

Short title: Pictish and Medieval diet at Portmahomack.

Full title: From Picts to Parish: stable isotope evidence of dietary change at Medieval Portmahomack, Scotland.

Authors:

Shirley Curtis-Summers^{a,*}, Jessica A. Pearson^b, Angela L. Lamb^c

^a School of Archaeological and Forensic Sciences, University of Bradford, Bradford, BD7 1DP, United Kingdom.

^b Department of Archaeology, Classics and Egyptology, University of Liverpool, Liverpool, L69 7WZ, United Kingdom.

^c NERC Isotope Geosciences Laboratory, British Geological Survey, Keyworth, Nottingham, NG12 5GG, United Kingdom.

*Corresponding Author.

Email address: s.curtis-summers@bradford.ac.uk (S. Curtis-Summers).

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ABSTRACT

In this study, period-specific dietary trends, along with socio-economic and religious influences on foods consumed by Pictish and medieval inhabitants from Portmahomack are investigated. Bone collagen from human adults (n=137) and fauna (n=71) were analysed for stable carbon and nitrogen isotope ratios to enable dietary reconstructions of the whole adult skeletal assemblage. Adult mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from all periods (6th to 17th century) were $-19.5\text{‰} \pm 1.3\text{‰}$ and $13.3\text{‰} \pm 1.7\text{‰}$ respectively. A diachronic change in diet between early medieval Pictish lay and monastic communities (periods 1-3) and the later medieval parish layfolk (periods 4-5) was found that suggests changing socio-economic and religious influences, along with age and gender differences in diet that reflect possible divisions in labour and status. Faunal data also reflected a diachronic change in diet, most likely related to a change in animal husbandry practices over time. This is the first large-scale study on the Portmahomack assemblage and presents new isotope data to provide a more comprehensive insight into Pictish and medieval subsistence patterns, along with evidence of how religious and social foci may influence diet over time. Such comprehensive investigations can only be adopted by analysing the whole skeletal assemblage, providing robust faunal baselines and inter- and intra-site comparisons. Most importantly, this significant new evidence fundamentally changes our knowledge of diet and subsistence in medieval Scotland and the potential influences therein.

1. INTRODUCTION

The potential of investigating religious communities specifically has been highlighted as an important line of enquiry, to understand aspects of social and religious hierarchies, and economic influences within religious estates, for example (Gilchrist, 1995, 2005; Threlfall-Holmes, 2005; Coppack, 2006). Early medieval documents, such as annals (e.g. *Annals of Ulster*), laws (e.g. *Adomnán's Law*) and saints' lives (e.g. *Vita Columbae*) are important sources of information (Swan, 1994; Sharpe, 1995; Etchingham, 1999; Menzies, 2009; Flechner, 2016, 2019), yet because they mostly concentrated on political events, religious administration or saintly deeds, they are not wholly representative of everyday life during this period. Later medieval documents indicate, sometimes in considerable detail, the products and income from estates, but not what was consumed or by whom (Dyer, 1988, 1989; Harvey, 1993, 2006; Threlfall-Holmes, 2005). Aside from such investigations, efforts to reconstruct the lifeways of individuals from medieval Christian communities have gained momentum over the past few years (e.g. Müldner, Montgomery, Cook, Ellam, Gledhill, &

Lowe, 2009; Müldner & Richards, 2005, 2007a, 2007b; Curtis-Summers, Montgomery, & Carver, 2014; Kancle, Montgomery, Gröcke & Caffell, 2018). However, there has been little direct bioarchaeological evidence of diet and health in medieval Scotland, and only more recently has such evidence been forthcoming from Eastern Scotland (Lamb, Melikian, Ives, & Evans, 2012; Curtis-Summers et al., 2014; Britton, McManus-Fry, Cameron, Duffy, Masson-MacLean, Czere, Smith, Stones, Winfield, & Müldner, 2018; Britton, 2019). This study presents new primary evidence from stable carbon and nitrogen isotope analysis that offers a rare opportunity to understand the diets of Pictish and medieval communities of varying social and religious strata in the northern Highlands; what influenced the types of foods consumed by these communities and considers the wider context of subsistence in medieval Scotland.

1.1 Society and religion

The Highlands of Scotland were susceptible throughout the first and second millennia AD to population pressure from the north, east, west and south (Carver, 2016). The northern Highlands was a disputed frontier zone that was controlled by various rulers including the Pictish King Bridei in the 7th century, Norse lords from the 9th century, and clan chiefs from around the 12th century, when control of Scottish lands was taken by the crown under David I. Hereafter, feudalism emerged, although regions of Ross and Moray continued to be outside of the control of the Canmore kings and the clan system continued (Woolf, 2007; Foster, 2017; Newton, 2019). Religious foci also underwent many changes across Scotland during the medieval period. During the 6th to 7th century, pagan Picts in eastern Scotland were converting to Christianity through influence and pressure from the Irish in the west and the Angles in the south. During this time, Christian monastic communities appeared in Scotland, forming the vanguard of the conversion process. In the 8th and 9th centuries, monasteries around the coast of Britain, such as Lindisfarne, Iona, and Portmahomack attracted attention from Scandinavian raiders, and thereafter, penetration and settlement of Anglo-Scandinavian communities, especially in the northern and western isles of Britain (Carver, 2016). Hostility between Scotland and England grew throughout the middle ages and immigration from western Scotland and Ireland continued, as indicated by the replacement of Pictish place names with Gaelic ones, for example (Woolf, 2007; Clancy, 2016).

1.2 Diet and subsistence

Dietary reconstructions of past communities often reflect their economy and social organisation, which is of interest in periods and places of high mobility or instability. A number of dietary reconstructions of medieval Christian inhabitants from both monastic and secular communities have elucidated religious influences on the types of food consumed (e.g. Barrett, Locker, & Roberts, 2004; Barrett & Richards, 2004; Müldner & Richards, 2005; Olsen, White, Longstaffe, Rühli, Warinner & Salazar-García, 2016). Historical sources on medieval diet come in the form of manorial and monastic accounts of food acquisitions (e.g. Harvey, 1993; Dyer, 1988, 1989), animal rearing (e.g. Hamerow, 2002) and penitentials on food and fasting (e.g. Brown, 2003). Overall, reconstructing medieval diets is complex because the types of foods consumed would have depended on factors such as regional differences, seasonality, social and religious status (Dyer, 1989; Spencer, 2000; Barrett, Beukens & Nicholson, 2001; Barrett & Richards, 2004). During the medieval period, fasting was observed up to three days a week, plus Christian holidays, such as Advent and Lent, totalling around one hundred and fifty fast days per year (Grant, 1988; Fagan, 2006). All Christian orders were expected to adhere to fasting Rules and encourage their lay communities to do so, although some, such as the Cistercians, were more austere and had a stricter life (*arctior vita*) than other orders, such as the Augustinians (Milis, 1992). There are no direct historical sources relating to the everyday diets of lay and monastic communities in early medieval Scotland, although we may draw parallels from Irish sources on fasting rules. Irish legal tracts, hagiography and penitentials would have had great influence on the diets of both the lay and monastic communities across Ireland, and one would assume across Scotland also (Frantzen, 2014; Flechner, 2019). Evidence of a very strict monastic Rule (*regula ualde stricta*) is suggested in the Life of Fintán (*Vita Fintani*) whereby certain monastic communities refused dairy during fasting periods (Heist, 1965; Flechner, 2016). In his Life of Columba (*Vita Columbae*), Adomnán, ninth abbot of Iona, gave clues to subsistence practices by writing about the monks' engaging in arable and pastoral farming at the abbey (Graham-Campbell & Batey, 1998). Although not a direct source of comparison to early medieval Scotland, Anglo-Saxon law codes may also prove useful in understanding to what extent peasants obeyed religious fasting rules. For example, *Wihfred's laws* (AD 695), included clauses to punish peasant workers who broke fasting rules (Frantzen, 2014). Fasting punishments are also found in the *Collectio Canonum Hibernensis* (Flechner, 2019).

Fish consumption across Britain increased after the 8th century, due to population growth, an increase in the fishing trade and a rising demand for fish to replace meat on religious fast days (Barrett & Richards, 2004; Fagan, 2006). Prior to widespread fish

preservation methods, access to fresh marine fish was restricted to coastal dwellers or those of high status, who could afford relatively quick transportation of the goods. The practice of preserving fish by smoking, salting and pickling grew in the 13th century made it widely available across all social strata and enabled people to store fish for much longer, thereby accessing an important source of protein throughout the winter months when other resources were low (Spencer, 2000; Fagan, 2006; Galloway, 2017). Increased access enabled Christian layfolk to substitute meat for fish on fast days, which the Church encouraged to promote the Christian faith and strengthen social cohesion (Woolgar, 1999, 2006; Jotischky, 2011). The consumption of fish increased to such a level in the late medieval period that it is mentioned in lay textual evidence. For example, one 15th century schoolboy wrote in his book “Thou wyll not beleve how wery I am off fysshe, and how moch I desir that flesch were cum ageyn. For I have ete none other but salt fysh this Lent” (Nelson, 1956: 8, in Fagan, 2006: 149). Many religious estates had their own fishponds and strict fishery rights (Bond, 1988), and freshwater fish would be a regular inclusion on the tables of the clergy at religious houses such as Durham Cathedral Priory, especially during fasting periods (Threlfall-Holmes, 2005).

It is not until the 13th century that historical records begin to record the contribution of animal by-products, such as milk, cheese and butter, to the diets of medieval lay people (Woolgar, 2006). Before the spread of the Black Death in Britain around 1348-1350 (Benedictow, 2004), most peasants relied on plant-based foods, the most common being barley, wheat and oats to make bread, ale and pottage. Aside from catastrophic events such as starvation, due to harvest failures, and disease epidemics, medieval diets were generally healthy (Roberts & Cox 2003). This may have been especially true for the peasantry who consumed a range of fresh fruit and vegetables, especially when access to animal protein was scarce. The aristocracy however, believed raw vegetables to be disease-ridden, fueled by texts such as *The Book of Keruyng*, which in 1508 warned its readers to ‘beware of green sallettes’ (Spencer, 2000).

By the 15th century, peasant diets changed and wheat, ale, fish and meat consumption increased, adding to a range of foodstuffs that provided a range of vitamins for good nutrition (Dyer, 1989). Faunal evidence from medieval sites in Britain reflects a predominance of cattle bones, with sheep and pig bones often following in prevalence (Burton, 1994; Greene, 1989, 2005; O’Connor, 2000; Carver, 2016). The types of foods consumed by servants who worked in noble households varied depending on their position and were in some respects healthier than free peasants. In 1363, the *Act on the Diet and Apparel of Servants* stated that servants’ food consisted of “meat or fish once a day, the remains of other foods, milk, cheese,

and other provisions [bread and ale] according to the employee's rank" (Hammond, 2005: 57). Large quantities of deer bones were found at Iona, suggesting venison contributed to a predominantly meat-based diet (Ralston & Armit, 2003), which is mirrored at a number of monastic sites around Britain, including Portmahomack (Carver et al., 2016).

Sugar consumption, along with other spices, was largely confined to elite diets in the medieval period (Spencer, 2000). By the late 14th century, sugar consumption had become more widespread by the aristocracy, although it was still too costly for peasant households (Woolgar, 1999; Newhauser, 2013). Most historical texts on sugar refer to its importation and exportation to and from Scotland, and only rarely do we see evidence to suggest its actual consumption for culinary or even medicinal purposes (e.g. NLS.MS.5112.f61^a). What we do know however, is that as early as the mid-16th century, sugar was being purchased by the elite of the northern Highlands, along with other costly foodstuffs. Alexander Ross of Easter Ross, for example, purchased "*twey laiffe cannered suicre* [two loaves of candied sugar]" and "*thrie pundis suicur cande* [sugar candy]", along with other imported items such as pepper and ginger (McGill, 1909: 264; Worthington, 2011; 2019). Honey was also a regular foodstuff in many households and was used as a food sweetener, as the main ingredient for mead, for making candles and for its medicinal and antibacterial properties. Most beehives were restricted to private lands in manorial and monastic estates (Woolgar, 1999; Stavelly & Fitzgerald, 2004; Dyer, 2006), although it is likely that peasants also consumed honey if they had access to it from wild or domesticated beehives (Rigby, 2003). The importance of honey in the medieval period is attested in law tracts on bees and bee-keeping; the Irish tract *Bechbretha* ('bee judgements') for example, had regulations on bee swarms and their maintenance (Ó Cróinín, 2013: 106). Closer to Portmahomack across the Moray Firth lies Pluscarden Abbey in Elgin, which was established by Alexander II in 1230 and has some of the oldest evidence for bee-keeping in the form of bee-boles that are still present within the walls of the abbey (Harris, 2007).

Aside from poor nutrition due to harvest failures or disease epidemics (Dyer, 1988, 1998; Roberts & Cox, 2003), medieval diets were generally nutritious and included a range of fresh fruit and vegetables; cereals, dairy and when possible, fish and meat. However, with population increase during the later medieval period and more of the peasantry moving to busy towns across England and Scotland (especially after the Black Death), an occupational shift occurred that in some cases exacerbated illness and reduced access to healthy foods

^a A medical recipe of 'The Restorative Jelly for a Consumption' is taken from the original 17th/18th century manuscript: *Medical recipes of the family of Erskine of Alva*. National Library Scotland, Edinburgh. NLS.MS.5112.f61.

(Benedictow, 2004; Dyer, 1998; Roberts & Cox, 2003). Within religious estates, there were wide variations, from strict dietary asceticism within one religious order, to over-indulgence in another. The relaxation of fasting rules also grew over time, with a range of loopholes devised to avoid meat being proscribed on fast days. For example, some monks would regularly take bloodletting holidays and become patients of the infirmary, thereby enabling them to consume meat on fast days (Jotischky, 2011; Myers, 1995). Diet in the medieval period was therefore greatly dependent on multiple factors and influences, religion being one that was deeply embedded in the social and spiritual psyche.

1.3 Archaeological background

Portmahomack is situated on the Tarbat Peninsula in northeast Scotland, which overlooks the Dornoch Firth to the west, with the Moray Firth to the south and the Cromarty Firth to the southwest (Figure 1). The area of archaeological interest is centered on St Colman's church (NH 915 840) and the archaeological importance of this area was known from the 18th century, when antiquarians observed carved stones that depicted both Pictish and Christian symbolism (Allen & Anderson, 1903; Carver, 2016; Carver et al., 2016). Modern archaeological investigations (1994-2007), under the direction of Professor Martin Carver, discovered a Pictish monastic settlement and recovered a wealth of finds, from butchery and glass-, leather- and metal-working, to the manufacture of vellum to make books (Carver & Spall, 2004; Carver et al., 2016). The church underwent different phases of rebuilding and expansion, from an 8th century simple monastery, to a 17th century extended and restructured church, reflecting the needs of the growing parish church community over time (Carver, 2016; Carver et al., 2016).

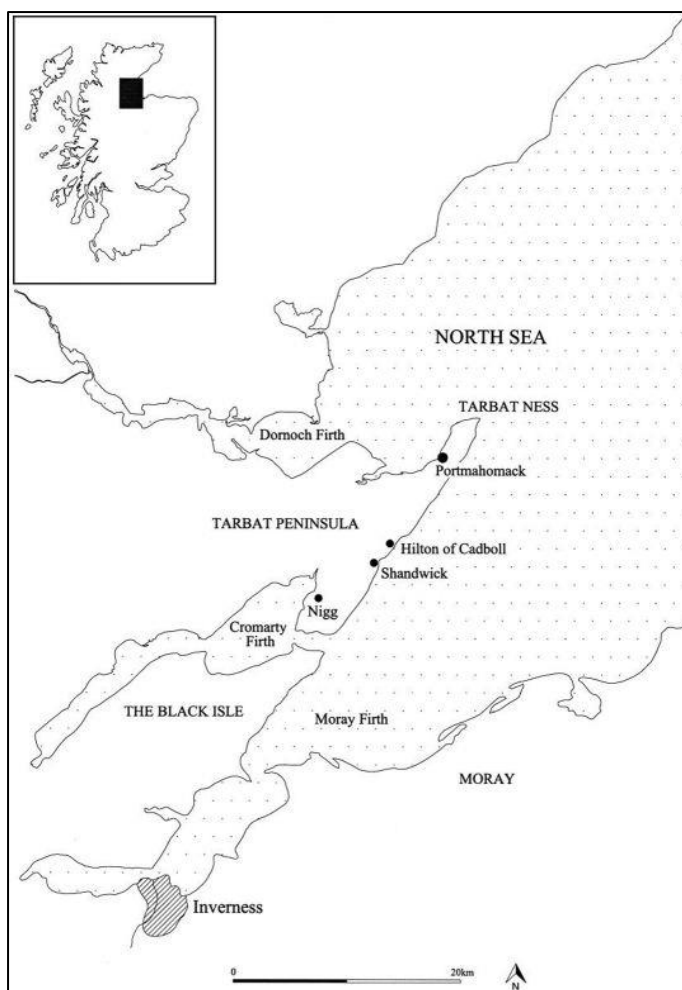


Figure 1. Location map of Portmahomack (Carver, 2005).

