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ANGLO SAXON CHRONOLOGY PROJECT
AMINO ACID AND STABLE ISOTOPE ANALYSES OF DATED SKELETONS

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Nancy Beavan, Simon Mays, Alex Bayliss, John Hines and Gerry McCormac

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SUMMARY
We present the results of amino acid and stable isotope analysis for human bone from ninety-five articulated skeletons, including fourteen replicates of select specimens. All skeletons had been radiocarbon dated previously at the Queen's University, Belfast. The amino acid analyses and carbon-nitrogen ratios indicate that the collagen in most samples was moderately well preserved. Stable isotope values for the group as a whole are consistent with an overall terrestrial diet.

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1 INTRODUCTION

The overall aim of the English Heritage funded research project, *Anglo-Saxon England c AD 570–720. the chronological basis* is to provide accurate estimates of archaeological chronology that span only a few decades (at 95% probability). The project uses Bayesian chronological modelling (Bronk Ramsey 1995; Buck *et al* 1996) to combine high-precision radiocarbon dates on human bone with sequences produced by correspondence analysis of the artefact types recovered from graves (Greenacre 1984; 1992; Høilund Nielsen 1995).

The rate of change in atmospheric ^{14}C in the Anglo-Saxon period makes such resolution feasible, although only within a context of precise and accurate radiocarbon measurement. The protocols adopted to safeguard the accuracy and reproducibility of the radiocarbon measurements produced as part of this project are described by McCormac *et al* (2011). The series of radiocarbon measurements on decadal blocks of known-age wood spanning the period under consideration, and measured quasi-simultaneously with the human bone samples, have been reported already (McCormac *et al* 2004; 2008).

This report details the amino acid and stable isotope analyses that were primarily undertaken as part of the quality assurance procedures for this project. The accuracy of radiocarbon dates on human bone can be affected by a number of factors, of which we consider three here.

First, bone protein is susceptible to deterioration in burial environments and may be too poorly preserved for accurate dating (Gillespie *et al* 1984; Masters 1987; van Klinken 1999). Second, bone protein chemical preparation methods must adequately remove contamination of the protein by exogenous carbon that comes from soil humic acids, whose more negative carbon values can alter protein carbon signatures as well as alter the typical amino acid profiles of pure bone protein. We examine these two issues using amino-acid analysis to examine the divergence from typical preserved bone protein profiles, and carbon: nitrogen ratios for isotopic evidence of the extent of protein breakdown and the removal of exogenous carbon after chemical pretreatment of the samples.

Third, bone may take up carbon from a variety of reservoirs, not all of which are in equilibrium with the terrestrial biosphere as recorded in contemporaneous tree-rings, which provide our calibration data (Tauber 1984; Lanting and van der Plicht 1998; Arneborg *et al* 1999). We investigate diet in the dated individuals for the potential presence of dietary components which would have an effect upon radiocarbon calibration. For example, food sources from freshwater and marine biomes may contain radiocarbon values that are depleted relative to terrestrial biomes. Some terrestrial aquatic sources have the potential to introduce radiocarbon offsets via dissolved carbonate from certain geologies (Ascough *et al* 2007; Culleton 2006). This carbon component would be radiocarbon "dead," with the potential for imparting significant and

anomalously old ages, as the dissolved inorganic carbon is synthesised by aquatic plants and becomes part of the aquatic food-chain. However, there is no information on freshwater radiocarbon offsets for fish in the overall region in which these sites are situated; and while the proportion of all types of fish in the diet is of interest, we focus upon the proportion of marine fish in the diet.

The marine environment also contains less radiocarbon than the contemporary atmosphere due to ocean mixing of surface waters with ^{14}C-depleted deep water. The dissolved inorganic carbon enters the food chain via marine plant synthesis, imparting a radiocarbon offset to marine organisms. Bone from individuals who derive some of their diet from this reservoir – such as humans eating marine fish or shellfish - will have an apparently older radiocarbon age than a contemporary sample derived purely from the atmosphere. The scale of the marine offset varies regionally, but is in the order of 400 radiocarbon years for English coastal waters (Harkness 1983).

The relationships between stable isotopes and diet are complex and as yet incompletely understood (Bayliss *et al* 2004; Petchey and Green 2005; Hedges and Reynard 2007) but better understanding of regional isotope affects and possible ways to undertake dietary analysis offer possibilities to improve these calculations (Beavan Athfield *et al* 2008). We use a regional dataset of food-source stable isotope values and compare two methods of estimating diet-source proportions of various possible foods from human isotopic signature. The estimation of the proportion of marine foods in the diet is then used to calculate the radiocarbon offset we might expect from a marine-sourced dietary component, and how the presence of marine-sourced components effects our calibration of human radiocarbon ages.

2 SAMPLE PREPARATION

2.1 Physical and chemical preparation

Bones prepared by the Rafter Radiocarbon laboratory were physically examined for root inclusions and burial dirt. All surfaces were either mechanically dremmeled or pared with a scalpel to remove bone that had been in contact with the burial environment and/or appeared degraded. Each sample was then pulverized in a Retch mill to < 450µm, and chemically treated using a modified Longin (1971) method. Samples were demineralized in 0.5M HCl while being stirred at room temperature for at least 1 hour. Insoluble collagen was filtered from the solution, rinsed, and dried in a vacuum oven at 40°C. Up to 80mgs of collagen was then gelatinised with 0.01M HCl in a nitrogen atmosphere at 90°C for 16 hours. The soluble gelatin was then double-filtered through Whatman™ GF/C and 0.45µm Acrodisc™ filters, and lyophilized to weighed yields.

Collagen prepared at the Queen's University, Belfast (UB) was processed according to methods outlined in Longin (1971) and Pearson (1983).

2.2 Measurement of carbon and nitrogen stable isotopes

Bone gelatin was chemically pretreated at the Rafter Radiocarbon laboratory and analysed at Iso-trace New Zealand for nitrogen and carbon ($\delta^{15}N$, $\delta^{13}C$, %N, and %C) using the elemental analyser isotope ratio mass spectrometry (EA-IRMS) technique. The standard equipment used is a Carlo Erba NA1500 coupled to a Europa 20/20 IRMS. The typical amount of sample analysed is 1mg and each sample analysed is performed in duplicate. All reference materials and internal standards are calibrated and traceable to the international standards V-PDB for 13C (Craig 1953; 1957) and Air for ^{15}N (Bohlke and Coplen 1995). The standard for collagen carbon and nitrogen is EDTA, run after every six duplicates of bone gelatin. Analytical precision for these analyses is typically ±0.07‰ and ±0.18‰ for nitrogen, based upon the SD of EDTA internal standards within each run. We report $\delta^{13}C$, $\delta^{15}N$, %C and %N, and atomic CN ratios.

The "Total Errors" reported for ^{15}N and ^{13}C include the 1σ standard deviations associated with analytical (machine error) and chemical preparation of the bone protein (1σ SD of the stable isotope analysis of each sample). The latter are based upon pre-treatment experiments on five separate preparations of a cattle humerus from a late Iron Age/early Roman site at Beckford, Worcestershire. These are derived from the weighted mean variation over thirty analyses, from which preparation error is estimated at 0.25‰ for nitrogen and 0.30‰ for carbon. The combined standard deviation of pre-treatment error and analytical error is given by:

$$\Delta Z = \sqrt{\Delta A^2 + \Delta B^2}$$

ΔZ= total error for isotope
ΔA= quoted analytical error for run for isotope
ΔB= weighted mean calculation of experimental pre-treatment variation for isotope

The range of calculated total error over all analysis was ±0.31 to 0.36‰ for carbon and ±0.31 to 0.39‰ for nitrogen.

At the Belfast Radiocarbon Dating laboratory, the carbon dioxide produced for dating by the positive pressure flow-through combustion system (McCormac *et al* 2011, section 2.3) was sub-sampled for stable isotope measurement. The ratio of ^{13}C to ^{12}C was measured using the elemental analyser isotope ratio mass spectrometry (EA-IRMS) technique in VG 602e Micromass. The fractionation reported in these results might derive from the combustion process in addition to the natural isotopic composition of the dated material. This measurement reflects the true fractionation in the dated sample and so is appropriate for age calculation.

These values were used for the age calculation of samples converted to benzene at Belfast before October 2001. Because of a technical problem affecting measurements made on bone samples in the mass spectrometer used at Belfast between October 2001

and June 2006, however, the $\delta^{13}C$ values on gelatin prepared at Rafter Radiocarbon and measured at Isotrace New Zealand were used for the age calculation of samples converted to benzene at Belfast during this period. These values have been offset by the mean difference between the $\delta^{13}C$ values measured in Belfast on the dated protein and the $\delta^{13}C$ values measured in New Zealand on bone gelatin prepared at Rafter from the same samples in the period before October 2001. This allows for any additional fractionation that may have derived from the combustion process at Belfast. The total measurement error on the $\delta^{13}C$ values used to calculate these radiocarbon ages was taken as the square root of the sum of the squares of the total error estimate quoted by New Zealand and the standard deviation on the mean offset. Full details of the measurement and calculation of the $\delta^{13}C$ values used in age calculation for this project are provided in McCormac *et al* (2011, section 10).

2.3 Amino-acid analysis method

Amino groups were analytically determined in hydrolysates from sub-samples of Rafter laboratory gelatin and Queen's University collagen at the University of Otago's Protein Microchemistry Facility. Amino acids were analysed by a picotag reverse-phase system (Waters) using phenylthiocarbamyl (PTC) derivatization and analysed by narrow-bore RP-APLC as described in Hubbard (1995). Aliquots of each hydrolysate were measured in duplicate and are reported in residues /1000 calculated from pmol results, with a typical error of ±5 residues/1000.

3 QUALITY ASSURANCE: CARBON AND NITROGEN STABLE ISOTOPE AND AMINO ACID SCREENING

3.1 Introduction

Two of the three factors noted in the Section I Introduction that can affect skeletal bone's suitability for dating are the preservation state of bone protein and contamination with exogenous carbon. The Anglo Saxon chronology project used two methods by which to screen bone protein as part of the quality assurance procedures: carbon to nitrogen ratios (atomic C:N ratios) and amino-acid analysis.

3.1.1 Carbon/nitrogen (C:N) ratios

Stable isotope analysis of carbon and nitrogen provides a screening method to determine the survival of protein and the extent of exogenous carbon contamination in archaeological bone. The atomic C:N ratio of a given sample is compared to the expected carbon and nitrogen percentage range found in modern and well preserved bone protein. Atomic C:N ratios (cf DeNiro 1985) are calculated using the formula:

Atomic CN = (%C / %N) x 1.1666

The optimum C:N ratio range for well preserved bone protein is 2.9 to 3.6, established by DeNiro (1985) in a series of analyses on archaeological bone of different preservation states. Bone protein is on average 35% to 40% carbon and 15% to 20% nitrogen. However, combinations of a range of carbon from 30% to 50%, and nitrogen of 7% to 22% can produce C:N ratios in the acceptable range. Lower nitrogen percentages indicate protein degradation, and higher carbon percentages can indicate exogenous contamination. Therefore, the percentages of carbon and nitrogen are in themselves important as an assurance of protein survival or absence of carbon contamination.

Table 1 lists the $\delta^{13}C$ and $\delta^{15}N$ values, the %C and %N values, and the atomic C:N ratios for samples of gelatin prepared from whole bone by Rafter Radiocarbon from each dated skeleton. The conventional radiocarbon ages (Stuiver and Polach 1977) and $\delta^{13}C$ used for age calculation are also reported (see above section 1.2 and McCormac *et al* (2011, section 10)). For many specimens the $\delta^{13}C$ and $\delta^{15}N$ values, the %C and %N values, and the atomic C:N ratios are also reported for sub-samples of the collagen prepared for dating at Queen's University Belfast.

The entire Anglo Saxon dataset has a mean C:N ratio of 3.2, with one significant outlier of 4.2 (Grubbs test, z-score 6.985, $P<0.05$) for UB-6042 Castledyke South, grave 88. The result for UB-6042 with 50.8% carbon and 14% nitrogen, suggests the possible presence of an exogenous carbon contaminant; the C:N outside of the DeNiro acceptance range is due to nitrogen of 14%, although this nitrogen value is in itself not indicative of badly preserved protein. This observation can be compared with UB-6040, Castledyke South grave 53, with 57.3% carbon, but C:N ratio of 2.9; this ratio falls within the acceptable DeNiro range, due to the 23.4% nitrogen present (Table 1).

Table 2 lists the replicate $\delta^{13}C$ and $\delta^{15}N$ values, the %C and %N values, and atomic C:N ratios for fourteen of the dated skeletons. In all cases, replicate measurements were made on separate gelatin preparations from whole bone undertaken by Rafter Radiocarbon. These results demonstrate the reproducibility of the $\delta^{13}C$ and $\delta^{15}N$ values quoted. For $\delta^{13}C$, all pairs are statistically consistent (at 95% confidence; Ward and Wilson 1978). For $\delta^{15}N$, only one pair is statistically inconsistent at 95% confidence (although this is consistent at 99% confidence). This is in line with statistical expectation. There was a mean difference of 0.3‰ in replication of $\delta^{13}C$, with maximum difference of 0.8‰ for Lechlade, grave 40 repeats; for repeat analysis of $\delta^{15}N$, there was a mean difference of 0.4‰, with a maximum difference of 1.1‰ for Lechlade, grave 18.

We also investigated the extent of variation in stable isotope values between the freeze-dried bone gelatin as prepared by Rafter laboratory, and collagen prepared by the Queen's University, Belfast laboratory (Table 1). The Queen's University processing of bone produces a material that is in appearance and consistency quite different from the Rafter gelatin, which is created in a sealed tube under an inert (N2) atmosphere and

freeze-dried. The Queen's University collagen, while optimal for Liquid Scintillation Counting, has variable water content as a result of its processing method. The percentage of carbon and nitrogen in mass spectrometry is calculated relative to the known weight of the sample analysed, and so varying water content in a sample affects apparent weight, and thus the % isotope value in the analysis. Another difference in the Belfast method of producing collagen is that the protein is heated in the presence of oxygen, which can create Maillard reactions producing caramelizing reactions between certain amino groups and sugars, and which could alter apparent carbon and nitrogen elemental values.

The effect of water content on the percent element calculations is illustrated by the stable isotope analyses on the Belfast collagen where %C and %N are consistently lower than the equivalent values for Rafter freeze-dried gelatin (Table 1). As the calculation of % element in mass spectrometry requires an accurate entry of starting sample weight, Belfast collagen that itself contains varying percentages of water will necessarily return inaccurate % element values.

Figure 1 shows the offsets between the $\delta^{13}C$ values measured in New Zealand on the protein extracted for dating by Queen's University, Belfast and the $\delta^{13}C$ values measured in New Zealand on gelatin extracted from the same skeletons. This shows that the process used to extract protein for dating from the bone samples at Belfast introduces a very small enrichment in $\delta^{13}C$ of up to 1.2‰.

Figure 2 shows the offsets between the $\delta^{15}N$ values measured in New Zealand on the protein extracted for dating by Queen's University, Belfast and the $\delta^{15}N$ values measured in New Zealand on gelatin extracted from the same skeletons. This shows that the process used to extract protein for dating from the bone samples at Belfast also introduces a very small enrichment in $\delta^{15}N$ of up to 1.4‰.

Why this occurs is not clear; if it were an effect of the Maillard reactions (which give Belfast collagen its distinctive toffee-like colour and consistency) one would expect that variation of stable isotope values might relate to altered amino acid profiles caused by the different preparation methods between freeze-dried gelatin and Belfast collagen. We examine differences in amino acid analysis results that are likely due to different preparation methods in section 3.1.2.

3.1.2 Amino acid analysis

Amino acid analysis was used as a second screening method for bone protein preservation in addition to C:N ratios. Amino acid analysis compares a suite of seven key amino acids: hydroxyproline (Hyp), aspartic acid (Asp), glutamic acid (Glu), proline (Pro), glycine (Gly), alanine (Ala), and arginine (Arg) (Stafford *et al* 1988) against expected amounts of each amino in the profile composition of modern, unaltered bone protein (Veit *et al* 2006; van Klinken and Mook 1990).

The relative percentages of amino acids in fossil collagen can be altered by exogenous amino acids in the burial environment, or oxidation/deamination due to the differential solubility of amino acids (Tuross 2002; van Klinken and Mook 1990; Turban-Just and Schramm 1998; DeNiro and Weiner 1988; Long *et al* 1989; Law and Hedges 1989; Weiner and Bar-Yosef 1990). Degraded collagen has a relative increase in smaller amino acids, including alanine and glycine (Turban-Just and Schramm 1998, 111), with Gly/Ala ratios that deviate from the ideal 2.8 expected for un-degraded bone. Glycine residues comprise approximately one third of the amino residues in collagen. Low glycine concentrations in fossil bones indicate deterioration of this amino acid; higher concentrations than expected for pristine bone could indicate contamination with exogenous glycine (van Klinken and Mook 1990, 157). Aspartic acid is abundant in non-collagenous bone proteins as well as in the environment (ie bacterial protein), and Gly/Asp ratios are frequently used to test for contamination (DeNiro and Weiner 1988; Long *et al* 1989; Law and Hedges 1989; Weiner and Bar-Yosef 1990). Hydroxyproline is not bone specific, as exogenous hydroxyproline occurs in soil as a free amino acid and can originate from decayed plant remains and fungi (Radhakrishnan and Giri 1954; Greenstein and Winitz 1961) or diatom cell walls (Hardy 1985.) Therefore, hydroxyproline values less than 101 ± 5 ppt are suggestive of protein deterioration, whereas values greater than 101 would indicate the presence of exogenous hydroxyproline. Glutamic acid is also abundant in the burial environment and as an outcome of diagenisis likely to contribute to a fossil bone profile (van Klinken and Mook 1990).

In Table 3 we compare the atomic C: N ratios for the dated skeletons measured on gelatin processed at Rafter Radiocarbon with the expected C:N range for modern or well-preserved prehistoric collagen (2.9–3.6; DeNiro 1985), and the Gly/Asp and Gly/Ala ratios with ideal Gly/Ala (2.8) and Gly/Asp (6.2) ratios relative to a modern collagen profile (van Klinken and Mook 1990, 156). Gly/Asp ratios of greater than 6–7 are expected for pure to well-preserved collagen (Weiner and Bar-Yosef 1990). Together these multiple indicators provide a better assessment of the robustness of the bone protein than any one analysis alone.

