Stable Isotope Evidence for Dietary Contrast Between Pictish and Medieval Populations at Portmahomack, Scotland

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THE PICTISH AND MEDIEVAL SITE at Portmahomack contained four skeletal populations belonging respectively to the late Iron Age/early Pictish period (6th/7th century), to a monastery of the late Pictish/early medieval period (8th century), to a Norse and Scottish trading place (9th to 11th century) and to a late medieval parish (15th century). Carbon and nitrogen isotope analyses of bone and tooth root collagen from sample individuals from each period were measured for dietary reconstruction. Faunal bone collagen was also assessed to provide dietary comparisons. The results demonstrate a marked change in diet between the early and late medieval communities at Portmahomack. Faunal data also presented dietary differences between the early and later medieval periods, perhaps related to a change in husbandry practices. Due to the dearth of carbon and nitrogen isotope studies on medieval skeletal collections in many areas of Britain and Ireland, this study provides valuable data to enhance our knowledge of food consumption and subsistence in the medieval period.

INTRODUCTION

The diet of a community reflects its economy and social organisation; such matters are of particular interest in periods and places characterised by high mobility or instability. The Highlands of Scotland was susceptible throughout the first and second millennia AD to population pressure from north, east, west and south. In the late Iron Age or early Pictish period (6th/7th century), the pagan people of eastern Scotland were under pressure from Christian polities both from the Irish in the west and the Angles from the south. Between the 6th and the 8th century the first Christian monastic communities are thought to have appeared, forming the vanguard of the conversion process. In the 9th century, Scotland attracted belligerent interest from the Norse, resulting in penetration and settlement especially in the northern and western isles. The High Middle Ages witnessed documented hostility from England and continued immigration from the west as indicated by the widespread replacement of Pictish by Gaelic place names. The Highlands are not blessed with wide arable lands; barley, cattle, sheep and fish are likely to have been exploited, but the balance between them in any one period indicates the relative emphasis on sedentary and mobile groups and between settled and disputed territory.

Archaeological evidence suggests that cattle were a highly important commodity for meat and milk throughout the medieval period in Ireland and Scotland, particularly in the uplands and among mobile clans.[4] By contrast, the coasts of the Firthlands in the north-east were fertile areas for the growing of wheat and barley to the present day. Based on present resources, exploitation of both freshwater and saltwater fish is to be expected. Images of salmon feature on Pictish symbol stones of the 7th century.[5] However, investigations of excavated assemblages and stable isotope evidence suggest a high terrestrial meat protein intake in the early medieval period, with very little marine protein consumption, even on coastal sites,[6] although faunal evidence elsewhere does suggest some evidence for marine exploitation.[7] There is also an expectation, based on later medieval practice, that monastic communities would eat fish. The Rule of St. Benedict (c AD 560) proscribed the consumption

of meat on fast days, unless a person was ill,[8] and in the later medieval period, many Christians followed this rule, substituting fish for meat. Religious and social influences on food consumption in the medieval period came mainly from penitentials,[9] although fasting practices among the early communities in the north are poorly documented. Before the spread of the Black Death in Scotland in AD 1350,[10] most peasants relied on cereals, yet by the 15th century peasant diets changed with the consumption of wheat, ale, fish and meat, providing a range of vitamins that were previously deficient in the diet of many people.[11]

The reconstruction of diet is especially revealing where a site features a succession of different types of settlement in the same place, and can offer a long lasting sequence of cemetery evidence with preserved human bone and rich assemblages of faunal and plant remains. Portmahomack on Tarbat Ness in Easter Ross, which was studied by excavation and analysis between 1994 and 2013, offers both. Stable isotope analysis was applied to forty individuals ranging in date from the 6th to the 16th centuries (Fig 1). The purpose of the exploratory investigation reported here was to determine variations in diet from carbon and nitrogen isotopes in bone and tooth root collagen, and draw some first conclusions on the significance of the differences encountered.

THE SITE AND SEQUENCE AT PORTMAHOMACK

The excavated site is situated in the coastal village of Portmahomack on the Tarbat Peninsula in north-east Scotland (Fig 2), with the area of archaeological interest focussed on St Colman's church.[12] The historical importance of this site was recognised in the early 20th century AD, when Allen and Anderson published carved stones found in and around the church, including one with a Latin inscription.[13] The modern campaign (between 1994 and 2007) recovered another 200 fragments of carved stones including one carrying an image of Apostles. The excavations also unearthed a wealth of finds relating to craft-working activities, including butchery, glass, leather, vellum and metal-working.[14] These suggest evidence of an early Christian literate community at Portmahomack.[15]

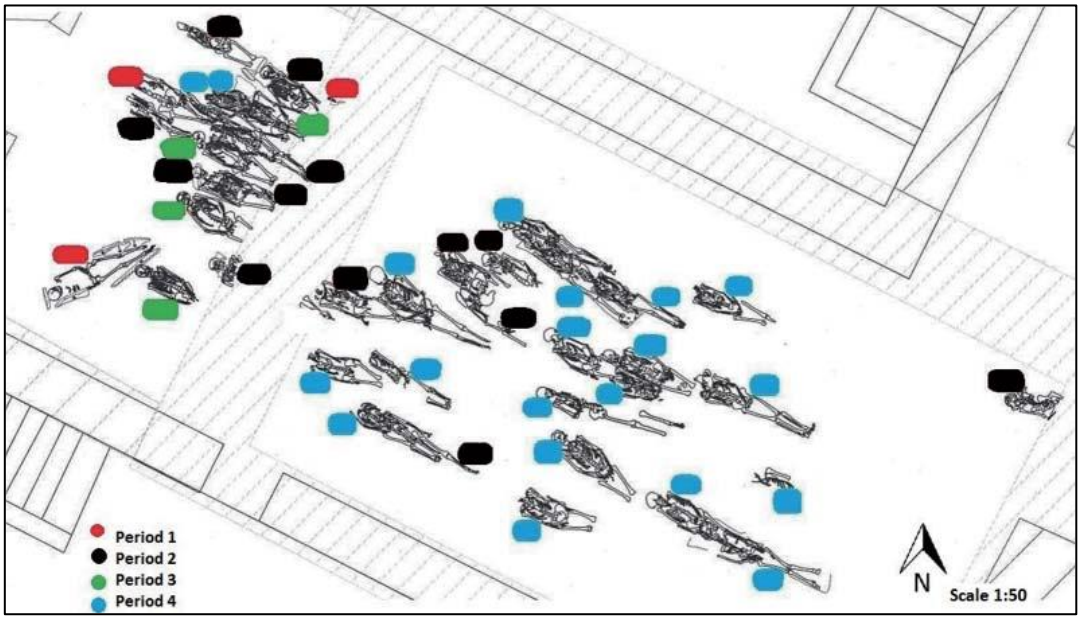

Fig. 1. Burial plan of individuals analysed in this study. Scale 1:50. © Martin Carver, 2012.

The excavated sequence began with a cemetery of long cist graves on a ridge between an inland valley and the Dornoch Firth. These graves were radiocarbon-dated (Carver 2012; Appendix B) to the 6th and 7th centuries (the late Iron Age or early Pictish period, here Period 1). There were traces of a contemporary settlement with round houses and evidence for ard cultivation and metalworking. Faunal remains were few, but there were surviving deposits of barley and wheat. This was succeeded by a major development associated with the establishment of a Pictish monastery (late 7th to early 9th century — here Period 2). There was an expansion of the burial ground with graves marked by a profusion of stone sculptures. The valley was dammed, creating a pool, and a paved road led across a bridge towards metal workshops. The whole area was enclosed by a D-shaped ditch. This phase was rich in the faunal remains of land mammals, especially cattle, and sea mammals but not fish. In the early 9th century the monastery was raided, sculpture broken up and the workshops burnt down, but the settlement revived as an industrial centre making metal objects and weights, but no vellum or sculpture (Period 3). The burial ground continued with low level and spasmodic use and had petered out together along with the production by the 11th century. In the 12th century, the former monastic site was chosen as the site of Tarbat's first parish church. A small residential development made its appearance in the 13th century, accompanied by shell and fish middens. In the 15th century, there was an upsurge in activity in the village, principally the production of iron. At the same time, intensive burial returned to the nave of the church, which continued to be used until the reformation in the late 16th century (Period 4).[16]

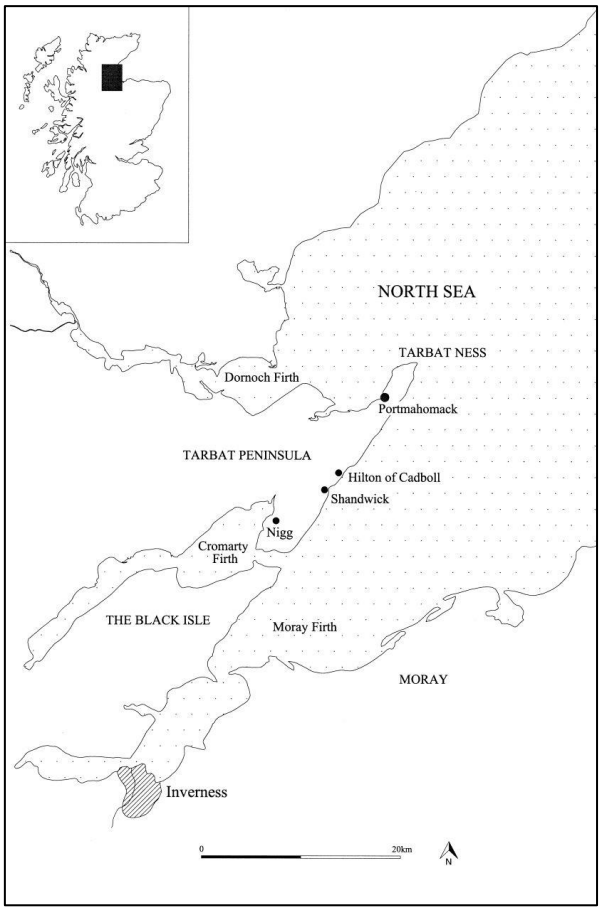

Fig. 2. Location map of Portmahomack. © Martin Carver, 2005.