1.4 Burials at Portmahomack

The burials at Portmahomack were well stratified and contained 178 articulated human skeletons of adults (Table 1) and non-adults. Radiocarbon dates on a selection of human remains across all periods, indicate dates between the mid-6th to late-17th century, and along with stratigraphic evidence, the burials comprised of four chronological periods (Carver et al., 2016). These burials represent various demographic profiles of an adult Pictish lay group in period 1; a predominantly male Pictish monastic group in periods 2-3, a normal family group of men, women and children in period 4, and a predominantly non-adult group in period 5, which is when adult burials had shifted to outside the church (Carver et al., 2016). Different burial types were discovered, including stone-lined cist, head-box, shrouded and coffined graves. However, there is overlap of burial types between periods, such as cist burials in periods 1 and 2; and shrouded burials in periods 1, 2 and 4, which represent a range of mortuary practices over time and are discussed in more detail elsewhere (Maldonado Ramírez, 2011; Maldonado, 2011; Carver et al., 2016).

Table 1. Adult burials excavated per period (after Carver et al., 2016).

Period	Descriptor	Date ranges	Adult males	Adult females	? Sex	Adult age ranges
1	Late Iron Age/Early Pictish (Lay/Proto-monastic)	AD 550-700	9	4	0	18-60+
2	Late Pictish (Monastic)	AD 700-800	49	2	2	18-60+
3	Scotto-Norse (Post-monastic)	AD 800-1100	5	0	0	18-59
4	Medieval (Lay)	1100-1600 CE	39	25*	1	18-60+
5	Post Medieval (Lay)	1600-1700 CE	1	1	0	18-59
Total burials by sex			103	32	3	
Total adult burials			138			

* One sample was not included in this study (see section 2.1).

2. MATERIALS AND METHODS

Stable carbon and nitrogen isotope analysis was undertaken on the early to late medieval adult skeletal assemblage. These communities spanned over 1,000 years and archaeological, historical and isotopic evidence reflect changing socio-economic (e.g. shifting farming to fishing economies), political (e.g. from Norse control to clan affiliations) and religious (e.g. from Irish Christianity, to Roman Catholicism, to Presbyterianism) foci, making them an importance source of information to reconstruct past lifeways (Curtis-Summers et al., 2014; Carver, 2016; Carver et al., 2016).

2.1 Human sample selection

Human bone samples from 97 adult individuals were analysed for carbon and nitrogen isotopes. Results are combined with established data from a pilot study on 40 adult bone samples (Curtis-Summers et al., 2014) to provide a more comprehensive dietary reconstruction of the Portmahomack adult population. Archaeological investigations found burials from period 3 to be closely associated chronologically and culturally, with those from period 2. After a Viking raid on the monastery (AD 780-810), its economic function changed but the burials remained the same as period 2, in both their type and location, and a monastic continuum, albeit much smaller, is suggested (Carver et al., 2016). Therefore, these burials are reported here together as ‘period 2-3’. Adult isotope data presented here therefore

comprise of period 1 (n=13), period 2-3 (n=58), period 4 (n=64), and period 5 (n=2). One sample from period 4 (adult female, SK92) failed due to insufficient collagen yield and is therefore not included.

2.2 Faunal sample selection

Bone samples were taken from 55 fauna, comprising a range of terrestrial (cattle, sheep/goat, pig, red deer, roe deer and dog), marine (cod, haddock, horse mackerel, saithe, pollack, otter, conger eel), and freshwater (char) species. Most animal bones were excavated from sector 2, an area of various workshops including animal processing and metal working (Carver et al., 2016). Terrestrial and aquatic species, age and MNI (Minimum Number of Individuals) were recorded from over 850 identified contexts (Seetah, 2011, 2016; Holmes, 2012, 2016). Bone from a range of different skeletal elements were selected, from contexts that spanned periods 1-4 (Carver et al., 2016). No faunal samples from period 5 were available for analysis, although faunal isotope data from period 4 serve as appropriate comparisons, due to close chronological contemporaneity and location (Carver et al., 2014). Samples were selected with the aim to represent as many chronological and/or occupational phases as possible. Results are combined with established data from 16 faunal bone samples (Curtis-Summers et al., 2014) to provide a much more robust faunal isotopic baseline for human dietary reconstructions from a range of terrestrial, marine and freshwater species.

2.3 Stable isotopes and palaeodietary reconstruction

The application of stable carbon and nitrogen isotope analysis in palaeodietary studies is based upon the principle that elements such as carbon and nitrogen are incorporated and preserved in body tissues (e.g. bone and tooth collagen, hair, nails) through the types of foods consumed during life, which results in measurable isotope ratios in the tissue analysed. Stable isotope palaeodietary analysis is now a well-established technique and discussed at length elsewhere (e.g. DeNiro, 1987; Schwarcz & Schoeninger, 1991; Britton, 2017). One challenge with using bone for isotope analysis is the variation of bone turnover rates and determining how long prior to death bone collagen may reflect an individual's diet. Bone turnover rate differs depending on age, sex and the element analysed. The rate of adult bone collagen turnover differs greatly between cortical (e.g. femur) and trabecular (e.g. rib) bone, at around 3%/yr and 18%/yr respectively. Additionally, bone turnover in non-adults is much greater from around 300%/yr at birth for both cortical and trabecular bone, to 19%/yr and 35%/yr respectively by the age of 15 years (Valentin 2003). Isotope ratios in children will reflect a

much shorter dietary signal than adults and young adults may therefore reflect dietary signatures that are closer to older children than to older adults. If isotope altering factors such as physiological stress can be ruled out, carbon and nitrogen isotope data may reflect diet from around the last 5 years of life in children or the last 20 years of life in adults (Stenhouse & Baxter 1979; Fuller, Molleson, Harris, Gilmour, & Hedges, 2006; Fahy, Deter, Pitfield, Miszkiewicz, & Mahoney, 2017; Beaumont, Craig Atkins, Buckberry, Haydock, Horne, Howcroft, Mckenzie, & Montgomery, 2018).

2.4 Laboratory methods

Stable carbon and nitrogen isotope analysis was undertaken on 97 human and 55 faunal bones. Bone samples were removed from the skeletal elements with bone clippers, then cut with a stainless steel, flexible dental saw with a diamond cutting edge. Where possible, bones were cut longitudinally to preserve the length of the collagen fibrils and therefore retain its strength (Buehler 2006). Sample preparation and isotope analysis procedures followed Richards & Hedges (1999) using a modified Longin (1971) method (Brown et al., 1988). This method uses diluted aqueous hydrochloric acid (0.5M HCl_(aq)) to minimise collagen destruction that may occur when using more concentrated HCl (Pearson, 2004; Figueiredo, Cunha, Martins, Freitas, Judas, & Figueiredo, 2011). Approximately 200-500mg of bulk bone was immersed in 0.5M HCl_(aq) until demineralised; rinsed with ultrapure H₂O (18.2MΩ.cm), solubilised in a pH3 HCl solution at 70°C in a heat block for 48 hours, filtered (9ml - 60-90µm EZee™) to remove solid particles or contaminants, frozen at -35°C, then freeze-dried, with the resultant collagen weighed (0.585mg to 0.625mg) in duplicate for mass spectrometric analysis. δ¹³C and δ¹⁵N in collagen were analysed using Continuous Flow-Elemental Analyser-Isotope Ratio Mass Spectrometry (CF-EA-IRMS) comprised of an Elemental analyser (Thermo Finnigan Flash 1112 EA) coupled to a Delta plus XL isotope ratio mass spectrometer via a ConFlo III interface. All mass spectrometry analysis was undertaken at the NERC Isotope Geosciences Laboratory (NIGL) stable isotope facility, Nottingham, UK. δ¹³C and δ¹⁵N ratios were calibrated using an in-house reference material M1360p (powdered gelatine from British Drug Houses) with expected delta values of -20.45‰ (calibrated against USGS 40 & 41) and +8.12‰ (calibrated against N-1 and N-2, IAEA) for C and N respectively. M1360P was run every 6th sample and the precision was better than ± 0.1‰ at one standard deviation (1σ) at ±0.08‰ and ±0.07‰ for δ¹³C and δ¹⁵N respectively.

3. RESULTS AND DISCUSSION

The isotopic data and collagen quality indicators for both humans and fauna are in Tables 2 and 5. Where relevant, stable carbon and nitrogen isotope results for each sample group (n) are presented by the range of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values and the difference of each range ($\Delta^{13}\text{C}_{\text{max-min}}$ or $\Delta^{15}\text{N}_{\text{max-min}}$). Also presented are mean (average) $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values and associated standard deviation (\pm). Where statistically significant ($p < 0.05$), the results of paired *t*-test to compare means from human isotope data will be presented.

3.1 Faunal carbon and nitrogen isotope results

All faunal isotope results and collagen quality indicators from periods 1-4 are presented in Table 2. One faunal sample (PK/A/1544) falls below the minimum %C of 30wt.% but is within the acceptable range for %N (10–20wt.%), collagen yield and C:N ratios. Collagen quality indicators for all remaining fauna are within the acceptable ranges. Faunal isotope data was not statistically assessed due to low sample numbers per species. Nonetheless, faunal isotope data presented here provides an important baseline to enable human dietary reconstructions (Figure 2).

Table 2. Faunal isotope data and quality collagen indicators.

Sample number	Species	Period	Bone analysed	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	%C	%N	C/N	% Collagen
C3122/4	Cattle	2	Rib	-22.3	6.8	41.9	15.2	3.2	5.6
C3122/5	Cattle	2	Rib	-22.4	6.4	42.1	15.3	3.2	6.8
C3122/6	Cattle	2	Rib	-22.2	6.4	41.6	15.2	3.2	5.3
C3122/7	Cattle	2	Long bone	-21.8	6.6	42.5	15.2	3.2	6.2
C3122/8	Cattle	2	Long bone	-22.4	5.9	42.2	15.3	3.3	7.1
C3122/9	Cattle	2	Humerus	-21.8	6.2	42.1	15.2	3.2	4.3
C3122/10	Cattle	2	Humerus	-22.0	3.4	42.0	15.0	3.2	6.4
C1280/2	Cattle	4	Tibia	-22.0	10.0	42.2	15.4	3.3	6.8
PK/A/1179	Cattle	3	Rib	-22.2	7.2	42.4	15.2	3.3	6.0
PK/A/3470	Cattle	1	Rib	-21.5	7.2	42.4	15.5	3.2	15.2
PK/A/3535B	Cattle	1	Rib	-22.5	4.7	42.1	15.2	3.3	11.7
PK/A/2117	Cattle	2	MC	-22.4	6.1	39.5	13.5	3.4	2.2
PK/A/1733	Cattle	3	Rib	-21.9	6.5	42.5	15.0	3.3	2.2
PK/A/1734	Cattle	3	Rib	-22.6	5.0	44.3	15.7	3.3	13.6
PK/A/3545A	Cattle	3	Rib	-21.7	5.4	44.4	15.8	3.3	19.2
PK/A/3545B	Cattle	3	Metacarpal	-22.4	6.1	42.7	14.9	3.3	10.0

PK/A/3562D	Cattle	3	Metacarpal	-22.0	5.8	43.4	15.5	3.3	13.6
PK/A/1250B	Cattle	3	Phalanx	-22.0	5.5	42.3	15.2	3.3	6.1
PK/A/1823A	Cattle	3	Rib	-21.9	5.9	41.5	14.8	3.3	0.8
PK/A/1823B	Cattle	3	Right MC	-21.3	5.7	41.9	14.9	3.3	8.8
PK/A/3233B	Red deer	2	Phalanx	-21.8	6.9	40.6	14.6	3.2	8.5
PK/A/3455B	Red deer	2	Phalanx	-22.0	7.1	41.5	14.9	3.2	11.1
PK/A/3562C	Red deer	3	Metatarsal	-21.6	6.6	43.1	15.6	3.2	14.8
PK/A/1877B	Red deer	4	Metacarpal	-22.1	4.3	42.7	14.9	3.4	10.1
PK/A/1250C	Red deer	3	Phalanx	-22.3	5.2	42.1	14.8	3.3	11.1
PK/A/3324	Roe deer	2	Antler	-21.6	3.8	42.0	15.0	3.3	13.6
PK/A/3562A	Roe deer	3	Skull	-22.1	3.9	41.9	14.2	3.5	5.6
PK/A/1544	Sheep/Goat	2	Humerus	-22.0	9.1	27.8	10.0	3.3	0.2
PK/A/2491	Sheep/Goat	2	Metatarsal	-21.8	7.8	42.3	15.2	3.3	8.1
PK/A/1284B	Sheep/Goat	3	Metacarpal	-21.7	8.5	41.7	14.7	3.3	5.2
PK/A/3562E	Sheep/Goat	3	Pelvis	-22.2	9.6	43.2	15.1	3.3	0.5
PK/A/3562F	Sheep/Goat	3	Pelvis	-22.0	7.4	43.2	14.6	3.5	13.9
PK/A/1427	Sheep/Goat	4	Left Radius	-22.0	9.5	41.1	14.9	3.2	8.7
PK/A/1877C	Sheep/Goat	4	Astragalus	-22.2	4.7	42.7	15.2	3.3	13.9
PK/A/1250A	Sheep/Goat	3	Left Radius	-22.0	8.1	41.0	14.7	3.3	9.7
C1280/1	Sheep/Goat	4	Metacarpal	-22.0	8.8	41.7	14.7	3.3	2.2
PK/A/3535A	Pig	1	Phalanx	-22.4	7.9	41.8	15.0	3.3	7.8
PK/A/2448	Pig	2	Scapula	-22.2	7.6	42.1	15.0	3.3	9.8
PK/A/3233A	Pig	2	Ulna	-21.8	7.3	37.7	13.3	3.3	3.9
PK/A/3455A	Pig	2	Mandible	-22.0	7.8	44.2	15.7	3.3	1.9
PK/A/1284A	Pig	3	Mandible	-21.4	9.4	42.5	15.1	3.3	11.0
PK/A/1918	Pig	3	Phalanx	-21.6	8.5	42.1	15.2	3.2	13.5
PK/A/3562B	Pig	3	Pelvis	-22.5	9.2	42.7	14.7	3.4	8.5
PK/A/1575	Pig	3	Scapula	-21.7	8.9	41.1	14.6	3.3	10.6
C3122/1	Pig	2	Skull	-21.4	8.8	42.7	15.4	3.2	3.2
C3122/2	Pig	2	Zygomatic	-21.5	8.1	40.8	14.8	3.2	1.5
C3122/3	Pig	2	Skull	-21.4	8.3	41.0	15.0	3.2	3.6
C1280/4	Pig	4	Sphenoid	-21.1	12.0	41.5	14.8	3.2	3.4
C1280/5	Pig	4	Metacarpal	-21.7	11.8	41.8	15.0	3.3	3.9
PK/A/3297	Dog	2	Mandible	-19.3	10.3	41.9	15.1	3.3	5.5
C1280/3	Dog	4	Left humerus	-16.8	15.3	41.5	14.9	3.2	2.9
PK/A/2004A	Dog	4	Vert	-19.5	11.3	42.1	14.8	3.3	9.7
PK/A/2004B	Otter	4	Mandible	-12.1	17.6	41.7	14.6	3.3	2.2
PK/F/3193	Char	2	Vert	-14.4	9.7	36.1	13.2	3.2	2.9
PK/F/3446	Char	2	Vert	-15.0	10.0	39.9	14.8	3.2	1.8
PK/F/2568	Char	3	Vert	-14.9	10.9	41.9	14.4	3.4	0.2
C1303/1	Cod	4	Vert	-12.4	14.3	41.1	14.6	3.2	1.3
PK/F/1678	Cod	2	Vert	-12.3	14.9	41.6	14.6	3.3	0.3
PK/F/1270A	Cod	3	Rib	-11.5	14.5	41.5	15.2	3.2	0.2