Six skeletons were used to test the reproducibility of the amino acid analysis. Duplicate sample analyses were run on Apple Down, grave 117, Edix Hill, grave 48, Gally Hills, primary burial, Melbourn, SK1204 SG77, and St Peter's Tip, graves 42 and 113 (Table 4). All six replicates showed variability in the analysis, with non-reproducibility on certain amino acids at much greater than twice the ± 5% quoted error on the analyses. Gally Hills failed to reproduce one amino acid (Gly); Edix Hill, grave 48, Melbourn, SK1204 SG77, and St Peter's Tip, grave 113 failed to reproduce two amino acids (Hyp and Asp, Hyp and Pro, and Pro and Gly respectively); and Apple Down, grave 117 and St Peter's Tip, grave 42 did not reproduce Hyp/Pro/Gly and Hyp/Glu/Gly/Ala, respectively. Difficulties with first analysis runs on these and other samples were reported by the Protein Microchemistry facility and re-run, with overall continuing poor resolution. The implications of these results for our assessment of the quality of collagen preservation based on the resolution

of key amino acid ratios (Gly/Ala, Gly/Asp) are summarized in Table 4. Poor resolution of glycine in re-runs of Gally Hills (UB-4727 and UB-4928) and St Peter's Tip, grave 42 (UB-4998 and UB-6946) account for the largest differences in Gly/Alsp ratios among the re-runs (2.7 and 2.3, respectively).

Finally, we address the question of collagen prepared for dating at Queen's University, Belfast having different $\delta^{13}C$ and $\delta^{15}N$ values than in the freeze-dried gelatin prepared at Rafter Radiocarbon in a comparative set of 36 duplicate atomic C:N ratios and amino acid analyses of freeze-dried gelatin versus Belfast collagen (Table 5). Overall, Gly/Asp and Gly/Asp ratios for freeze-dried gelatin agree well with expected ratios for intact collagen profiles (van Klinken and Mook 1990, 156). There is a notable variation in residues/1000 in the profiles for Belfast collagen, especially in lower amounts of aspartic acid, which cause the Gly/Asp ratios to rise well beyond optimal levels. Amino acids themselves each have distinctive $\delta^{13}C$ and $\delta^{15}N$ signatures (Rustad 2009; Metges and Petzke 1997), and the alteration of $\delta^{13}C$ and $\delta^{15}N$ in the Belfast collagen may be linked to the variation in the amino acid profiles.

3.1.3 Discussion: Amino Acid and CN analysis

For the eighty burials for which amino profiles were completed (Table 3), hydroxyproline is consistently below the expected 101 residues/1000 for well-preserved collagen (mean 75 residues/1000, min=39 residues/1000, max=119 residues/1000, SD=13 residues/1000). Glutamic acid in most burials is 1 to 25 residues/1000 above the expected value, and glycine values in approximately half of the samples are 38 to 45 residues/thousand higher than the expected values. In particular, a combination of low hydroxyproline, increased glycine, and alanine, and variation from an ideal Gly/Ala ratio of 2.8 occurs in burials from Edix Hill (UB-4509, UB-4511, and UB-4512), Marina Drive (UB-4550 and UB-4553), Melbourn (UB-4883, UB-4884, UB-4887, UB-4890, and UB-6479), and St Peter's Tip (UB-4926, UB-4927, UB-4930, UB-4931, UB-4963, and UB-6478). Thirty-five of the eighty burials fall below the ideal Gly/Asp ratio of 6.2 for well-preserved collagen based on van Klinken and Mook (1990). Low values for hydroxyproline can suggest protein deterioration and exclude exogenous contaminants, which would have increased hydroxyproline values relative to the expected amino-acid profiles for well-preserved collagen. However, duplicate analysis of six samples (Table 4) point to variable difficulties in resolving hydroxyproline, proline, glycine, and aspartic acid in the repeat analyses, and so perhaps not too much emphasis should be placed on these results.

In contrast, CN ratios for these and other burials are uniformly within the expected range for well preserved collagen (2.9–3.6; DeNiro 1985), with the exception of Castledyke South (UB-6042) with a C:N ratio of 4.2. Despite the variability of the collagen amino-acid profiles discussed above, CN ratios may indeed be the best indicator of protein preservation. A similar finding was observed by Brock *et al* (2007) who determined that, from a number of pre-screening criteria tested, %N, %C and CN ratio may return the best correlation to protein preservation. Amino-acid profiles would, however, indicate the

presence of exogenous contaminants in higher hydroxyproline and glycine values. Additionally, while significant variation in amino acids may alter total carbon and nitrogen stable isotope values, degraded protein or the possible presence of exogenous amino acids may not necessarily prohibit obtaining reliable radiocarbon dates for individuals if the exogenous materials are of similar age to the burials.

4 DIETARY ANALYSIS

4.1 Stable isotopes and diet

In this section we review stable isotope data to describe the isotopic variation among the Anglo Saxon dataset, and to infer the composition of diet for the dated individuals, including the potential presence of marine and freshwater components and the consequent affect upon radiocarbon calibration.

The most common isotopes used in stable isotope analysis of diet are $\delta^{13}C$ and $\delta^{15}N$. Isotope value ranges for foods from a particular source environment can be assumed from known global averages (cf DeNiro and Epstein 1978; 1981) but analysis can also employ region-specific faunal databases (Britton *et al* 2008; Beavan Athfield *et al* 2008; Jay and Richards 2006).

Dietary studies such as Ambrose and Norr (1993) suggest that $\delta^{15}N$ of bone protein tracks dietary protein sources, rather than the whole diet, and essential amino acids from these protein sources influence a consumers overall $\delta^{15}N$ values. Nitrogen isotopes ($\delta^{15}N$) generally infer the trophic level (ie a poorer protein source such as terrestrial vegetation versus terrestrial animal protein) and in certain circumstances, the biome source of protein in the diet (ie terrestrial protein versus marine foods) due to the increasingly enriched values of $\delta^{15}N$ as one progresses up the food chain (the 'trophic level effect'). Some non-dietary factors can also influence $\delta^{15}N$ values, such as nutritional stress (Fuller *et al* 2005).

Diets that are wholly terrestrial generally result in human value mean of about -20‰ for $\delta^{13}C$ and δ15N of +5‰ to +12‰ (depending upon the type and amount of animal protein in the diet). Diets of marine fish and shellfish sources typically produce values in human consumers of $\delta^{13}C$ –12‰ and $\delta^{15}N$ of +12‰ to +22‰ (DeNiro and Epstein 1978; 1981; Schoeninger *et al* 1983.) Diets which are not derived solely from one ecosystem source will result in an isotopic signature which is based upon the proportion of each type of food source in the diet; whether this relationship is linear, and what appropriate endpoints are for foods from different environments, is a point of debate (Ambrose and Norr 1993; Müldner and Richards 2005; Hedges and Reynard 2007). The $\delta^{13}C$ of consumer collagen principally reflects the protein portion of the diet but the spacing between $\delta^{13}C$ in collagen and diet may vary, depending on whether the carbon

isotope value of the protein equals that of the whole diet (Harrison and Katzenburg 2003).

Our main concern for the Anglo-Saxon chronology is the potential for diet-induced radiocarbon offsets. Individuals can take up carbon from their diet from a variety of reservoirs, some of which are not in equilibrium with the terrestrial biosphere (Tauber 1984; Lanting and van der Plicht 1998; Arneborg *et al* 1999), and the potential for offsets to radiocarbon ages must be addressed for accurate calibration of the Anglo Saxon human bone ages. In the following sections we undertake a statistical analysis of the stable isotope data, and work with these data to estimate the potential diet mixtures of the populations using two dietary mixing model methods.

4.1.1 Results

Details of all the stable isotope and radiocarbon analysis performed on freeze-dried gelatin from the ninety-five skeletons and fourteen replicate samples are provided in Table 1. The statistical treatment in this section first considered the entire dataset of 95 skeletons (including the weighted means of the fourteen replicate analyses). We then considered a group of 92 sexed skeletons, excluding UB-4959, UB-4550, and UB-4958 that did not have sex inferred from osteological data or the accompanying artefact assemblage.

Statistical analysis of the isotope data first checked for outliers by Grubbs test, then tested conformity to Gaussian distributions by the Kolmogorov and Smirnov test. Sites with five or more individuals return normal distributions for nitrogen; for carbon, Dover Buckland is not normally distributed. Several of the sites have fewer than four individuals and conformation to Gaussian distributions cannot be assessed. Appropriate parametric or non-parametric analysis and post hoc tests are then employed (Motulsky 1998). Statistical analysis employed Graphpad Instat v3.05 (Graphpad Software; www.graphpad.com).

In the isotope data for the 95 skeletons, mean $\delta^{13}C$ was –20.2‰, sd 0.40. Castledyke South, grave 96 (UB-6035) with a value of –21.3‰ was furthest from the inter-quartile range for the median but not significantly so ($z=2.818$, $P>0.05$). Mean $\delta^{15}N$ was +9.6‰, sd 0.76. Castledyke South, grave 13 (UB-6036) with a value of +11.5‰ was furthest from the inter-quartile range for the median but again not significantly so ($z=2.414$, $P>0.05$). The range of $\delta^{13}C$ is –21.3‰ to –19.14‰, and for $\delta^{15}N$ the range is +8.0‰ to +11.5‰. There are no significant changes in these values during the period covered by this study (Fig 3). We note a negligible correlation between $\delta^{13}C$ and $\delta^{15}N$ values ($R^2 = 0.0071$) among the overall Anglo-Saxon population. If marine resources had played a significant role in diet, one would expect a positive correlation of enriched $\delta^{13}C$ with $\delta^{15}N$ (Fig 4).

At this point we can make a general observation about the source diets that produced these mean isotope signatures. If a 5‰ offset between diet (tissue) and consumer

collagen (bone) values is assumed for carbon, then the sources of $\delta^{13}C$ are –26.3‰ to –24.1‰. If a trophic enrichment of 4‰ is subtracted for nitrogen, the indicative mean dietary protein sources have $\delta^{15}N$ values of +4.0‰ to +7.5‰. These ranges for carbon and nitrogen in themselves suggest mainly terrestrial range vegetation and protein sources if we simply assumed global isotopic ranges for specific food source environments.

We then examined inter- and intra-site stable isotope distributions for the ninety-one skeletons for which there is osteological and/or inferred sex data, and we included both adults and sub-adults. We also treat sites with fewer than five individuals separately. In section 4.4 further statistical treatment of a dataset limited to adult burials with sex determined by osteological standards will examine isotopic variation by gender, age, and geography.

In the ninety-two skeletons with sex identified by osteological methods or by inference from the accompanying grave goods (39 male and 53 female), stable isotope results remain fairly consistent when compared by sex alone. The fifty-three females have a mean $\delta^{13}C$ of –20.3 ‰, sd 0.39 (range –21.3‰ to –19.5‰) and the thirty-nine males have a mean $\delta^{13}C$ of –20.0‰, sd 0.38 (range –20.8‰ to –19.1‰.) Male mean $\delta^{15}N$ was +9.6‰, sd 0.67 (range +8.0‰ to +10.8‰) and the female mean $\delta^{15}N$ was +9.7‰, sd 0.82 (range +8.0‰ to +11.5‰). Males and females differ in $\delta^{13}C$ by 0.3‰ and in $\delta^{15}N$ by 0.1‰ but the differences were not statistically significant ($\delta^{13}C$, $\chi^2=0.0$, $\delta^{15}N$, $\chi^2=0.0$; $\chi^2(5\%)=3.8$, $\nu=1$ for both).

There is isotopic variation by site. The $\delta^{13}C$ values from Dover Buckland are not normally distributed, and the nonparametric Kruskal-Wallis test shows there is significant variation among site medians (KW=39.261, corrected for ties P<0001). Dunn's multiple comparisons post hoc tests indicate that the Castledyke South median $\delta^{13}C$ of –20.9‰ is significantly depleted relative to Dover Buckland ($\delta^{13}C$ –19.8‰), Mill Hill ($\delta^{13}C$ –19.7‰), and St Peter's Tip ($\delta^{13}C$ –19.9‰) at P<0.001 for all. The $\delta^{13}C$ at Dover Buckland, Mill Hill, and St Peter's Tip is significantly enriched over the most depleted site of Castledyke South, and suggests that these sites may have rather different dietary protein source contributions.

For $\delta^{15}N$, there were no significant differences among the mean values for the sites of Castledyke South, Edix Hill, Melbourn, Water Lane, Lechlade, Marina Drive, Dover Buckland, Mill Hill, and St Peter's Tip (Kolomogorov and Smirnov normality test and Bartlett's sd test, followed by one-way ANOVA, P=0.2632.) Castledyke South's overall mean $\delta^{15}N$ of +10.2, sd 0.74‰ is the most enriched of this group, and which is interesting because of its depleted median $\delta^{13}C$ signature, discussed above. Castledyke South also contains the highest overall $\delta^{15}N$ in the entire Anglo Saxon dataset (+11.5‰; UB-6036).

Castledyke South's enriched nitrogen and depleted carbon signatures point to terrestrial sources of dietary protein. The median $\delta^{13}C$ of –20.9‰ at Castledyke South, which is

situated on the south bank of the Humber estuary, indicates terrestrial range diet sources relative to the enriched $\delta^{13}C$ values of comparative sites of Dover Buckland, Mill Hill, and St Peter's Tip, which are in proximity to the coast in Kent. These sites are therefore of special interest as we examine marine and freshwater fish proportions in diets (see section 4.3).

The intra-site variation was examined by a χ^2 evaluation of the highest and lowest $\delta^{15}N$ values within site and by sex (Table 6a–m). Among females, there was a significant difference of 2.7‰ between the lowest $\delta^{15}N$ value in an adult at Lechlade (UB-4984) compared to the highest $\delta^{15}N$ value in a 30–49 year-old at the same site (UB-4504)(χ^2=37.35, χ^2(5%)=3.8, ν=1). As the Lechlade females include three sub-adults, there may be age-related variation in isotopic values (Privat *et al* 2002; Richards *et al* 2002). Among Lechlade males there was a significant difference of 2.8‰ between a +50 year-old individual (UB-4981) and a 30–49 year-old (UB-4683) (χ^2=37.59, χ^2(5%)=3.8, ν=1). Lesser but significant differences in nitrogen were also apparent among females at Castledyke South, Marina Drive, West Heslteron (in which sub-adults are present), as well as Dover Buckland, Edix Hill, and Melbourn, Water Lane. Among male adults, there are significant differences in nitrogen at Castledyke South, Melbourn, Water Lane, Mill Hill, St Peter's Tip, and Westgarth Gardens (Table 6a–m). Additional statistical tests within the Anglo Saxon adult population alone are presented in Section 4.3.

Small sample numbers (1–4 individuals) at the remaining sites limit the power of our statistical review of these differences, but some observations can be made at Apple Down, Berinsfield, Buttermarket, West Heslerton, and Westgarth Gardens. There are no significant differences among the sites in $\delta^{13}C$ (KW=2.213, P=6967) or in $\delta^{15}N$ (KW=6.486; P = 0.1657). The mean carbon and nitrogen values in the group of smaller sites (–20.13‰, sd 0.42 and +9.73‰ sd 0.71, respectively) are not significantly different from the mean carbon and nitrogen values in the larger sites ($\delta^{13}C$, χ^2=0.1, $\delta^{15}N$, χ^2=0.1; χ^2(5%)=3.8, ν=1 for both). But at Buttermarket, where we have only one male and one female, the female at +10.7±0.31‰ is significantly enriched in $\delta^{15}N$ in comparison to the male at 9.4±0.31‰ (χ^2=8.8, χ^2(5%)=3.8, ν=1; Table 6m).

4.1.2 Discussion

The variation observed in stable isotope values among Castledyke and St Peter's Tip, Mill Hill, and others may be associated with geographic factors that influenced access to different aquatic sources for fishing. For example, some of the higher $\delta^{15}N$ values seen in coastal sites such as Dover Buckland, Mill Hill, and St Peter's Tip, are also found at sites which lie in proximity to rivers (Berinsfield, Edix Hill, and Lechlade), as well as at inland sites such as Marina Drive and West Heslerton without near access to substantial rivers. The geographic distribution of isotope values is examined in Section 5.

We also consider that the variation within or between sites could be indicative of a status-based dietary difference, as, for instance, previously seen in a fifth- to sixth-century Anglo Saxon cemetery at Berinsfield (Privat *et al* 2002) and status differences as determined by burial type in a Roman era cemetery at Poundbury (Richards *et al* 1998). In section 4.3 we present calculations of diet proportions for five food sources for sites and for individuals in order to determine the proportions of various food sources in these diets, and in Section 5 we examine site variation by sex and age.

4.2 Assessing the presence and dietary contribution of marine resources

We used diet proportional calculations specifically to identify and quantify the presence of marine resources - and their associated radiocarbon offsets - in Anglo Saxon diet.

The power of interpolation calculations has been challenged based on their underlying assumptions, such as whether there is a consistent linear relationship of diet with isotopic signature and overestimation of percent marine (Beavan Athfield *et al* 2008; Bayliss *et al* 2004; Focken 2004; Focken and Becker 1998). Other considerations are the selection of appropriate trophic enrichment factors and diet baseline endpoints. δ^{15}N value ranges are associated with the food source trophic level and the source biome (e.g. terrestrial versus marine).

In the next section we discuss our selection of isotopic inputs for estimating diet proportions, and we compare two methods of identifying and calculating percent marine in Anglo Saxon diets.

4.2.1 Results

We first present a graphic representation of where Anglo Saxon isotopes sit in relation to regional dietary sources. We have constructed diet-to-collagen value boxes based upon reported δ^{15}N and δ^{13}C values for archaeological fauna from various sites in England (Müldner 2005; Birchall 2002; Richards *et al* 2006; Jay and Richards 2006; Privat *et al* 2002; Richards 2000; O'Connell and Lawler 2009; Müldner and Richards 2005; 2007) and freshwater, andromenous, and marine fish (Müldner 2005; Richards *et al* 2006). For a trophic enrichment factor - the enrichment of δ^{15}N and δ^{13}C between diet source bone values and consumer bone values - we take into consideration previous discussions concerning the per mil factor for both carbon and nitrogen (see van der Merwe and Vogel 1978; Peterson and Fry 1987; Hedges and Reynard 2007). Here we use a trophic enrichment factor of 1‰ based on ^{13}C upon enrichments in herbivores (Jay and Richards 2006) and 4‰ for ^{15}N, based on evidence for trophic enrichments in breastfeeding children and nursing women (Richards *et al* 2002).

In Figure 5, the "terrestrial vegetation" box uses minimum and maximum cattle values from data cited above as a proxy for where human collagen values would be with a

vegetarian diet. We similarly use minimum and maximum values from previously published sources cited above for "terrestrial animal protein" (domestic fowl, sheep, and cattle), "freshwater fish", "salmonid" and "eel" boxed ranges, but to approximate were human consumers would sit in relation to these food source, we have added the trophic enrichment factors of 1‰ for $\delta^{13}C$ (cf Jay and Richards 2006) and 4‰ for $\delta^{15}N$ (cf Richards *et al* 2002).