THE BURIALS AT PORTMAHOMACK

The burials at Portmahomack were well stratified and comprise four distinct groups: 16 cist burials of Period 1 (6th/7th century), 51 monastic burials of Period 2 (8th century), seven burials from Period 3 (9th/11th century — but here included with Period 2) and 86 from Period 4 (the great majority from the 15th century). The Period 1 burials are characterised by the presence of long-cist graves. They contained adult men or women and were high status, having originally been marked by burial mounds. The Period 2 burials were predominately adult males; these featured head-supports and are assigned to the monastic phase. Only seven burials were recognised from Period 3 and these followed continuously on from Period 2, using the same burial rites. Period 4 burials represent the population of the parish founded during the 12th century. Burials from this period are those of men women and children and the majority date to the 15th and 16th centuries. There were examples of high status graves, notably Burial 30 and 36 which contained a succession of two large males in the same grave and a selective use of coffins (11 male (including probable male) burials, four females (including probable females) and four sub-adults)[17]. Except for sub-adults, burial in the church ceased definitively about AD 1620 when the church was reformed and a stone floor was laid (Period 5).[18]

PRINCIPALS AND METHODS

A number of systematic changes in nitrogen ($\delta^{15}N$) ratios have been observed when organic matter is transferred up the food chain, for example, from plants to herbivores to carnivores. This 'trophic level effect' is estimated at 3‰ to 5‰ enriched in ^{15}N for each trophic level.[19] Nitrogen isotopes are therefore used to examine tropic level effects and to measure the level of marine versus animal protein consumption. Carbon ($\delta^{13}C$) isotope ratios vary between terrestrial and marine ecosystems and between plants of different photosynthetic pathways. These photosynthetic pathways are termed C_3, C_4 and CAM, the latter of which can alternate between C_3 and C_4 pathways and mirror their $\delta^{13}C$ values. C_3 plants, which are found in most temperate zones and are native to Europe, include plants such as wheat, barley and oats.[20] C_4 plants include tropical vegetation such as sugar cane, maize, millet and sorghum.[21] No natural C_4 vegetation exists in Britain and before foods like sugar cane were imported in the late medieval period, this dietary component was rare,[22] although recent studies have discovered a possible C_4 dietary component in individuals from Roman period sites in England.[23]

Bone turns over at a rate of around ten to thirty years,[24] depending on the type of bone.[25] Unlike bone, tooth dentine does not continuously remodel,[26] hence, tooth dentine should retain $\delta^{13}C$ and $\delta^{15}N$ values from when it was formed during childhood.[27] The root apex of the mandibular first permanent molar (M1), the tooth chosen for this study, is completed by around 9 to 11.5 years,[28] hence reflecting a dietary signature from around this age. Stable isotope data can therefore elucidate the diet of an adult's life from the last ten years or so and from childhood if tooth dentine collagen is measured.

Human cortical rib samples from 40 adult humans (*n*=3 Period 1, *n*=13 Period 2, *n*=4 Period 3, *n*=20 Period 4) were selected and for ten of these (*n=2* Period 2, *n=3* Period 3, *n*=4 Period 4), a sample of first molar bulk root dentine was also taken. Bone samples were taken

from 16 animals from Periods 2 and 4: cattle, sheep, pig, dog and cod. Sample preparation and isotope analysis procedures followed Richards and Hedges,[29] with an extra stage of ultrafiltration as proposed by Brown et al,[30] following a modified Longin method.[31] These procedures are described in Appendix A.

RESULTS

All $\delta^{13}C$ and $\delta^{15}N$ data are presented in Tabs 1, 2 and 3. The majority of samples yielded good quality collagen, with those for the human samples ranging from 1.2 wt. % to 12.4 wt. %,[32] One tooth sample (140T) was excluded due to a low collagen yield of 0.2 wt. %. All weight percentages for carbon and nitrogen fell within the acceptable range of 30–50 wt. % for carbon and 10–20 wt. % for nitrogen. C:N ratios for human and faunal samples were between 3.2 and 3.6 and are therefore within the acceptable range of well-preserved collagen.[33] Although there are some differences, in $\delta^{13}C$ and $\delta^{15}N$ values between the Period 1 and Period 2 burials, no great distinctions were noted overall between Periods 1–3. Therefore, human and faunal samples from the early medieval periods (1–3) will be hereafter referred to as the 'EMG' (early medieval group), with those from Period 4 referred to as the 'LMG' (later medieval group). The most useful comparison noted by this research to date is between the 8th-century monastery (Period 2) and the 15th-century parish community (Period 4).

TABLE 1

$\delta^{13}C$ and $\delta^{15}N$ faunal bone collagen results and archaeological data from Portmahomack.

Sample No.	Animal/ Bone analysed	Mass Collagen (mg)	$\delta^{13}C$	$\delta^{15}N$	Collagen Yield (%)[B]	%C	%N	C:N[C]	Period
C3122/1	Pig/skull	12.6	-21.4	8.8	3.2	42.7	15.4	3.2	2
C3122/2	Pig/zygomatic	6.1	-21.5	8.1	1.5	40.8	14.8	3.2	2
C3122/3	Pig/skull (juvenile)	15.0	-21.4	8.3	3.6	41.0	15.0	3.2	2
C3122/4	Cattle/rib	21.7	-22.3	6.8	5.6	41.9	15.2	3.2	2
C3122/5	Cattle/rib	27.2	-22.4	6.3	6.8	42.1	15.3	3.2	2
C3122/6	Cattle/rib	21.6	-22.2	6.4	5.3	41.6	15.2	3.2	2
C3122/7	Cattle/long bone	26.2	-21.8	6.6	6.2	42.5	15.2	3.3	2
C3122/8	Cattle/long bone	26.7	-22.4	5.9	7.1	42.2	15.3	3.2	2
C3122/9	Cattle/humerus	16.3	-21.8	6.2	4.3	42.1	15.2	3.2	2
C3122/10	Cattle/humerus	25.6	-21.9	3.4	6.4	42.0	15.0	3.3	2
C1280/1	S/G metacarpal	8.5	-22.0	8.8	2.2	41.7	14.7	3.3	4
C1280/2	Cattle/tibia	29.4	-22.0	10.0	6.8	42.2	15.4	3.2	4
C1280/3	Dog/L.humerus	11.5	-16.8	15.3	2.9	41.5	14.9	3.2	4
C1280/4	Pig/sphenoid	14.1	-21.1	11.9	3.4	41.5	14.8	3.3	4
C1280/5	Pig 4th metacarpal	15.7	-21.7	11.8	3.9	41.8	15.0	3.2	4
C1303/1	Cod vertebra	5.7	-12.3	14.3	1.3	41.1	14.6	3.3	4

[B] Yield (%) = Mass mg collagen / weight (bone) mg x 100

[C] Acceptable C:N ratio (see DeNiro 1985)

FAUNAL BONE COLLAGEN DATA

Faunal samples from Portmahomack (Tab 1) were included in this study to provide comparable data to interpret the human $\delta^{13}C$ and $\delta^{15}N$ values (Fig 3). Mean $\delta^{13}C$ and $\delta^{15}N$ values for the EMG cattle (n=7) were -22.1‰ ± 0.3‰ (1σ) and 5.9‰ ± 1.2‰ (1σ) respectively. One cattle sample (C3122/10) from the EMG is considerably lower when

compared to mean $\delta^{15}N$ values from cattle in the same period. This difference ($\Delta = 3.0‰$) may be due to a number of factors, such as originating from a different geographical region and consuming different types of fodder or grazing on unimproved pasture, which resulted in lower $\delta^{15}N$ values.[34] For example, $\delta^{15}N$ values in chaff and cereal straw are suggested to be lower and more variable than in grain.[35] The faunal baseline shift in $\delta^{15}N$ values from the EMG to LMG periods is reflected in the human isotope ratios. The $\delta^{15}N$ ratios for humans from the EMG and LMG are higher than corresponding cattle, sheep/goat and pigs, reflecting a trophic level increase. Human isotope values are therefore higher than the fauna by around 2‰ - 6‰ in $\delta^{15}N$ and 2‰ - 3‰ in $\delta^{13}C$.

TABLE 2

$\delta^{13}C$, $\delta^{15}N$ human bone and dentine collagen results and archaeological data from Portmahomack.