PK/F/2061	Cod	3	Dentary	-12.8	15.1	41.0	14.0	3.4	1.2
PK/F/1346	Cod	4	Vert	-12.7	15.0	39.2	13.4	3.4	2.2
PK/F/1882	Cod	4	Vert	-12.8	13.0	41.3	14.7	3.3	5.6
PK/F/3168	Gadid/Cod	2	Dentary	-12.5	14.3	42.5	14.5	3.4	0.2
PK/F/1283	Gadid/Cod	4	Vert	-14.6	13.0	42.5	13.7	3.6	0.3
PK/F/1293	Haddock	4	Vert	-14.3	14.4	42.7	14.4	3.5	0.8
PK/F/2534	H.mackerel	2	Vert	-13.8	13.2	41.9	15.1	3.2	0.4
PK/F/1270B	Pollack	3	Vert	-13.1	15.2	41.4	14.1	3.4	2.3
PK/F/1374	Pollack	4	Rib	-13.1	15.5	41.1	14.5	3.3	4.4
PK/F/1387	Pollack	4	Vert	-13.0	14.7	41.3	13.8	3.5	0.4
PK/F/1004	Saithe	4	Para-sphenoid	-13.7	13.0	43.5	15.1	3.4	4.1
PK/F/1348	Conger eel	4	Vert	-14.0	14.5	37.7	13.4	3.3	0.5

Bold data from Curtis-Summers et al. (2014)

Terrestrial fauna analysed include cattle, sheep/goat, red deer, and roe deer and omnivore species of pig and dog. All faunal samples have $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values that are consistent with those from the British Holocene (Müldner & Richards, 2005; Richards, Fuller, & Molleson, 2006; Jay & Richards, 2007). Mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values and differences between terrestrial fauna and humans that represent the Pictish phases (periods 1-3) and the later medieval phases (periods 4-5) are presented in Table 3. There is an increase in both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values for period 1-3 humans compared to herbivores of 1.5‰ and 5.7‰ respectively, and for humans compared to omnivores of 1.1‰ and 3.5‰ respectively. From period 4-5, human mean values were increased in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ compared to herbivores by 3.6‰ and 7.3‰ respectively, and by 1.3‰ and 2.2‰ compared to omnivores. An increase of < 1‰ in $\delta^{13}\text{C}$ values may reflect trophic level effects (e.g. Wada and Hattori 1976; McConnaughey and McRoy 1979; Schoeninger & DeNiro 1984), although more recent studies have suggested a value of 2‰ to be more appropriate (e.g. Barnes, Sweeting, Jennings, Barry, & Polunin, 2007). All herbivore $\delta^{13}\text{C}$ values are similar and reflect a predominantly C_3 diet, with no apparent C_4 input. Although there is some evidence of human C_4 consumption, in the form of millet, during the Roman period in southern England (Müldner et al., 2011; Pollard et al., 2011), there is currently no convincing evidence to suggest isotopically identifiable consumption of such foods in medieval Scotland. Although not beyond the realms of possibility, it is unlikely that most of the later medieval parish community were consuming C_4 in the form of sugar, despite its acquisition and consumption by certain members of the elite in and around Easter Ross from the 16th century (McGill, 1909; Worthington, 2019). Differences in $\delta^{15}\text{N}$ values between herbivore species may reflect

varied feeding strategies or animals imported from different geographical regions that were fed on different types of fodder. For example, the period 4 cattle had a $\delta^{15}\text{N}$ value that was a trophic level higher than those from period 2-3, which may suggest that in later periods, cattle were grazed on nearby coastline or salt marsh plants, which have been found to elevate nitrogen values (Britton, Müldner, & Bell, 2008). However, even though salt marsh plants may also influence carbon isotope signatures, no significant differences in $\delta^{13}\text{C}$ values were found between cattle from different periods. A ‘salt marsh effect’ is plausible considering the Dornoch Firth and Morrich More, located to the west of Portmahomack, has some of the most extensive areas of salt marsh in Britain (The Joint Nature Conservation Committee, 2009). Moreover, a shift in cattle nitrogen isotope values has also been found at other Scottish sites such as Newark Bay (Barrett & Richards, 2004), East Lothian (Jay & Richards, 2007) and Kirkhill, Fife (Modzelewski, 2008). Overall, differences in regional resources and a change in animal management practices may account for some variation in herbivore isotope values at Portmahomack.

The isotope data for the omnivorous animals appear to reflect a mixed diet that most likely included human food waste. For example, pig $\delta^{15}\text{N}$ values from period 4 are a trophic level higher than those from previous periods, which mirror a diachronic shift in human diets over time, with the inclusion of aquatic protein in later periods, as demonstrated by an increase in both carbon and nitrogen values and a significant increase in fish bone remains (Carver et al., 2016; Holmes, 2016). No real conclusions can be drawn from such small samples, but a typically varied omnivorous diet of C_3 plants, and scavenging human or coastline waste is suggested, as it is from other sites (Richards et al., 2006; Kosiba, Tykot, & Carlsson, 2007).

Table 3. Differences in mean human and terrestrial faunal $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values.

Period 1-3 (mean human data)				Period 4-5 (mean human data)			
$\delta^{13}\text{C}$ (‰)		$\delta^{15}\text{N}$ (‰)		$\delta^{13}\text{C}$ (‰)		$\delta^{15}\text{N}$ (‰)	
-20.5 (± 0.4)		12.0 (± 0.7)		-18.5 (± 1.1)		14.8 (± 1.3)	
Period 1-3 (mean faunal data)				Period 4-5 (mean faunal data)			
Herbivore		Omnivore		Herbivore		Omnivore	
$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)
-22 (± 0.3)	6.3 (± 1.4)	-21.6 (± 0.8)	8.5 (± 0.8)	-22.1 (± 0.1)	7.5 (± 2.4)	-19.8 (± 1.9)	12.6 (± 1.6)
P1-3 Human to herbivore mean difference		P1-3 Human to omnivore mean difference		P4-5 Human to herbivore mean difference		P4-5 Human to omnivore mean difference	
$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)
1.5	5.7	1.1	3.5	3.6	7.3	1.3	2.2

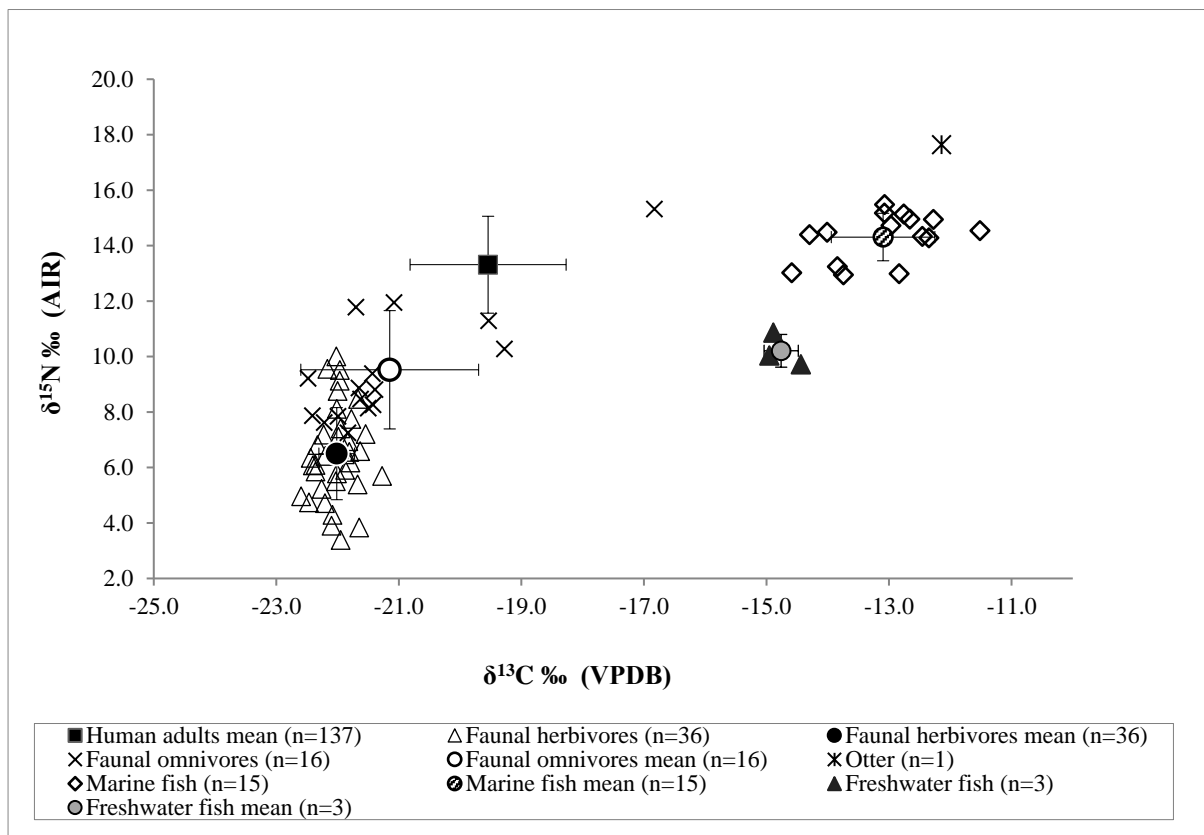


Figure 2. Adult human and faunal mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values. Mean error bars are ± 1 standard deviation.

A selection of marine (haddock, cod, pollock, saithe; horse mackerel and conger eel) and freshwater (char) fish was analysed, and differences between mean human and aquatic fish $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values are presented in Table 4. Although there are some differences in aquatic isotope data from this study, they are within normal variation for marine and freshwater isotope values from the British Holocene and therefore provide useful aquatic baselines (Dufour, Bocherens, & Mariotti, 1999; Richards et al., 2006; Grupe, Heinrich, & Peters, 2009). From periods 1 to 3, humans had a lower $\delta^{13}\text{C}$ mean value compared to both freshwater (5.7‰) and marine (7.8‰) fish. The human mean $\delta^{15}\text{N}$ value for periods 1 to 3 is lower by 2.6‰ when compared to marine fish, although increased by 1.8‰ compared to freshwater fish. Some freshwater fish have been found to have $\delta^{15}\text{N}$ values similar to terrestrial carnivores (Shoeneringer & DeNiro, 1984), and variation in $\delta^{15}\text{N}$ values occur in freshwater foodwebs, to some extent, more so than in marine foodwebs (Fry 2006). Comparisons from period 1 to 3 suggest minimal freshwater and marine fish were consumed

by the Pictish lay and monastic communities, which is supported by the miniscule amount of aquatic bones recovered during excavation (Carver et al., 2016; Holmes, 2016).

For periods 4 to 5, the human mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values were lower compared to marine fish by 5.1‰ and 0.7‰ respectively. The otter $\delta^{13}\text{C}$ value from period 4 was -12.1‰ and as expected from a marine mammal, it yielded the greatest $\delta^{15}\text{N}$ value within the faunal sample set at 17.6‰. When compared to the human mean isotope values from this period, the otter had increased $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of 6.4‰ and 2.8‰ respectively, which suggests humans from period 4-5 were not consuming marine mammal protein, although more samples would need to be analysed to rule this out completely. Compared to the earlier periods, there is an increase in human $\delta^{13}\text{C}$ values and when we consider individual isotope data, it is evident that a large proportion, if not the majority, during this period were consuming greater amounts of marine fish.

Table 4. Differences in mean human and aquatic $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values.

Period 1-3 (mean human data)				Period 4-5 (mean human data)	
$\delta^{13}\text{C}$ (‰)		$\delta^{15}\text{N}$ (‰)		$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)
-20.5 (\pm 0.4)		12.0 (\pm 0.7)		-18.5 (\pm 1.1)	14.8 (\pm 1.3)
Period 1-3 (mean aquatic data)				Period 4-5 (mean aquatic data)	
Freshwater		Marine		Marine	
$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)
-14.8 (\pm 0.2)	10.2 (\pm 0.5)	-12.7 (\pm 0.7)	14.6 (\pm 0.7)	-13.4 (\pm 0.7)	14.1 (\pm 0.9)
P1-3 Human to freshwater mean difference		P1-3 Human to marine mean difference		P4-5 Human to marine mean difference	
$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)
5.7	1.8	7.8	2.6	5.1	0.7

No freshwater fish were available for analysis from period 4-5.

3.2 Adult human carbon and nitrogen isotope results

All human isotope results and collagen quality indicators from periods 1-5 are presented in Table 5 and Figures 2-12. Collagen yields for human samples ranged from 1.2 to 26.0 wt.%, hence above the recommended 1% for well-preserved collagen (van Klinken, 1999). Most samples are within the acceptable range of weight percentages for carbon (%C) and nitrogen (%N) of 30–50wt.% and 10–20wt.% respectively (van Klinken, 1999), although three (SK38, SK56, SK138) fall just outside of these ranges. However, the C:N ratios for these samples (3.3 to 3.4) are within the accepted range of 2.9–3.6 for good quality collagen (DeNiro, 1985) and are therefore included in this study. Combined isotope data presented here (Table 5; Figure 3) represent 97 adults from this study and 40 adults from established data (Curtis-Summers et al., 2014). Adult human $\delta^{13}\text{C}$ values from all periods (n=137) ranged

between -21.2‰ and -15.5‰ ($\Delta^{13}\text{C}_{\text{max-min}}$ 5.7‰), with a mean of $-19.5\text{‰} \pm 1.3\text{‰}$. The $\delta^{15}\text{N}$ values ranged between 10.0‰ and 17.6‰ ($\Delta^{15}\text{N}_{\text{max-min}}$ 7.6‰), with a mean of $13.3\text{‰} \pm 1.7\text{‰}$. Two distinct groups are visible, from periods 1-3 (6th to 11th century) and from periods 4-5 (12th to 17th century). There are some outliers, for example, the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values for one individual from period 2-3 (SK144) is similar to those from period 4, and a small number of adults from period 4 (n=6) have $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values similar to those from periods 1-3. However, the majority of period 4 and 5 adults show a distinction in diet compared to earlier periods.

Table 5. Human isotope data and quality collagen indicators.