Individual Anglo Saxon isotope signatures were then plotted against the dietary isotope-range boxes. The plot indicates that all skeletons are enriched in $\delta^{13}C$ and $\delta^{15}N$ to points well above pure "terrestrial vegetation" ranges, and the human values sit well within the range of "terrestrial animal protein" sources, yet they do not necessarily exclude overlaps of freshwater fish and eel isotope ranges.

We next present two methods of calculating the proportion of these food sources for the Anglo Saxons. The first method to estimate dietary proportions is ISOSOURCE, a mixing model which derives probable diet-source partitions from up to seven diet sources. ISOSOURCE produces a set of solutions derived from the combination of source proportions that satisfy an isotopic mass balance mixing model, with descriptive statistics to characterize the distribution of feasible solutions (Phillips and Gregg 2003). While the mixing model was first developed for source proportional diet determinations in ecology (see Phillips *et al* 2005), it has also previously been successfully applied in archaeology (Newsome *et al* 2004; Beavan Athfield *et al* 2008).

We address two of the issues raised by Müldner and Richards (2005) concerning suitable end points and the handling of trophic enrichment factors when stable isotope mixing models are used for archaeological situations. For the ISOSOURCE calculations we used the mean $\delta^{13}C$ and $\delta^{15}N$ values for foods collated from British archaeological sites (Richards *et al* 2006; Jay and Richards 2006; Privat *et al* 2002; Richards 2000; Müldner and Richards 2005; DeNiro and Epstein 1978): "terrestrial vegetation" (−21.8‰ for carbon and +4.9‰ for nitrogen), "terrestrial animal protein" (−21.5‰ and +5.9‰), "eel" (−23.3‰ and +10.9‰), "freshwater fish" (−21.7‰ and +13.7‰), "salmonid" (−15.0‰ and +11.2‰), and "marine" (−13.1‰ and +13.5‰). The mean of each food type was also given a trophic enrichment factor of 1‰ for ^{13}C and 4‰ for ^{15}N, except for "terrestrial vegetation", as the cattle who are proxies for human vegetarians have essentially already provided the trophic enrichment factor. The ISOSOURCE calculations were then run for males and females overall, then for males and females in each site (Table 6a–m), as well as for individuals (Table 7).

ISOSOURCE results indicate that for Anglo Saxon females, overall, diets consisted of 43.7±11.0% terrestrial vegetation, 24.5±19.1% terrestrial protein, 10.0±7.0% eel, 8.5±6.3% freshwater fish, 7.4±5.1% salmonids, and 5.9±4.1% marine fish (N calculations=597,278). For all males ISOSOURCE indicated 46.0±9.9% terrestrial vegetation, 22.1±17% terrestrial protein, 8.0±5.8% eel, 7.0±5.3% freshwater fish, 9.4±6.1% salmonids, and 7.5±4.9% marine fish (N calculations=552,610).

In calculations from the mean isotopic values in males and female skeletons by site, the estimated amount of marine fish ranged from 3.1±2.7% (Castledyke South females) to 9.3±5.8% (Mill Hill males). The calculations for individuals in all sites suggest that marine fish made up from 1.4% (Castledyke South: grave 94) to 12.7% (St Peter's Tip: grave 42).

We had commented in section 4.2 that, while the most enriched $\delta^{15}N$ among sites was observed at Castledyke South, the mean $\delta^{13}C$ for Castledyke South was also significantly depleted, relative to comparative sites like Dover Buckland, Mill Hill, and St Peter's Tip with mean $\delta^{13}C$ values between −19.74‰ and −19.86‰. The depleted carbon suggests a different source for protein in the diet which would also be providing enriched nitrogen values for Castledyke South. ISOSOURCE calculations suggest that Castledyke South diets were proportionally influenced more by eel and freshwater fish than marine sources (Table 6c). Geography may play a role here, in determining the type of aquatic biome from which food could be gathered. Castledyke South is on the south bank of the Humber estuary, while Dover Buckland, Mill Hill, and St Peter's Tip are in proximity to the coast in Kent. If small proportions of fish are contributing to the slightly elevated nitrogen values in these sites, the mean $\delta^{13}C$ value of −20.79‰ for women at Castledyke South suggests a non-marine source for that fish component. Castledyke South's females and males have non-marine fish proportions of 35.5±8.2% and 25.5±6.1%, respectively, represented largely by eel and freshwater fish. In the Kent coastal sites, mean non-marine fish estimates for Dover Buckland (females 24.7±5.8%; males 23.5±7.1%), Mill Hill (females 25.2±5.9%, males 23.8±5.7%), and St Peter's Tip (females 21.8± 5.3%, males 24.7±5.9%) indicate that salmonids dominate the calculations (Tables 6a–m; Table 7). In Figure 6 the percentage of marine, andromenous, and non-marine fish has been plotted for individual skeletons from each site, and we provide a map of the regional variation in the components of marine and non-marine fish in Figure 7.

We now turn to a second method of estimating diet-source proportions from human isotopic signature, by interpolation calculations of percent marine from $\delta^{13}C$. Here we use the formula of Mays (1997):

$$\%\text{marine} = 100 \times (\delta_T - \delta_{CO}) \div (\delta_T - \delta_M)$$

where δ_{CO} is the $\delta^{13}C$ value of collagen, δ_T is the average $\delta^{13}C$ of terrestrial dietary sources, Δ_{CD} is the fractionation factor (δ_{CO}.-δ_{diet}) and δ_M is the average $\delta^{13}C$ of marine resources, the values for which are:

δ_T: −21.5±0.6‰ for $\delta^{13}C$

δ_M: −12.0±1.5‰ for $\delta^{13}C$

For the Mays (1997) method, we have calculated error on the percent equivalent of the per mil standard deviation's of isotope values used here for δ_T and δ_M, and the associated

error on each skeleton's δ_{CO}. These percent equivalents are then squared, summed, and divided by 3, and the square root taken for the combined percent error for each skeleton.

While Mays (1997) calculations on $\delta^{13}C$ alone return higher estimates of percent marine than ISOSOURCE, the two methods compare well within the estimated errors for each (Table 7). Other authors have observed that linear interpolation between end-point values of marine and terrestrial may overestimate source contributions (Beavan Athfield *et al* 2008; Bayliss *et al* 2004; Focken 2004). Focken (2004) demonstrated that back-calculation of percentage C4 and C3 components in a mixed diet overestimated the C4 ($\delta^{13}C$ enriched) component by up to 11%.

4.2.2 Discussion

ISOSOURCE results indicate that, overall, Anglo Saxon females and males have largely terrestrial plant and protein-based diets, with freshwater fish averaging about 26% and marine fish from 1.4% to 12.7%, and with notable inter- and intra site variations. Mays (1997) $\delta^{13}C$ back-calculation estimates only the marine proportion of the diet, and returns higher estimates of percent marine (2.1% to 25.3%) in comparison with the ISOSOURCE calculations (Table 7; Figs 7–8).

Our interest in the amount of fish from different biomes relates to effects upon radiocarbon ages from both marine and freshwater offsets. The marine environment contains less radiocarbon than the contemporary atmosphere, so bone which derives some of its carbon content from this reservoir will have an apparently older radiocarbon age than a contemporary sample derived purely from the atmosphere. The scale of the marine offset varies regionally, but is in the order of 400 radiocarbon years for English coastal waters (Harkness 1983). Some terrestrial aquatic sources may have the potential to introduce radiocarbon offsets via dissolved carbonate from certain geologies (Ascough *et al* 2007; Culleton 2006). This carbon component would be radiocarbon "dead" with the potential for imparting significant and anomalously old ages as the dissolved inorganic carbon is synthesised by aquatic plants and becomes part of the aquatic food-chain. There is no information on freshwater radiocarbon offsets for fish in the overall region in which these sites are situated.

There is some historical and archaeological evidence for fish consumption in Anglo Saxon sites. Recent research into fishing and fish-consumption in Anglo-Saxon England (Barrett *et al* 2004a–b) has shown a dramatic growth of large-scale marine fishing and the wide distribution of the catches only around the end of the tenth century AD. The data also suggest that there had previously been a steady growth in the quantity of herring being landed from at least the eight century to the tenth; in the eight century, however, this marine fish is found only at sites of special character - monasteries, and wícs - located very close to the sea. The fishbone evidence from earlier sites is dominated by freshwater and estuarine species: especially cyprinids (carp family) and eel. There is also evidence of the regular collection of shellfish. At the monastery at Hartlepool (Co Durham), however,

there was clearly some offshore catching of gaddids (cod and related species) in the late seventh and eight centuries (Huntley and Rackham 2007, 109–10; 120–2). At Flixborough (South Humberside), the regular hunting and consumption of bottlenose dolphin, presumably from the Humber estuary, is clearly in evidence both in the eight and the tenth century: both periods for which a special status for this settlement site is therefore inferred, perhaps, again, monastic in the earlier period (Dobney *et al* 2007, 199–214; Loveluck 2007, 92–4; 147–57).

Of particular importance from the perspective of the current project is the fact that we do not know whether the apparently general increase in the provision of herring from the eight to tenth centuries can (negatively) be back-projected into the sixth and seventh centuries - which could imply that fishing then was limited almost entirely to riverine and estuarine trapping. A considerable number of fish-traps dating across the period from the fifth century to the ninth have been identified, especially in the major English rivers: the Thames, Trent, and Severn. The earliest reliably dated charters, from south-eastern England, of the second half of the seventh century, include watercourses and shores amongst the resource areas granted in a regular, if formulaic, manner, implying that the value of those zones, for fishing as well as other productive uses, was fully appreciated.

The Mays (1997) back-calculations provide higher estimates of the percentage of marine resources in the diet than do the ISOSOURCE calculations, but the calculated percent error ($c \pm 7.4\%$) on these overlap the ISOSOURCE estimates with their respective errors.

The ISOSOURCE calculations also produce large standard deviations on the mean percentage of terrestrial animal protein, eel, freshwater fish, salmonids, and marine fish, even with a regional dataset for foods. These large standard deviations may arise because our baseline data for protein sources is still incomplete for the task required, or because of the overlaps in the isotopic ranges of diet items (eg freshwater fish and terrestrial protein). Alternatively, our calculations may be hampered by too much information. For example, ISOSOURCE calculations of the vegetable portion of diet, which has only one source, consistently returns much smaller errors than for the five protein sources (terrestrial animal protein, eel, freshwater fish, salmonids, and marine fish) which may introduce larger standard deviations on solutions due to the isotopic overlapping of these sources. If measurements on sulphur isotopes ($\delta^{34}S$) had been obtained for these individuals we could better determine the source of protein rich foods in the diet using ISOSOURCE, as ^{34}S has distinctive ranges between terrestrial and marine which helps to pinpoint these sources and should help resolve the large errors currently quoted on the dietary estimates.

4.3 Anglo-Saxon diets: the effects of sex, age and geography

The aim of this section is to investigate differences in $\delta^{13}C$ and $\delta^{15}N$ (and by implication, differences in diet) according to age at death, sex, and geographical location of the sampled skeletons. Only adult burials for which sex could be determined using standard

osteological methods (Brothwell 1981) are included in this part of the study. Sub-adults are excluded as previous work (Privat *et al* 2002; Richards *et al* 2002) on other English Medieval material has shown significant age-related variation in isotopic values, and by implication diet, in sub-adults. There are 76 adults for whom sex was determined by osteological methods: 38 males and 38 females. These form the dataset for the analysis reported in this section.

Age at death was estimated primarily using dental wear (Brothwell 1981; Mays *et al* 1995). Individuals were classified as young, middle-aged, or older adults, corresponding approximately to 18–29 years, 30–49 years, and 50+ years respectively.

The archaeological sites from which the burials were excavated were classified as coastal (Dover Buckland, Mill Hill, and St Peter's Tip) or inland (Apple Down, Aston Clinton, Edix Hill, Berinsfield, Coddenham, Marina Drive, Ford, Gally Hills, Lakenheath, Lechlade, Melbourn Water Lane, West Heslerton, and Westgarth Gardens). Two sites, Barton-on-Humber and Buttermarket are located in the lower reaches of major rivers, and hence are classified here as riverine. For the inland sites, distance from the sea, measured in a straight line to the nearest point on the coast, was also recorded.

4.3.1 Results

There was no statistically valid correlation between $\delta^{13}C$ and $\delta^{15}N$ ($r=0.10$, $p=0.40$). Therefore the $\delta^{13}C$ and $\delta^{15}N$ data are analysed separately. Lilliefors tests indicated no evidence for departure from normality for the $\delta^{15}N$ data, permitting parametric statistics to be used in analysis. However, the $\delta^{13}C$ data departed from normality. Therefore the carbon data were analysed using non-parametric statistics, and the median and the inter-quartile range (IQR) were used, instead of mean and standard deviation (SD), as measures of central tendency and dispersion respectively.

There was no association between $\delta^{13}C$ and age at death. However, analysis of variance indicated an association between $\delta^{15}N$ and age for males which just attained conventional statistical significance ($F=3.29$, $p=0.05$). The Tukey HSD post hoc multiple comparison test indicated that the only between-group difference that attained statistical significance was between the 18–29 and 30–49 year age classes, the former being depleted in ^{15}N compared to the latter (mean values +9.1‰ to +9.7‰ respectively).

Summary statistics for the isotopic data, split by sex and location, are presented in Tables 8 and 9. These data indicate no difference in stable isotope values between males and females at any of the three geographical locations. In addition, there is no significant difference in the distributions of age at death in sites from the three geographical locations. Therefore, in the analyses directed at evaluating geographical differences in stable isotope data, individuals of all three age groups and both sexes are combined.

A Kruskal-Wallis one-way non-parametric analysis of variance indicated significant variation in $\delta^{13}C$ across the three geographical groups ($\chi^2=38.7$, $p<0.0001$). The post hoc non-parametric multiple comparison test of Dunn incorporating the modification for tied ranks (Dunn 1964; Zar 1999), revealed significant differences between the coastal group and the other two groups ($p<0.001$ in each case).

For the $\delta^{15}N$ data, analysis of variance indicates significant variation across the three geographical groups. The Tukey HSD post hoc multiple comparison test indicated a significant difference between the riverine group and the inland group ($P<0.05$).

For the inland sites, there is no association between distance from the coast and $\delta^{13}C$ ($r=-0.07$). However, there is a weak but statistically significant positive association between distance from the coast and $\delta^{15}N$ ($r=0.35$, $p=0.02$).

4.3.2 Discussion

As an alternative to the ISOSOURCE method and use of published values for UK archaeological fauna and fish, one of us (SM) has suggested human bone collagen $\delta^{13}C$ endpoints of approximately –21.5‰ and –12‰ for fully terrestrial and fully marine protein components of diets in a Medieval English context (Mays 1997). In this light, the $\delta^{13}C$ data indicate diets dominated by terrestrial resources at each geographic zone. The variation in $\delta^{13}C$ is low. That in $\delta^{15}N$ is somewhat greater, but this is as expected, given the multiplicity of factors that potentially contribute to variation in $\delta^{15}N$. For example, $\delta^{15}N$ differs in marine versus terrestrial environments; varies with trophic level so that animal products generally have higher $\delta^{15}N$ than plant foods (Bocherens and Drucker 2003) and freshwater foods often have elevated values (Müldner 2005); varies in different domestic animals (Müldner and Richards 2007); and differs in leguminous versus non-leguminous plants (DeNiro and Hastorf 1985). The nitrogen balance of the organism also affects $\delta^{15}N$ (Fuller *et al* 2005), and manuring practices influence $\delta^{15}N$ in crops (Bogaard *et al* 2007).

Comparison of the degree of variation in stable isotope ratios can be drawn with late Medieval Barton-on-Humber (situated in the same locality as the Castledyke site in the current work) (Beavan *et al* 2011). The Barton material came from a parish church, and so to all intents and purposes represents a single community. The material was split by period into six phases, most of about 100–200 years. The adult IQRs for $\delta^{13}C$ at Barton for the different phases range from 0.3–2.4‰; the SDs for $\delta^{15}N$ from 0.6–2.3‰. At Wharram Percy, an inland late Medieval site, the adult IQR for $\delta^{13}C$ was 0.49‰, the SD for $\delta^{15}N$ 1.04‰ (computed from data of Richards *et al* 2002). The results therefore suggest that, despite the geographical diversity of the current data, the variability in dietary protein sources between individuals was less than in a single riverine community, and was similar to that in a single inland community, in the late Medieval period.

An age pattern was found in $\delta^{15}N$ in males whereby those over about 30 years have elevated $\delta^{15}N$ compared with younger adults, although the difference in means is small (0.6‰). There was no interaction between age and geographical location that might explain this. This pattern echoes that found by Privat *et al* (2002) in a detailed study of the Berinsfield group. It would appear to suggest a minor dietary change during the male life-cycle, which did not have a parallel in females, with a slightly increased proportion of dietary protein at older ages coming from sources somewhat more enriched in ^{15}N. Cortical bone collagen turnover rates are only about 1.5–3% per year in adult males (Hedges *et al* 2007), so this finding must relate to a shift that occurred well before 30 years of age, probably during the latter part of the growth period. However, identifying more closely the age range at which this might have occurred is problematic given the imprecision of current skeletal ageing techniques.

There are some very minor, but nevertheless statistically significant differences in $\delta^{13}C$ between the three geographical zones. The coastal burials have less negative $\delta^{13}C$ than those from the other two locations. Given the less negative $\delta^{13}C$ of marine versus terrestrial foods, it would seem likely that, for the coastal people, marine foods tended to make up a somewhat greater proportion of protein sources than was the case at the other sites (or perhaps that in coastal locations domestic animals were fed, or allowed to forage for, marine foods such as seaweed). However, if this interpretation is correct, the question remains as to why there is no corresponding elevation of $\delta^{15}N$ in the coastal burials. As explained above, $\delta^{15}N$ in bone collagen is influenced by a multiplicity of factors, and our understanding of the causes of $\delta^{15}N$ variation in past populations remains incomplete. It may be that the contribution to inter-individual variability in $\delta^{15}N$ made by differential consumption of marine resources is eclipsed by that due to other factors (in other words, it is easier to pick out minor marine dietary components using analysis of bone collagen for $\delta^{13}C$ because, on current understanding, it appears to be influenced by fewer additional factors than is $\delta^{15}N$). In support of this is the lack of significant correlation between $\delta^{15}N$ and $\delta^{13}C$ in the sample as a whole (Fig 4). If differential consumption of marine foods were the dominant factor behind inter-individual variation in $\delta^{15}N$ then we would expect a correlation with $\delta^{13}C$. That this does not seem to be the case suggests that factors other than differential seafood consumption are the principal causes of inter-individual variation in $\delta^{15}N$.