Skeleton Number[A]	Mass Collagen (mg)	$\delta^{13}C$	$\delta^{15}N$	Collagen Yield (%)[B]	C:N[C]	Age[D]	Sex[D]	Period
166	44.4	-21.0	10.8	10.4	3.2	adult	F?	1
169	37.8	-20.7	10.0	8.8	3.2	26-45	M	1
172	41.9	-20.8	10.9	10.1	3.2	46+	F	1
116	43.9	-20.3	13.0	11.0	3.2	26-45	M	2
124	21.3	-20.8	11.4	5.1	3.2	17-25	M	2
124T	1.2	-21.2	11.7	0.6	3.3	17-25	M	2
127	45.4	-20.4	11.8	10.6	3.2	26-45	F?	2
128	18.4	-20.5	11.7	4.4	3.3	46+	M?	2
140	8.1	-20.3	12.5	2.0	3.2	17-25	M	2
144	10.6	-19.1	14.6	2.4	3.2	46+	M	2
144T	25.5	-19.9	14.6	8.1	3.2	46+	M	2
151	25.8	-20.6	12.6	6.6	3.2	46+	M	2
154	37.5	-20.4	11.8	9.3	3.2	26-45	M	2
160	32.7	-20.7	11.1	7.7	3.2	46+	M?	2
164	34.1	-20.2	12.8	8.3	3.2	26-45	M	2
168	15.1	-20.0	12.3	3.8	3.2	26-45	M?	2
171	11.7	-19.7	12.2	2.9	3.2	26-45	M	2
174	53.5	-21.1	11.4	12.4	3.2	adult	F?	2
136	5.5	-21.1	11.9	1.3	3.3	46+	M	3
147	21.5	-20.4	11.2	5.4	3.2	26-45	M	3
147T	12.0	-20.5	12.2	4.7	3.2	26-45	M	3
152	25.3	-20.5	11.7	6.0	3.2	26-45	M	3
152T	7.4	-20.9	12.6	3.5	3.2	26-45	M	3
158	33.9	-20.3	12.4	8.6	3.2	46+	M	3
158T	12.0	-20.5	12.8	4.7	3.2	46+	M	3
35	9.4	-17.3	15.4	2.4	3.2	17-25	M	4
64	29.5	-19.3	13.9	7.8	3.2	46+	M	4
69	4.8	-19.7	14.4	1.2	3.6	46+	F	4
83	26.8	-19.4	14.9	6.4	3.2	26-45	F?	4
85	22.1	-18.0	15.1	5.2	3.2	17-25	M?	4
88	14.8	-18.4	15.0	3.5	3.2	26-45	F	4
88T	10.5	-19.2	13.8	4.9	3.2	26-45	F	4
90	14.5	-17.9	15.1	3.7	3.2	46+	M	4
91	15.1	-19.8	14.0	3.5	3.2	26-45	F	4
93	35.1	-17.1	16.6	8.7	3.2	26-45	M	4
97	22.4	-18.3	14.9	5.2	3.2	46+	F?	4
98	32.5	-17.9	15.8	7.7	3.2	26-45	M	4
100	16.6	-19.3	15.0	3.8	3.2	26-45	F	4
100T	12.1	-19.1	15.8	5.6	3.2	26-45	F	4

102	31.5	-17.8	16.1	7.5	3.2	26-45	F	4
103	27.1	-18.0	15.5	7.0	3.2	26-45	M	4
105	27.4	-20.4	12.7	6.8	3.2	46+	F	4
106	14.8	-18.7	15.5	3.4	3.2	46+	F	4
108	28.2	-19.5	14.7	6.8	3.2	26-45	M	4
109	49.2	-18.2	14.4	11.5	3.2	46+	M	4
112	28.1	-18.9	14.3	7.1	3.2	46+	M	4
112T	17.1	-19.5	14.1	7.5	3.2	46+	M	4
113	23	-19.1	13.8	5.8	3.2	46+	M	4
113T	16.1	-20.0	13.1	7.7	3.2	46+	M	4

[A] Human bone samples taken from ribs. 'T' denotes tooth sample (permanent 1st molar root)
[B] Yield (%) = Mass mg collagen / weight (bone) mg x 100
[C] Acceptable C:N ratio (see DeNiro 1985)
[D] Ageing and sexing (M = male, F = female, ? = probable) information extracted from King (2000)

TABLE 3
Comparison of bone and dentine $\delta^{13}C$ and $\delta^{15}N$ values (measured in ‰) from Portmahomack.

Skeleton number	**Sex/Period**	**Bone $\delta^{13}C$**	**Dentine $\delta^{13}C$**	**($\Delta_{dentine-bone}$ $\delta^{13}C$)**	**Bone $\delta^{15}N$**	**Dentine $\delta^{15}N$**	**($\Delta_{dentine-bone}$ $\delta^{15}N$)**
124	M/2	-20.8	-21.2	0.4	11.4	11.7	0.3
144	M/2	-19.1	-19.9	0.7	14.6	14.6	0.0
147	M/3	-20.4	-20.5	0.1	11.2	12.2	1.0
152	M/3	-20.5	-20.9	0.4	11.7	12.6	0.9
158	M/3	-20.3	-20.6	0.3	12.4	12.8	0.4
88	F/4	-18.4	-19.2	0.8	15.0	13.8	1.2
100	F/4	-19.3	-19.1	0.2	15.0	15.8	0.8
113	M/4	-19.0	-20.0	1.0	13.8	13.1	0.7
112	M/4	-18.9	-19.5	0.6	14.3	14.1	0.3

HUMAN BONE COLLAGEN DATA

The human EMG (n=20) $\delta^{13}C$ values range between -21.1‰ and -19.1‰ (Δ = 2.0‰), with a mean of -20.5‰ ± 0.5‰ (1σ) and the $\delta^{15}N$ values range between 10.0‰ and 14.6‰ (Δ = 4.6‰), with a mean of 11.9‰ ± 1.0‰ (1σ). However, when the outlier (SK144) is removed, the differences for $\delta^{13}C$ and $\delta^{15}N$ are Δ = 1.4‰ and Δ = 3.0‰ respectively, suggesting that the majority of the EMG are within the same trophic level. LMG human (n=20) $\delta^{13}C$ values range between -20.4‰ and -17.1‰ (Δ = 3.3‰), with a mean of -18.7‰ ± 0.9‰ (1σ) and $\delta^{15}N$ values range from 12.7‰ to 16.6‰ (Δ = 3.9‰), with a mean of 14.9‰ ± 0.9‰ (1σ). Again, when the outlier from this group (SK105) is removed, the differences for $\delta^{13}C$ and $\delta^{15}N$ are reduced (Δ = 2.7‰ and Δ = 2.8‰ respectively). The $\delta^{13}C$ and $\delta^{15}N$ values are therefore higher in the LMG individuals compared to the EMG individuals (Fig 4), representing a diachronic change in diet over these periods at Portmahomack. Unpaired, independent two-sample t-tests revealed a significant difference between the EMG and LMG bone collagen isotope results for both $\delta^{13}C$ ($t_{(38)}$ = -7.97, p<.001***) and $\delta^{15}N$ ($t_{(38)}$ = -9.92, p<.001***) values (Fig 5).[36]

Within the EMG (Periods 1–3), Period 1 burials (SK166, SK169 and SK172) showed similar $\delta^{13}C$ values compared to the Monastic burials (Period 2). One adult male from Period 1 (SK169) had slightly lower $\delta^{15}N$ values than the rest of the EMG group, although not of

sufficient magnitude to suggest a trophic level difference (Fig 6). One adult male from Period 2 (SK144) had different isotope results to the rest of the group, with $\delta^{13}C$ and $\delta^{15}N$ values within the range of the LMG (Period 4) inhabitants. When compared to the mean $\delta^{13}C$ and $\delta^{15}N$ values of Period 2, the differences in carbon ($\Delta = 1.2‰$) and nitrogen ($\Delta = 2.4‰$) for SK144 suggest this individuals diet may have included some marine protein. One outlier from Period 4, an adult female (SK105), had the lowest $\delta^{13}C$ (-20.4‰), and $\delta^{15}N$ (12.7‰) values of this group. The isotope results from this individual fell within the Period 2 group and differed to the other LMG individuals in both $\delta^{13}C$ ($\Delta = 1.3‰$) and $\delta^{15}N$ ($\Delta = 2.0‰$), suggesting a more terrestrial-based diet.

Two-sample *t*-tests were performed to determine age and sex differences in diet within the LMG group and age differences within the EMG. Gendered-divisions in diet between the EMG could not be statistically tested due to uneven male-female sample numbers, although the $\delta^{13}C$ and $\delta^{15}N$ isotope values suggest a relatively homogeneous diet (Fig 7). Apart from SK105, mean $\delta^{13}C$ and $\delta^{15}N$ isotope values for LMG male and female bone collagen revealed little difference in $\delta^{13}C$ ($\Delta = 0.8‰$) and $\delta^{15}N$ ($\Delta = 0.3‰$) values. Statistical *t*-test results for $\delta^{13}C$ were significant ($t_{(20)} = 2.39$, $p<.05$*), although the $\delta^{15}N$ data revealed no significant difference ($t_{(18)} = 0.59$, $p>.05$).[37] However, replication with a larger sample size may decide whether there is a trend towards significance.