Skeleton No.	Period	C ¹⁴ dates*	Sex	Age	Bone sampled	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	%C	%N	C/N	% Collagen
SK1	4		?M	Adult	Hand phalanx	-18.5	15.4	46.8	16.7	3.3	21.4
SK5	4		F	46-59	Rib	-16.9	15.9	41.4	14.7	3.3	12.9
SK8	4		?M	18-25	Foot phalanx	-18.2	14.6	43.1	15.4	3.3	25.1
SK9	4		?M	46-59	Foot phalanx	-18.0	15.2	44.7	15.9	3.3	23.5
SK17	5		M	36-45	Rib	-19.6	14.4	46.8	16.2	3.4	19.8
SK18	4		M	36-45	Rib	-18.4	15.4	45.2	15.8	3.4	18.7
SK20	4		?F	46-59	Ilium	-18.1	16.3	42.2	14.9	3.3	17.6
SK23	5		F	46-59	Rib	-19.2	13.6	45.5	16.0	3.3	22.0
SK25	4		M	46-59	Rib	-19.1	14.3	41.9	15.0	3.3	14.5
SK28	4		F	46-59	Foot phalanx	-17.7	15.5	40.7	14.5	3.3	19.9
SK30	4		M	36-45	Rib	-19.1	13.7	47.4	16.8	3.3	21.9
SK31	4		M	36-45	Rib	-15.5	17.6	38.6	13.8	3.3	15.7
SK32	4		M	60+	Hand phalanx	-17.4	15.4	45.4	16.3	3.3	21.5
SK34	4		M	46-59	Rib	-16.8	16.7	39.9	14.2	3.3	11.8
SK35	4		M	18-25	Rib	-17.4	15.4	42.1	15.4	3.2	2.4
SK36	4		M	46-59	Rib	-19.0	13.9	45.4	16.1	3.3	19.2
SK37	4		M	26-35	Rib	-16.1	17.2	45.8	16.5	3.3	12.6
SK38	2		M	46-59	Rib	-20.6	12.5	27.6	9.6	3.4	3.0
SK39	2		?M	Adult	Fibula	-20.1	11.4	39.4	13.9	3.3	6.6
SK40	2		M	46-59	Rib	-20.3	12.3	42.6	15.0	3.3	11.1
SK41	4		M	18-25	Rib	-20.3	11.7	46.6	16.6	3.3	18.7
SK42	2		M	46-59	Rib	-19.7	12.9	45.8	15.9	3.4	19.5
SK43	4		M	46-59	Rib	-19.2	14.4	42.2	14.7	3.4	9.1
SK44	2		M	46-59	Rib	-20.4	12.1	45.2	15.9	3.3	22.6
SK45	2		M	46-59	Rib	-20.3	12.8	43.0	15.2	3.3	8.3
SK46	1		M	Adult	Hand phalanx	-20.0	13.1	43.9	15.3	3.4	9.6
SK47	2		M	26-35	Rib	-20.0	12.4	42.5	15.1	3.3	10.9
SK48	2		?M	36-45	Fibula	-20.7	13.2	37.6	12.8	3.4	6.2
SK49	4		?F	Adult	Foot phalanx	-20.8	11.1	45.8	16.2	3.3	22.8
SK50	2		?M	Adult	Femur	-20.2	11.4	40.5	14.0	3.4	6.3
SK51	2		M	36-45	Foot phalanx	-20.3	12.1	44.6	15.7	3.3	24.0
SK52	2		M	46-59	Hand phalanx	-20.3	12.1	45.3	15.7	3.4	8.0
SK53	2		M	46-59	Rib	-20.2	11.8	41.6	14.8	3.3	9.4
SK54	2		M	18-25	Rib	-20.5	12.1	46.7	16.4	3.3	21.6
SK55	4		?F	18-25	Rib	-19.1	13.6	44.8	16.1	3.3	16.3
SK56	4		M	46-59	Rib	-17.5	15.7	50.5	18.0	3.3	21.7
SK62	4		F	46-59	Rib	-19.0	14.2	45.2	16.2	3.3	22.7
SK64	4		M	46-59	Rib	-19.3	13.9	42.1	15.5	3.2	7.8
SK66	4		M	26-35	Rib	-18.3	14.9	43.5	15.7	3.2	23.6
SK67	4		F	26-35	Rib	-18.8	15.0	46.4	16.7	3.3	19.8

SK69	4		F	46-59	Rib	-19.7	14.4	41.8	13.5	3.6	1.2
SK72	4		?	18-25	Rib	-18.4	15.3	45.1	16.1	3.3	12.9
SK74	4		M	46-59	Metacarpal	-19.3	14.5	47.0	16.9	3.2	17.3
SK75	4		?M	Adult	Hand phalanx	-19.6	14.4	45.8	16.2	3.3	26.0
SK76	4		F	Adult	Zygomatic	-21.0	11.8	44.5	15.8	3.3	22.0
SK77	4		M	36-45	Rib	-15.9	17.1	43.4	15.5	3.3	13.8
SK78	4		F	26-35	Hand phalanx	-17.4	15.8	46.6	16.9	3.2	25.2
SK80	4		M	36-45	Rib	-17.6	16.3	45.9	16.5	3.3	13.8
SK82	4		F	36-45	Rib	-20.3	12.4	45.3	16.4	3.2	24.7
SK83	4		F	36-45	Rib	-19.4	14.9	43.5	15.9	3.2	6.4
SK84	4		M	46-59	Hand phalanx	-19.5	13.1	44.3	16.3	3.2	11.6
SK85	4		?M	18-25	Rib	-18.0	15.1	43.3	15.9	3.2	5.2
SK88	4		F	36-45	Rib	-18.4	15.0	44.1	16.2	3.2	3.5
SK90	4	1460-1660	M	60+	Rib	-18.0	15.1	43.4	15.8	3.2	3.7
SK91	4		F	26-35	Rib	-19.8	14.0	43.2	15.7	3.2	3.5
SK93	4		M	26-35	Rib	-17.1	16.6	43.1	15.6	3.2	8.7
SK95	4		F	46-59	Rib	-18.6	14.7	43.7	15.7	3.3	22.7
SK96	4		?M	Adult	Metatarsal	-19.0	14.1	44.0	15.8	3.3	13.5
SK97	4	1440-1640	?F	46-59	Rib	-18.3	15.0	44.2	16.2	3.2	5.2
SK98	4	1420-1620	M	26-35	Rib	-17.9	15.8	43.9	16.1	3.2	7.7
SK99	4		F	60+	Ilium	-17.1	16.2	44.5	15.8	3.3	22.0
SK100	4		F	26-35	Rib	-19.4	15.0	42.4	15.4	3.2	3.8
SK101	4	1440-1630	F	46-59	Rib	-18.5	14.8	47.0	16.6	3.3	24.8
SK102	4		F	36-45	Rib	-17.8	16.1	43.0	15.9	3.2	7.5
SK103	4		M	26-35	Rib	-18.0	15.6	43.6	16.1	3.2	7.0
SK104	4		M	Adult	Hand phalanx	-18.3	14.9	44.1	15.9	3.2	13.7
SK105	4		F	46-59	Rib	-20.4	12.7	43.6	16.0	3.2	6.8
SK106	4		F	60+	Rib	-18.7	15.5	43.9	15.9	3.2	3.4
SK108	4		M	36-45	Rib	-19.5	14.7	45.6	16.8	3.2	6.8
SK109	4		M	46-59	Rib	-18.2	14.4	43.2	15.8	3.2	11.5
SK111	3	1020-1210	M	26-35	Rib	-20.7	12.0	42.2	14.8	3.3	6.6
SK112	4	1280-1420	M	46-59	Rib	-18.9	14.4	43.0	15.8	3.2	7.1
SK113	4	1290-1430	M	36-45	Rib	-19.1	13.8	44.6	16.4	3.2	5.8
SK114	4		F	18-25	Rib	-17.5	15.2	38.2	13.6	3.3	9.2
SK115	4		F	Adult	Rib	-18.8	15.4	45.3	15.4	3.4	9.8
SK116	2	680-880	M	46-59	Rib	-20.3	13.0	42.2	15.3	3.2	11.0
SK117	4	1150-1270	M	18-25	Rib	-20.5	11.5	43.4	15.6	3.3	15.9
SK118	2		M	18-25	Metatarsal	-19.7	11.9	44.9	16.3	3.2	22.8
SK120	4		M	36-45	Rib	-19.5	14.3	44.4	15.8	3.3	11.7
SK121	2		M	26-35	Rib	-20.2	12.8	46.0	16.2	3.3	7.8
SK122	2		M	46-59	Rib	-20.3	12.4	42.1	15.6	3.2	9.2
SK123	2		M	60+	Hand phalanx	-20.4	12.6	44.2	15.6	3.3	24.6
SK124	2		M	18-25	Rib	-20.8	11.4	41.8	15.1	3.2	5.1
SK125	2		M	60+	Rib	-20.3	12.9	43.7	15.1	3.4	5.7
SK126	2		M	46-59	Rib	-20.9	10.8	38.5	13.6	3.3	5.9
SK127	2		?M	36-45	Rib	-20.4	11.8	41.2	15.1	3.2	10.6
SK128	2	640-770	?M	46-59	Rib	-20.5	11.7	42.0	14.9	3.3	4.4
SK129	2	670-880	?M	18-25	Rib	-20.6	11.3	44.0	15.4	3.4	10.3
SK130	2	660-780	?M	46-59	Rib	-20.7	12.1	43.6	15.0	3.4	7.5
SK131	1		F	46-59	Metacarpal	-20.9	10.4	43.9	15.4	3.3	22.8
SK133	2		M	60+	Rib	-20.3	12.2	44.3	15.4	3.4	20.3
SK134	4		M	18-25	Hand phalanx	-17.6	14.9	48.3	16.8	3.4	19.8
SK135	2		?M	46-59	Rib	-20.8	11.6	43.4	15.1	3.4	11.0
SK136	3	970-1040	M	36-45	Rib	-21.1	11.9	40.3	14.2	3.3	1.3
SK137	2		?M	36-45	Rib	-20.5	11.8	43.3	14.8	3.4	8.9
SK138	2		?	Adult	Femur	-20.9	11.4	27.4	9.7	3.3	4.7
SK139	2		M	46-59	Rib	-19.8	12.6	43.6	15.2	3.4	21.5
SK140	2		M	18-25	Rib	-20.3	12.6	40.5	14.6	3.2	2.0
SK141	2		M	36-45	Rib	-20.1	12.3	44.8	15.5	3.4	20.3
SK142	2		M	46-59	Sacrum	-20.4	11.8	40.1	14.2	3.3	8.2
SK143	2		M	60+	Rib	-20.0	12.4	39.8	13.7	3.4	7.2

SK144	2	680-890	M	46-59	Rib	-19.1	14.6	40.7	14.7	3.2	2.4
SK145	3		M	Adult	Rib	-20.5	12.3	42.7	14.7	3.4	9.9
SK146	1	660-780	F	26-35	Metatarsal	-20.6	11.0	42.9	15.4	3.3	23.6
SK147	3	720-960	M	26-35	Rib	-20.4	11.2	39.9	14.6	3.2	5.4
SK148	2		M	60+	Rib	-20.7	12.4	41.5	14.2	3.4	7.4
SK149	1		M	60+	Rib	-20.4	12.3	41.3	14.3	3.4	12.8
SK150	4		M	Adult	Hand phalanx	-19.3	14.4	42.1	15.0	3.3	23.8
SK151	2		M	46-59	Rib	-20.6	12.6	40.0	14.5	3.2	6.6
SK152	2	780-1000	M	26-35	Rib	-20.5	11.7	40.9	15.0	3.2	6.0
SK153	2	650-780	M	36-45	Rib	-20.3	12.0	42.5	14.7	3.4	16.1
SK154	2		M	46-59	Rib	-20.5	11.8	41.2	14.8	3.2	9.3
SK155	2		F	46-59	Rib	-20.7	12.0	43.5	15.6	3.3	22.2
SK156	3	970-1040	M	36-45	Rib	-20.9	12.0	41.4	14.2	3.4	5.0
SK157	2		M	46-59	Rib	-20.7	12.1	40.2	14.1	3.3	7.4
SK158	2	680-900	M	46-59	Rib	-20.3	12.4	40.8	14.9	3.2	8.6
SK160	2	680-880	?M	Adult	Rib	-20.7	11.1	40.7	14.9	3.2	7.7
SK161	4		M	36-45	Rib	-18.0	14.4	43.8	15.7	3.3	22.5
SK162	1	430-575	M	Adult	Hand phalanx	-21.2	10.9	44.0	15.4	3.3	23.6
SK163	1	640-690	M	36-45	Hand phalanx	-21.0	10.9	42.9	15.2	3.3	9.2
SK164	2		M	46-59	Rib	-20.2	12.8	40.5	14.8	3.2	8.3
SK165	2	650-780	?	Adult	Cuboid	-21.1	11.1	43.2	14.9	3.4	18.4
SK166	1		?F	Adult	Rib	-21.0	10.8	49.5	18.0	3.2	10.4
SK167	2		M	Adult	Rib	-21.1	11.1	45.3	16.0	3.3	20.1
SK168	2		?M	36-45	Rib	-20.0	12.3	42.1	15.4	3.2	3.8
SK169	1	610-680	M	26-35	Rib	-20.7	10.0	46.2	17.0	3.2	8.8
SK170	1	580-660	M	26-35	Rib	-20.6	11.9	41.8	14.6	3.3	14.3
SK171	2	660-850	M	36-45	Rib	-19.7	12.2	43.3	15.9	3.2	2.9
SK172	1	570-650	F	46-59	Rib	-20.8	10.8	41.3	15.2	3.2	10.1
SK173	2		M	46-59	Manubrium	-20.3	13.1	42.9	15.0	3.3	10.5
SK174	2		?F	Adult	Rib	-21.1	11.4	40.7	15.0	3.2	12.4
SK176	2		M	46-59	Rib	-20.1	12.8	41.2	14.4	3.3	10.9
SK186	1	420-610	M	26-35	Rib	-20.7	11.2	44.2	15.7	3.3	21.1
SK187	1	540-650	?M	36-45	Rib	-20.4	11.3	42.2	14.5	3.4	4.8
SK188	1		?M	Adult	Patella	-21.1	11.9	42.9	15.3	3.3	20.9
SK189	2		M	26-35	Rib	-21.1	11.7	37.2	12.9	3.4	4.6
SK192	4		M	36-45	Rib	-18.3	15.6	44.0	15.7	3.3	19.9
					Mean	-19.5	13.3				
					1 SD	1.27	1.75				

Bold isotope data from Curtis-Summers et al. (2014).

* C¹⁴ calibrated dates AD (95% confidence), from Carver et al. (2016).

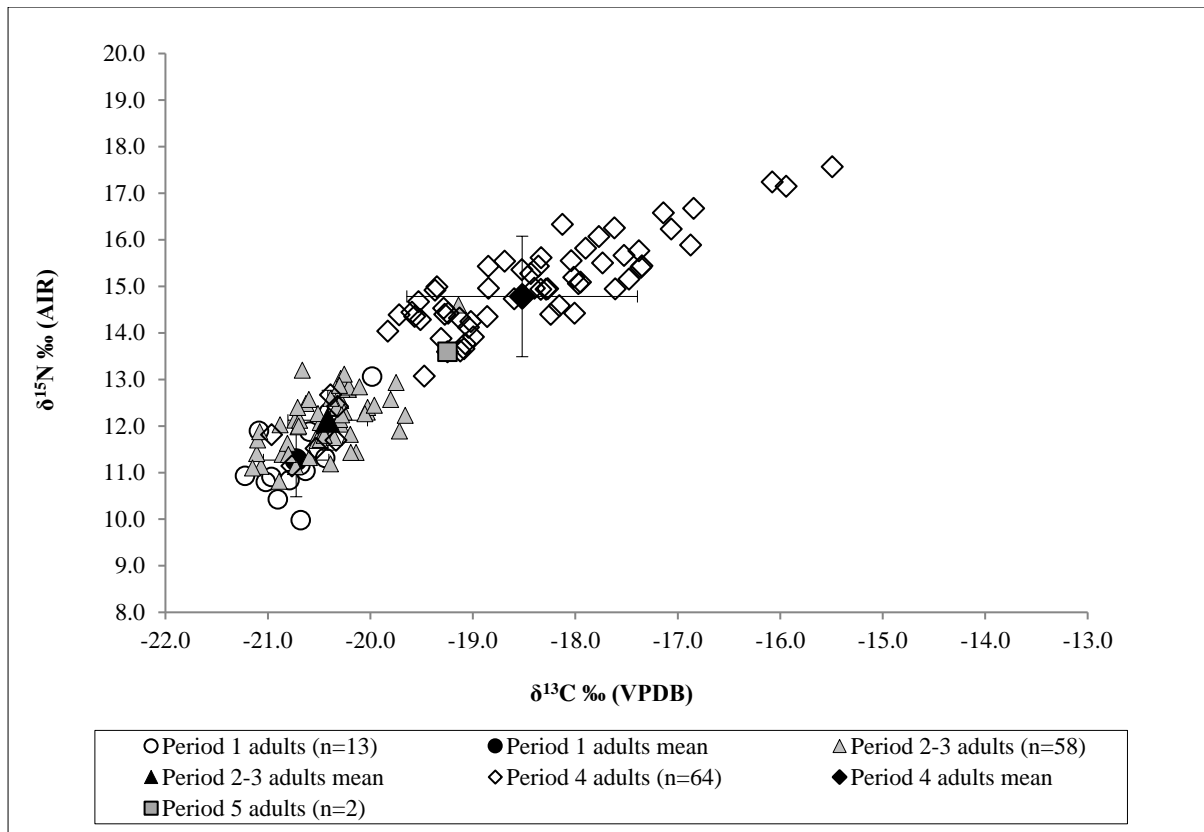


Figure 3. Adult human $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from periods 1-5. Mean error bars are ± 1 standard deviation.