Mean $\delta^{13}C$ at the coastal locations is more negative than in some late Medieval English coastal settlements (e.g. Newcastle and Hartlepool: −18.6‰ and −18.2‰ respectively) and also in a late Medieval urban centre (York: −18.8‰ to −19.7‰) (Mays 1997; Müldner and Richards 2007). If the above interpretation of the current $\delta^{13}C$ data is correct, then the seafood component of the coastal Anglo-Saxon series is, whilst greater than at coeval non-coastal sites, rather less than at later Medieval coastal ports and inland trading centres. This may be consistent with the suggestion of Barrett *et al* (2004a–b), based on faunal evidence, that there was an expansion of marine fishing in England around AD 1000, and that prior to this exploitation of marine resources was minor. It was

anticipated that if marine resources were regularly traded inland, then one might observe an association between increasing distance from the coast and more negative $\delta^{13}C$. There was no indication of any such trend.

Turning to the nitrogen isotope data, the $\delta^{15}N$ are significantly greater in the riverine sites than the inland sites. As noted above, interpretation of $\delta^{15}N$ data from bone collagen is complex, but the observation that freshwater resources tend to have rather elevated $\delta^{15}N$, suggests that increased consumption of riverine resources in communities situated in the lower reaches of major watercourses may be a factor here. The data (Table 8) indicate that it is in fact the females from the riverine sites that have the elevated $\delta^{15}N$. However, the sex difference in diet at riverine locations is not statistically significant, reflecting the small sample size for males (two individuals). That there are only two males from riverine sites means that we cannot adequately characterise male diets at these locations, so it would be unwise, on the currently available data, to argue that the inland/riverine dietary difference was solely restricted to females.

For inland sites, there was a positive correlation between distance from the coast and $\delta^{15}N$. This association was weak and, as discussed above, intra-site variation is very minor. It is difficult to explain this trend in dietary terms - for example, it is the opposite of what might be expected if the variation were due to proximity of marine food resources.

5 CONCLUSIONS

Results on the replicate $\delta^{13}C$ and $\delta^{15}N$ values, the %C and %N values, and atomic C:N ratios for fourteen of the dated skeletons were statistically consistent (at 95% confidence; Ward and Wilson 1978) and demonstrate the reproducibility of the $\delta^{13}C$ and $\delta^{15}N$ values quoted. For $\delta^{15}N$, only one pair is statistically inconsistent at 95% confidence (although this is consistent at 99% confidence).

We also examined the extent of variation in stable isotope values between the freeze-dried bone gelatin as prepared by Rafter laboratory, and collagen prepared by the Queen's University, Belfast laboratory. As the calculation of % element in mass spectrometry requires an accurate entry of starting sample weight, Belfast collagen, which contains varying percentages of water, will necessarily return inaccurate % element values. We also found offsets between the $\delta^{13}C$ values measured in New Zealand on the protein extracted for dating by Queen's University, Belfast and the $\delta^{13}C$ values measured in New Zealand on gelatin extracted from the same skeletons. This shows that the process used to extract protein for dating from the bone samples at Belfast introduces a very small enrichment in $\delta^{13}C$ of up to 1.2‰ and in $\delta^{15}N$ of up to 1.4‰.

The two screening methods for protein preservation - the atomic C:N ratios and amino acid analysis - generally confirmed the suitability of bone for radiocarbon dating and stable isotope analysis. CN ratios for the burials are within the expected range for well-

preserved collagen (2.9–3.6; DeNiro 1985). Difficulties with resolving certain amino acids during analysis may mitigate the interpretation of protein degradation inferred by a combination of low hydroxyproline, increased glycine, and alanine, and variation from an ideal Gly/Ala ratio of 2.8 and ideal Gly/Asp ratio of 6.2.

The stable isotopic data indicate that protein sources in human diets at all sites studied were overwhelmingly terrestrial. The mean isotopic values for the Anglo Saxons (δ^{13}C −20.15‰, SD 0.4, and δ^{15}N +9.66‰, SD 0.75) are not significantly different from the −20.0‰ and +10.3‰ for the Anglo Saxon period reported by Müldner and Richards (2005) in their diachronic examination of diet at York, in which they also found little evidence for marine fish.

We also reported on specific intra-site and inter-site differences that may be associated with sex, age, and geographical location. This is discussed further in Mays and Beavan (2012).

We employed a graphic method (Fig 5) and two different mixing models to estimate the proportion of different food sources. Our main purpose was to assess the proportion of marine protein in Anglo Saxon diets for the possible impact on the accurate calibration of radiocarbon ages from the skeletons. Our calculations using ISOSOURCE and Mays (1997) with δ^{13}C suggests that marine fish, if available or utilised, usually made up less than 10% in these diets and would not affect radiocarbon ages significantly.

A subset of the data examined differences by age, sex and geographical relationships. For males, adults over about 30 years had slightly enriched δ^{15}N compared with younger adults. There was no evidence for age differences in δ^{15}N in females or in δ^{13}C for either sex. There was no evidence of any sex differences in δ^{13}C or δ^{15}N at sites in any of the three geographic locations. There were some differences between communities in inland, riverine, and coastal locations, consistent with seafood making a greater contribution to dietary protein in coastal communities and freshwater resources being more important in communities situated in the lower reaches of major rivers. However, the differences were very minor. Overall, despite the geographical spread of the current dataset, dietary protein sources appear of similar or greater homogeneity than was the case even within single communities in later Medieval times.

The slightly greater consumption of marine and freshwater resources inferred for coastal and riverine sites respectively may suggest that in times of shortage communities fell back on locally available wild resources, and that at coastal and riverine locations these included marine and freshwater resources respectively. Alternatively, marine and freshwater resources may, when available locally, have constituted a minor but regular supplement to foods generated by the agrarian economy. The current data does not permit distinction between these two scenarios.

While consumption of freshwater fish also has the potential to introduce radiocarbon offsets, currently there is sparse archaeological evidence for non-marine fish consumption in Anglo- Saxon sites, and little information on freshwater radiocarbon offsets for fish in the overall region in which these sites are situated. Notwithstanding the number of fish-traps which have been identified from the fifth century to the ninth centuries in major English rivers as evidence for riverine and estuarine fishing in the period, there is little evidence from site-associated fish remains to further support extensive fish consumption. Müldner and Richards (2005) had observed that higher $\delta^{15}N$ coupled with terrestrial range $\delta^{13}C$ could be indicative of some freshwater fish contribution to diet; but given the overlap of some freshwater fish isotopic values with terrestrial protein, teasing out <10% proportions of this food type in diet would be difficult by any current method. Our evaluation of the stable isotope data for the Anglo Saxon skeletons from furnished graves can, at best, provide informed and probable parameters for calibration of the radiocarbon ages.

Individuals were selected for inclusion in this study on the basis that they were accompanied by certain metalwork artefacts whose chronological distribution was of interest. Their relatively rich grave furnishings means that the individuals in the current study probably represent higher status members of Anglo-Saxon society. Whether our findings have a more general applicability must await further isotopic work on non-elite segments of Anglo-Saxon communities.

6 REFERENCES

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Table 1: Stable isotope, radiocarbon, and osteological results from ninety-nine skeletons (including fifteen replicate samples). Comparison of the Rafter preparation of gelatin with stable isotope analysis of Queen's University collagen is presented with total error calculated for Rafter gelatin; similar total error cannot be calculated for UB collagen. 1) Error on stable isotope analysis is determined from mean std dev at 1σ on EDTA standards within the stable isotope analysis run; 2) Total error reported for ^{15}N and ^{13}C includes analytical error and variation in stable isotope results associated with chemistry preparation of the bone protein; 3) Atomic CN ratio=(%C/%N)(14/12); 4) The radiocarbon results are conventional radiocarbon ages (Stuiver and Polach 1977); 5) The $\delta^{13}C$ measurements reported with the radiocarbon analysis are obtained from sub-samples of the CO2 from sample combustion taken before benzene production (McCormac et al 2011)*

		Carbon and nitrogen analysis of Rafter gelatin preparations								Radiocarbon analysis				Carbon and nitrogen analysis on UB collagen preparations								
Laboratory Number	Site	%C	$\delta^{13}C$ (‰)	error (±)[1]	total error (±)[2]	%N	$\delta^{15}N$ (‰)	error (±)[1]	total error (±)[2]	atomic CN[3]	^{14}C Age (BP)[4]	$\delta^{13}C$ (‰)[5]	error (±)[1]	%C	$\delta^{13}C$ (‰)	error (±)[1]	%N	$\delta^{15}N$ (‰)	error (±)[1]	atomic CN[3]	Osteological Age	Osteological Sex	Inferred Sex
UB-5208	Apple Down: grave 107	42.3	–20.3	0.2	0.36	15.0	8.0	0.2	0.32	3.3	1481±20	–20.6	0.5	15.2	–21.0	0.1	5.5	8.0	0.3	3.2	30–49	Female	Female
UB-4965	Apple Down: grave 117	45.6	–20.6	0.1	0.32	16.7	7.9	0.3	0.39	3.2	1475±21	–20.9	0.5	4.3	–20.7	0.1	1.4	8.2	0.15	3.6	50+	Female	Female
UB-6344	Apple Down: grave 117 (replicate)	38.5	–20.2	0.2	0.36	13.8	8.2	0.2	0.32	3.3	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	50+	Female	Female
UB-4835	Apple Down: grave 134	39.5	–20.2	0.2	0.36	14.4	8.7	0.2	0.32	3.2	1503±16	–20.5	0.5	nd	nd	nd	nd	nd	nd	nd	18–29	Female	Female
UB-4975	Aston Clinton: grave 12	39.3	–20.8	0.1	0.32	14.0	9.4	0.3	0.39	3.3	1517±19	–21.0	0.5	10.4	–20.3	0.1	3.7	10.0	0.15	3.3	50+	Female	Female
UB-4735	Berinsfield: grave 22	50.7	–19.9	0.12	0.32	18.4	10.3	0.26	0.36	3.2	1567±19	–20.1	0.5	nd	nd	nd	nd	nd	nd	nd	18–29	Female?	Female
UB-4736	Berinsfield: grave 28	31.4	–20.0	0.12	0.32	11.2	9.5	0.26	0.36	3.3	1526±21	–20.2	0.5	nd	nd	nd	nd	nd	nd	nd	30–49	Male	Male
UB-4739	Berinsfield: grave 134/1	39.9	–20.3	0.12	0.32	14.6	8.8	0.26	0.36	3.2	1561±21	–20.5	0.5	nd	nd	nd	nd	nd	nd	nd	50+	Female	Female
UB-4077	Buttermarket: grave 4275	42.4	–20.2	0.07	0.31	15.6	10.7	0.18	0.31	3.2	1476±24	–21.0	0.2	nd	nd	nd	nd	nd	nd	nd	Adult	Female	
UB-4046	Buttermarket: grave 4344	44.2	–20.1	0.07	0.31	16.4	9.4	0.18	0.31	3.2	1404±21	–20.2	0.2	nd	nd	nd	nd	nd	nd	nd	Adult		?Male
UB-6036	Castledyke South: grave 13	42.2	–20.9	0.1	0.32	18.3	11.5	0.3	0.39	2.7	1421±17	–21.2	0.5	4.7	–20.3	0.1	1.7	11.0	0.15	3.2	18–29	Female	Female
UB-6040	Castledyke South: grave 53	57.3	–21.1	0.1	0.32	23.4	10.2	0.3	0.39	2.9	1535±15	–21.4	0.5	7.3	–19.9	0.1	2.6	10.5	0.15	3.3	30–49	Female	
UB-6042	Castledyke South: grave 88	50.8	–20.3	0.1	0.32	14.0	10.1	0.3	0.39	4.2	1323±13	–20.6	0.5	16.3	–19.4	0.1	5.9	9.4	0.15	3.2	18–29	Female	Female
UB-6039	Castledyke South: grave 94, skeleton 1452	46.5	–20.5	0.1	0.32	17.8	10.1	0.3	0.39	3.0	1412±14	–20.8	0.5	nd	nd	nd	nd	nd	nd	nd	30–49	Male	Male
UB-6035	Castledyke South: grave 96	43.1	–21.3	0.1	0.32	18.1	11.0	0.3	0.39	2.8	1517±15	–21.6	0.5	13	–20.3	0.1	4.8	11.5	0.15	3.2	18–29	Female	Female
UB-6034	Castledyke South: grave 120	45.4	–20.9	0.1	0.32	14.7	9.7	0.3	0.39	3.6	1502±17	–21.2	0.5	20.3	–19.9	0.1	7.4	10.2	0.15	3.2	13–17	Female -	Female
UB-6037	Castledyke South: grave 134	48.5	–20.6	0.1	0.32	18.5	10.0	0.3	0.39	3.1	1544±14	–20.9	0.5	12	–19.7	0.1	4.4	10.6	0.15	3.2	13–17	Female -	Female
UB-6041	Castledyke South: grave 182	48.4	–20.5	0.1	0.32	17.6	8.9	0.3	0.39	3.2	1515±15	–20.8	0.5	11.1	–20.2	0.1	4	9.6	0.15	3.2	18–29	Male	
UB-6038	Castledyke South: grave 183	44.7	–21.0	0.1	0.32	16.7	9.9	0.3	0.39	3.1	1449±14	–21.3	0.5	6.9	–19.9	0.1	2.5	10.2	0.15	3.2	18–29	Female	Female
UB-4964	Coddenham: grave 308	45.9	–20.4	0.1	0.32	17.1	10.3	0.3	0.39	3.1	1417±16	–20.7	0.5	19.6	–19.6	0.1	7.1	10.6	0.15	3.2	30–49	Female	Female
UB-6472	Dover Buckland: grave 222	43.5	–19.8	0.2	0.36	16.1	9.8	0.2	0.32	3.2	1550±19	–20.1	0.5	25.4	–19.7	0.1	9.3	9.8	0.15	3.2	50+	Female	Female
UB-6472	Dover Buckland: grave 222 (replicate)	38.4	–20.1	0.1	0.32	14.1	9.6	0.2	0.32	3.2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	50+	Female	Female
UB-6473	Dover Buckland: grave 250	39.5	–19.8	0.2	0.36	14.4	10.4	0.2	0.32	3.2	1572±22	–20.1	0.5	23.3	–19.5	0.1	8.5	10.3	0.15	3.2	30–49	Female	Female
UB-6474	Dover Buckland: grave 264	39.2	–19.7	0.2	0.36	14.4	9.3	0.2	0.32	3.2	1528±17	–20.0	0.5	36.2	–19.8	0.1	13.3	9.4	0.15	3.2	30–49	Male	Male
UB-6474	Dover Buckland: grave 264 (replicate)	42.6	–20.0	0.1	0.32	15.9	9.5	0.2	0.32	3.1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	30–49	Male	Male
UB-6475	Dover Buckland: grave 323	37.4	–19.8	0.2	0.36	13.8	9.8	0.2	0.32	3.2	1491±18	–20.1	0.5	30.6	–19.9	0.1	11.2	9.3	0.15	3.2	30–49	Male	Male
UB-6476	Dover Buckland: grave 339	41.9	–19.7	0.2	0.36	15.6	8.9	0.2	0.32	3.1	1592±17	–20.0	0.5	35.5	–19.6	0.1	13	9.0	0.15	3.2	18–29	Female	Female
UB-4958	Dover Buckland: grave 375	43.0	–19.8	0.12	0.32	15.9	9.0	0.26	0.36	3.2	1493±18	–20.0	0.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	Nd
UB-4959	Dover Buckland: grave 391A	28.5	–20.3	0.12	0.32	10.3	9.8	0.26	0.36	3.2	1420±20	–20.5	0.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	Nd
UB-6477	Dover Buckland: grave 414	40.0	–19.8	0.2	0.36	14.8	9.4	0.2	0.32	3.2	1570±20	–20.1	0.5	32.6	–19.5	0.1	11.8	9.6	0.15	3.2	30–49	Male	Male
UB-4923	Edix Hill: grave 7	39.5	–20.3	0.1	0.32	14.3	10.4	0.3	0.39	3.2	1572±20	–20.6	0.5	nd	nd	nd	nd	nd	nd	nd	30–49	Male	Male
UB-4923	Edix Hill: grave 7 (replicate)	38.2	–20.4	0.1	0.32	14.1	10.7	0.2	0.32	3.2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	Nd
UB-4508	Edix Hill: grave 12	34.3	–20.0	0.12	0.32	12.5	10.2	0.26	0.36	3.2	1488±19	–20.2	0.2	nd	nd	nd	nd	nd	nd	nd	30–49	Male	Male
UB-4709	Edix Hill: grave 14	34.9	–20.4	0.12	0.32	12.5	10.4	0.26	0.36	3.3	1495±21	–20.7	0.5	nd	nd	nd	nd	nd	nd	nd	50+	Female	Female
UB-4509	Edix Hill: grave 33	37.5	–20.2	0.12	0.32	13.5	9.8	0.26	0.36	3.2	1521±18	–20.1	0.2	nd	nd	nd	nd	nd	nd	nd	18–29	Male	Male