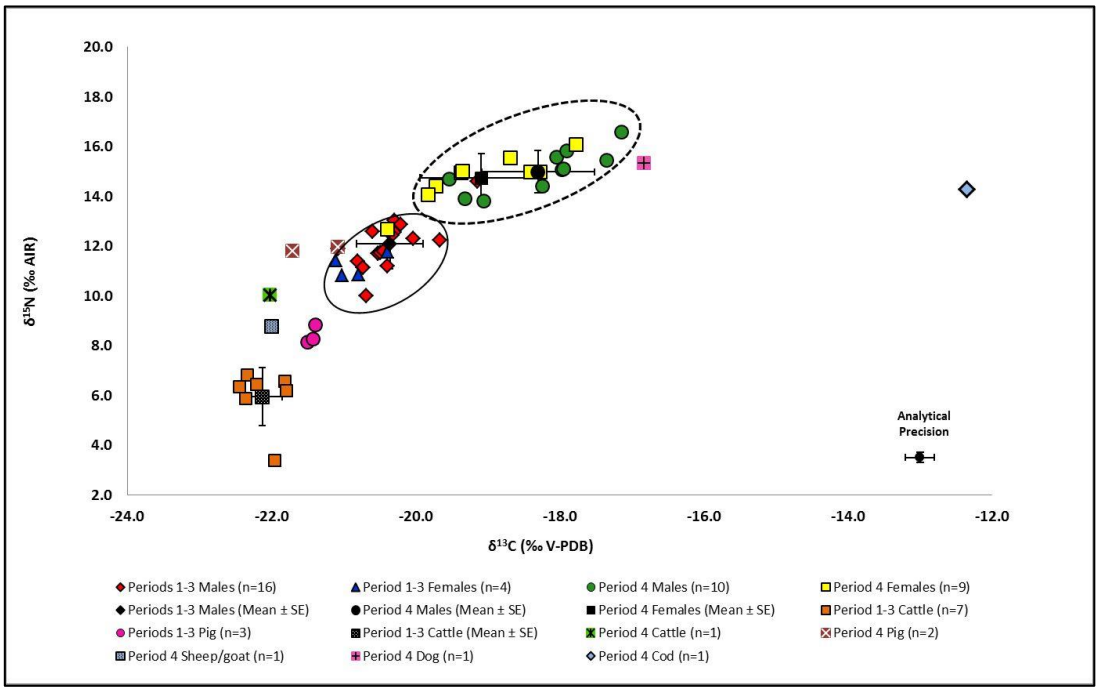

Fig. 3. Human and faunal bone collagen $\delta^{13}C$ and $\delta^{15}N$ isotope values with mean and standard errors (analytical precision: ± 0.2‰).

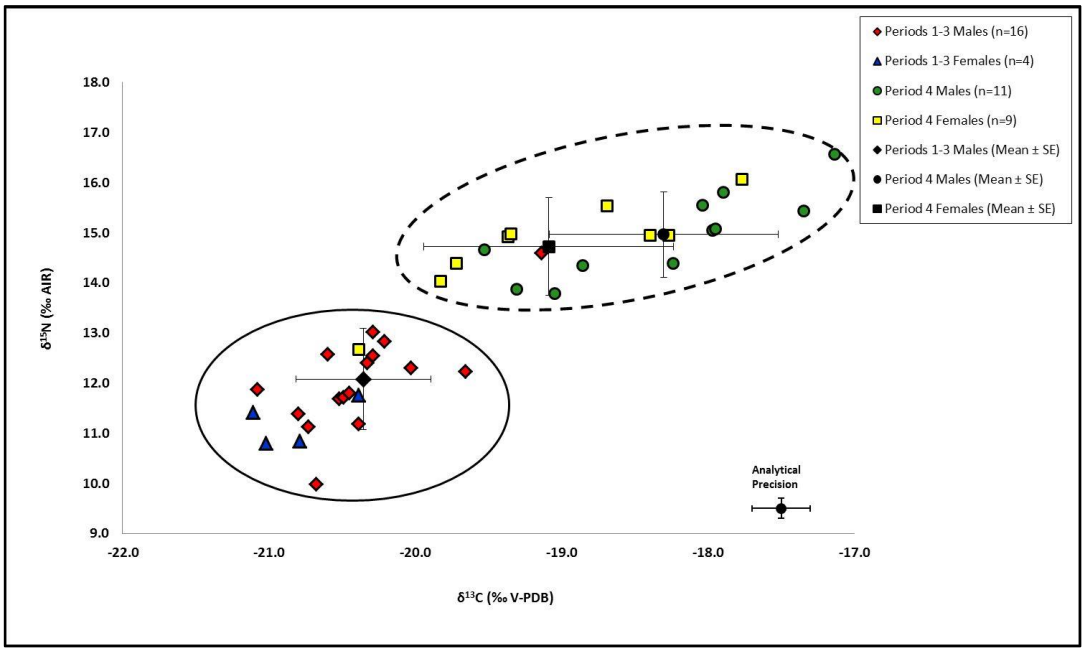

Fig. 4. Human bone collagen $\delta^{13}C$ and $\delta^{15}N$ isotope values with mean and standard errors for Periods 1–3 (bold circle) and Period 4 (dashed circle) males and females (analytical precision: ± 0.2‰).

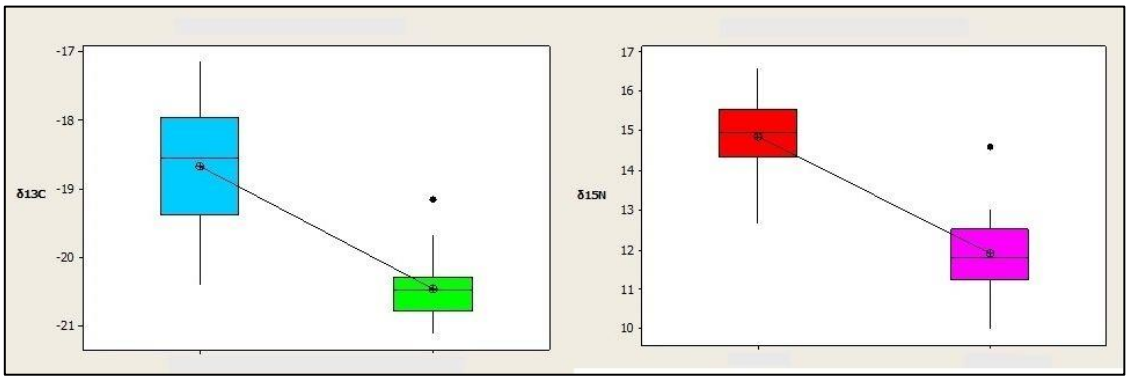

Fig. 5. Box-plots of $\delta^{13}C$ and $\delta^{15}N$ values of human bone collagen for period 4 (left boxes) and periods 1–3 (right boxes). Mean points and one standard deviation (1σ) shown. *= outlier: SK144.

Mean $\delta^{13}C$ and $\delta^{15}N$ isotope values for the 26–45 years and 46+ years age groups from the EMG revealed little difference in $\delta^{13}C$ (Δ = 0.2‰) and $\delta^{15}N$ (Δ = 0.3‰) values. Statistical *t*-test results found no significant difference for $\delta^{13}C$ ($t_{(18)}$ = 0.17, p>.05) and $\delta^{15}N$ ($t_{(18)}$ = -1.09 p>.05)[38]. The 17–25 years age groups from both the EMG and LMG periods has not been statistically tested due to low sample numbers (*n*=2). Mean $\delta^{13}C$ and $\delta^{15}N$ isotope values

for the 26–45 years and 46+ years age groups from the LMG revealed little difference in $\delta^{13}C$ (Δ = 0.3‰) and $\delta^{15}N$ (Δ = 1.0‰) values (Fig 8). Statistical *t*-test results for $\delta^{13}C$ found no significant difference ($t_{(20)}$ = 1.13, p>.05), although for $\delta^{15}N$, there was a significant difference ($t_{(20)}$ = 2.76, p<.05**).[39]

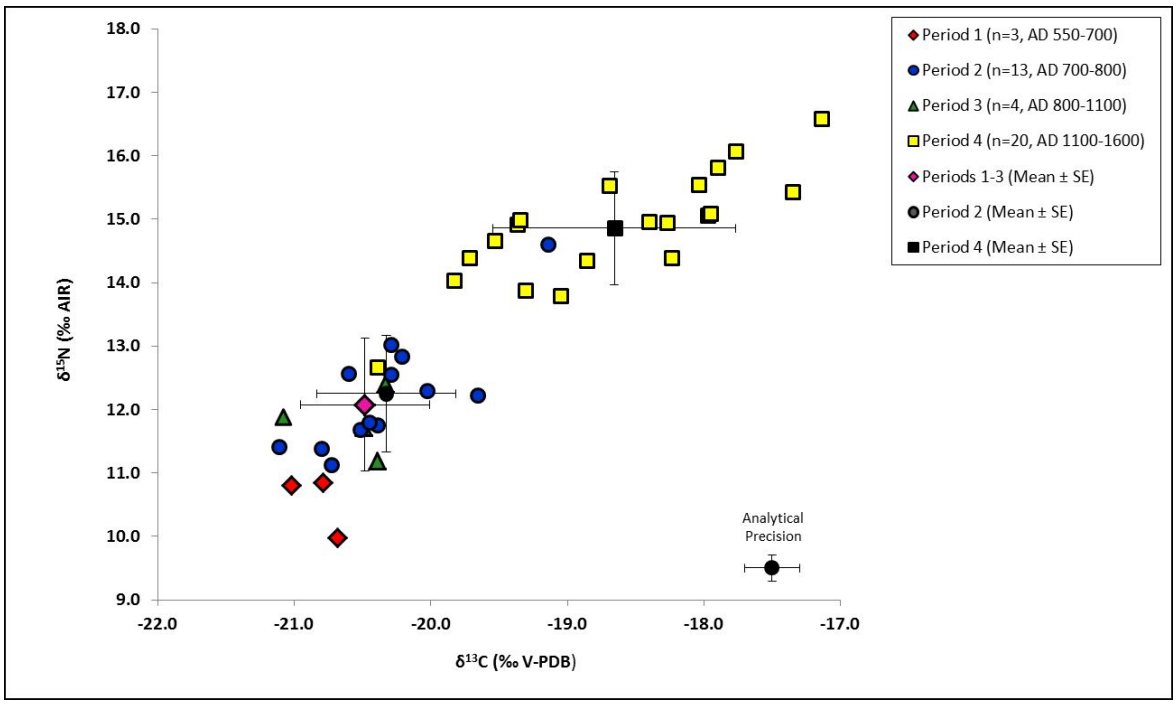

Fig. 6. Human bone collagen $\delta^{13}C$ and $\delta^{15}N$ isotope values with mean and standard errors for Periods 1–4 (analytical precision: ± 0.2‰).

