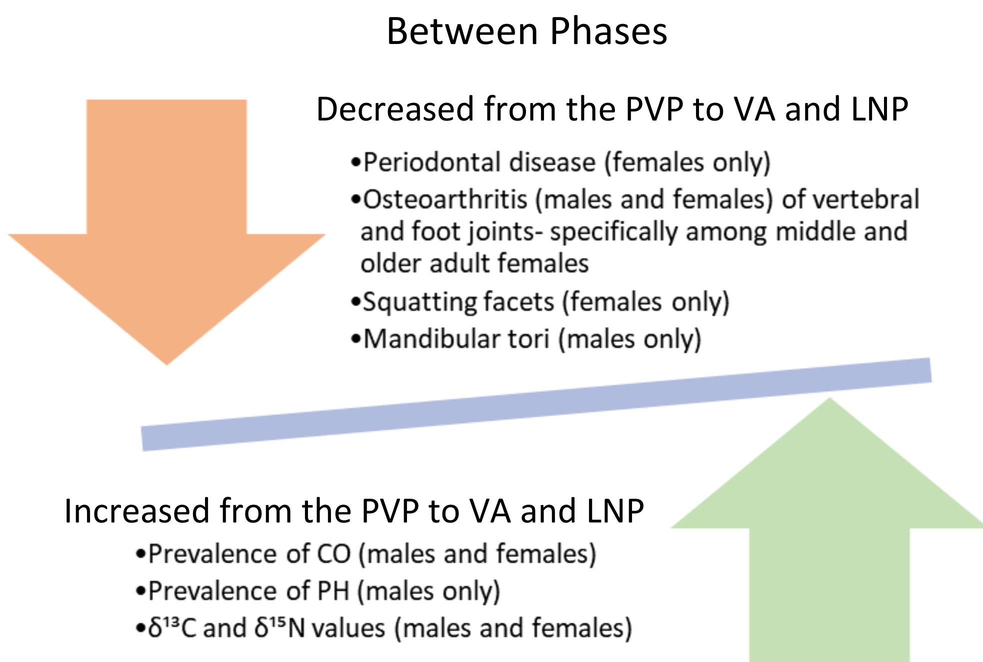

Figure 9.3. Summary of osteological and isotope results when compared by phase.

Osteological indicators that exhibited no difference in prevalence rates phases (among either sex):

- Age distribution
- Sex ratio
- Stature
- CF
- Dental attrition
- Platymeria or platycnemia
- OD
- Occupational/accidental trauma
- Calculus
- Caries
- AMTL
- Abscesses
- LEHs
- Specific and non-specific infections
- Violent Trauma

Previous stable isotope studies suggested males had diets higher in marine protein than females in the VA, which could indicate sex-based divisions in labour, with predominantly males fishing and females working the fields (Barrett 2012c; Barrett et al. 2000b; Barrett and Richards 2004). After compilation of isotope analysis done as part of this study and previously published isotope data, there were no observable differences in $\delta^{13}C$ and $\delta^{15}N$ values between males or females in any of the phases. While some osteological indicators suggest there were differences in some of the labour undertaken by each sex (higher rates of occupational trauma in males, for example), differences in prevalence rates of load-bearing indicators between age groups points to a more age-based division of labour (similar to interpretations from Portmahomack, Curtis-Summers et al. 2014).

9.3.2. Comparisons between sites and subsistence

Next, osteological prevalence rates and stable isotope ($\delta^{13}C$ and $\delta^{15}N$) values were compared between sites to assess uniformity or variation in overall health across Orkney within each phase. With place-name and bioarchaeological (faunal and botanical) evidence of an emerging hierarchical system of specialised producer sites supporting high-status consumer sites in the VA and LNP (see Chapter 2 for more detail), a growing difference in osteological markers of load-bearing and physical stress was expected between sites.