		Carbon and nitrogen analysis of Rafter gelatin preparations								Radiocarbon analysis				Carbon and nitrogen analysis on UB collagen preparations									
Laboratory Number	Site	%C	$\delta^{13}C$ (‰)	error (±)[1]	total error (±)[2]	%N	$\delta^{15}N$ (‰)	error (±)[1]	total error (±)[2]	atomic CN[3]	^{14}C Age (BP)[4]	$\delta^{13}C$ (‰)[5]	error (±)[1]	%C	$\delta^{13}C$ (‰)	error (±)[1]	%N	$\delta^{15}N$ (‰)	error (±)[1]	atomic CN[3]	Osteological Age	Osteological Sex	Inferred Sex
UB-4510	Edix Hill: grave 48	nd	nd	nd	nd	nd	nd	nd	nd	nd	1479±19	–20.2	0.2	nd	nd	nd	nd	nd	nd	nd	30–49	Male	Male
UB-4922	Edix Hill: grave 48 (replicate)	37.4	–20.6	0.1	0.32	13.4	9.5	0.3	0.39	3.3	1508±19	–20.9	0.5	nd	nd	nd	nd	nd	nd	nd	30–49	Male	Male
UB-4707	Edix Hill: grave 79	28.2	–20.3	0.12	0.32	10.2	8.8	0.26	0.36	3.2	1528±21	–20.6	0.5	nd	nd	nd	nd	nd	nd	nd	30–49	Female	Female
UB-4708	Edix Hill: grave 83	38.8	–20.2	0.12	0.32	14.3	10.9	0.26	0.36	3.2	1488±21	–20.4	0.5	nd	nd	nd	nd	nd	nd	nd	18–29	Female	Female
UB-4511	Edix Hill: grave 90	36.5	–20.1	0.12	0.32	13.1	9.6	0.26	0.36	3.3	1507±19	–20.3	0.2	nd	nd	nd	nd	nd	nd	nd	50+	Female	
UB-4511	Edix Hill: grave 90 (replicate)	39.6	–20.7	0.10	0.32	14.5	9.9	0.2	0.32	3.2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	50+	Female	
UB-4512	Edix Hill: grave 91	51.6	–20.2	0.12	0.32	18.4	10.7	0.26	0.36	3.3	1345±18	–20.5	0.2	nd	nd	nd	nd	nd	nd	nd	18–29		Female
UB-4976	Ford, Laverstock: barrow 2	40.4	–20.4	0.1	0.32	14.4	9.0	0.3	0.39	3.3	1464±16	–20.6	0.5	15.3	-19.7	0.1	5.5	9.9	0.15	3.2	30–49	Male	Male
UB-4920	Gally Hills: replicate (post PVA extraction)	42.5	–20.2	0.1	0.32	15.0	10.4	0.3	0.39	3.3	1419±18	–20.5	0.5	nd	nd	nd	nd	nd	nd	nd	Adult	Male	Male
UB-4727	Gally Hills: primary burial (PVA)	Not analysed due to PVA contamination	1487±16	-20.6	0.5	nd	nd	nd	nd	nd	nd	nd	Adult	Male	Male								
UB-6347	Lakenheath: ERL 104 4222	38.8	–19.8	0.2	0.36	13.5	9.2	0.2	0.32	3.4	1640±20	–20.1	0.5	19.1	–19.7	0.1	6.9	9.9	0.15	3.2	18–29	Male	
UB-4501	Lechlade: grave 14	40.4	–19.9	0.12	0.32	14.8	10.1	0.26	0.36	3.2	1321±21	–20.0	0.2	nd	nd	nd	nd	nd	nd	nd	13–17	Female	Female
UB-4984	Lechlade: grave 18	39.0	–20.4	0.1	0.32	13.9	8.0	0.3	0.39	3.3	1507±20	–20.7	0.5	9.5	–19.6	0.1	3.4	9.4	0.15	3.3	Adult	Female	Female
UB-4984	Lechlade: grave 18 (replicate)	37.3	–20.6	0.1	0.32	13.5	9.1	0.2	0.32	3.2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	Adult	Female	Female
UB-4683	Lechlade: grave 40	41.6	–19.7	0.2	0.36	15.3	10.5	0.2	0.32	3.2	1362±17	–20.1	0.2	nd	nd	nd	nd	nd	nd	nd	30–49	Male	Male
UB-4683	Lechlade: grave 40 (replicate)	42.8	–20.5	0.1	0.32	15.8	11.1	0.2	0.32	3.1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	30–50	Male	Male
UB-4983	Lechlade: grave 136	41.8	–20.7	0.1	0.32	14.6	9.8	0.3	0.39	3.3	1362±17	–20.1	0.5	8.2	–19.9	0.1	2.9	9.3	0.15	3.3	18–29	Female	Female
UB-4502	Lechlade: grave 138	43.6	–20.1	0.12	0.32	15.9	8.9	0.26	0.36	3.2	1391±18	–20.4	0.2	nd	nd	nd	nd	nd	nd	nd	18–29	Female	Female
UB-4503	Lechlade: grave 148	42.0	–20.1	0.12	0.32	15.2	10.9	0.26	0.36	3.2	1319±18	–19.3	0.2	nd	nd	nd	nd	nd	nd	nd	6–7		Female
UB-4982	Lechlade: grave 155	44.8	–20.7	0.1	0.32	15.7	9.7	0.3	0.39	3.3	1361±17	–21.0	0.5	9.1	–20.6	0.1	3.5	10.5	0.15	3.0	18–29	Male	Male
UB-4505	Lechlade: grave 172/1	44.1	–20.3	0.12	0.32	16.2	9.2	0.26	0.36	3.2	1383±19	–20.2	0.2	nd	nd	nd	nd	nd	nd	nd	30–49	Male	Male
UB-4506	Lechlade: grave 172/2	39.9	–20.0	0.12	0.32	14.5	8.9	0.26	0.36	3.2	1352±19	–20.2	0.2	nd	nd	nd	nd	nd	nd	nd	2–2.5		Female
UB-4504	Lechlade: grave 179	43.9	–20.2	0.12	0.32	16.1	11.4	0.26	0.36	3.2	1374±20	–20.3	0.2	nd	nd	nd	nd	nd	nd	nd	30–49	Female	Female
UB-4981	Lechlade: grave 183	39.8	–20.3	0.1	0.32	14.1	8.0	0.3	0.39	3.3	1469±18	–20.6	0.5	6.3	–20.1	0.1	2.3	9.4	0.15	3.2	50+	Male	Male
UB-4507	Lechlade: grave 187	44.0	–19.6	0.12	0.32	16.4	9.4	0.26	0.36	3.1	1398±19	–20.2	0.2	nd	nd	nd	nd	nd	nd	nd	30–49	Female	Female
UB-4549	Marina Drive: grave C7	33.2	–20.4	0.12	0.32	12.0	9.8	0.26	0.36	3.2	1328±19	–20.6	0.2	nd	nd	nd	nd	nd	nd	nd	18–29	Female	Female
UB-4553	Marina Drive: grave D10	30.3	–20.3	0.12	0.32	11.0	11.1	0.26	0.36	3.2	1326±21	–20.8	0.2	nd	nd	nd	nd	nd	nd	nd	18–29	Female	Female
UB-4550	Marina Drive: grave E1	36.1	–19.9	0.12	0.32	13.0	9.6	0.26	0.36	3.2	1379±19	–20.0	0.2	nd	nd	nd	nd	nd	nd	nd	7–12	nd	Nd
UB-4551	Marina Drive: grave E2	54.8	–20.2	0.12	0.32	20.2	10.4	0.26	0.36	3.2	1325±19	–20.3	0.2	nd	nd	nd	nd	nd	nd	nd	13–17		Female
UB-4552	Marina Drive: grave E3	45.2	–20.1	0.12	0.32	16.1	9.1	0.26	0.36	3.3	1370±19	–20.5	0.2	nd	nd	nd	nd	nd	nd	nd	7–12		Female
UB-4554	Marina Drive: grave F2	48.2	–19.9	0.12	0.32	17.3	9.4	0.26	0.36	3.3	1337±19	–20.8	0.2	nd	nd	nd	nd	nd	nd	nd	6		Female
UB-4889	Melbourn: SK1293, SG69	34.6	–20.2	0.12	0.32	12.4	9.4	0.26	0.36	3.3	1459±19	–20.4	0.5	nd	nd	nd	nd	nd	nd	nd	30–49		Female
UB-4890	Melbourn: SK1307 SG75	36.2	–20.3	0.12	0.32	12.8	9.6	0.26	0.36	3.3	1548±20	–20.6	0.5	nd	nd	nd	nd	nd	nd	nd	50+	Female	Female
UB-4886	Melbourn: SK1204 SG77	32.1	–20.0	0.12	0.32	11.4	8.9	0.26	0.36	3.3	1458±20	–20.3	0.5	nd	nd	nd	nd	nd	nd	nd	18–29	Male	
UB-6345	Melbourn: SK1204 SG77 (replicate)	38.3	–19.5	0.2	0.36	13.8	8.7	0.2	0.32	3.2	1516±23	–19.8	0.5	27.2	–19.5	0.1	9.8	9.0	0.15	3.2	18–29	Male	Male
UB-4885	Melbourn: InL1189 SG78	36.6	–20.1	0.12	0.32	13.3	9.5	0.26	0.36	3.2	1479±20	–20.3	0.5	nd	nd	nd	nd	nd	nd	nd	30–49	Female	Female
UB-4885	Melbourn: InL1189 SG78 (replicate)	41.3	–20.5	0.1	0.32	15.3	9.2	0.2	0.32	3.2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	30–49	Female	Female
UB-4884	Melbourn: SK1188 SG79	37.4	–20.4	0.12	0.32	13.3	10.4	0.26	0.36	3.3	1404±19	–20.6	0.5	nd	nd	nd	nd	nd	nd	nd	50+	Male	

		Carbon and nitrogen analysis of Rafter gelatin preparations								Radiocarbon analysis				Carbon and nitrogen analysis on UB collagen preparations									
Laboratory Number	Site	%C	$\delta^{13}C$ (‰)	error (±)[1]	total error (±)[2]	%N	$\delta^{15}N$ (‰)	error (±)[1]	total error (±)[2]	atomic CN[3]	^{14}C Age (BP)[4]	$\delta^{13}C$ (‰)[5]	error (±)[1]	%C	$\delta^{13}C$ (‰)	error (±)[1]	%N	$\delta^{15}N$ (‰)	error (±)[1]	atomic CN[3]	Osteological Age	Osteological Sex	Inferred Sex
UB-4884	Melbourn: SK1188 SG79 (replicate)	32.5	–20.4	0.1	0.32	11.9	10.2	0.2	0.32	3.2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	50+	Male	
UB-4882	Melbourn: SK1187 SG80	40.0	–20.1	0.12	0.32	14.3	9.3	0.26	0.36	3.3	1378±20	–20.4	0.5	nd	nd	nd	nd	nd	nd	nd	50+	Male	Male?
UB-4887	Melbourn: SK 1229 SG82	34.8	–20.3	0.12	0.32	12.7	9.3	0.26	0.36	3.2	1421±20	–20.6	0.5	nd	nd	nd	nd	nd	nd	nd	18–29	Female	Female
UB-4888	Melbourn: SK1271 SG89	38.5	–20.3	0.12	0.32	13.5	9.1	0.26	0.36	3.3	1536±19	–20.6	0.5	nd	nd	nd	nd	nd	nd	nd	30–49	Female	Female
UB-4883	Melbourn: SK1038, SG95	35.8	–20.1	0.12	0.32	13.0	10.3	0.26	0.36	3.2	1416±20	–20.4	0.5	nd	nd	nd	nd	nd	nd	nd	30–49	Female	Female
UB-6479	Mill Hill: grave 40	39.9	–19.5	0.2	0.36	14.7	8.8	0.2	0.32	3.2	1555±22	–19.8	0.5	32.2	–19.5	0.1	11.7	8.8	0.15	3.2	30–49	Male	Male
UB-4728	Mill Hill: grave 64	45.6	–19.5	0.12	0.32	17.0	9.4	0.26	0.36	3.1	1496±22	–19.8	0.5	nd	nd	nd	nd	nd	nd	nd	18–29	Female?	Female
UB-4729	Mill Hill: grave 68	47.4	–19.5	0.12	0.32	17.5	10.2	0.26	0.36	3.2	1503±22	–19.7	0.5	nd	nd	nd	nd	nd	nd	nd	13–17		Female
UB-4730	Mill Hill: grave 79	31.0	–19.1	0.12	0.32	11.4	10.1	0.26	0.36	3.2	1542±18	–19.4	0.5	nd	nd	nd	nd	nd	nd	nd	30–49		Male
UB-4921	Mill Hill: grave 81	21.4	–20.3	0.1	0.32	7.7	9.3	0.3	0.39	3.3	1560±16	–20.6	0.5	nd	nd	nd	nd	nd	nd	nd	Adult	Male	Male
UB-4731	Mill Hill: grave 93	44.1	–19.8	0.12	0.32	16.2	10.1	0.26	0.36	3.2	1508±18	–20.1	0.5	nd	nd	nd	nd	nd	nd	nd	30–49	Male	Male
UB-4732	Mill Hill: grave 94	47.1	–19.7	0.12	0.32	17.0	9.9	0.26	0.36	3.2	1561±20	–20.0	0.5	nd	nd	nd	nd	nd	nd	nd	50+	Male	Female
UB-4733	Mill Hill: grave 95	36.0	–19.9	0.12	0.32	13.3	10.0	0.26	0.36	3.1	1606±20	–20.1	0.5	nd	nd	nd	nd	nd	nd	nd	50+	Female	Female
UB-4734	Mill Hill: grave 105C	60.7	–20.3	0.12	0.32	22.1	9.6	0.26	0.36	3.2	1587±19	–20.5	0.5	nd	nd	nd	nd	nd	nd	nd	30–49	Female	Female
UB-4961	St Peter's Tip: grave 8	45.5	–19.5	0.1	0.32	16.5	9.5	0.3	0.39	3.2	1447±17	–19.8	0.5	18.5	–18.9	0.1	6.7	9.4	0.15	3.2	50+	Male	Male
UB-4930	St Peter's Tip: grave 42	44.5	–19.4	0.1	0.32	16.1	8.7	0.3	0.39	3.2	1414±19	–19.7	0.5	nd	nd	nd	nd	nd	nd	nd	18–29	Male	Male
UB-6346	St Peter's Tip: grave 42 (replicate)	41.3	–19.0	0.2	0.36	15.0	8.1	0.2	0.32	3.2	1435±16	–19.3	0.5	25.5	–19.0	0.1	9.2	8.8	0.15	3.2	18–29	Male	Male
UB-4925	St Peter's Tip: grave 68	40.0	–19.5	0.1	0.32	14.5	10.2	0.3	0.39	3.2	1466±16	–19.7	0.5	nd	nd	nd	nd	nd	nd	nd	30–49	Male	Male
UB-4925	St Peter's Tip: grave 68 (replicate)	40.0	–19.3	0.1	0.32	15.0	10.3	0.2	0.32	3.1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	30–49	Male	Male
UB-6032	St Peter's Tip: grave 73A	58.8	–20.9	0.1	0.32	21.2	8.5	0.3	0.39	3.2	1422±17	–21.2	0.5	12.7	–19.7	0.1	4.6	8.6	0.15	3.2	13–17	Female -	Female
UB-6534	St Peter's Tip: grave 113 (replicate)	39.8	–19.4	0.2	0.36	14.4	8.8	0.2	0.32	3.2	1311±18	–19.7	0.5	34.5	–19.1	0.1	12.6	8.9	0.15	3.2	18–29	Male	
UB-4924	St Peter's Tip: grave 113	41.4	–19.7	0.1	0.32	15.0	8.3	0.3	0.39	3.2	1261±16	–20.0	0.5	nd	nd	nd	nd	nd	nd	nd	18–29	Male	Male
UB-4929	St Peter's Tip: grave 194	41.2	–20.0	0.1	0.32	15.0	9.9	0.3	0.39	3.2	1485±18	–20.3	0.5	nd	nd	nd	nd	nd	nd	nd	30–49	Male	Male
UB-4962	St Peter's Tip: grave 196	44.9	–19.9	0.1	0.32	16.3	9.1	0.3	0.39	3.2	1445±16	–20.2	0.5	31.9	–19.0	0.1	11.6	9.4	0.15	3.2	30–49	Male	Male
UB-4963	St Peter's Tip: grave 208	43.4	–19.8	0.1	0.32	15.4	9.5	0.3	0.39	3.3	1432±21	–20.1	0.5	14.7	–19.1	0.1	5.2	9.7	0.15	3.3	50+	Female	Female
UB-4926	St Peter's Tip: grave 212	37.7	–20.0	0.1	0.32	13.5	10.4	0.3	0.39	3.3	1537±18	–20.3	0.5	nd	nd	nd	nd	nd	nd	nd	30–49	Male	Male
UB-4928	St Peter's Tip: grave 250	39.8	–20.1	0.1	0.32	14.5	9.5	0.3	0.39	3.2	1458±18	–20.4	0.5	nd	nd	nd	nd	nd	nd	nd	50+	Male	Male
UB-4927	St Peter's Tip: grave 263	38.6	–19.8	0.1	0.32	14.2	9.3	0.3	0.39	3.2	1471±18	–20.0	0.5	nd	nd	nd	nd	nd	nd	nd	30–49	Male	Male
UB-4927	St Peter's Tip: grave 263 (replicate)	40.7	–19.7	0.1	0.32	15.2	9.7	0.2	0.32	3.1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	30–49	Male	Male
UB-4931	St Peter's Tip: grave 318	39.7	–20.0	0.1	0.32	14.4	9.7	0.3	0.39	3.2	1498±21	–20.3	0.5	nd	nd	nd	nd	nd	nd	nd	30–49	Male	Male
UB-6478	St Peter's Tip: grave 360	40.2	–20.1	0.2	0.36	14.5	10.6	0.2	0.32	3.2	1414±16	–20.4	0.5	nd	nd	nd	nd	nd	nd	nd	30–49	Male	Male
UB-6033	West Heslerton: grave 113	59.9	–20.8	0.1	0.32	20.3	10.6	0.3	0.39	3.4	1497±17	–21.1	0.5	12	–20.0	0.1	4.4	10.8	0.15	3.2	13–17	Female -	Female
UB-4706	West Heslerton: 002BA 00536	47.1	–19.9	0.12	0.32	17.2	9.0	0.26	0.36	3.2	1395±20	–20.2	0.5	nd	nd	nd	nd	nd	nd	nd	12–15		Female
UB-4705	West Heslerton: 002BA 00606	27.2	–20.3	0.12	0.32	9.9	8.9	0.26	0.36	3.2	1502±21	–20.6	0.5	nd	nd	nd	nd	nd	nd	nd	50+	Female	Female
UB-4985	Westgarth Gardens: grave 11	42.9	–20.8	0.1	0.32	15.3	8.4	0.3	0.39	3.3	1528±18	–21.1	0.5	19.9	–20.2	0.1	7.4	9.5	0.15	3.1	30–49	Male	Male
UB-4836	Westgarth Gardens: grave 27	44.5	–19.8	0.2	0.36	16.1	9.6	0.2	0.32	3.2	1560±20	–20.1	0.5	nd	nd	nd	nd	nd	nd	nd	Adult		Female
UB-4682	Westgarth Gardens: grave 66	41.1	–19.9	0.2	0.36	15.2	9.9	0.2	0.32	3.2	1491±18	–20.2	0.2	nd	nd	nd	nd	nd	nd	nd	30–49	Male	Male

Table 2: replicate carbon and nitrogen stable isotope measurements on whole bone samples from 14 skeletons. The 1σ differences in replicate stable isotopes measurements for $\delta^{13}C$ were a mean of 0.3‰, with maximum difference of 0.8‰ (Lechlade grave 40); for $\delta^{15}N$, there was a mean difference of 0.4‰, with a maximum of 3.3‰ (Edix Hill grave 48). 1) Error on stable isotope analysis is determined from mean std dev at 1σ on EDTA standards within the stable isotope analysis run; 2) Total error reported for ^{15}N and ^{13}C includes analytical error and variation in stable isotope results associated with chemistry preparation of the bone protein (see Section 2.2); 3) Atomic CN ratio=(%C/%N)(14/12)*