HUMAN DENTINE COLLAGEN DATA

No tooth samples were provided for females from the EMG or the Period 1 male at Portmahomack, thus no dentine collagen has been analysed for these individuals. The mean $\delta^{13}C$ and $\delta^{15}N$ values for the EMG males (*n*=5) are -20.6‰ ± 0.5‰ (1σ), and 12.8‰ ± 1.0‰ (1σ) respectively. Individual $\delta^{13}C$ and $\delta^{15}N$ values for the LMG females (*n*=2) are -19.2‰ and 13.8‰ (SK88) and -19.1‰ and 15.8‰ (SK100) respectively. Individual $\delta^{13}C$ and $\delta^{15}N$ values for the LMG males (*n*=2) are -20.0‰ and 13.1‰ (SK113) and -19.5‰ and 14.1‰ (SK112) respectively (Tab 3).

DISCUSSION

Generally, all faunal samples from Portmahomack appear to have $\delta^{13}C$ and $\delta^{15}N$ values that are consistent with those from comparable sites,[40] although some isotopic differences between the two groups are evident. For example, $\delta^{15}N$ values are higher for Period 4 cattle versus those from earlier Period 2 cattle (Δ = 4.1‰) and for Period 4 versus Period 2 pigs (Δ = 3.5‰) at Portmahomack. However, there was no real difference in cattle and pig $\delta^{13}C$ values from both periods. Interestingly, the Period 4 dog sample from Portmahomack differs greatly, compared to same species isotope result at East Lothian[41] in both its $\delta^{13}C$ (Δ = 8‰) and $\delta^{15}N$ (Δ = 4‰) values. Pigs and dogs have been found to have high $\delta^{15}N$ values, suggesting they may have consumed foods similar to that of humans and

possibly scavenged marine foods from the coastline.[42] High $\delta^{15}N$ values from Period 4 pigs are probably due to these animals consuming human refuse, resulting in the ^{15}N enrichment.

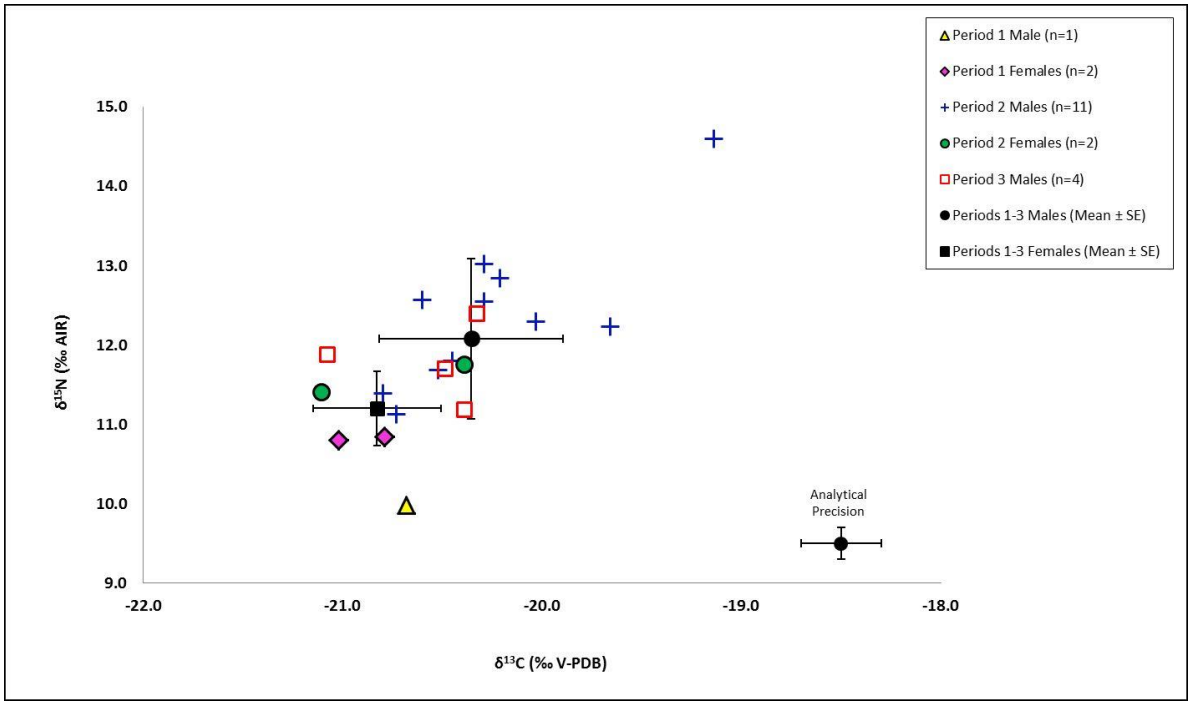

Fig. 7. Male and female bone collagen $\delta^{13}C$ and $\delta^{15}N$ isotope values with mean and standard errors for Periods 1–3 (EMG). Analytical precision: ± 0.2‰.

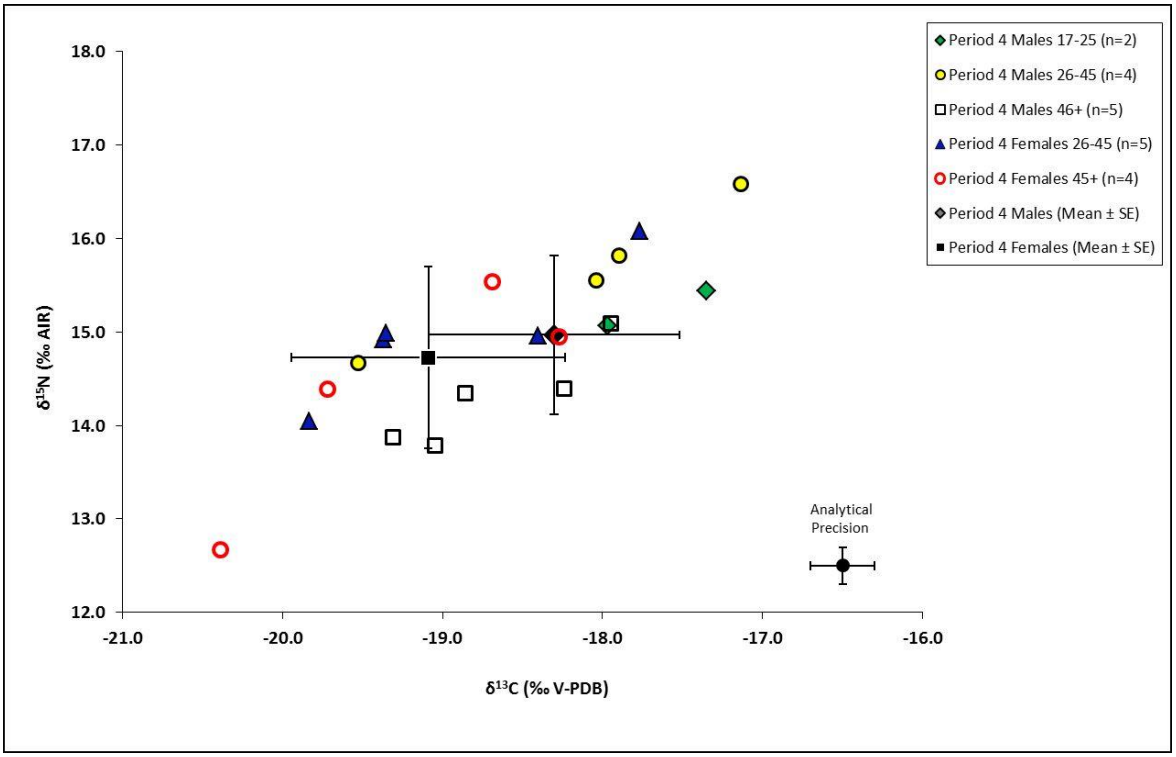

Fig. 8. Human bone collagen $\delta^{13}C$ and $\delta^{15}N$ isotope values with mean and standard errors for Period 4 (LMG) age categories (analytical precision: ± 0.2‰).

Higher herbivore $\delta^{15}N$ values from Period 4 at Portmahomack, compared to those from other sites discussed here may suggest possible differences in animal feeding strategies, although due to low faunal sample numbers, further investigation is needed. Although herbivore $\delta^{15}N$ values from the British Iron Age to medieval period ranges from around +4‰ to +7‰,[43] differences in regional resources and socio-economic practices may produce isotopic differences. The herbivores from Period 4 at Portmahomack may have grazed around coastal areas, such as salt marshes, which have been found to produce higher herbivore $\delta^{15}N$ values compared to inland sites.[44] The Tarbat peninsula is near some of the most extensive areas of salt marsh in Britain,[45] which may explain the Period 4 cattle $\delta^{15}N$ value, which is higher (Δ = 2‰) than those reported by Britton et al[46] This however does not explain why herbivores from the EMG at Portmahomack have lower $\delta^{15}N$ values, although a different socio-economic strategy may simply be the cause, with herbivores from this phase being confined to inland grazing.