While stature and demographic patterns did not vary by site within each phase, there were certain indicators of health and diet that did. Overall, there was a disparity in nutrition and osteological indicators of load-bearing between eastern and western sites that emerged in the VA and evolved in the LNP, suggesting differences in diet and lifeways between the two sides of the archipelago. Within the PVP, Westness females exhibited higher rates of CO than females from the other sites, while males from the eastern sites of Newark, Scar and the Brough of Deerness exhibited a higher prevalence of abscesses. In the VA, there was a greater disparity in health between eastern and western sites, with males from western sites exhibiting higher prevalence rates of PH (and nearly significantly higher rates of scurvy) as well as load-bearing indicators including osteoarthritis (OA) of shoulder joints and squatting facets. In the LNP, males from eastern sites exhibited higher prevalence rates of periodontal disease, platymeria, OD, OA of vertebral, sternocostal and knee joints and a higher rate of occupational/accidental trauma which included crush and torsion fractures. Females from eastern sites exhibited higher prevalence rates of periodontal disease, abscesses, platymeria, OA of vertebral, hand and jaw joints. The higher proportion of eastern individuals with load-bearing indicators in the LNP correlated with a higher proportion of the eastern population being from plaggen sites. This could suggest the formation of plaggen soils requiring manual labour contributed to the higher prevalence rates of load-bearing indicators. The growing differences in prevalence rates between sites in the VA and LNP could support the model of increased site specialisation, with producer sites handling the bulk of the manual labour to provide goods for consumer sites.

9.3.3. Geographic origin and ethnicity

Identifying locals and non-locals through strontium and oxygen isotopes allowed for a comparison of geographic origin with expressions of ethnicity, as represented by the inclusion of Scandinavian grave goods. The results from a recent aDNA study (Margaryan et al. 2020) allowed for a limited comparison of genetic affinity and mobility isotopes, alongside burial practice as evidence of ethnicity and religion among twelve individuals. It was interesting to note that three of the individuals with Scandinavian-style grave goods lacked either isotopic evidence for migration and/or aDNA evidence of Scandinavian ancestry, suggesting an association with Scandinavian goods may have been a form of asserting high status, rather than primarily representing geographic or ancestral origin.

9.3.4. Migration, diet and health

The higher prevalence rates of osteological indicators of PH, scurvy and OA of shoulder joints at western VA sites suggest not only differences in nutrition and subsistence activities but has wider implications for VA and LNP Scandinavian settlement in Orkney. OA of shoulder joints could have resulted from habitual physical strain on shoulder muscles, such as would be needed for rowing. Combined with the higher prevalence of indicators of scurvy this could suggest a larger portion of the males on the western side of the archipelago were traders or migrants, regularly active in long-distance travel with limited access to foods rich in vitamin C. As the most likely trade routes would have involved sailing along the western coast of Orkney, the western side of the archipelago would have a larger proportion of migrants or traders (Richard Bates et al. 2020; Crawford 1987). Although the relationship between ethnicity, geographic origin and religion in the VA (and in the LNP) was undoubtedly complex, males with Scandinavian grave goods exhibited a higher prevalence of scurvy and were taller on average than the VA males without grave goods, even though some of the former grew up locally (according to strontium and oxygen). The lasting effects of Scandinavian migration that began in the

VA continued through the LNP and later, with long-long-term differences in subsistence, diet and health emerging between the two halves of the archipelago.

9.4. Limitations of the study

Several limitations of this study are worthy of final consideration. First, though most of the human remains included in the analyses were analysed by the author, some collections, including the bulk of the Pierowall collection (except for two individuals) and the Newark Bay individuals housed at NHM (Natural History Museum, London), were not accessible for first-hand osteological or isotope analysis. While osteological analysis by multiple investigators with specialised expertise is advantageous, relying on another investigator's observations also allows for inter-observer error. Where first-hand analysis was not possible, the methodology employed by previous investigators was reviewed and (where possible) standardized across all collections (per Chapter 3 Methodology), to minimize such error. Eight individuals from NHM and the Orkney Museum (OM) were re-analysed to spot-checked for consistency between the author and previous investigators.