Laboratory Number	Site/context	%C	$\delta^{13}C$ (‰)	error (±)1	total error $(\pm)^2$	%N	$\delta^{15}N$ (‰)	error (±)1	total error $(\pm)^2$	atomic CN[3]	χ^2 ($\delta^{13}C$ ± total error) ($\chi^2(5\%)=3.8$; $\nu=1$ for all)	χ^2($\delta^{15}N$ ± total error) ($\chi^2(5\%)=3.8$; $\nu=1$ for all)
UB-4965	Apple Down: grave 117	45.6	–20.6	0.1	0.3	16.7	7.9	0.3	0.4	3.2	0.7	0.4
UB-6344	Apple Down: grave 117 (replicate)	38.5	–20.2	0.2	0.4	13.8	8.2	0.2	0.3	3.3		
UB-6472	Dover Buckland: grave 222	43.5	–19.8	0.2	0.4	16.1	9.8	0.2	0.3	3.2	0.3	0.2
UB-6472	Dover Buckland: grave 222 (replicate)	38.4	–20.1	0.1	0.3	14.1	9.6	0.2	0.3	3.2		
UB-6474	Dover Buckland: grave 264	39.2	–19.7	0.2	0.4	14.4	9.3	0.2	0.3	3.2		
UB-6474	Dover Buckland: grave 264 (replicate)	42.6	–20.0	0.1	0.3	15.9	9.5	0.2	0.3	3.1	0.3	0.2
UB-4923	Edix Hill: grave 7	39.5	–20.3	0.1	0.3	14.3	10.1	0.3	0.4	3.2	0.0	1.2
UB-4923	Edix Hill: grave 7 (replicate)	38.2	–20.4	0.1	0.3	14.1	10.7	0.2	0.3	3.2		
UB-4511	Edix Hill: grave 90	36.5	–20.1	0.1	0.3	13.1	9.6	0.3	0.4	3.3	1.5	0.4
UB-4511	Edix Hill: grave 90 (replicate)	39.6	–20.7	0.1	0.3	14.5	9.9	0.2	0.3	3.2		
UB-4984	Lechlade: grave 18	39.0	–20.4	0.1	0.3	13.9	8.0	0.3	0.4	3.3	0.2	4.8
UB-4984	Lechlade: grave 18 (replicate)	37.3	–20.6	0.1	0.3	13.5	9.1	0.2	0.3	3.2		
UB-4683	Lechlade: grave 40	41.6	–19.7	0.2	0.4	15.3	10.5	0.2	0.3	3.2	2.6	1.8
UB-4683	Lechlade: grave 40 (replicate)	42.8	–20.5	0.1	0.3	15.8	11.1	0.2	0.3	3.1		
UB-4886	Melbourn: SK1204 SG77	32.1	–20.0	0.1	0.3	11.4	8.9	0.3	0.4	3.3	1.1	0.2
UB-6345	Melbourn: SK1204 SG77 (replicate)	38.3	–19.5	0.2	0.4	13.8	8.7	0.2	0.3	3.2		
UB-4885	Melbourn: lnL1189 SG78	36.6	–20.1	0.1	0.3	13.3	9.5	0.3	0.4	3.2	0.7	0.4
UB-4885	Melbourn: lnL1189 SG78 (replicate)	41.3	–20.5	0.1	0.3	15.3	9.2	0.2	0.3	3.2		

Laboratory Number	Site/context	%C	$\delta^{13}C$ (‰)	error (±)1	total error (±)^2	%N	$\delta^{15}N$ (‰)	error (±)1	total error (±)^2	atomic CN^3	χ^2 ($\delta^{13}C$ ± total error) ($\chi^2(5\%)=3.8$; $\nu=1$ for all)	χ^2($\delta^{15}N$ ± total error) ($\chi^2(5\%)=3.8$; $\nu=1$ for all)
UB-4884	Melbourn: SK1188 SG79	37.4	–20.4	0.1	0.3	13.3	10.4	0.3	0.4	3.3		
UB-4884	Melbourn: SK1188 SG79 (replicate)	32.5	–20.4	0.1	0.3	11.9	10.2	0.2	0.3	3.2	0.0	0.2
UB-4930	St Peter's Tip: grave 42	44.5	–19.4	0.1	0.3	16.1	8.7	0.3	0.4	3.2	0.7	1.4
UB-6346	St Peter's Tip: grave 42 (replicate)	41.3	–19.0	0.2	0.4	15.0	8.1	0.2	0.3	3.2		
UB-4925	St Peter's Tip: grave 68	40.0	–19.5	0.1	0.3	14.5	10.2	0.3	0.4	3.2	0.2	0.0
UB-4925	St Peter's Tip: grave 68 (replicate)	38.8	–19.3	0.1	0.3	14.6	10.3	0.2	0.3	3.1		
UB-4924	St Peter's Tip: grave 113	41.4	–19.7	0.1	0.3	15.0	8.3	0.3	0.4	3.2	0.4	1.0
UB-6534	St Peter's Tip: grave 113 (replicate)	39.8	–19.4	0.2	0.4	14.4	8.8	0.2	0.3	3.2		
UB-4927	St Peter's Tip: grave 263	38.6	–19.8	0.1	0.3	14.2	9.3	0.3	0.4	3.2	0.0	0.6
UB-4927	St Peter's Tip: grave 263 (replicate)	40.7	–19.7	0.1	0.3	15.2	9.7	0.2	0.3	3.1		

Table 3: Amino acid and CN results for freeze-dried gelatin on eighty-five burials and fourteen replicate samples. Amino acid analysis of the skeletons are compared to expected values for amino acid profiles in un-degraded bone (van Klinken and Mook 1990,156), the CN range for modern and good prehistoric collagen (DeNiro 1985), and ideal Gly/Ala and Gly/Asp ratios based upon a modern collagen profile of van Klinken and Mook (1990, 156)

Laboratory Number	Site/Context	Residues per 1000 (± 5 residues/1000)							atomic C:N	Gly/Ala	Gly/Asp
		Hydroproline (Hyp)	Aspartic acid (Asp)	Glutamic acid (Glu)	Proline (Pro)	Glycine (Gly)	Alanine (Ala)	Arginine (Arg)			
Ideal Amino Acid and CN ratios		101	51	75	116	317	113	49	2.9–3.6	2.8	6.2
UB-5208	Apple Down: grave 107	74	58	94	103	348	116	47	3.3	3.0	6.0
UB-4965	Apple Down: grave 117	80	56	89	129	318	112	47	3.2	2.8	5.7
UB-6344	Apple Down: grave 117 (replicate)	104	50	97	102	299	123	54	3.3	2.4	6.0
UB-4835	Apple Down: grave 134	74	54	90	100	359	114	50	3.2	3.1	6.6
UB-4975	Aston Clinton: grave 12	79	60	97	137	321	112	47	3.3	2.9	5.3
UB-4735	Berinsfield: grave 22	82	49	70	120	352	122	44	3.2	2.9	7.2
UB-4736	Berinsfield: grave 28	85	49	71	117	346	122	45	3.3	2.8	7.1
UB-4739	Berinsfield: grave 134/1	73	55	95	101	332	119	47	3.2	2.8	6.1
UB-4964	Coddenham: grave 308	79	54	90	130	321	117	48	3.1	2.7	5.9
UB-6472	Dover Buckland: grave 222	77	53	95	105	339	117	50	3.2	2.9	6.3
UB-6473	Dover Buckland: grave 250	75	56	99	98	340	114	50	3.2	3.0	6.0
UB-6474	Dover Buckland: grave 264	75	49	89	106	347	116	51	3.2	3.0	7.1
UB-6475	Dover Buckland: grave 323	75	53	95	101	322	116	52	3.2	2.8	6.0
UB-6476	Dover Buckland: grave 339	75	49	88	104	354	115	51	3.1	3.1	7.3
UB-6477	Dover Buckland: grave 414	75	52	94	105	333	117	51	3.2	2.8	6.5
UB-4923	Edix Hill: grave 7	76	44	83	106	364	114	51	3.2	3.2	8.2
UB-4508	Edix Hill: grave 12	42	72	89	123	314	137	57	3.2	2.3	4.4
UB-4709	Edix Hill: grave 14	82	51	83	142	322	95	51	3.3	3.4	6.3
UB-4509	Edix Hill: grave 33	48	60	84	135	339	137	56	3.2	2.5	5.6
UB-4510	Edix Hill: grave 48	39	73	94	118	309	129	56	3.3	2.4	4.2
UB-4922	Edix Hill: grave 48 (replicate)	73	57	89	110	316	126	50	3.3	2.5	5.5
UB-4707	Edix Hill: grave 79	82	50	81	116	313	122	54	3.2	2.6	6.3

Laboratory Number	Site/Context	Residues per 1000 (± 5 residues/1000)							atomic C:N	Gly/Ala	Gly/Asp
		Hydroproline (Hyp)	Aspartic acid (Asp)	Glutamic acid (Glu)	Proline (Pro)	Glycine (Gly)	Alanine (Ala)	Arginine (Arg)			
Ideal Amino Acid and CN ratios		101	51	75	116	317	113	49	2.9–3.6	2.8	6.2
UB-4708	Edix Hill: grave 83	79	58	83	124	314	110	52	3.2	2.8	5.4
UB-4511	Edix Hill: grave 90	47	61	83	135	334	137	53	3.3	2.4	5.5
UB-4512	Edix Hill: grave 91	47	60	83	134	341	136	53	3.3	2.5	5.7
UB-4976	Ford, Laverstock: barrow 2	77	53	93	135	308	117	48	3.3	2.6	5.8
UB-4727	Gally Hills: primary burial	77	71	91	111	306	116	53	3.3	2.6	4.3
UB-4727	Gally Hills: primary burial	77	71	91	111	306	116	53	3.3	2.6	4.3
UB-4920	Gally Hills: primary burial (replicate)	77	52	95	101	362	114	42	3.3	3.2	7.0
UB-6347	Lakenheath: ERL 104 4222	100	51	95	100	312	119	51	3.3	2.6	6.1
UB-4501	Lechlade: grave 14	65	47	88	139	310	123	54	3.2	2.5	6.7
UB-4984	Lechlade: grave 18	76	61	95	128	306	112	47	3.3	2.7	5.1
UB-4683	Lechlade: grave 40	76	49	89	99	355	118	50	3.2	3.0	7.2
UB-4502	Lechlade: grave 138	64	55	91	133	308	121	53	3.2	2.5	5.6
UB-4503	Lechlade: grave 148	66	47	88	136	309	123	55	3.2	2.5	6.6
UB-4982	Lechlade: grave 155	82	38	95	136	322	114	48	3.3	2.8	8.5
UB-4505	Lechlade: grave 172/1	81	50	70	114	346	121	45	3.2	2.9	6.9
UB-4506	Lechlade: grave 172/2	86	48	72	119	351	121	44	3.2	2.9	7.3
UB-4504	Lechlade: grave 179	90	48	71	114	347	118	46	3.2	2.9	7.2
UB-4981	Lechlade: grave 183	80	58	93	131	311	115	48	3.3	2.7	5.4
UB-4507	Lechlade: grave 187	81	47	69	117	347	122	45	3.1	2.8	7.4
UB-4549	Marina Drive: grave C7	53	64	87	117	346	123	52	3.2	2.8	5.4
UB-4553	Marina Drive: grave D10	56	53	83	124	354	119	51	3.2	3.0	6.7
UB-4550	Marina Drive: grave E1	60	66	100	133	392	127	59	3.2	3.1	5.9
UB-4551	Marina Drive: grave E2	56	68	92	118	339	122	55	3.2	2.8	5.0
UB-4552	Marina Drive: grave E3	53	59	90	113	348	121	51	3.3	2.9	5.9
UB-4554	Marina Drive: grave F2	55	66	94	114	349	121	53	3.3	2.9	5.3
UB-4889	Melbourn: SK1293, SG69	75	53	87	121	336	129	50	3.3	2.6	6.4
UB-4890	Melbourn: SK1307 SG75	73	55	94	117	325	129	50	3.3	2.5	5.9
UB-4886	Melbourn: SK1204 SG77	72	55	90	118	316	125	51	3.3	2.5	5.8

Laboratory Number	Site/Context	Residues per 1000 (± 5 residues/1000)							atomic C:N	Gly/Ala	Gly/Asp
		Hydroproline (Hyp)	Aspartic acid (Asp)	Glutamic acid (Glu)	Proline (Pro)	Glycine (Gly)	Alanine (Ala)	Arginine (Arg)			
Ideal Amino Acid and CN ratios		101	51	75	116	317	113	49	2.9–3.6	2.8	6.2
UB-6345	Melbourn: SK1204 SG77 (replicate)	98	50	92	99	324	116	51	3.2	2.8	6.5
UB-4885	Melbourn: lnL1189 SG78	73	50	89	122	320	129	51	3.2	2.5	6.4
UB-4884	Melbourn: SK1188 SG79	76	45	90	118	327	130	53	3.3	2.5	7.2
UB-4882	Melbourn: SK1187 SG80	81	43	90	122	314	128	49	3.3	2.4	7.3
UB-4887	Melbourn: SK 1229 SG82	74	43	87	120	332	130	51	3.2	2.5	7.7
UB-4888	Melbourn: SK1271 SG89	72	52	86	112	326	128	52	3.3	2.5	6.2
UB-4883	Melbourn: SK1038, SG95	76	49	89	118	328	130	52	3.2	2.5	6.7
UB-6479	Mill Hill: grave 40	72	55	90	114	325	129	49	3.2	2.5	5.9
UB-4728	Mill Hill: grave 64	76	69	90	112	310	110	53	3.1	2.8	4.5
UB-4729	Mill Hill: grave 68	79	65	87	115	318	112	52	3.2	2.8	4.9
UB-4730	Mill Hill: grave 79	80	61	86	117	320	112	53	3.2	2.8	5.2
UB-4921	Mill Hill: grave 81	73	51	91	115	322	127	47	3.3	2.5	6.3
UB-4731	Mill Hill: grave 93	81	62	88	120	318	106	53	3.2	3.0	5.1
UB-4732	Mill Hill: grave 94	81	61	85	121	318	111	51	3.2	2.9	5.2
UB-4733	Mill Hill: grave 95	78	61	88	121	312	110	51	3.1	2.8	5.1
UB-4734	Mill Hill: grave 105C	81	63	86	121	314	112	53	3.2	2.8	5.0
UB-4961	St Peter's Tip: grave 8	83	58	93	130	314	115	45	3.2	2.7	5.5
UB-4930	St Peter's Tip: grave 42	69	53	97	119	339	126	51	3.2	2.7	6.4
UB-6346	St Peter's Tip: grave 42 (replicate)	119	53	112	113	218	141	56	4.2	1.6	4.1
UB-4925	St Peter's Tip: grave 68	60	51	98	118	346	125	52	3.2	2.8	6.8
UB-6032	St Peter's Tip: grave 73A	99	51	90	102	328	121	50	3.2	2.7	6.4
UB-4924	St Peter's Tip: grave 113	71	46	98	120	344	128	51	3.2	2.7	7.4
UB-6534	St Peter's Tip: grave 113 (replicate)	75	47	93	103	358	119	50	3.2	3.0	7.6
UB-4929	St Peter's Tip: grave 194	70	50	97	116	345	125	52	3.2	2.8	7.0
UB-4962	St Peter's Tip: grave 196	77	56	92	135	311	120	47	3.2	2.6	5.6
UB-4963	St Peter's Tip: grave 208	82	69	97	137	327	123	48	3.3	2.7	4.7
UB-4926	St Peter's Tip: grave 212	70	49	98	118	341	126	53	3.3	2.7	7.0
UB-4928	St Peter's Tip: grave 250	69	53	99	119	334	124	52	3.2	2.7	6.2

Laboratory Number	Site/Context	Residues per 1000 (± 5 residues/1000)							atomic C:N	Gly/Ala	Gly/Asp
		Hydroproline (Hyp)	Aspartic acid (Asp)	Glutamic acid (Glu)	Proline (Pro)	Glycine (Gly)	Alanine (Ala)	Arginine (Arg)			
Ideal Amino Acid and CN ratios		101	51	75	116	317	113	49	2.9–3.6	2.8	6.2
UB-4927	St Peter's Tip: grave 263	70	51	99	118	341	125	52	3.2	2.7	6.7
UB-4931	St Peter's Tip: grave 318	69	53	98	120	340	124	49	3.2	2.7	6.4
UB-6478	St Peter's Tip: grave 360	67	55	98	122	336	125	51	3.2	2.7	6.1
UB-6033	West Heslerton: grave 113	102	49	92	104	342	126	52	3.4	2.7	7.0
UB-4706	West Heslerton: 002BA 00536	80	56	83	125	314	111	49	3.2	2.8	5.7
UB-4705	West Heslerton: 002BA 00606	83	51	80	133	308	109	52	3.2	2.8	6.0
UB-4985	Westgarth Gardens: grave 11	79	56	93	131	321	116	48	3.3	2.8	5.7
UB-4836	Westgarth Gardens: grave 27	71	53	96	119	340	123	52	3.2	2.8	6.4
UB-4682	Westgarth Gardens: grave 66	73	51	99	118	342	125	53	3.2	2.7	6.7

Table 4: Gly/Ala, Gly/Asp, and CN ratios on duplicate analysis of six skeletons

Ideal Amino Acid and CN ratios		2.8	6.2	2.9–3.6
Site/context	Laboratory Number	Gly/Ala	Gly /Asp	CN
Apple Down: grave 117	UB-4965	2.8	5.7	3.2
	UB-6344	2.4	6.0	3.2
Edix Hill: grave 48	UB-4510	2.4	4.2	3.3
	UB-4922	2.5	5.5	3.3
Gally Hills: primary burial	UB-4727	2.6	4.3	3.3
	UB-4920	3.2	7.0	na
Melbourn: SK1204 SG77	UB-4886	2.5	5.8	3.3
	UB-6345	2.8	6.5	3.2
St Peter's Tip: grave 42	UB-4930	2.2	6.4	3.2
	UB-6346	1.6	4.1	3.2
St Peter's Tip: grave 113	UB-4924	2.7	7.4	3.2
	UB-6534	3.0	7.6	3.2

Table 5: Comparison of amino acid and stable isotope analyses for replicate samples of freeze-dried gelatin prepared at Rafter radiocarbon and collagen from Queen's University, Belfast for samples from the same skeletons. Amino acid analysis of the skeletons are compared to expected values for amino acid profiles in un-degraded bone (van Klinken and Mook 1990,156) and ideal Gly/Ala and Gly/Asp ratios based upon a modern collagen profile of van Klinken and Mook (1990, 156). Amino acid analyses are reported with typical ±5 residues/1000. 1) Error on stable isotope analysis is determined from mean error on EDTA standards within the stable isotope analysis run; 2) Total error reported for ^{15}N and ^{13}C includes analytical error and variation in stable isotope results associated with chemistry preparation of the bone protein (see text); similar total error cannot be calculated for UB collagen; 3) atomic CN ratio = (%C/%N)(14/12)*