Relative to the faunal data, human $\delta^{13}C$ values for the EMG reflect a predominantly terrestrial C_3-based diet with no input of C_4 or marine resources. $\delta^{15}N$ values for these individuals are a trophic level higher (+2-5‰) than the cattle and pigs from the same period. This, along with the archaeological faunal remains, suggests the community from the EMG were consuming a significant amount of terrestrial animal protein, such as pork, beef, lamb and dairy products. The earliest burials at Portmahomack (Period 1) have $\delta^{13}C$ and $\delta^{15}N$ values similar to the monastic phase (Period 2), suggesting they consumed terrestrial animal protein and C_3 plant foods but no marine protein consumption. Two outliers, one from Period 2 (SK144) and one from Period 4 (SK105) attest to the dietary variation that can occur within a community. The adult male from Period 2 (SK144) had higher $\delta^{13}C$ and $\delta^{15}N$ values than his contemporaries, suggesting that as well as consuming terrestrial animal protein and C_3-based plant foods, he also had access to marine protein. Conversely, the adult female from Period 4 (SK105) had $\delta^{13}C$ and $\delta^{15}N$ values more in line with the majority of the EMG. When the isotope values for this individual are compared to the faunal results from the same period, a diet of C_3-based plant foods and animal protein is suggested, with no marine protein consumed.

Contrary to the earlier periods, $\delta^{13}C$ and $\delta^{15}N$ values from the LMG reflect a significant trophic level increase in $\delta^{15}N$ and a shift towards higher $\delta^{13}C$ ratios. Based on archaeological and isotopic evidence, these inhabitants had a diet that probably included beef, lamb, (including dairy foods), cereals (eg bread, pottage), pork and marine fish. Although it has been suggested that manuring significantly increases $\delta^{15}N$ values in cereals,[47] a major component of cereal grain in the LMG diet would be needed to reflect such high $\delta^{15}N$ values, which does not appear evident. Other explanations for greater $\delta^{13}C$ and $\delta^{15}N$ values in these individuals include increased $\delta^{13}C$ values in herbivores that grazed on seaweed,[48] or on salt marshes, which can increase $\delta^{15}N$ values.[49] Such occurrences would result in a shift in human carbon and nitrogen isotope ratios, through consumption of these animals. Human isotope results from both the main periods of burial at Portmahomack appear to correlate with associated faunal isotope data, suggesting normal trophic level increases and isotopic shifts, due to the consumption of animal and possibly marine protein.

DIETARY DIFFERENCES RELATING TO SEX

Long cist graves are a common occurrence in south-east Scotland during the early medieval period, yet only a small proportion have been discovered in north-east Scotland.[50] It has been suggested that long cist graves do not necessarily denote a Christian burial rite, but rather they were an existing mortuary practice adopted by religious communities.[51] Two adult females from Period 1 (SK172 and SK166) were buried in long cist graves, which may suggest a form of differentiation in their burial rite, compared to the dug grave, containing an adult male, from the same period. The $\delta^{15}N$ values of these individuals (Fig 7) suggest that they were consuming similar foods to the majority of the EMG, although the female sample numbers for Period 1 (n=2) and Period 2 (n=2) were too small to provide an informative statistical comparison against the corresponding males. As previously mentioned, mean $\delta^{13}C$ and $\delta^{15}N$ isotope values for the Period 4 male and female bone collagen (Fig 8) revealed little significant statistical difference suggesting both men and women from this group consumed similar foods of C_3 plants and terrestrial and marine protein. Therefore, a gendered-division in diet at Portmahomack cannot be ascertained from these data alone.

DIETARY DIFFERENCES RELATING TO AGE

When individual $\delta^{13}C$ and $\delta^{15}N$ values are plotted for the 26–45 years and 46+ years age groups from the EMG burials (Fig 9), no significant difference in diet relating to age is apparent for the corresponding males, apart from the one outlier (SK144) previously discussed. The 26–45 female (SK127) from Period 2 had slightly higher $\delta^{13}C$ and $\delta^{15}N$ values than the other females, although larger sample numbers would be needed to provide any conclusive interpretations. Statistical results previously mentioned revealed no significant difference for either $\delta^{13}C$ or $\delta^{15}N$ values between these two age groups, suggesting individuals of different ages consumed similar foods although the long-term average of diet represented in the adult human bone collagen measured here may hide short-term dietary fluctuations that may have occurred at particular periods of life.

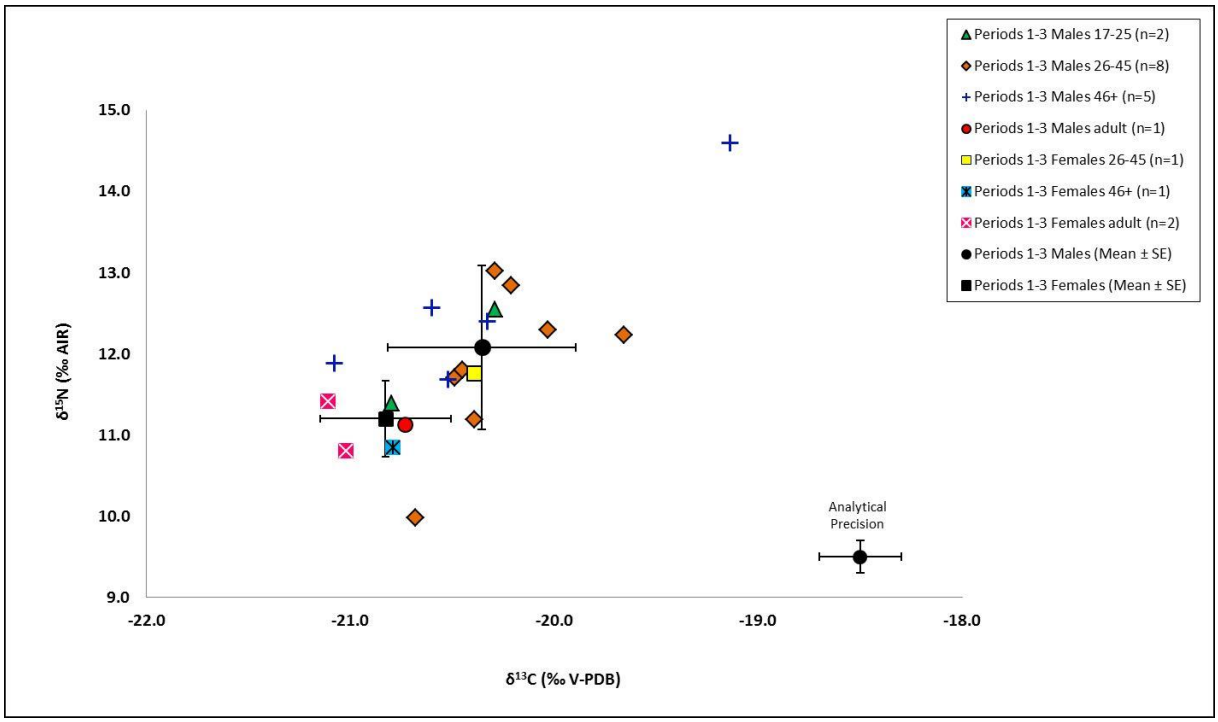

Fig 9. Human bone collagen $\delta^{13}C$ and $\delta^{15}N$ isotope values with mean and standard errors for Periods 1-3 (EMG) age categories (analytical precision: ± 0.2‰).

Mean $\delta^{13}C$ and $\delta^{15}N$ isotope values for the 26–45 years and 46+ years age groups from the LMG suggest no difference in diet, although the aforementioned statistical *t*-test results for $\delta^{15}N$ showed a fairly significant difference between the two age groups. This suggests that some of the 26–45 years individuals had a higher intake of animal protein than some of the 46+ years individuals (Fig 8). This is most notable in the 26–45 male (SK93) that has the highest $\delta^{13}C$ and $\delta^{15}N$ isotope values out of the whole group and a whole trophic level difference compared to, for example, the two 45+ males (SK64 and SK113) that have the lowest $\delta^{15}N$ isotope values out of the males from this group. This may reflect a division in the types of protein that was being consumed, with some of the younger individuals possibly consuming different types of marine protein than the older individuals. This difference may suggest a labour-division in diet, where the younger individuals' ability to work required a better or different diet, although analysis of a larger sample size would be required to prove conclusive.

BONE AND DENTINE COLLAGEN COMPARISONS

Any differences between dentine and bone collagen isotope values ($\Delta_{dentine\text{-}bone}$) may reflect a change in diet from adolescence to adulthood.[52] An increase in animal and/or marine protein consumption during adulthood may produce higher $\delta^{13}C$ and $\delta^{15}N$ values in bone collagen than in dentine collagen. $\delta^{13}C$ and $\delta^{15}N$ values for bone and dentine collagen were obtained for nine individuals from Periods 2–4.

Within the EMG, only one individual (SK144) had no difference in dentine to bone ($\Delta_{dentine\text{-}bone}$) for $\delta^{15}N$, suggesting no significant change in protein intake during this individuals lifetime. All $\delta^{15}N$ values for dentine collagen from Period 2 were higher than bone

collagen and $\delta^{13}C$ values were within the C_3 terrestrial range of -20‰ to -35‰.[53] Conversely, two individuals (SK88 and SK113) from the LMG had higher $\delta^{13}C$ and $\delta^{15}N$ values in bone collagen, than in dentine collagen. These differences may suggest a different protein intake during adulthood for the LMG and conversely, during childhood for the EMG individuals. The change in the LMG diet may be due to the necessity to consume more animal protein in adulthood for sustenance during the working day. The EMG difference may imply that the monks at Portmahomack accepted oblates (children presented to monasteries to become monks or nuns) and their diet conformed to that of the monks by adulthood. However, although the practice of accepting oblates was common at many medieval monasteries,[54] only one child burial was found from the monastic levels at Portmahomack, suggesting that oblates either survived to adulthood or this practice was not performed here.