3.2.1 Human adult diets: Pictish lay period 1 (c.550 – c.700)

Period 1 adult human (n=13) $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values are presented in Table 6 and Figure 4. The $\delta^{13}\text{C}$ values ranged between -21.2‰ and -20.0‰ ($\Delta^{13}\text{C}_{\text{max-min}}$ 1.2‰), with a mean of $-20.7\text{‰} \pm 0.3\text{‰}$, and $\delta^{15}\text{N}$ values between 10.0‰ and 13.1‰ ($\Delta^{15}\text{N}_{\text{max-min}}$ 3.1‰), with a mean of $11.3\text{‰} \pm 0.8\text{‰}$. Few faunal bones were recovered from period 1, although the remains of barley and wheat were recovered (Seetah, 2016; Carver et al., 2016). This may suggest a predominantly C_3 plant-based diet, although a shifting faunal isotope baseline cannot be ruled out. Overall, the isotope data suggests human diets from period 1 were homogeneous and consisted of C_3 plants (e.g. barley), with some terrestrial herbivore and omnivore (e.g. beef, lamb, pork) protein. There is a possibility that this small Pictish group were seasonal inhabitants of the site and engaged in small-scale hunting for animal meat, rather than practicing year-round animal husbandry. The isotope data suggests there is no apparent input from marine or freshwater fish, which is supported by a lack of fish bones recovered from this period (Holmes, 2016; Carver et al., 2016).

Table 6. Period 1 adult human and faunal $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data.

Period 1				
SK No.	Sex	Age	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$
SK46	M	Adult	-20.0	13.1
SK131	F	46-59	-20.9	10.4
SK146	F	26-35	-20.6	11.0
SK149	M	60+	-20.4	12.3
SK162	M	Adult	-21.2	10.9
SK163	M	36-45	-21.0	10.9
SK166	?F	Adult	-21.0	10.8
SK169	M	26-35	-20.7	10.0
SK170	M	26-35	-20.6	11.9
SK172	F	46-59	-20.8	10.8
SK186	M	26-35	-20.7	11.2
SK187	?M	36-45	-20.4	11.3
SK188	?M	Adult	-21.1	11.9
		min	-21.2	10.0
		max	-20.0	13.1
		mean	-20.7	11.3
		1 SD	0.3	0.8

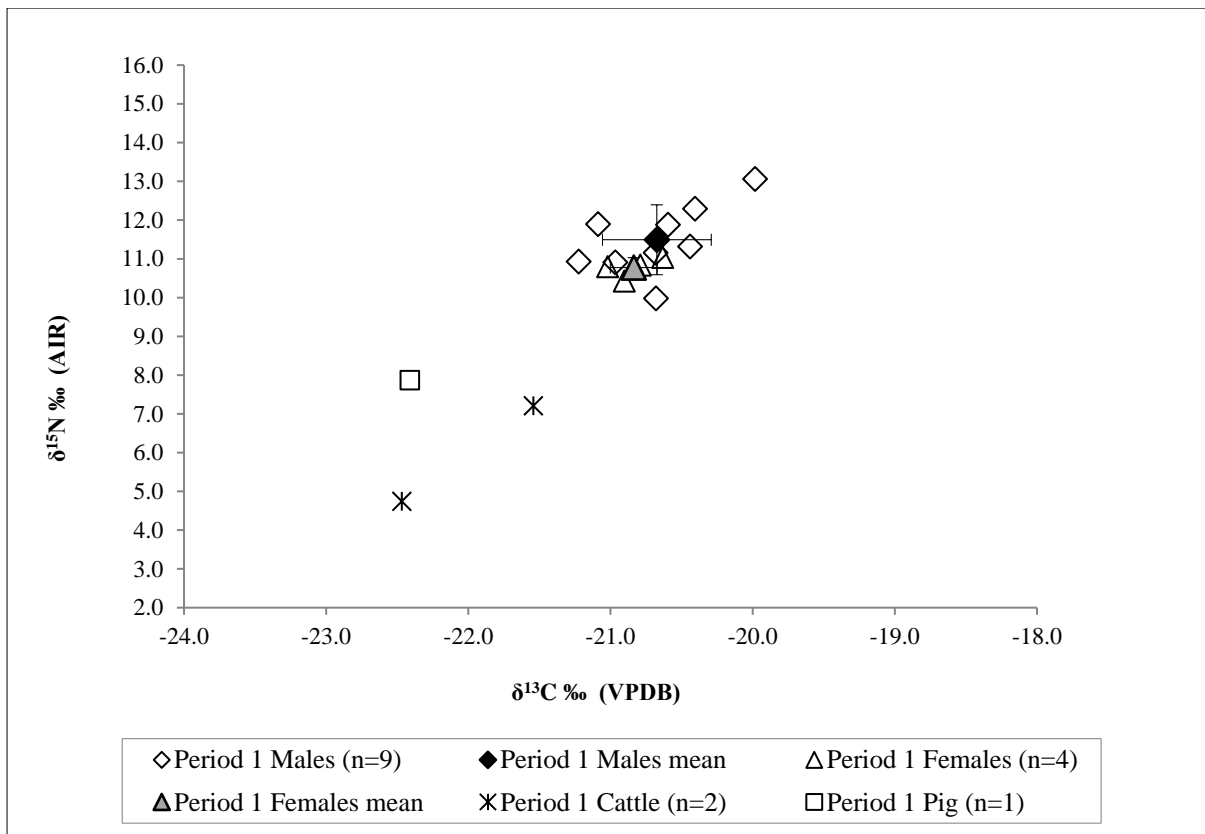


Figure 4. Period 1 adult human and faunal $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values. Mean error bars are ± 1 standard deviation.

3.2.2 Human adult diets: Pictish monastic period 2-3 (c.700 – c.1100)

Period 2-3 adult human (n=58) $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values are presented in Table 7 and Figures 5 and 6. The $\delta^{13}\text{C}$ values ranged between -21.1‰ and -19.1‰ ($\Delta^{13}\text{C}_{\text{max-min}}$ 2.0‰), with a mean of $-20.4\text{‰} \pm 0.4\text{‰}$ and $\delta^{15}\text{N}$ values between 10.8‰ and 14.6‰ ($\Delta^{15}\text{N}_{\text{max-min}}$ 3.8‰), with a mean of $12.1\text{‰} \pm 0.6\text{‰}$. A significant difference was found between periods 1 and 2-3, with the latter having higher $\delta^{13}\text{C}$ ($t(20) = 2.09, p = 0.008$) and $\delta^{15}\text{N}$ ($t(16) = 2.12, p = 0.003$). This may suggest that greater quantities of terrestrial protein were being consumed by the Pictish monks compared to the earlier Pictish lay group, and although very few marine and freshwater fish bones were recovered from this period (Holmes, 2012, 2016), there may have been minimal fish consumption by some at the monastery (Figure 6). For example, all adult $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values are within the same trophic level, although there is one individual (SK144) with a noticeably higher $\delta^{13}\text{C}$ value (1.3‰) that may suggest this individual consumed some marine and/or freshwater protein. It is plausible to suggest some form of religious ranking occurred at the monastery, with the possibility that this individual was a senior monk who had privileged rights to aquatic foods that were not afforded to most of the monastic brethren. Monastic hierarchy from the early medieval period onwards in Britain and Ireland is attested to in various historical sources, with titles such as *manaig* (peasants), *firmanaig* (monks), *servi* (oblates), *ministry* (attendants), and *princeps* (head) denoting ones rank associated with monastic settlements (Swan, 1994; Flechner, 2016, 2019). Strontium and oxygen isotope analysis on SK144 suggests he was of local origin (Walther et al., 2016); hence a different cultural or geographical influence on his diet for example, can be ruled out. Moreover, isotope analysis on bulk tooth dentine suggests some individuals from period 2-3 were consuming more animal protein during childhood than during adulthood (Curtis-Summers et al, 2014). It is plausible to suggest the monks at Portmahomack may have been following some early form of the Benedictine Rule of fasting, or one based on early Irish penitentials that did not stipulate fish as a replacement for meat on fast days, hence it being largely absent in the period 2-3 diets. As well as cattle being used for meat consumption, dairy farming appears to have been practiced at the monastery, based on the mortality pattern of cattle (Seetah, 2011; 2016). One caveat to note is that the consumption of dairy and meat protein from the same animal cannot be distinguished isotopically (O’Connell & Hedges, 1999), so attempts to separate these out are futile. However, there are clues from early medieval texts that suggest although foregoing the consumption of dairy was not compulsory on fast days, some Rules (e.g. *Vita Fintani*) note a strict abstinence from dairy during fasting

periods (Heist, 1965; Flechner, 2016). Overall, the majority of monks from period 2-3 had a fairly homogenous diet, consuming predominantly C₃ plants (e.g. bread and pottage) and terrestrial protein (e.g. beef, lamb, pork and venison), which correlates with the expectation of uniformity in daily monastic life and adherence to religious dietary regimes (e.g. Sharpe, 1995; Jotischky, 2011). However, there appears to be some discrete dietary shifts that suggest religious influences on the diets of those within the monastic community; from oblates' diets adapting to that of the monastic brethren, and some monks of higher rank eating fish on special feast days or when entertaining guests, as was the right of heads of medieval religious houses (Fagan, 2006).

Table 7. Period 2-3 adult human and faunal $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data.

Period 2-3				
SK No.	Sex	Age	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$
SK38	M	46-59	-20.6	12.5
SK39	?M	Adult	-20.1	11.4
SK40	M	46-59	-20.3	12.3
SK42	M	46-59	-19.7	12.9
SK44	M	46-59	-20.4	12.1
SK45	M	46-59	-20.3	12.8
SK47	M	26-35	-20.0	12.4
SK48	?M	36-45	-20.7	13.2
SK50	?M	Adult	-20.2	11.4
SK51	M	36-45	-20.3	12.1
SK52	M	46-59	-20.3	12.1
SK53	M	46-59	-20.2	11.8
SK54	M	18-25	-20.5	12.1
SK111	M	26-35	-20.7	12.0
SK116	M	46-59	-20.3	13.0
SK118	M	18-25	-19.7	11.9
SK121	M	26-35	-20.2	12.8
SK122	M	46-59	-20.3	12.4
SK123	M	60+	-20.4	12.6
SK124	M	18-25	-20.8	11.4
SK125	M	60+	-20.3	12.9
SK126	M	46-59	-20.9	10.8
SK127	?M	36-45	-20.4	11.8
SK128	?M	46-59	-20.5	11.7
SK129	?M	18-25	-20.6	11.3
SK130	?M	46-59	-20.7	12.1
SK133	M	60+	-20.3	12.2
SK135	?M	46-59	-20.8	11.6

SK136	M	36-45	-21.1	11.9
SK137	?M	36-45	-20.5	11.8
SK138	?	Adult	-20.9	11.4
SK139	M	46-59	-19.8	12.6
SK140	M	18-25	-20.3	12.6
SK141	M	36-45	-20.1	12.3
SK142	M	46-59	-20.4	11.8
SK143	M	60+	-20.0	12.4
SK144	M	46-59	-19.1	14.6
SK145	M	Adult	-20.5	12.3
SK147	M	26-35	-20.4	11.2
SK148	M	60+	-20.7	12.4
SK151	M	46-59	-20.6	12.6
SK152	M	26-35	-20.5	11.7
SK153	M	36-45	-20.3	12.0
SK154	M	46-59	-20.5	11.8
SK155	F	46-59	-20.7	12.0
SK156	M	36-45	-20.9	12.0
SK157	M	46-59	-20.7	12.1
SK158	M	46-59	-20.3	12.4
SK160	?M	Adult	-20.7	11.1
SK164	M	46-59	-20.2	12.8
SK165	?	Adult	-21.1	11.1
SK167	M	Adult	-21.1	11.1
SK168	?M	36-45	-20.0	12.3
SK171	M	36-45	-19.7	12.2
SK173	M	46-59	-20.3	13.1
SK174	?F	Adult	-21.1	11.4
SK176	M	46-59	-20.1	12.8
SK189	M	26-35	-21.1	11.7
		min	-21.1	10.8
		max	-19.1	14.6
		mean	-20.4	12.1
		1 SD	0.4	0.6

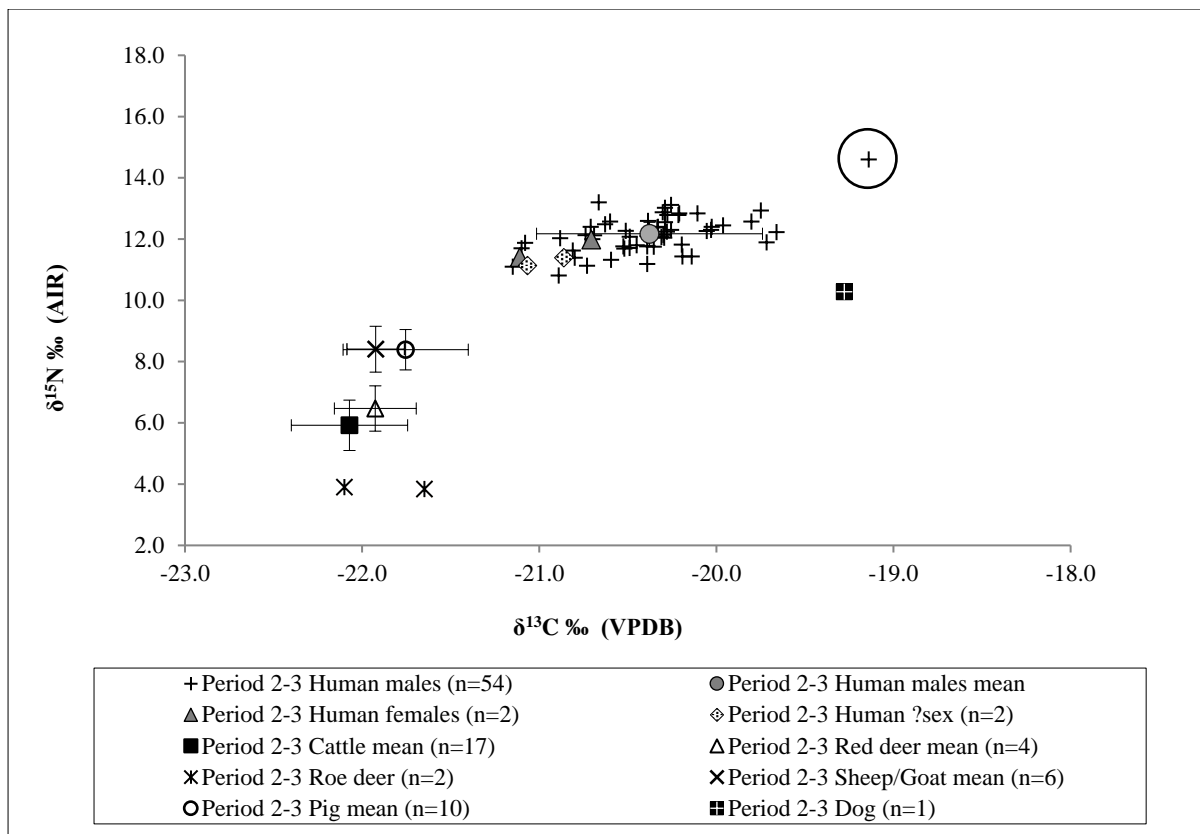


Figure 5. Period 2-3 adult human and terrestrial faunal $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values (SK144 circled). Mean error bars are ± 1 standard deviation.