		Amino acid analysis (± 5 residues/1000)									Carbon and nitrogen analysis								
Laboratory Number	Site/context	Hydroproline (Hyp)	Aspartic (Asp)	Glutamic (Glu)	Proline (Pro)	Glycine (Gly)	Alanine (Ala)	Arginine (Arg)	Gly/Ala	Gly/Asp	%C	$\delta^{13}C$ (‰)	error (±)[1]	total error (±)[2]	%N	$\delta^{15}N$ (‰)	error (±)1	total error (±)[2]	atomic CN[3]
Ideal Amino Acid values		101	51	75	116	317	113	49	2.8	6.2									
UB-4965	Apple Down: grave 117	80	56	89	129	318	112	47	2.8	6	45.6	−20.6	0.1	0.32	16.7	7.9	0.3	0.39	3.2
	UB collagen	75	30.7	82	128	338	127	52	2.7	11	4.3	−20.7	0.1	na	1.4	8.2	0.15	na	3.6
UB-4975	Aston Clinton: grave 12	79	60	97	137	321	112	47	2.9	5	39.33	−20.8	0.1	0.32	13.96	9.35	0.3	0.39	3.3
	UB collagen	79	44	85	226	309	126	54	2.5	7	10.4	−20.3	0.1	na	3.7	10	0.15	na	3.3
UB-4964	Coddenham: grave 308	79	54	90	130	321	117	48	2.7	6	45.9	−20.4	0.1	0.32	17.1	10.3	0.3	0.39	3.1
	UB collagen	80	44	92	123	343	137	51	2.5	8	19.6	−19.6	0.1	na	7.1	10.6	0.15	na	3.2
UB-4983	Lechlade: grave 136	64	47	75	106	293	94	38	3.1	6	41.8	−20.7	0.1	0.32	14.6	9.8	0.3	0.39	3.3
	UB collagen	80	38	79	141	297	133	56	2.2	8	8.2	−19.9	0.1	na	2.9	9.3	0.15	na	3.3
UB-4982	Lechlade: grave 155	82	38	95	136	322	114	48	2.8	8	44.8	−20.7	0.1	0.32	15.7	9.7	0.3	0.39	3.3
	UB collagen	76	28	67	137	336	138	54	2.4	12	9.1	−20.6	0.1	na	3.5	10.5	0.15	na	3.0
UB-4984	Lechlade: grave 18	76	61	95	128	306	112	47	2.7	5	39	−20.4	0.1	0.32	13.9	8	0.3	0.39	3.3
	UB collagen	79	24	70	148	350	147	55	2.4	14	9.5	−19.6	0.1	na	3.4	9.4	0.15	na	3.3
UB-4981	Lechlade: grave 183	80	58	93	131	311	115	48	2.7	5	39.8	−20.3	0.1	0.32	14.1	8	0.3	0.39	3.3
	UB collagen	81	35	76	138	305	128	54	2.4	9	6.3	−20.1	0.1	na	2.3	9.4	0.15	na	3.2
UB-4962	St Peter's Tip: grave 196	77	56	92	135	311	120	47	2.6	6	44.9	−19.9	0.1	0.32	16.3	9.1	0.3	0.39	3.2
	UB collagen	72	33	88	130	328	140	53	2.3	10	31.9	−19.0	0.1	na	11.6	9.4	0.15	na	3.2
UB-4963	St Peter's Tip: grave 208	82	69	97	137	327	123	48	2.7	5	43.4	−19.8	0.1	0.32	15.4	9.5	0.3	0.39	3.3
	UB collagen	82	29	69	144	401	139	49	2.9	14	14.7	−19.1	0.1	na	5.2	9.7	0.15	na	3.3
UB-4961	St Peter's Tip: grave 8	83	58	93	130	314	115	45	2.7	5	45.5	−19.5	0.1	0.32	16.5	9.5	0.3	0.39	3.2
	UB collagen	74	30	80	137	324	147	53	2.2	11	18.5	−18.9	0.1	na	6.7	9.4	0.15	na	3.2
UB-4985	Westgarth Gardens: grave 11	79	56	93	131	321	116	48	2.8	6	42.9	−20.8	0.1	0.32	15.3	8.4	0.3	0.39	3.3
	UB collagen	71	41	94	127	350	142	52	2.5	9	19.9	−20.2	0.1	na	7.4	9.5	0.15	na	3.1
UB-4508	Edix Hill: grave 12	42	72	89	123	314	137	57	2.3	4	-	-	-	-	-	-	-	-	-
	UB collagen	70	50	112	182	138	191	71	0.7	3	-	-	-	-	-	-	-	-	-
UB-4709	Edix Hill: grave 14	82	51	83	142	322	95	51	3.4	6	-	-	-	-	-	-	-	-	-
	UB collagen	84	69	88	139	346	134	55	2.6	5	-	-	-	-	-	-	-	-	-
UB-4509	Edix Hill: grave 33	48	60	84	135	339	137	56	2.5	6	-	-	-	-	-	-	-	-	-
	UB collagen	59	63	126	174	121	188	71	0.6	2	-	-	-	-	-	-	-	-	-
UB-4510	Edix Hill: grave 48	39	73	94	118	309	129	56	2.4	4	-	-	-	-	-	-	-	-	-
	UB collagen	64	56	117	194	131	212	67	0.6	2	-	-	-	-	-	-	-	-	-
UB-4707	Edix Hill: grave 79	82	50	81	116	313	122	54	2.6	6	-	-	-	-	-	-	-	-	-
	UB collagen	77	41	87	123	318	121	52	2.6	8	-	-	-	-	-	-	-	-	-
UB-4708	Edix Hill: grave 83	79	58	83	124	314	110	52	2.8	5	-	-	-	-	-	-	-	-	-
	UB collagen	62	45	113	140	179	105	83	1.7	4	-	-	-	-	-	-	-	-	-
UB-4511	Edix Hill: grave 90	47	61	83	135	334	137	53	2.4	6	-	-	-	-	-	-	-	-	-
	UB collagen	47	57	95	127	361	136	51	2.7	6	-	-	-	-	-	-	-	-	-
UB-4512	Edix Hill: grave 91	47	60	83	134	341	136	53	2.5	6	-	-	-	-	-	-	-	-	-
	UB collagen	60	57	113	190	165	210	65	0.8	3	-	-	-	-	-	-	-	-	-

		Amino acid analysis (± 5 residues/1000)									Carbon and nitrogen analysis								
Laboratory Number	Site/context	Hydroproline (Hyp)	Aspartic (Asp)	Glutamic (Glu)	Proline (Pro)	Glycine (Gly)	Alanine (Ala)	Arginine (Arg)	Gly/Ala	Gly/Asp	%C	$\delta^{13}C$ (‰)	error (±)[1]	total error (±)[2]	%N	$\delta^{15}N$ (‰)	error (±)1	total error (±)[2]	atomic CN[3]
Ideal Amino Acid values		101	51	75	116	317	113	49	2.8	6.2									
UB-4976	Ford, Laverstock: barrow 2	77	53	93	135	308	117	48	2.6	6	-	-	-	-	-	-	-	-	-
	UB collagen	74	39	83	124	337	130	51	2.6	9	-	-	-	-	-	-	-	-	-
UB-4727	Gally Hills: primary burial	77	71	91	111	306	116	53	2.6	4	-	-	-	-	-	-	-	-	-
	UB collagen	85	53	116	166	112	179	69	0.6	2	-	-	-	-	-	-	-	-	-
UB-4549	Marina Drive: grave C7	53	64	87	117	346	123	52	2.8	5	-	-	-	-	-	-	-	-	-
	UB collagen	59	39	84	142	314	143	52	2.2	8	-	-	-	-	-	-	-	-	-
UB-4553	Marina Drive: grave D10	56	53	83	124	354	119	51	3.0	7	-	-	-	-	-	-	-	-	-
	UB collagen	60	49	94	139	312	140	51	2.2	6	-	-	-	-	-	-	-	-	-
UB-4550	Marina Drive: grave E1	60	66	100	133	392	127	59	3.1	6	-	-	-	-	-	-	-	-	-
	UB collagen	57	37	95	142	318	146	52	2.2	9	-	-	-	-	-	-	-	-	-
UB-4551	Marina Drive: grave E2	56	68	92	118	339	122	55	2.8	5	-	-	-	-	-	-	-	-	-
	UB collagen	62	39	85	142	320	140	53	2.3	8	-	-	-	-	-	-	-	-	-
UB-4552	Marina Drive: grave E3	53	59	90	113	348	121	51	2.9	6	-	-	-	-	-	-	-	-	-
	UB collagen	61	40	89	144	321	141	53	2.3	8	-	-	-	-	-	-	-	-	-
UB-4554	Marina Drive: grave F2	55	66	94	114	349	121	53	2.9	5	-	-	-	-	-	-	-	-	-
	UB collagen	52	36	75	118	259	115	45	2.3	7	-	-	-	-	-	-	-	-	-
UB-4734	Mill Hill: grave 105C	81	63	86	121	314	112	53	2.8	5	-	-	-	-	-	-	-	-	-
	UB collagen	81	41	93	122	333	123	54	2.7	8	-	-	-	-	-	-	-	-	-
UB-4728	Mill Hill: grave 64	76	69	90	112	310	110	53	2.8	4	-	-	-	-	-	-	-	-	-
	UB collagen	75	46	92	125	339	135	51	2.5	7	-	-	-	-	-	-	-	-	-
UB-4729	Mill Hill: grave 68	79	65	87	115	318	112	52	2.8	5	-	-	-	-	-	-	-	-	-
	UB collagen	68	46	94	123	343	143	51	2.4	7	-	-	-	-	-	-	-	-	-
UB-4730	Mill Hill: grave 79	80	61	86	117	320	112	53	2.8	5	-	-	-	-	-	-	-	-	-
	UB collagen	68	44	92	129	321	136	53	2.4	7	-	-	-	-	-	-	-	-	-
UB-4731	Mill Hill: grave 93	81	62	88	120	318	106	53	3.0	5	-	-	-	-	-	-	-	-	-
	UB collagen	77	36	82	124	345	131	54	2.6	10	-	-	-	-	-	-	-	-	-
UB-4732	Mill Hill: grave 94	81	61	85	121	318	111	51	2.9	5	-	-	-	-	-	-	-	-	-
	UB collagen	74	42	89	125	329	131	52	2.5	8	-	-	-	-	-	-	-	-	-
UB-4733	Mill Hill: grave 95	78	61	88	121	312	110	51	2.8	5	-	-	-	-	-	-	-	-	-
	UB collagen	75	41	92	130	328	140	52	2.4	8	-	-	-	-	-	-	-	-	-
UB-4705	West Heslerton: 002BA 00606	83	51	80	133	308	109	52	2.8	6	-	-	-	-	-	-	-	-	-
	UB collagen	40	59	90	105	292	118	61	2.5	5	-	-	-	-	-	-	-	-	-
UB-4706	West Heslerton: 002BA 00536	80	56	83	125	314	111	49	2.8	6	-	-	-	-	-	-	-	-	-
	UB collagen	74	55	123	198	147	200	77	0.7	3	-	-	-	-	-	-	-	-	-

Tables 6a–m. ISOSOURCE isotopic mass balance mixing model (Phillips and Gregg 2003) based on mean $\delta^{13}C$ and $\delta^{15}N$, and statistical tests on variance between high and low $\delta^{15}N$ for males and females in individual sites. Significant variation between highest and lowest $\delta^{15}N$ for each sex within sites may indicate different sources or richness of protein in diet. ISOSOURCE results for each site use means given for $\delta^{13}C$ and $\delta^{15}N$, relative to known means for food sources (terrestrial vegetable, terrestrial protein, eel, freshwater fish, salmonid, and marine) collated from British archaeological sites (Richards et al 2006; Jay and Richards 2006; Privat et al 2002; Richards 2000; Müldner and Richards 2005; DeNiro and Epstein 1978); the mean of each food type had bio-magnification factors of +1‰ for carbon and +4‰ for nitrogen added before calculations

Table 6a. Similar diets of females from Appledown; ISOSOURCE terrestrial vegetation portion of diet indicates high proportion of terrestrial vegetation in diet

Laboratory Number	Site/Context	$\delta^{13}C$ (‰)	total error (±)**	$\delta^{15}N$ (‰)	total error (±)**	Osteological Age	Osteological Sex/Inferred Sex
UB-5208	Apple Down: grave 107	–20.3	0.36	+8.0	0.32	30–49	Female
UB-4835	Apple Down, grave 134	–20.2	0.36	+8.7	0.32	18–29	Female
UB-4965	Apple Down: grave 117	–20.4	0.24	+8.1	0.25	50+	Female
	mean	–20.3	0.32	+8.3	0.3		
ISOSOURCE	%	error					
Terrestrial vegetation	61.5	6.9		‰ difference between highest and lowest $\delta^{15}N$: 0.7‰			
Terrestrial protein	14.6	11.5		χ^2-Test: df=1 T= 2.4 (5% 3.8)			
Eel	4.9	3.9					
Freshwater fish	4.4	3.5					
Salmonid	8.1	5.3					
Marine	6.5	4.3					

Table 6b: Significant difference between the two females at Berinsfield; for UB-4735, the $\delta^{15}N$ enrichment of +1.5‰ points to higher proportions or a different source of protein in the diet

Laboratory Number	Site/Context	$\delta^{13}C$ (‰)	total error (±)**	$\delta^{15}N$ (‰)	total error (±)**	Osteological Age	Osteological Sex/Inferred Sex
UB-4739	Berinsfield: grave 134/1	–20.3	0.32	+8.8	0.36	50+	Female
UB-4735	Berinsfield: grave 22	–19.9	0.32	+10.3	0.36	18–29	Female
	mean	–20.1	0.32	+9.5	0.36		
ISOSOURCE	%	error					
Terrestrial vegetation	46.8	9.9		‰ difference between highest and lowest $\delta^{15}N$: 1.5‰			
Terrestrial protein	22.1	17.1		χ^2-Test fails at 5% - $\delta^{15}N$ range Berinsfield females χ^2-Test: df=1 T=8.649 (5% 3.8)			
Eel	8.1	5.9					
Freshwater fish	7.1	5.4					
Salmonid	8.8	5.8					
Marine	7	4.7					
UB-4736	Berinsfield: grave 22	–20.0	0.32	+9.5	0.36	30–49	Male
ISOSOURCE	%	error					
Terrestrial vegetation	47.3	9.6					
Terrestrial protein	21.3	16.5					
Eel	7.6	5.6					
Freshwater fish	6.7	5.1					
Salmonid	9.5	6.2					
Marine	7.6	5					

Table 6c: Significant variation in highest and lowest $\delta^{15}N$ for both females and males at Castledyke

Laboratory Number	Site/Context	$\delta^{13}C$ (‰)	total error (±)**	$\delta^{15}N$ (‰)	total error (±)**	Osteological Age	Osteological Sex/Inferred Sex
UB-6034	Castledyke South: grave 120	–20.9	0.32	+9.7	0.39	13–17	Female
UB-6037	Castledyke South: grave 134	–20.6	0.32	+10.0	0.39	13–17	Female
UB-6036	Castledyke South: grave 13	–20.9	0.32	+11.5	0.39	18–29	Female
UB-6038	Castledyke South: grave 183	–21.0	0.32	+9.9	0.39	18–29	Female
UB-6042	Castledyke South: grave 88	–20.3	0.32	+10.1	0.39	18–29	Female
UB-6035	Castledyke South: grave 96	–21.3	0.32	+11.0	0.39	18–29	Female
UB-6040	Castledyke South: grave 53	–21.1	0.32	+10.2	0.39	30–49	Female
	mean	–20.9	0.32	+10.3	0.39		
ISOSOURCE	%	error					
Terrestrial vegetation	39.4	10.2		‰ difference between highest and lowest $\delta^{15}N$: 1.8‰			
Terrestrial protein	22	17.5		χ^2-Test fails at 5%: df=1 T=10.7 (5% 3.8)			
Eel	18.7	10.1					
Freshwater fish	12.8	9.3					
Salmonid	4	3.3					
Marine	3.1	2.7					
UB-6041	Castledyke South: grave 182	–20.5	0.32	+8.9	0.39	18–29	Male
UB-6039	Castledyke South: grave 94	–20.5	0.32	+10.1	0.39	30–49	Male
	mean	–20.5	0.32	+9.5	0.39		

ISOSOURCE	%	error					
Terrestrial vegetation	46	10.6		‰ difference between highest and lowest $\delta^{15}N$: 1.2‰			
Terrestrial protein	23.6	18.5		χ^2-Test fails at 5%: df=1 T=4.7 (5% 3.8)			
Eel	10.5	7.1					
Freshwater fish	8.8	6.5					
Salmonid	6.2	4.5					
Marine	4.9	3.6					

Table 6d: Significant difference in highest/lowest $\delta^{15}N$ seen only in females at Dover Buckland. This table and calculations exclude UB-4958 (Dover Buckland, grave 375) and UB-4959 (Dover Buckland, grave 391A) as these skeletons have no sex data

Laboratory Number	Site/Context	$\delta^{13}C$ (‰)	total error (±)**	$\delta^{15}N$ (‰)	total error (±)**	Osteological Age	Osteological Sex/Inferred Sex
UB-6476	Dover Buckland: grave 339	–19.7	0.36	+8.9	0.32	18–29	Female
UB-6473	Dover Buckland: grave 250	–19.8	0.36	+10.4	0.32	30–49	Female
UB-6472	Dover Buckland: grave 222	–20.0	0.24	+9.7	0.23	50+	Female
	mean	–19.8	0.32	+9.7	0.29		
ISOSOURCE	%	error					
Terrestrial vegetation	45.6	9.5		‰ difference between highest and lowest $\delta^{15}N$: 1.5‰			
Terrestrial protein	21.1	16.3		χ^2-Test fails at 5%: df=1 T=11.0 (5% 3.8)			
Eel	7.4	5.4					
Freshwater fish	6.5	5					
Salmonid	10.8	6.9					
Marine	8.6	5.5					
UB-6474	Dover Buckland: grave 264	–19.9	0.24	+9.4	0.23	30–49	Male
UB-6475	Dover Buckland: grave 323	–19.8	0.36	+9.8	0.32	30–49	Male
UB-6477	Dover Buckland: grave 414	–19.8	0.36	+9.4	0.32	30–49	Male
	mean	–19.8	0.32	+9.5	0.29		
ISOSOURCE	%	error					
Terrestrial vegetation	48.2	8.8		‰ difference between highest and lowest $\delta^{15}N$: 0.4‰			
Terrestrial protein	19.5	15.1		χ^2-Test df=1 T=0.8 (5% 3.8)			
Eel	6.7	9					

Freshwater fish	5.9	4.6					
Salmonid	10.9	6.9					
Marine	8.7	5.6					

Table 6e: Significant difference in highest/lowest $\delta^{15}N$ seen only in females at Dover Buckland. This table and calculations exclude UB-4958 (Dover Buckland, grave 375) and UB-4959 (Dover Buckland, grave 391A) as these skeletons have no sex data