SITE COMPARISONS: AN OVERALL PERSPECTIVE

When comparable isotope data from a selection of archaeological sites in Europe are compared to the EMG and LMG results from Portmahomack, a pattern emerges that is consistent with recent studies that suggest a diachronic change in diet from the Iron Age to medieval periods in Europe.[55] The isotope data from the EMG at Portmahomack (Fig 10) has similar mean isotopic values to those from the Iron Age site of Winton House (East Lothian) and the Pictish sites of Lundin Links (Fife) and Westness (Orkney),[56] which reflect a predominantly terrestrial-based diet, with significant levels of animal protein intake. Isotope results from Westness have been interpreted to suggest that some marine protein was consumed, although arable and pastoral farming was the dominant form of subsistence during the Pictish phase.[57] Although these are coastal sites, the isotopic values do not reflect a significant input in marine consumption, suggesting these coastal dwellers either chose not to exploit resources from the sea or did not have the means to do so. In comparison, the sites of Belle Vue (York), Berinsfield (Oxon), Dublin (Co. Dublin) and Owenbristy (Co. Galway), Ireland[58] all have lower $\delta^{15}N$ values, with the latter having the least enriched $\delta^{13}C$ values, suggesting that a diet predominantly of vegetation, rather than meat was consumed.[59] When compared to the EMG at Portmahomack, these isotope values are within the same trophic level, although the lower $\delta^{15}N$ values suggest predominant consumption of C_3 plants, such as barley and wheat, with some terrestrial animal protein, although at Berinsfield and Dublin, some inclusion of fish consumption is proposed.[60] The two sites that stand out the most in the EMG comparisons are the Viking sites of Newark Bay (Orkney) and Birka (Sweden).[61] Newark Bay has the most enriched $\delta^{13}C$ values, which reflects more marine protein consumption than the earlier Pictish phase at Westness and the emergence of a gendered-division in food consumption, with males eating more fish than females.[62] Birka has the highest $\delta^{15}N$ values, suggesting those of high status consumed freshwater fish, rather than marine fish and vice versa for those buried with weapons.[63] From all comparisons, it is interesting to note that those of closest geographical location and date to Portmahomack (Winton House, Lundin Links and Westness)[64] appear to have very similar diets of predominantly terrestrial foods but no fish consumption. The isotope values from the English (Belle Vue and Berinsfield)[65] and Irish (Owenbristy and Dublin)[66] sites reflect different types of terrestrial foods consumed compared to the EMG at Portmahomack, with perhaps lesser

amounts of terrestrial animal protein consumed, and those from the Viking sites (Newark Bay and Birka)[67] stand out as having a significant amount of fish in their diets.

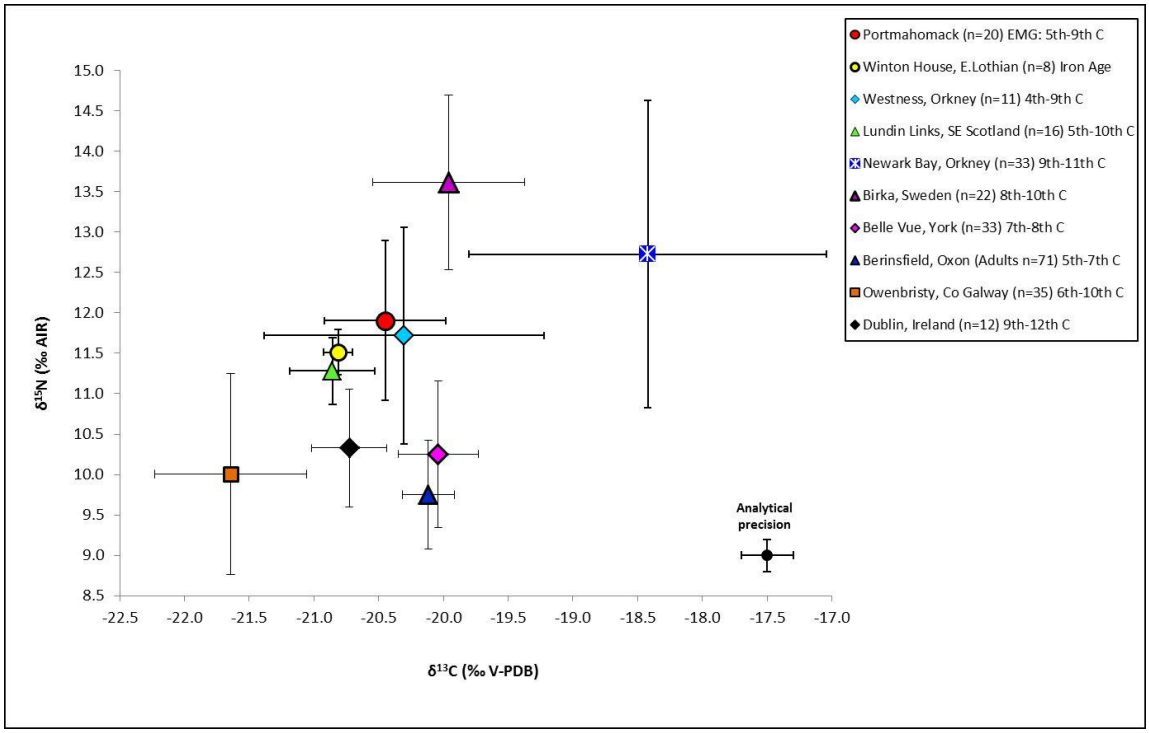

Fig 10. $\delta^{13}C$ and $\delta^{15}N$ mean values from sites comparable to EMG at Portmahomack. Analytical precision: ± 0.2‰ (After Barrett and Richards 2004; Geber 2011; Jay and Richards 2007; Knudson et al.2012; Linderholm et al. 2008; Modzelewski 2008; Müldner and Richards 2007a; Müldner et al. 2009; Privat et al. 2002).

Isotope results from the LMG at Portrmahomack reflect a significant increase in marine consumption, with $\delta^{13}C$ values shifting towards the marine range, with the mean $\delta^{13}C$ values being similar to comparable sites of Newark Bay, Auldhame (East Lothian), St Andrew Priory (Fishergate, York), Koksijde (Belgium) and the high status group at Whithorn Cathedral Priory (Dumfries and Galloway) (Fig 11).[68] However, there are marked differences in $\delta^{15}N$ values between the LMG at Portmahomack and these sites, the interpretation of which ranges from possible freshwater rather than marine protein consumption at Auldhame[69] and mainly terrestrial, with some marine protein at Koksijde,[70] to varying amounts of marine fish consumption at St Andrew Priory[71] and a significant amount of marine consumption, resulting in a 'strong marine spike' at Newark Bay.[72]

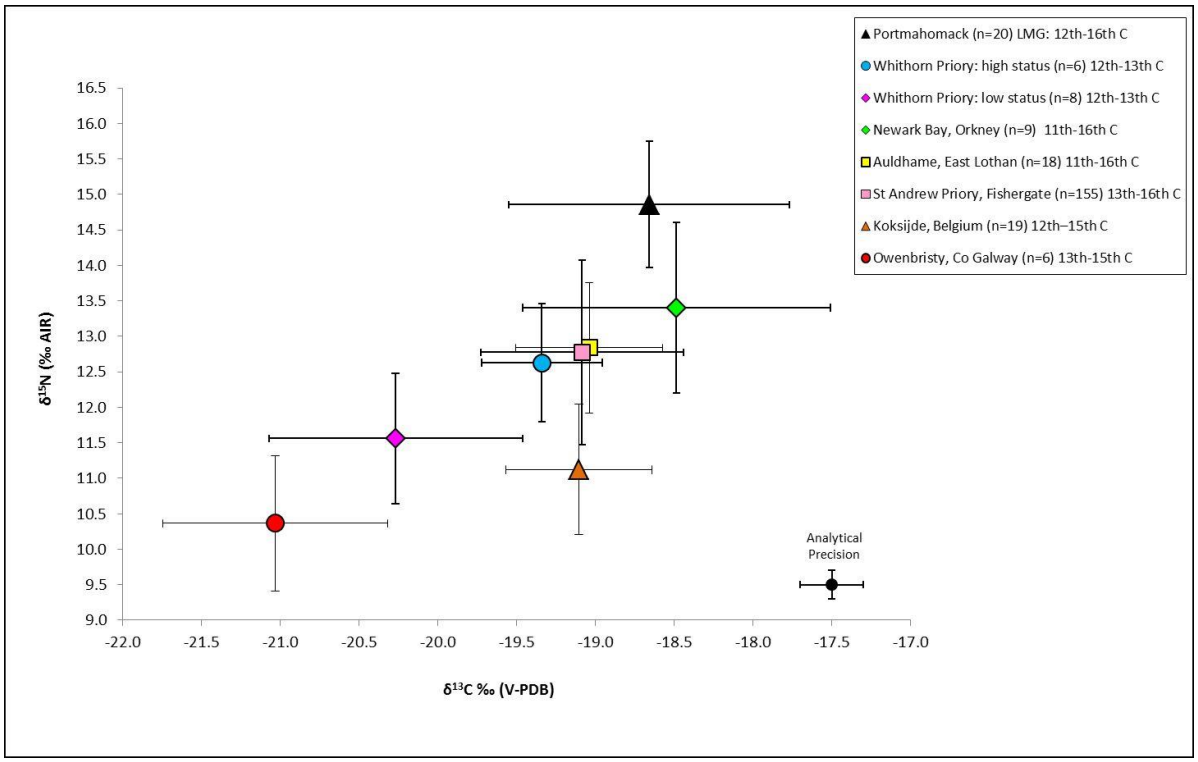

Fig 11. $\delta^{13}C$ and $\delta^{15}N$ mean values from sites comparable to LMG at Portmahomack. Analytical precision: ± 0.2‰ (After Barrett and Richards 2004; Geber 2011; Lamb et al. 2012; Müldner and Richards 2007b; Müldner et al. 2009; Polet & Katzenberg 2003).