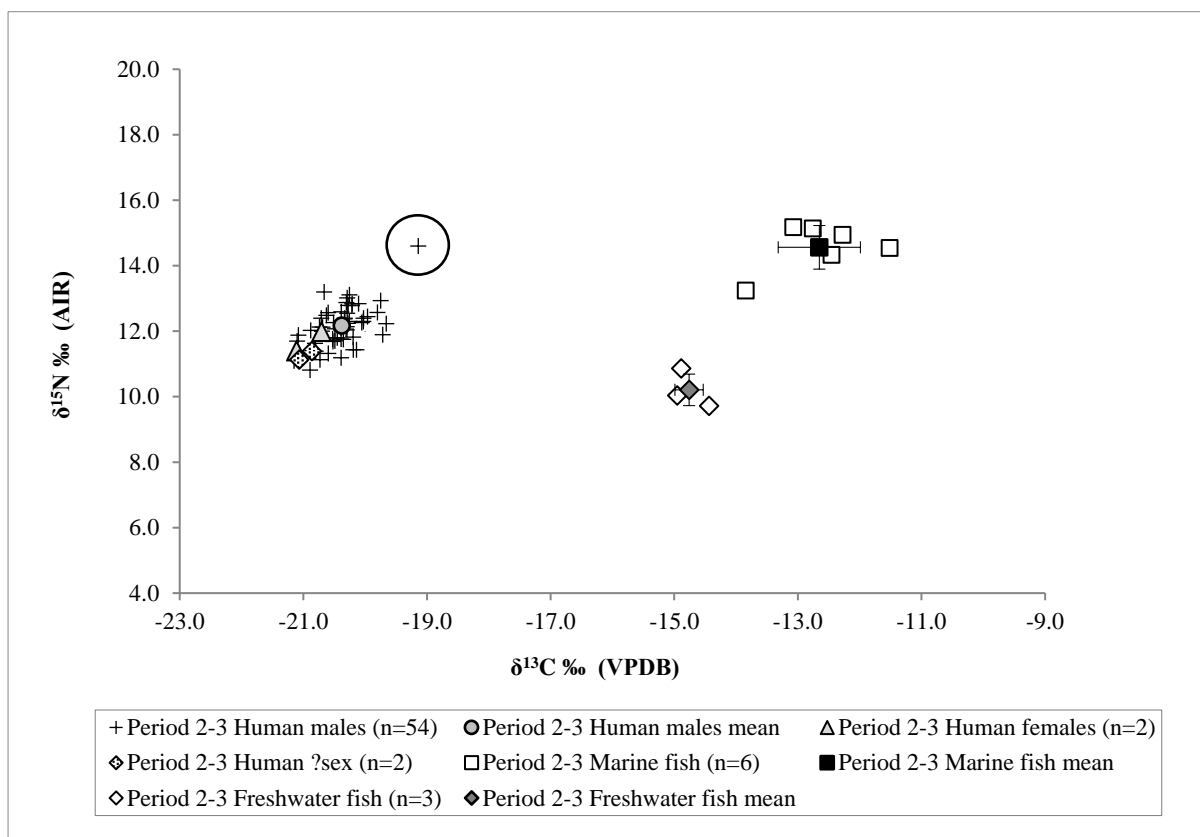


Figure 6. Period 2-3 adult human and aquatic fish $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values (SK144 circled). Mean error bars are ± 1 standard deviation.

3.2.3 Human adult diets: medieval lay periods 4 and 5 (c.1100 – c.1700)

Period 4-5 adult human (n=66) $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values are presented in Table 8 and Figures 7 and 8. The $\delta^{13}\text{C}$ values ranged between -21.0‰ and -15.5‰ ($\Delta^{13}\text{C}_{\text{max-min}}$ 5.5‰), with a mean of $-18.5\text{‰} \pm 1.1\text{‰}$. The $\delta^{15}\text{N}$ values were between 11.1‰ and 17.6‰ ($\Delta^{15}\text{N}_{\text{max-min}}$ 6.5‰), averaging $14.8\text{‰} \pm 1.3\text{‰}$. This data reflects wide variation that reveals a whole trophic level increase and higher $\delta^{13}\text{C}$ in some individuals, suggesting certain people were consuming greater amounts of aquatic protein compared to those with lower $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values. Additionally, six adults from this period have noticeably lower $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values that are closer to those from period 2-3 (Figure 7). Apart from these outliers, the isotope data suggests the majority of adults consumed terrestrial C_3 and animal resources similar to those from periods 1 and 2-3 (e.g. bread, beef, lamb and pork), but with the inclusion of marine and freshwater fish in their diets (Figure 8). Mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from period 4 were higher than period 1 for both $\delta^{13}\text{C}$ by 2.2‰ ($t(66) = 2.00, p < 0.001$) and $\delta^{15}\text{N}$ by 3.5‰ ($t(26) = 2.06, p < 0.001$). Period 4 also had more enriched isotope values compared to period 2-3 by 1.9‰ for $\delta^{13}\text{C}$ ($t(79) = 1.99, p < 0.001$) and by 2.7‰ for $\delta^{15}\text{N}$ ($t(94) = 1.99, p < 0.001$). The isotope data reflects a diachronic change in diet from the earlier Pictish phases (periods 1 and 2-3) to the later medieval parish phase (period 4). Most notably, the carbon enrichment in the later period reflects an increase in marine fish consumption that is not seen in the earlier Pictish phases, which is also supported by the evidence of fish bones being found in much greater quantities in period 4 (Carver et al., 2016). This increase in fish consumption coincides with growing populations and an increase in the fish trade, partly connected to the growing widespread adherence to Christian fasting practices in Britain (Barrett & Richards, 2004). This evidence may therefore reflect a shift in religious dietary influences over time, from the Pictish monastic brethren following one type of fasting practice that did not require fish to replace meat, to the later medieval parish church community following a different rule of fasting, by which time the replacement of meat with fish became popular (Fagan 2006). The period 5 adults (n=2) had $\delta^{13}\text{C}$ values of -19.2‰ and -19.6‰, and $\delta^{15}\text{N}$ values of 13.6‰ and 14.4‰. Their $\delta^{13}\text{C}$ values appear more comparable to those from period 2-3 (-20.4‰) than the majority of period 4. Their diets may have been influenced by the changing religious foci from Roman Catholic to Presbyterian during this period, which is interesting to note, considering these two individuals are the mid-17th century Tarbat parish Minister, William

Mackenzie and his wife (Carver, 2016). Based on strontium and oxygen isotope analysis, Minister Mackenzie travelled to Portmahomack from the Western Isles by the age of 7 years (Walther et al., 2016); although whether his childhood origin had any influence on his diet some thirty years later cannot be ascertained from this data alone. Minister and Mrs Mackenzie followed the Presbyterian faith, which acknowledged fast days, but did not specifically require dietary fasting of replacing fish with meat as part of its doctrine (Brown, 1997). Fasting may not only reflect religious dietary adherence, but political gestures too and indeed the two are often intertwined. For example, in 1621 while parliament was voting on the suspension of non-conforming ministers, Scottish Presbyterians gathered to fast and pray in protest (Ryrie, 2013). To separate religious from political influences on dietary practices in the past is however no easy task and beyond the scope of this study.

Table 8. Period 4-5 adult human and faunal $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data.

Period 4-5				
SK No.	Sex	Age	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$
SK1	?M	Adult	-18.5	15.4
SK5	F	46-59	-16.9	15.9
SK8	?M	18-25	-18.2	14.6
SK9	?M	46-59	-18.0	15.2
SK17*	M	36-45	-19.6	14.4
SK18	M	36-45	-18.4	15.4
SK20	?F	46-59	-18.1	16.3
SK23*	F	46-59	-19.2	13.6
SK25	M	46-59	-19.1	14.3
SK28	F	46-59	-17.7	15.5
SK30	M	36-45	-19.1	13.7
SK31	M	36-45	-15.5	17.6
SK32	M	60+	-17.4	15.4
SK34	M	46-59	-16.8	16.7
SK35	M	18-25	-17.4	15.4
SK36	M	46-59	-19.0	13.9
SK37	M	26-35	-16.1	17.2
SK41	M	18-25	-20.3	11.7
SK43	M	46-59	-19.2	14.4
SK49	?F	Adult	-20.8	11.1
SK55	?F	18-25	-19.1	13.6
SK56	M	46-59	-17.5	15.7
SK62	F	46-59	-19.0	14.2
SK64	M	46-59	-19.3	13.9
SK66	M	26-35	-18.3	14.9

SK67	F	26-35	-18.8	15.0
SK69	F	46-59	-19.7	14.4
SK72	?	18-25	-18.4	15.3
SK74	M	46-59	-19.3	14.5
SK75	?M	Adult	-19.6	14.4
SK76	F	Adult	-21.0	11.8
SK77	M	36-45	-15.9	17.1
SK78	F	26-35	-17.4	15.8
SK80	M	36-45	-17.6	16.3
SK82	F	36-45	-20.3	12.4
SK83	F	36-45	-19.4	14.9
SK84	M	46-59	-19.5	13.1
SK85	?M	18-25	-18.0	15.1
SK88	F	36-45	-18.4	15.0
SK90	M	60+	-18.0	15.1
SK91	F	26-35	-19.8	14.0
SK93	M	26-35	-17.1	16.6
SK95	F	46-59	-18.6	14.7
SK96	?M	Adult	-19.0	14.1
SK97	?F	46-59	-18.3	15.0
SK98	M	26-35	-17.9	15.8
SK99	F	60+	-17.1	16.2
SK100	F	26-35	-19.4	15.0
SK101	F	46-59	-18.5	14.8
SK102	F	36-45	-17.8	16.1
SK103	M	26-35	-18.0	15.6
SK104	M	Adult	-18.3	14.9
SK105	F	46-59	-20.4	12.7
SK106	F	60+	-18.7	15.5
SK108	M	36-45	-19.5	14.7
SK109	M	46-59	-18.2	14.4
SK112	M	46-59	-18.9	14.4
SK113	M	36-45	-19.1	13.8
SK114	F	18-25	-17.5	15.2
SK115	F	Adult	-18.8	15.4
SK117	M	18-25	-20.5	11.5
SK120	M	36-45	-19.5	14.3
SK134	M	18-25	-17.6	14.9
SK150	M	Adult	-19.3	14.4
SK161	M	36-45	-18.0	14.4
SK192	M	36-45	-18.3	15.6
		min	-21.0	11.1
		max	-15.5	17.6
		mean	-18.5	14.8
		1 SD	1.1	1.3

* Period 5 adults

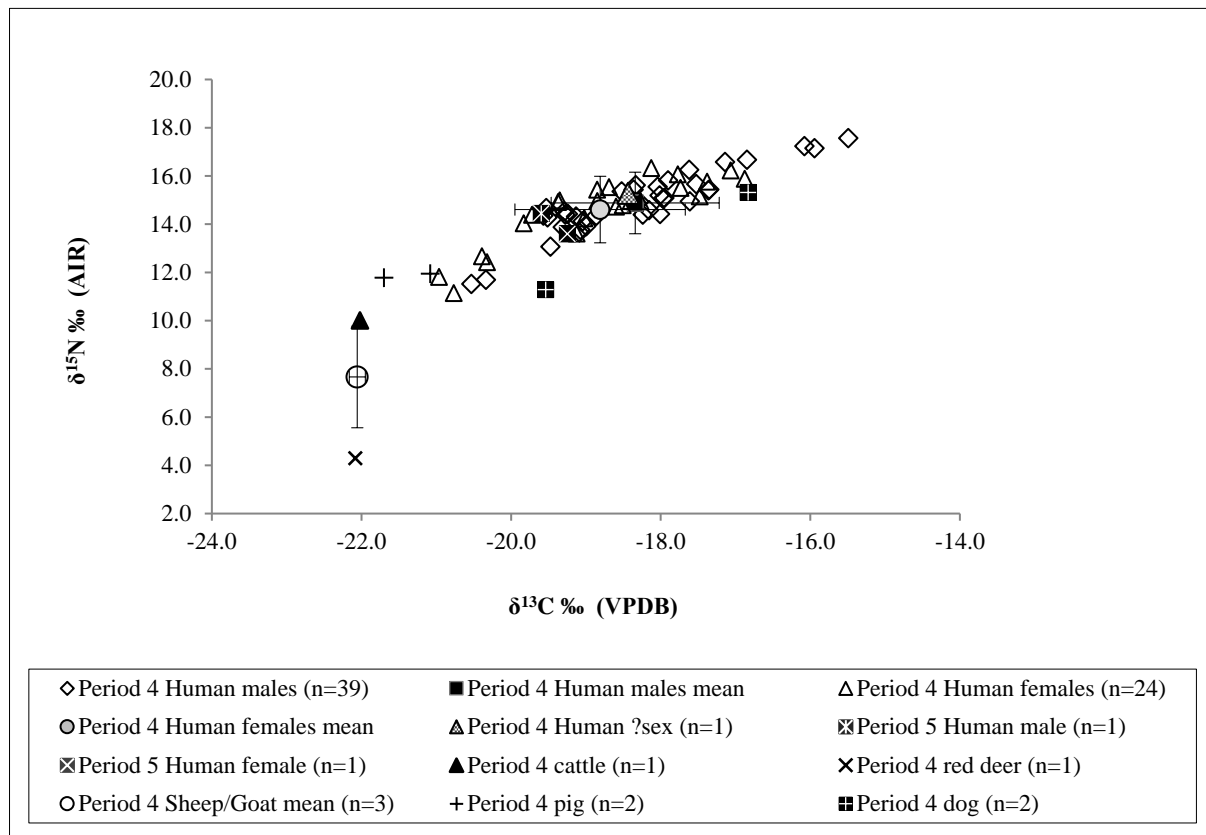


Figure 7. Adult human and terrestrial faunal $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from periods 4 and 5. Mean error bars are ± 1 standard deviation.

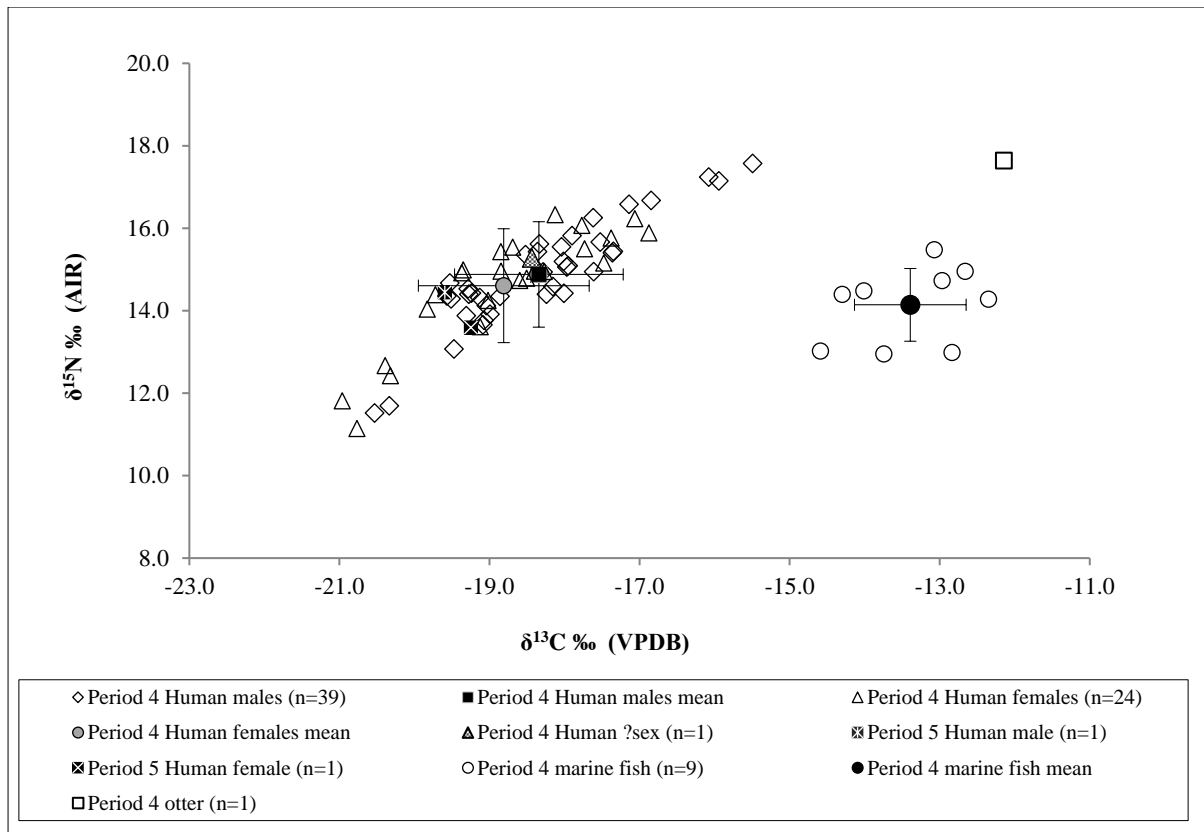


Figure 8. Adult human and aquatic faunal $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from periods 4 and 5. Mean error bars are ± 1 standard deviation.