Another limitation of the study regards inter-site comparison of subsistence practices. Site excavation reports including zooarchaeological, archaeobotanical and archaeoichthyological analyses were consulted to build a site profile of subsistence practices from which to compare osteological evidence of health and stable isotope evidence of diet. Unfortunately (and through no fault of the expertise of the authors of these reports), the excavation techniques and level of care taken in excavation of these sites varied. For example, while sites like Quoygrew and Pool were meticulously excavated and remains sieved through mesh, sites such as Skaill, Deerness (excavated at an earlier date) did not involve that level of meticulousness. The varying precision with which these sites were excavated substantially limits our ability to interpret site function and the correlation between site subsistence and diet and health.

9.5. Recommendations for future work

The skeletal collections analysed for this study hold vast potential for understanding not only the lives of those who lived through the VA in Orkney but for understanding human resilience, adaptation and native-Scandinavian cultural hybridization on a larger scale. There are many directions in which future studies of these collections could further the field of Scottish archaeology and northern studies, one of which would involve additional radiocarbon dating of the Newark Bay collection. While 44 individuals have already been dated (Barrett and Richards 1999; Barrett 2000; etc.), the lack of extant excavation records does not allow for the phasing of the whole cemetery. While additional radiocarbon dates may not help with that problem, they may help explain temporal trends in pathology, trauma and mortality at Newark Bay. Specifically, only four of the 120 infant, child and juvenile burials have been dated. This severely limits our understanding of how some of the most vulnerable and poorly studied individuals in society were affected by large-scale socioeconomic and cultural transition in the VA and LNP. The high prevalence rates of infant mortality and childhood nutritional deficiency at Newark Bay hints at a harsher period of adaptation than can be inferred from the adult population, though chronological trends are not yet discernible. In addition to the dating of infants and children, the Newark Bay collection would benefit from the dating and sequential dentine analysis of specific individuals, including 69(033) at NHM and Sk011 and 69(CC3B) at OM. All three individuals bear evidence of violent trauma indicative of interpersonal conflict and might add substantially to the limited number of individuals with violent trauma from this period. This has potentially substantial implications for the study of inter-personal and inter-cultural conflict during the Pictish/Norse transition.

As previously discussed, sequential dentine $\delta^{13}C$ and $\delta^{15}N$ values from the first molars of several PVP, VA and LNP individuals lacked a clear weaning signal in the first three years of life. While the sample size in this study was limited to eight individuals, the trends observed could indicate a substantial shift in child-rearing, breastfeeding or weaning practices in this period. Further sequential dentine analysis of first molars (corresponding to between birth and 9 years of age) and female third molars (ages 17-20.5) could also provide information on fertility rates and diets of females during pregnancy and what kind of effect the socioeconomic transition of the VA and LNP would have had on reproduction rates. This could also offer insight into the large proportion of infant and children's burials at Newark Bay.

9.6. Concluding Remarks

Despite the limitations of this study, it was the first of its kind to incorporate both osteological and isotope analysis of PVP, VA and LNP human remains from Orkney to discern trends in health, diet and subsistence through the Pictish/Norse transition. Although the Orkney Mainland constitutes a relatively small area of land, there were obvious differences in health and diet between the eastern and western sides of the island. Differences between eastern and western sites were apparent in the prevalence rates of nutritional deficiencies (mostly indicators of scurvy), osteological markers of occupational stress and/or load-bearing, as well as in $\delta^{13}C$ and $\delta^{15}N$ values indicative of diet. Subsistence practices and diet were likely highly affected by not only the environment and land quality, but by VA and LNP trade routes from the northwest, bringing access to foreign goods and peoples. While an association with Scandinavian ethnicity (at least through burial practice) was not limited to those born or raised in Scandinavia, there was evidence that those associated with the Scandinavian elite class had slightly different diets and ways of life than their contemporaries.

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