Clerics at Whithorn Cathedral Priory were consuming a greater proportion of marine foods compared to the low status lay population.[73] These results support the probability that a significant amount of marine protein was consumed by the LMG at Portmahomack, which is in stark contrast to the EMG. The least enriched in both $\delta^{13}C$ and $\delta^{15}N$ values are from Owenbristy, Co Galway, where there appears to be little change in terrestrial food consumption, compared to the 6th- to 10th-century.[74] Parallels can be found at Knockrobbin Hill (Co Wicklow) and Cappogue Castle (Co Dublin), suggesting a predominance of plant based foods with minimal terrestrial animal protein consumption.[75] An increase in marine consumption in the mid- to late-medieval period has been associated with growing populations and an increase in the fish trade, as well as a widespread adherence to Christian fasting practices.[76]

It is suggested that in medieval Scotland the predominant dietary intake of terrestrial protein, such as lamb, beef and pork, reflected a high status diet; marine foods, such as salted herring or cod, were consumed by lower status individuals, with terrestrial animals rarely killed for meat consumption.[77] This appears to be the case at Portmahomack, where the EMG consumed terrestrial protein but no marine foods, whereas the subsequent LMG had a wider dietary intake of foods including both terrestrial and marine protein. This is in contrast to some studies from Scottish monastic sites that suggest the monks' consumption of fish reflected a high status diet, whereas terrestrial protein was consumed by lower status individuals.[78] Cod fishing had increased in Tarbat by AD 1670 and by AD 1845 the *New Statistical Account of Scotland* recorded that herring curing became so important at Portmahomack that the population doubled in size seasonally with people coming from all

over the Highlands to assist with the herring curing,[79] suggesting that marine fish had become an important commodity for trade as well as consumption at Portmahomack.

CONCLUSIONS

This study has provided new faunal and human stable isotope data from Portmahomack on the Tarbat peninsula, thereby contributing to current themes on reconstructions of medieval diets. The 8th-century monastic community had a high terrestrial protein diet, shown by isotopic data and faunal remains to have favoured beef but not fish. The immediately preceding Period 1 (Iron Age/Pictish) and succeeding Period 3 (Scottish/Norse) phases did not differ markedly in their isotope values, but the sample size for these periods in this exploratory project was small, hence further investigation with larger sample sizes is needed. The Iron Age/Pictish assemblages included a rich deposit of barley and wheat, notably absent from the monastic phase which was probably supplied with grain from an external source.

There is a statistically significant diachronic change in diet between the early medieval communities who ate predominantly terrestrial plant and animal protein and the subsequent parish church family community at Portmahomack who also ate terrestrial plant and animal protein plus marine fish. This temporal increase in carbon and nitrogen isotope ratios was also found in the faunal data and may reflect a change in husbandry practices in the later medieval period, such as increased manuring[80] and/or salt marsh grazing.[81] No dietary differences relating to sex was found in the LMG but younger adults had higher $\delta^{15}N$ values and although this finding was only weakly significant, it may suggest they ate more marine protein than the older individuals. No significant change in diet from childhood to adulthood was found for either the EMG or LMG.

Overall, the results are suggestive of an early medieval monastic community who reared animals for a number of uses, including human consumption, yet they chose not to exploit nearby marine resources relying heavily on terrestrial-based foods. In contrast, isotope evidence suggests the subsequent later medieval inhabitants at Portmahomack consumed a wide variety of foods, including animal protein from pork, beef, lamb and fish, which is supported by the faunal remains present. This may have been partly due to an increase in the fishing trade, which supplied a cheap and plentiful food resource.[82] Archaeological evidence[83] along with stable isotope data presented here suggests the diets of the individuals from the LMG at Portmahomack reflect a homogeneous community, who farmed the land and exploited the sea.

The results from this study are consistent with other isotope data that suggest a change in diet, from early medieval terrestrial food consumption, through to later medieval marine exploitation in Scotland.[84] Dietary reconstructions using stable isotope analysis from Scottish sites are still quite sparse compared to English sites. This study not only provides new stable isotope data from the first excavated Pictish monastery, but offers new insights into medieval diet overall, thereby contributing to a greater understanding of social, religious and economic influences on diet in Scottish antiquity. This study has reinforced the power of stable isotope analysis to shed light on a sequence of communities and their subsistence therein. Future work will explore inter- and intra-site variations of diet, combining this data with evidence of

disease and trauma, in pursuit of reconstructing aspects of food consumption, nutritional health and lifestyle markers on the bodies of individuals from Portmahomack's past.

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APPENDIX A: SAMPLE PREPARATION

Approximately 200–300 mg of bone and tooth were cleaned by air abrasion and demineralised in 0.5 M hydrochloric acid (HCl) at a refrigerated temperature of 4°C for several days. Each sample was rinsed in deionised water (H_2O) and three drops of 0.5 M dilute HCl was added to produce a pH 3 solution. The samples were then gelatinised in a Techne Dri-block DB.2A heating block at 70º C for 48 hours. After gelatinisation, each sample was fed through an Amicon® Ultra Ezee® 60–90µm filter to a clean test tube, with the insoluble residue retained in the filter. Although an additional step of ultrafiltration is not a strict requirement of stable isotope sample preparation, its use may aid the isolation of intact 'collagen'.[85] An Amicon® Ultra -4 Centrifugal Filter tube for each sample was filled with 0.1 M sodium hydroxide solution (NaOH) and centrifuged for twenty minutes to remove any contaminants. Each sample was placed into an ultrafilter tube and centrifuged, with the remaining filtered liquid transferred to clean test-tubes and frozen at -35ºC. All samples were then freeze-dried, weighed (0.9–1.1 mg) and analysed in duplicate using a Roboprep-CN analyser, coupled to a Europa Scientific 20–20 continuous flow isotope ratio mass spectrometer (CF–IRMS). All mass-spectrometric analysis was performed at the University of Bradford's Stable Light Isotope Facility. $\delta^{13}C$ and $\delta^{15}N$ ratios are reported relative to the international standards of Vienna-PDB and AIR respectively. International standards used were N_2 ($\delta^{15}N$ value of +20.41‰) and IAEA 600 ($\delta^{13}C$ and $\delta^{15}N$ values of -27.77‰ and +1.0‰ respectively). The analytical precision for both carbon and nitrogen was ± 0.2‰ (1σ).[86]

APPENDIX B. DATING INFORMATION

Skeleton Number	Sex	Period	Sample material	Age BP	C14 cal dates (AD) 95% (88%) 1σ	Lab No.
169	M	1	Rib	1375±30	610-680	SUERC-33412 (GU-23373)
172	F	1	L.2nd Metatarsal	1498±34; 1395±30	570-650 (mean)	OxA-9699; SUERC-37079
116	M	2	L.Humerus	1268±28	680-880	OxA-13489
128	M?	2	R.Humerus	1364±28	640-770	OxA-13487
144	M	2	R.Humerus	1304±28	680-890	OxA-13488
160	M?	2	L.Femur	1283±27	680-880	OxA-13486
171	M	2	Rib	1325±30	660-850	SUERC-33414 (GU-23375)
136	M	3	Rib	1020±30	970-1040 (960-1050)	SUERC-33406 (GU-23370)
147	M	3	R.Humerus	1213±31	720-960	OxA-13485
152	M	3	R.Humerus	1120±35	780-1000	GU-9297
158	M	3	R.Humerus	1215±35	680-900	GU-9296
90	M	4	R.Humerus	439±30	1460-1660	OxA-13521
97	F?	4	R.Humerus	475±27	1440-1640	OxA-13762
98	M	4	Rib	520±30	1420-1620	SUERC-33400 (GU-23364)
112	M	4	Rib	710±30	1280-1420	SUERC-33403 (GU-23367)
113	M	4	R.Tibia	659±27	1290-1430	OxA-13491

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[33] DeNiro 1985.
[34] Upper case Greek delta letter (Δ) refers to difference between isotope mean values. Lower case Greek delta letter (δ) refers to the measurement of deviation in isotope ratios from a particular standard.
[35] Bogaard et al 2007.
[36] Exact p values for both $\delta^{13}C$ and $\delta^{15}N$ are p=.000.
[37] Exact p values are p=.027 and p=.565 respectively.
[38] Exact p values are p=.864 and p=.289 respectively.
[39] Exact p values are p=.273 and p=.012 respectively.
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[83] Carver 2008.
[84] Eg Barrett and Richards 2004.
[85] Brown et al 1988; Richards et al 2008.
[86] Lower case Greek letter sigma (σ) refers to standard deviation. The analytical precision for both carbon and nitrogen was ± 0.2‰ (1σ).