3.2.4 Human age and sex comparisons

Different communities inhabited Portmahomack for over 1,000 years, during which time socio-economic, cultural and religious foci changed (Carver, 2016; Carver et al., 2016). It is therefore prudent to compare period-specific sex and age groups rather than the whole early to late medieval population. The mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values for males and females from periods 1 to 5 are presented in Table 9. From most periods, there is little difference between mean male and female $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ mean values. This may suggest an overall homogenous diet within these communities, although variation within periods needs to be considered. From period 1, a number of male individuals had higher $\delta^{15}\text{N}$ values than females ($t(10) = 2.23$, $p = 0.053$), suggesting some males consumed greater amounts of terrestrial animal protein than females. It is noteworthy that period 1 males had a greater prevalence of dental calculus (Curtis-Summers, 2015), which may be partly caused by a protein-rich diet (Hillson 1996). It is not known what religious practices this Pictish lay group would have followed, if any; therefore, any association with religious influences on diet cannot be affirmed. The evidence may suggest that a gendered-division in diet occurred, possibly due to cultural

norms, such as males hunting for terrestrial animals, and a necessity for them to consume greater amounts of meat for sustenance. No statistically significant differences were found between males and females from periods 4-5, although there is noticeable individual isotopic variation, (Figures 5 to 8), which may suggest some gendered-division in diet.

Table 9. Mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values and differences for males and females from periods 1 to 5.

Period 1			Period 2-3			Period 4-5		
M (n=9) mean	F (n=4) mean	Differences	M (n=54) mean	F (n=2) mean	Differences	M (n=40) mean	F (n=25) mean	Differences
$\delta^{13}\text{C}$ (‰)	$\delta^{13}\text{C}$ (‰)	$\delta^{13}\text{C}$ (‰)	$\delta^{13}\text{C}$ (‰)	$\delta^{13}\text{C}$ (‰)	$\delta^{13}\text{C}$ (‰)	$\delta^{13}\text{C}$ (‰)	$\delta^{13}\text{C}$ (‰)	$\delta^{13}\text{C}$ (‰)
-20.7 (± 0.4)	-20.8 (± 0.2)	0.1	-20.4 (± 0.4)	-20.9 (± 0.3)	0.5	-18.4 (± 1.1)	-18.8 (± 1.1)	0.4
$\delta^{15}\text{N}$ (‰)	$\delta^{15}\text{N}$ (‰)	$\delta^{15}\text{N}$ (‰)	$\delta^{15}\text{N}$ (‰)	$\delta^{15}\text{N}$ (‰)	$\delta^{15}\text{N}$ (‰)	$\delta^{15}\text{N}$ (‰)	$\delta^{15}\text{N}$ (‰)	$\delta^{15}\text{N}$ (‰)
11.5 (± 0.9)	10.8 (± 0.3)	0.7	12.2 (± 0.6)	11.7 (± 0.4)	0.5	14.9 (± 1.3)	14.6 (± 1.4)	0.3

When investigating age divisions in diet from period 1, no significant difference between male age groups was found, and female sample numbers per age group were too low for comparisons, which is also the case for period 2-3 females. Mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values for period 2-3 males are -20.4‰ ($\pm 0.4\text{‰}$) and 11.8‰ ($\pm 0.5\text{‰}$) for 18-25 years; -20.5‰ ($\pm 0.3\text{‰}$) and 12.0‰ ($\pm 0.5\text{‰}$) for 26-35 years, -20.4‰ ($\pm 0.4\text{‰}$) and 12.2‰ ($\pm 0.4\text{‰}$) for 36-45 years, -20.3‰ ($\pm 0.4\text{‰}$), 12.4‰ ($\pm 0.7\text{‰}$) for 46-59 years, and -20.3‰ , ($\pm 0.2\text{‰}$) and 12.5‰ ($\pm 0.2\text{‰}$) for 60+ years. Period 2-3 males aged 18-25 had lower $\delta^{15}\text{N}$ values compared to the 60+ age group ($t(6) = 2.45$, $p = 0.038$) (Figure 9). This suggests older monks, who may have had elevated status, consumed greater amounts of terrestrial protein compared to their younger counterparts. Bone turnover rates needs to be considered however, and an alternative interpretation is that an older childhood dietary signal may be reflected in $\delta^{15}\text{N}$ values for those aged 18-25.

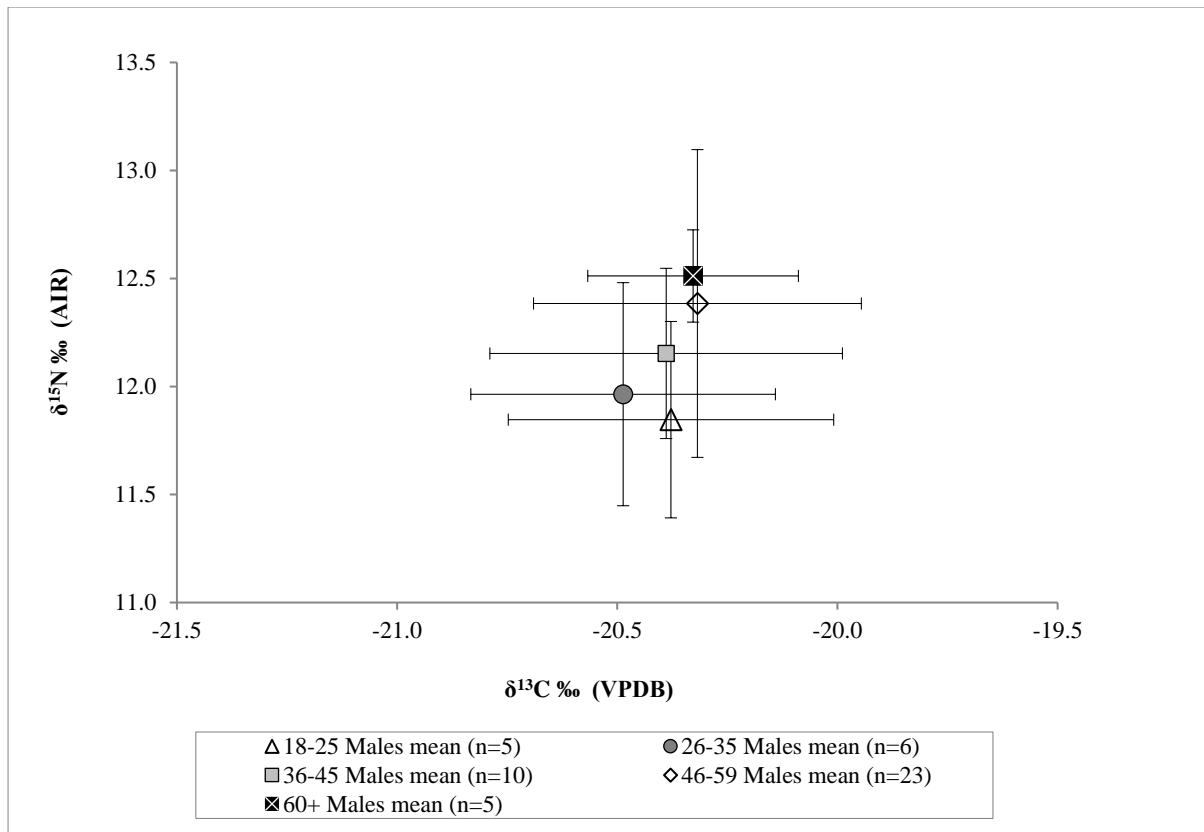


Figure 9. Mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values for period 2-3 adult males. Mean error bars are ± 1 standard deviation.

When comparing isotope values between different age groups from period 4-5, some variation in mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values is evident. Males aged 18-25 have mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of -18.7‰ ($\pm 1.3\text{‰}$) and 13.9‰ ($\pm 1.6\text{‰}$) respectively. These are lower in both $\delta^{13}\text{C}$ (1.2‰) and $\delta^{15}\text{N}$ (2.2‰) compared to those aged 26-35 who have mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of -17.5‰ ($\pm 0.8\text{‰}$) and 16.0‰ ($\pm 0.8\text{‰}$) respectively (Figure 10). A significant difference $\delta^{15}\text{N}$ values was found between these two groups with those aged 26-35 years having higher $\delta^{15}\text{N}$ values ($t(8) = 2.31, p = 0.032$). This may suggest that some 18-25 year-old males were consuming smaller amounts of animal protein, most notably the case for two individuals (SK41, SK117) that have the lowest $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from rib bone collagen, although another individual aged 18-25 (SK35) had noticeably higher $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from rib bone collagen, reflecting isotopic variation within the same age group and from the same type of bone analysed. Alternatively, considering bone turnover rates, an older childhood isotope signature may be retained if SK41 and SK117 were still in their older teens at death (Valentin, 2003; Hedges, Clement, Thomas, & O'Connell, 2007; Fahy et al., 2017). Males aged 26-35 and 46-59 from period 4-5 had mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of -17.5‰ ($\pm 0.8\text{‰}$) and 16.0‰ ($\pm 0.8\text{‰}$), and -18.7‰ ($\pm 0.8\text{‰}$) and 14.5‰ ($\pm 0.9\text{‰}$) respectively. This

gives a difference of 1.2‰ for carbon and 1.5‰ for nitrogen, which does not reflect significant trophic level increases, despite a statistical difference found between these two groups, in both $\delta^{13}\text{C}$ ($t(7) = 2.36, p = 0.049$) and $\delta^{15}\text{N}$ ($t(8) = 2.31, p = 0.020$). This may however, suggest some individuals aged 26-35 were consuming greater amounts of protein than others aged 46-59, possibly reflecting a labour-division in diet, with younger males consuming more animal protein than older males to sustain them during work. Isotope variation from age-related physiological changes, however, need to be considered as a factor (Hedges et al., 2007; Fahy et al., 2017). Although these burials are confidently assigned to this period from stratigraphic evidence (Carver et al., 2016), future radiocarbon dating may explain these divisions in diet.

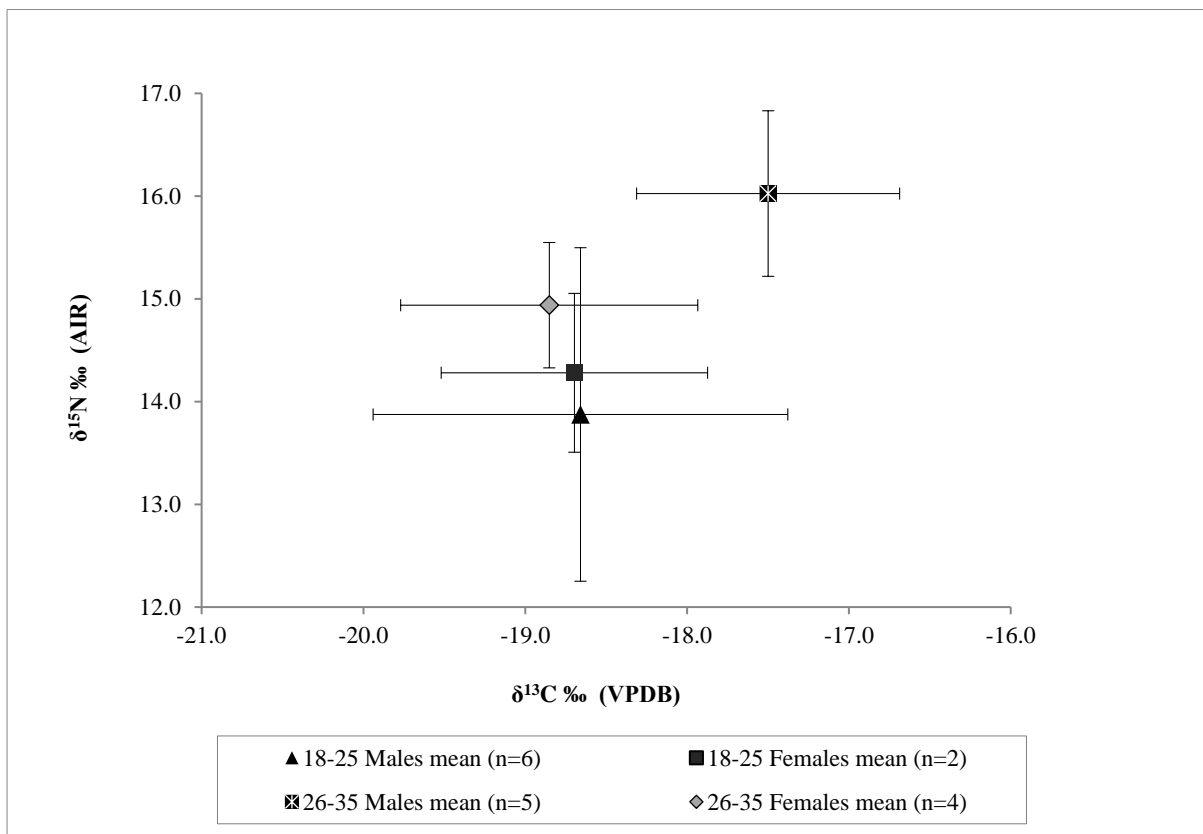


Figure 10. $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ mean values for period 4 younger adult age groups. Mean error bars are ± 1 standard deviation.

Period 4-5 adults from the older age categories of 36-45 and 45-59 have mean $\delta^{15}\text{N}$ values that are within the same trophic level (Fig. 11), with a minimal difference (0.8‰). There is a difference in mean $\delta^{13}\text{C}$ values of 1.1‰, which may suggest some trophic level increase in diet (Schoeninger and DeNiro, 1984). This is most likely due to increased fish

consumption, which is more noticeable when individual isotope values are considered (Figure 8). One male and one female aged 60+ had the highest $\delta^{13}\text{C}$ values of the whole group at -17.4‰ and -17.1‰ respectively. This is also evident when compared to the two other individuals of the same age group, especially the two females who had the most noticeable difference in $\delta^{13}\text{C}$ values (1.6‰). This carbon isotope variation, even within the same age group, attests to the variation of fish consumption during this time. This coincides with the emergence of Highland communities increasingly exploiting marine resources and adopting a mixed subsistence strategy of fishing and farming (Sinclair, 1793).

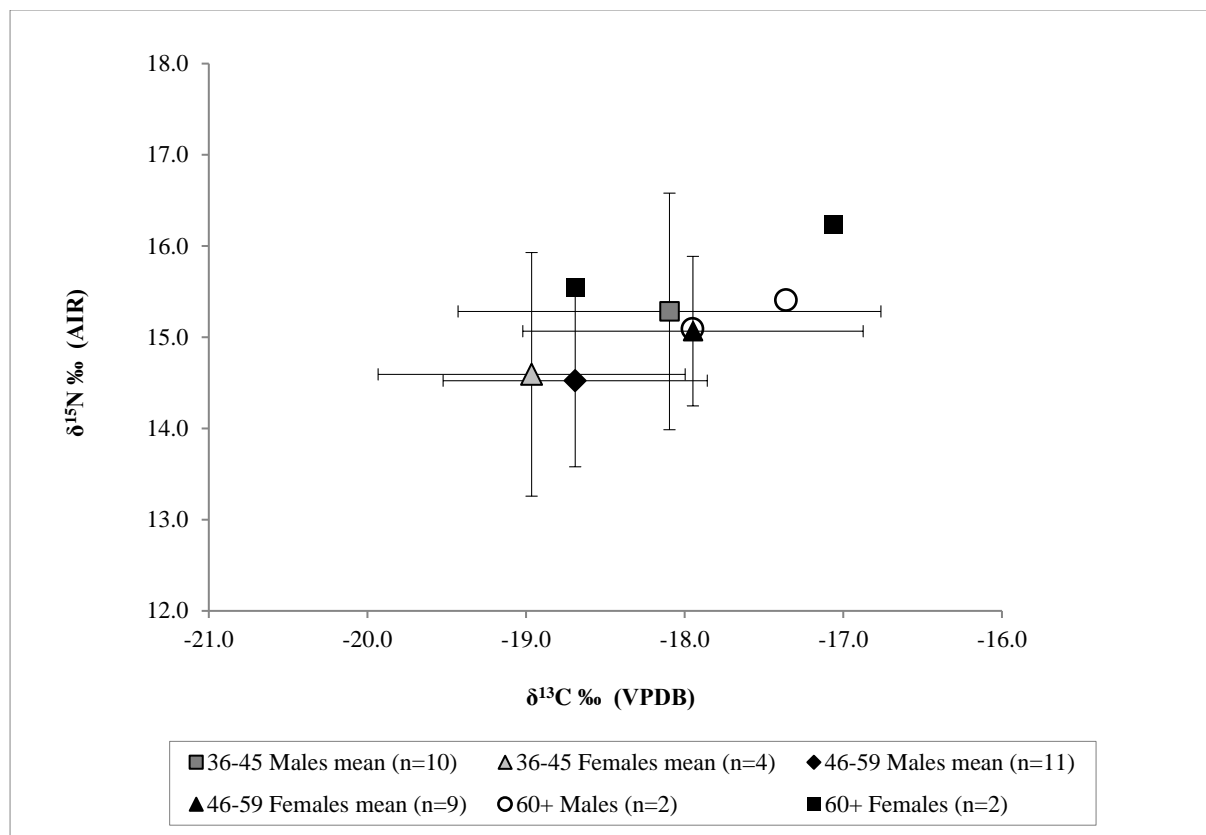


Figure 11. $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from period 4 older adult age groups. Mean error bars are ± 1 standard deviation.

3.3 Site comparisons

Mean adult bone collagen $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from periods 1 (Pictish lay), 2-3 (Pictish monastic), and 4 to 5 (mid-late medieval lay) at Portmahomack are compared to a range of early to late medieval sites to investigate multi-period dietary patterns. Period 1-3 results are compared to the early-mid medieval sites of Lundin Links, Fife (Modzelewski, 2008), Westness, Orkney (Barrett & Richards, 2004), Belle Vue, York (Müldner & Richards,

2007a), Berinsfield, Oxon (Privat, O'Connell, & Richards, 2002), Dublin, Ireland (Knudson, O'Donnabhain, Carver, Cleland, & Douglas Price, 2012), Owenbristy, Ireland (Geber, 2010), Newark Bay (Barrett & Richards, 2004), and Birka, Sweden (Linderholm, Jonson, Svensk, & Lidén, 2008). Period 4 and 5 results are compared to the mid-late medieval sites of Newark Bay, Orkney (Barratt & Richards, 2004), St Andrew Priory, York (Müldner & Richards, 2007b), Whithorn (Müldner et al., 2009), Koksijde, Belgium (Polet & Katzenberg, 2003), Constitution Street (Britton, 2019), and Owenbristy (Geber, 2010). Comparing palaeodietary data across a range of geographical and multi-period sites will enhance our understanding of medieval dietary patterns. Additionally, isotope data from Scottish sites with long periods of activity and varying cultural and religious foci, as at Portmahomack, are much needed to build a wider picture of diet in medieval Scotland (Britton, 2019).

3.3.1. Early-mid medieval comparisons (4th to 12th century)

Mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from periods 1 to 3 at Portmahomack reflect similar results to those from the Pictish sites of Lundin Links and Westness (Figure 12), suggesting generally homogenous diets within Pictish communities. The Anglo-Saxon sites of Belle Vue, and Berinsfield, and the Viking site of Dublin have lower mean $\delta^{15}\text{N}$ values compared to periods 1-3 but similar $\delta^{13}\text{C}$ values. This is interesting considering some fish consumption has been suggested for the latter two sites, although at Berinsfield, this is linked to poor people consuming freshwater fish (Knudson et al., 2012; Privat et al., 2002). Considering the cultural and geographical variation of these sites, this isotopic difference, albeit slight, is expected. Overall these data suggest diets that consisted predominantly of C_3 plant foods, such as barley and wheat, with significant levels of terrestrial animal protein intake and in some cases, fish consumption. This supports evidence that a noticeable increase in fish consumption did not occur until the mid-medieval period onwards, influenced by growing populations, deep-sea fishing and widespread adherence to Christian fasting practices (Barrett et al., 2004; Barrett & Richards, 2004). A diet that consisted of predominantly vegetation, rather than meat, has been suggested for the ecclesiastical site of Owenbristy (Geber, 2010). This may reflect Irish religious dietary influences that in some cases involved strict fasting regimes (e.g. *Vita Fintani*). Two sites that stand out compared to Portmahomack are Birka, and Newark Bay. Birka has the highest mean $\delta^{15}\text{N}$ value and has been suggested to reflect people of high status consuming freshwater fish, rather than marine fish (Linderholm et al., 2008), although its $\delta^{13}\text{C}$ values are similar to the majority of other sites compared here. Newark Bay has the most enriched ^{13}C values, which reflect high marine protein intake

(Barratt & Richards, 2004), more so than all other comparable sites from the early-mid medieval period, with a difference of 2.0‰ when compared to Portmahomack. The lack of fish consumption from the Pictish coastal sites may suggest these people either did not have the means to exploit marine resources or chose not to do so. The latter explanation is more plausible considering the various forms of evidence to suggest Pictish relationships with the sea, such as boats and sea beasts depicted on Pictish stones, and naval bases as at Burghead (Edwards & Ralston 1980; Woolf, 2007; Henderson & Henderson, 2004; Fraser, 2009; Oram, 2007; Foster, 2017). Additionally, the *Annals of Tigernach* recorded that in AD 729 “a hundred and fifty Pictish ships were wrecked upon Ros-Cuissine” (Anderson 1922: 226), further attesting to the scale of Pictish sea power.

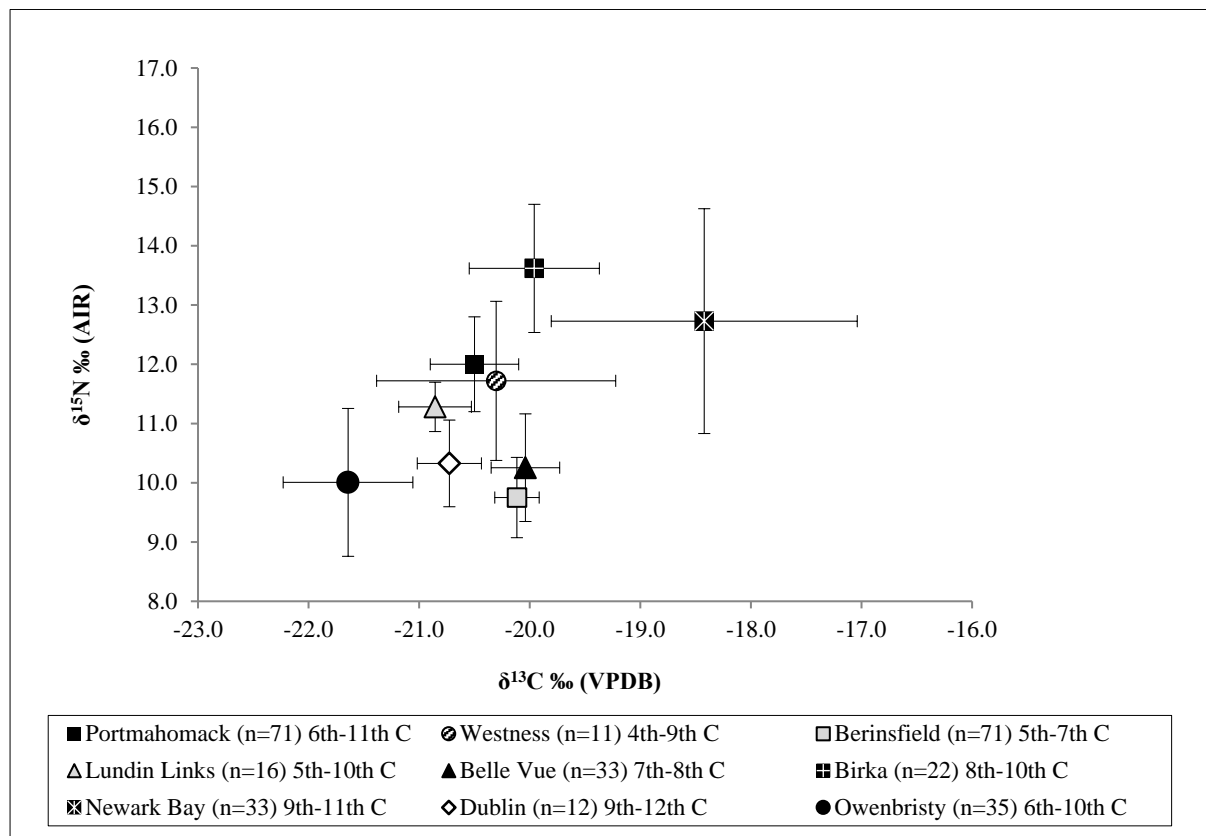


Figure 12. Mean human $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from sites comparable to early medieval Portmahomack (periods 1-3). Mean error bars are ± 1 standard deviation.

3.3.2. Mid-Late medieval comparisons (11th to 17th century)

In contrast to periods 1 to 3 at Portmahomack, isotope results from period 4 reflect a significant increase in marine fish consumption. The two adults from period 5 are less enriched in carbon and nitrogen isotopes compared to most adults from period 4. The $\delta^{13}\text{C}$

values from this period are most similar to Newark Bay, followed by St Andrew Priory, and the high status group at Whithorn (Figure 13). There are marked differences in $\delta^{15}\text{N}$ values at Koksijde, Constitution Street, and most notably at Owenbristy. Owenbristy has a mean $\delta^{15}\text{N}$ value (10.4‰) that is a whole trophic level below the period 4 group at Portmahomack by 4.4‰ and a difference in mean $\delta^{13}\text{C}$ (-21.0‰) of 2.5‰. Similar to the early medieval period at Owenbristy, strict Irish Christian dietary regimes appears to be still reflected in the later phases at this site, with little meat and fish consumption amongst the ecclesiastical community, a pattern that is not mirrored by the period 2-3 monastic community at Portmahomack.

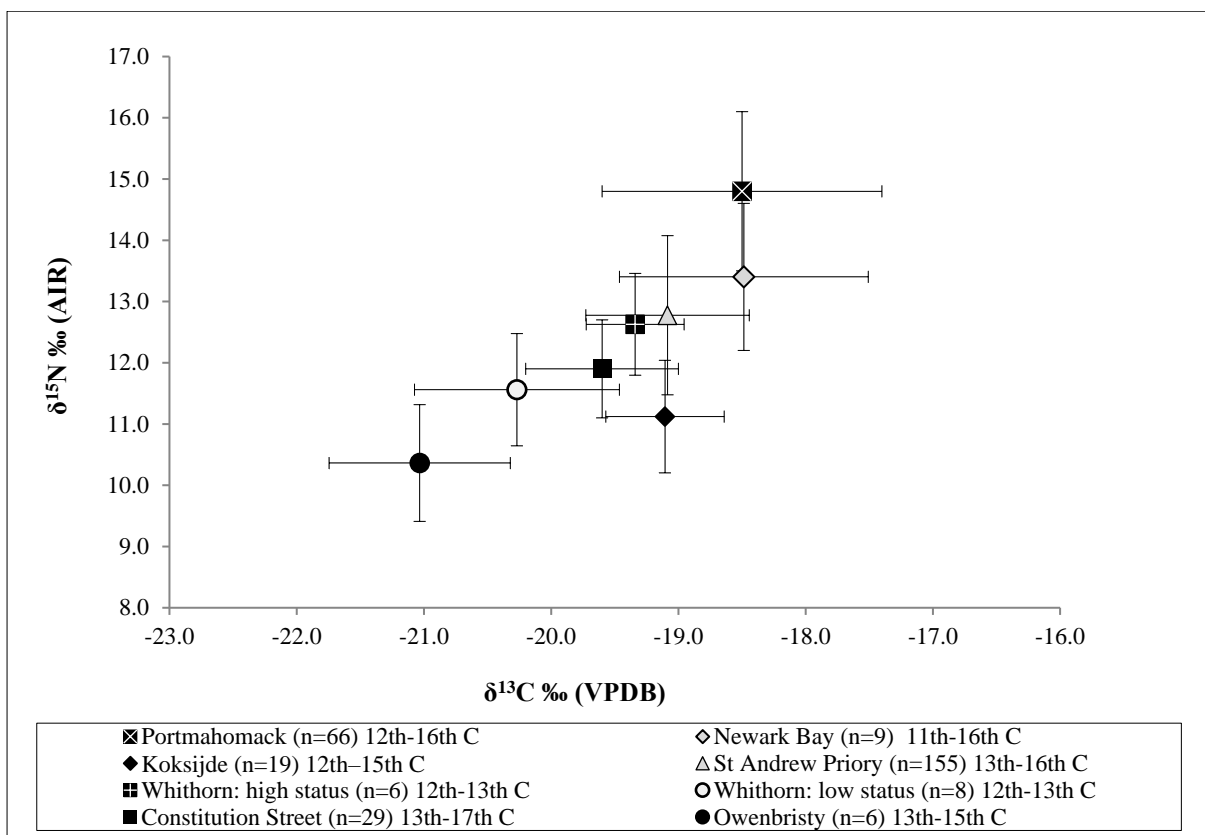


Figure 13. Mean human $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from sites comparable to mid-late medieval Portmahomack (periods 4-5). Mean error bars are ± 1 standard deviation.

Isotope data from Newark Bay has been suggested to reflect significant amounts of marine consumption from the Viking period onwards that peaked in the later medieval period (Barratt & Richards, 2004). From St Andrew Priory, ‘varying amounts’ of marine consumption has been suggested (Müldner & Richards, 2007b: 168), and from Whithorn greater amounts of marine protein consumption by the high status ecclesiastics compared to

low status layfolk is suggested (Müldner et al., 2009). From Constitution Street, marine protein consumption varied between individuals (Britton, 2019). Lay period 4 at Portmahomack has the most elevated carbon and nitrogen mean ratios compared to all sites (excluding Newark Bay for carbon) and the aforementioned sites, a whole trophic level difference is reflected compared to Owenbristy, Whithorn (low status), and Koksijde. Carbon and nitrogen isotope ratios of the Whithorn (high status) and St Andrew Priory groups are within the same trophic levels to Portmahomack and it is interesting to note that all followed the Rule of St Augustine during the mid-late medieval period. From the 13th to 16th century, the layfolk at Portmahomack followed the Augustinian Rule, under the direction of the Premonstratensian Abbey at Fearn (Carver, 2016). There is a slight enrichment of mean carbon and nitrogen isotope values from Portmahomack compared to St Andrew Priory (0.6‰ and 2.0‰ respectively) and Whithorn high status (0.8‰ and 2.2‰ respectively), which may suggest greater consumption of marine protein. The Rule of St Augustine was not as strict in its dietary regime, compared to St Benedict's Rule for example, and dietary variation is expected. Therefore, although there may have been a religious influence on the uniformity in diet for some religious houses, environmental and socio-political influences would have also been a factor. What may have occurred at Portmahomack in the mid-late medieval period was a new coastal influence on diets that emerged from the rapid growth of the fishing trade in the area and ease of access to marine resources due to the community's coastal proximity, combined with the communities adherence to religious dietary regimes. Whatever the reason, the diets of the Portmahomack parish church communities during mid-late medieval period are unique compared to some contemporaneous sites and reflect a community of economic change and growth.

These comparisons provide an overview of ecclesiastical and lay diets during the early to late medieval periods, which suggests that the diet of the Pictish lay and monastic communities at Portmahomack were similar to that of other contemporaneous sites in northeast Scotland, reflecting some regional dietary homogeneity that was largely influenced by socio-economic, environmental and early religious factors. In contrast, significant amounts of marine protein were consumed at most mid-late medieval sites, with the isotope evidence for fish consumption at Portmahomack being notable.

5. CONCLUSIONS

Stable isotope data presented here elucidate variations in diet that reflected age- sex- and/or period-specific differences between certain groups. Results revealed a diachronic change in diet over time; no significant amounts of marine or freshwater fish were consumed by the Pictish lay or monastic communities (periods 1-3), yet a significant increase in marine fish consumption by the period 4 and 5 parish layfolk is evident. These results correlate with other isotope studies that provide evidence for a predominantly terrestrial based diet in the early medieval period and increased fish consumption in mid-later medieval periods, the latter of which is highly notable at Portmahomack. This diachronic change in diet reflects self-sufficient Pictish communities living off the land yet choosing not to exploit nearby aquatic resources, with no need to consume fish as part of their fasting regime. This is in stark contrast to evidence from the later medieval parish church community, where an increase in fish demand reflects changing religious influences on fasting practices and the growing popularity for replacing meat with fish on fast days. Socio-political, economic, environmental and religious factors are so intertwined that it may be difficult to determine a specific influence, if one existed. However, the evidence presented here indicates the important religious influence on food consumption and, therefore, the influence on the lives of the people in Portmahomack. This evidence clearly attests to the usefulness of providing primary data from bioarchaeological studies to reconstruct aspects of religious influences on Christian lifeways and importantly, rare insights into the dietary and socio-economic patterns of Pictish and medieval communities in Scotland.

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