Laboratory Number	Site/Context	$\delta^{13}C$ (‰)	total error (±)**	$\delta^{15}N$ (‰)	total error (±)**	Osteological Age	Osteological Sex/Inferred Sex
UB-4708	Edix Hill: grave 83	–20.2	0.32	+10.9	0.36	18–29	Female
UB-4512	Edix Hill: grave 91	–20.2	0.32	+10.7	0.36	18–29	Female
UB-4707	Edix Hill: grave 79	–20.3	0.32	+8.8	0.36	30–49	Female
UB-4709	Edix Hill: grave 14	–20.4	0.32	+10.4	0.36	50+	Female
UB-4511	Edix Hill: grave 90	–20.4	0.32	+9.8	0.24	50+	Female
	mean	–20.3	0.30	+10.1	0.34		
ISOSOURCE	%	error					
Terrestrial vegetation	39	11.9		‰ difference between highest and lowest $\delta^{15}N$: 2.1‰			
Terrestrial protein	26.6	20.8		χ^2-Test fails at 5%: df=1 T=17.0 (5% 3.8)			
Eel	11.7	7.9					
Freshwater fish	9.8	7.2					
Salmonid	7.2	5.1					
Marine	5.7	4.1					
UB-4508	Edix Hill: grave 12	–20.0	0.32	+10.2	0.36	30–49	Male
UB-4509	Edix Hill: grave 33	–20.2	0.32	+9.8	0.36	18–29	Male
UB-4923	Edix Hill: grave 7	–20.3	0.23	+10.5	0.25	30–49	Male
	mean	–20.2	0.29	+10.2	0.33		
ISOSOURCE	%	error					
Terrestrial vegetation	37.9	12		‰ difference between highest and lowest $\delta^{15}N$: 0.7‰			
Terrestrial protein	27	20.9		χ^2-Test df=1 T=2.6 (5% 3.8)			
Eel	11.5	7.8					
Freshwater fish	9.7	7.1					
Salmonid	7.8	5.4					
Marine	6.2	4.3					

Table 6f: Lechlade returns the largest per mil differences between highest and lowest $\delta^{15}N$ for both males and females

Laboratory Number	Site/Context	$\delta^{13}C$ (‰)	total error (±)**	$\delta^{15}N$ (‰)	total error (±)**	Osteological Age	Osteological Sex/Inferred Sex
UB-4503	Lechlade: grave 148	–20.1	0.32	+10.9	0.36	6–7	Female
UB-4506	Lechlade: grave 172/2	–20.0	0.32	+8.9	0.36	2–2.5	Female
UB-4501	Lechlade: grave 14	–19.9	0.32	+10.1	0.36	13–17	Female
UB-4983	Lechlade: grave 136	–20.7	0.32	+9.8	0.36	18–29	Female
UB-4502	Lechlade: grave 138	–20.1	0.32	+8.9	0.36	18–29	Female
UB-4504	Lechlade: grave 179	–20.2	0.32	+11.4	0.36	30–49	Female
UB-4507	Lechlade: grave 187	–19.6	0.32	+9.4	0.36	30–49	Female
UB-4984	Lechlade: grave 18	–20.5	0.23	8.7	0.25	Adult	Female
	mean	–20.1	0.31	+9.7	0.35		
ISOSOURCE	%	error					
Terrestrial vegetation	44.3	10.5		‰ difference between highest and lowest $\delta^{15}N$: 2.7‰			
Terrestrial protein	23.5	18.2		χ^2-Test fails at 5%: df=1 T=38.0 (5% 3.8)			
Eel	8.9	6.3					
Freshwater fish	7.7	5.8					
Salmonid	8.7	5.8					
Marine	6.9	4.6					
UB-4982	Lechlade: grave 155	–20.7	0.32	+9.7	0.39	18–29	Male
UB-4505	Lechlade: grave 172/1	–20.3	0.32	+9.2	0.36	30–49	Male
UB-4981	Lechlade: grave 183	–20.3	0.32	+8.0	0.39	50+	Male

UB-4683	Lechlade: grave 40	–20.1	0.24	+10.8	0.23	30–49	Male
	mean	–20.4	0.30	+9.4	0.35		
ISOSOURCE	%	error					
Terrestrial vegetation	47.2	10.3		‰ difference between highest and lowest δ^{15}N: 2.8‰			
Terrestrial protein	23	17.9		χ^2-Test fails at 5% df=1 T=38.2 (5% 3.8)			
Eel	9.5	6.6					
Freshwater fish	8	6					
Salmonid	6.9	4.8					
Marine	5.5	3.9					

Table 6g: Significant differences in highest and lowest $\delta^{15}N$ in Marina Drive females

Laboratory Number	Site/Context	$\delta^{13}C$ (‰)	total error (±)**	$\delta^{15}N$ (‰)	total error (±)**	Osteological Age	Osteological Sex/Inferred Sex
UB-4549	Marina Drive: grave C7	–20.4	0.32	+9.8	0.36	18–29	Female
UB-4553	Marina Drive: grave D10	–20.3	0.32	+11.1	0.36	18–29	Female
UB-4551	Marina Drive: grave E2	–20.2	0.32	+10.4	0.36	13–17	Female
UB-4552	Marina Drive: grave E3	–20.1	0.32	+9.1	0.36	7–12	Female
UB-4554	Marina Drive: grave F2	–19.9	0.32	+9.4	0.36	6	Female
	mean	–20.2	0.32	+10.0	0.36		
ISOSOURCE	%	error			0.36		
Terrestrial vegetation	40.3	11.6		‰ difference between highest and lowest $\delta^{15}N$: 2.0‰			
Terrestrial protein	25.9	20.2		χ^2-Test fails at 5%: df=1 T=15.4 (5% 3.8)			

Table 6h: Significant differences in highest and lowest $\delta^{15}N$ in Melbourn females and males

Laboratory Number	Site/Context	$\delta^{13}C$ (‰)	total error (±)**	$\delta^{15}N$ (‰)	total error (±)**	Osteological Age	Osteological Sex/Inferred Sex
UB-4885	Melbourn, lnL89 SG78	–20.3	0.23	+9.3	0.24	30–49	Female
UB-4887	Melbourn: SK 1229 SG82	–20.3	0.32	+9.3	0.36	18–29	Female
UB-4883	Melbourn: SK1038, SG95	–20.1	0.32	+10.3	0.36	30–49	Female
UB-4888	Melbourn: SK1271 SG89	–20.3	0.32	+9.1	0.36	30–49	Female
UB-4889	Melbourn: SK1293, SG69	–20.2	0.32	+9.4	0.36	30–49	Female
UB-4890	Melbourn: SK1307 SG75	–20.3	0.32	+9.6	0.36	50+	Female
	mean	–20.3	0.31	+9.5	0.34		
ISOSOURCE	%	error					
Terrestrial vegetation	46.2	10.4		‰ difference between highest and lowest $\delta^{15}N$: 1.2‰			
Terrestrial protein	23.2	18.1		χ^2-Test fails at 5%: df=1 T=5.6 (5% 3.8)			
Eel	9.3	6.5					
Freshwater fish	7.9	5.9					
Salmonid	7.5	5.1					
Marine	5.9	4.1					
UB-4882	Melbourn: SK1187 SG80	–20.1	0.32	+9.3	0.36	50+	Male
UB-4884	Melbourn: SK1188 SG79	–20.4	0.32	+10.3	0.24	50+	Male
UB-4886	Melbourn: SK1204 SG77	–19.8	0.27	+8.8	0.24	18–29	Male

	mean	−20.1	0.27	+9.5	0.29		
ISOSOURCE	%	error					
Terrestrial vegetation	46.8	9.9		‰ difference between highest and lowest δ^{15}N: 1.5‰			
Terrestrial protein	22.1	17.1		χ^2-Test fails at 5% df=1 T=19.5 (5% 3.8)			
Eel	8.1	5.9					
Freshwater fish	7.1	5.4					
Salmonid	8.8	5.8					
Marine	7	4.7					

Table 6i: Significant differences in highest and lowest $\delta^{15}N$ in Mill Hill males

Laboratory Number	Site/Context	$\delta^{13}C$ (‰)	total error (±)**	$\delta^{15}N$ (‰)	total error (±)**	Osteological Age	Osteological Sex/Inferred Sex
UB-4734	Mill Hill grave 105c	–20.3	0.32	+9.6	0.36	30–49	Female
UB-4728	Mill Hill grave 64	–19.5	0.32	+9.4	0.36	18–29	Female?
UB-4729	Mill Hill grave 68	–19.5	0.32	+10.2	0.36	13–17	Female
UB-4733	Mill Hill grave 95	–19.9	0.32	+10.0	0.36	50+	Female
	mean	–19.8	0.32	+9.8	0.36		
ISOSOURCE	%	error					
Terrestrial vegetation	44.3	9.8		‰ difference between highest and lowest $\delta^{15}N$: 0.8‰			
Terrestrial protein	21.9	16.9		χ^2-Test df=1 T=2.5 (5% 3.8)			
Eel	7.7	5.7					
Freshwater fish	6.8	5.2					
Salmonid	10.7	6.8					
Marine	8.6	5.5					
UB-6479	Mill Hill grave 40	–19.5	0.36	+8.8	0.32	30–49	Male
UB-4730	Mill Hill grave 79	–19.1	0.32	+10.1	0.36	30–49	Male
UB-4921	Mill Hill grave 81	–20.3	0.32	+9.3	0.39	Adult	Male
UB-4731	Mill Hill grave 93	–19.8	0.32	+10.1	0.36	30–49	Male
UB-4732	Mill Hill grave 94	–19.7	0.32	+9.9	0.36	50+	Male
	mean	–19.7	0.33	+9.6	0.36		
ISOSOURCE	%	error					
Terrestrial vegetation	47.4	8.8		‰ difference between highest and lowest $\delta^{15}N$: 1.3‰			
Terrestrial protein	19.4	14.9		χ^2-Test fails at 5% df=1 T=7.3 (5% 3.8)			
Eel	6.5	4.9					
Freshwater fish	5.8	4.6					
Salmonid	11.5	7.3					

Marine	9.3	5.8					

Table 6j: Significant differences in highest and lowest $\delta^{15}N$ in St Peter's Tip males. While $\delta^{15}N$ of 9‰ or more indicates moderately rich protein, females also have significantly higher proportion of terrestrial vegetation in their diets than males (χ^2-Test: df=1 T=16.131(5% 3.8))

Laboratory Number	Site/Context	$\delta^{13}C$ (‰)	total error (±)**	$\delta^{15}N$ (‰)	total error (±)**	Osteological Age	Osteological Sex/Inferred Sex
UB-4963	St Peter's Tip: grave 208	–19.8	0.32	+9.5	0.39	50+	Female
UB-6032	St Peter's Tip: grave 73A	–20.9	0.32	+8.5	0.39	13–17	Female?
	mean	–20.4	0.32	+9.0	0.39		
ISOSOURCE	%	error					
Terrestrial vegetation	52.1	9.2		‰ difference between highest and lowest $\delta^{15}N$: 1.0‰			
Terrestrial protein	20.4	16		χ^2-Testdf=1 T=3.3 (5% 3.8)			
Eel	7.9	5.7					
Freshwater fish	6.8	5.2					
Salmonid	7.1	4.8					
Marine	5.6	3.9					
UB-4924	St Peter's Tip: grave 113	–19.6	0.24	+8.6	0.25	18–29	Male
UB-4929	St Peter's Tip: grave 194	–20.0	0.32	+9.9	0.39	30–49	Male
UB-4962	St Peter's Tip: grave 196	–19.9	0.32	+9.1	0.39	30–49	Male
UB-4926	St Peter's Tip: grave 212	–20.0	0.32	+10.4	0.39	30–49	Male
UB-4928	St Peter's Tip: grave 250	–20.1	0.32	+9.5	0.39	50+	Male
UB-4927	St Peter's Tip:	–19.7	0.23	+9.5	0.25	30–49	Male

	grave 263						
UB-4931	St Peter's Tip: grave 318	−20.0	0.32	+9.7	0.39	30–49	Male
UB-4930	St Peter's Tip: grave 42	−19.2	0.24	+8.3	0.25	18–29	Male
UB-4925	St Peter's Tip: grave 68	−19.4	0.23	+10.3	0.25	30–49	Male
UB-4961	St Peter's Tip: grave 8	−19.5	0.32	+9.5	0.39	50+	Male
UB-6478	St Peter's Tip: grave 360	−20.1	0.36	+10.6	0.32	30–49	Male
	mean	−19.8	0.30	+9.6	0.34		
ISOSOURCE	%	error					
Terrestrial vegetation	46.9	9.1		‰ difference between highest and lowest δ^{15}N: 2.3‰			
Terrestrial protein	20.3	15.7		χ^2-Test fails at 5% df=1 T=8.807 (5% 3.8)			
Eel	7	5.2					
Freshwater fish	6.2	4.8					
Salmonid	10.8	6.9					
Marine	8.7	5.5					

Table 6k: Significant difference between highest and lowest $\delta^{15}N$ among West Heslerton females

Laboratory Number	Site/Context	$\delta^{13}C$ (‰)	total error (±)**	$\delta^{15}N$ (‰)	total error (±)**	Osteological Age	Osteological Sex/Inferred Sex
UB-6033	West Heslerton: grave 113	–20.8	0.32	+10.6	0.39	13–17	Female
UB-4705	West Heslerton: 002BA 00606	–20.3	0.32	+8.9	0.36	50+	Female
UB-4706	West Heslerton: 002BA 00536	–19.9	0.32	+9.0	0.36	12–15	Female
	mean	–20.3	0.32	+9.5	0.37		
ISOSOURCE	%	error					
Terrestrial vegetation	46.2	10.4		‰ difference between highest and lowest $\delta^{15}N$: 1.7‰			
Terrestrial protein	23.2	18.1		χ^2-Test fails at 5% df=1 T=10.3 (5% 3.8)			
Eel	9.3	6.5					
Freshwater fish	7.9	5.9					
Salmonid	7.5	5.1					
Marine	5.9	4.1					

Table 6l: Significant difference between highest and lowest $\delta^{15}N$ between two Westgarth males

Laboratory Number	Site/Context	$\delta^{13}C$ (‰)	total error (±)**	$\delta^{15}N$ (‰)	total error (±)**	Osteological Age	Osteological Sex/Inferred Sex
UB-4836	Westgarth Gardens: grave 27	−19.8	0.36	+9.6	0.32	Adult	Female
ISOSOURCE	%	error					
Terrestrial vegetation	46.9	9.1					
Terrestrial protein	20.3	15.7					
Eel	7	5.2					
Freshwater fish	6.2	4.8					
Salmonid	10.8	6.9					
Marine	8.7	5.5					
UB-4985	Westgarth Gardens: grave 11	−20.8	0.32	+8.4	0.39	30–49	Male
UB-4682	Westgarth Gardens: grave 66	−19.9	0.36	+9.9	0.32	30–49	Male
	mean	−20.4	0.34	+9.2	0.36		
ISOSOURCE	%	error					
Terrestrial vegetation	49.7	9.8		‰ difference between highest and lowest $\delta^{15}N$: 1.5‰			
Terrestrial protein	21.7	17		χ^2-Test fails at 5% df=1 T=8.8 (5% 3.8)			
Eel	8.7	6.1					
Freshwater fish	7.4	5.6					
Salmonid	7	4.8					
Marine	5.5	3.9					

Table 6m: Buttermarket, female versus male. There is a significant difference in $\delta^{15}N$ between the two skeletons

Laboratory Number	Site/Context	$\delta^{13}C$ (‰)	total error (±)**	$\delta^{15}N$ (‰)	total error (±)**	Osteological Age	Osteological Sex/Inferred Sex
UB-4077	Buttermarket: grave 4275	–20.2	0.31	+10.7	0.31	Adult	Female
ISOSOURCE	%	error					
Terrestrial vegetation	32.7	12.3					
Terrestrial protein	28.5	21.6					
Eel	13.7	8.9					
Freshwater fish	11.4	8.1					
Salmonid	7.6	5.3					
Marine	6.1	4.3					
UB-4046	Buttermarket: grave 4344	–20.1	0.31	+9.4	0.31	Adult	?Male
ISOSOURCE	%	error					
Terrestrial vegetation	48.1	9.6		‰ difference between highest and lowest $\delta^{15}N$: 1.3‰			
Terrestrial protein	21.3	16.5		χ^2-Test fails at 5% - $\delta^{15}N$ female vs male χ^2-Test df=1 T=8.792 (5% 3.8)			
Eel	7.8	5.7					
Freshwater fish	6.8	5.2					
Salmonid	8.9	5.8					
Marine	7.1	4.7					

Table 7: ISOSOURCE isotopic mass balance mixing model (Phillips and Gregg 2003) and back-calculation of the marine component of diet from $\delta^{13}C$ only following Mays (1997) for individual skeletons. Sites where replicate isotopic analysis was completed on the skeleton show all UB identification numbers associated with the skeleton. For skeletons with replicate analysis, the mean isotopic values of each analysis were averaged and used in the calculations

Laboratory Number	Site	ISOSOURCE							Mays (1997) ($\delta^{13}C$)
		# solutions	% vegetation	% terrestrial animal protein	% eel	% freshwater fish	% salmonids	% marine fish	% marine fish
UB-5208	Apple Down: grave 107	133,813	65.4±6.0	12.2±9.8	4.0±3.2	3.5±3.0	8.2±5.4	6.6±4.3	12.6±7.5
UB-4965	Apple Down: grave 117	167,613	63.6±6.6	13.9±11.0	4.7±3.7	4.2±3.4	7.5±5.0	6.0±4.0	11.6±7.4
UB-6344									
UB-4835	Apple Down: grave 134	282,543	56.8±7.7	16.8±13.1	5.8±4.4	5.1±4.1	8.6±5.6	6.9±4.5	13.7±7.5
UB-4975	Aston Clinton: grave 12	390,996	47.8±10.0	21.8±17.3	12.6±7.8	9.7±7.1	4.6±3.6	3.6±2.9	7.4±7.4
UB-4735	Berinsfield: grave 22	844,766	37.4±11.6	26.3±20.3	10.1±7.1	8.7±6.5	9.7±6.4	7.8±5.1	16.8±7.4
UB-4736	Berinsfield: grave 28	513,801	47.3±9.6	21.3±16.5	7.6±5.6	6.7±5.1	9.5±6.2	7.6±5	15.8±7.4
UB-4739	Berinsfield: grave 134/1	323,171	55.0±8.4	18.4±14.3	6.6±4.9	5.8±4.5	7.9±5.2	6.3±4.2	12.6±7.4
UB-4077	Buttermarket: grave 4275	958,945	32.7±12.3	28.5±21.6	13.7±8.9	11.4±8.1	7.6±5.3	6.1±4.3	13.7±7.4
UB-4046	Buttermarket: grave 4344	490,624	48.1±9.6	21.3±16.5	7.8±5.7	6.8±5.2	8.9±5.8	7.1±4.7	14.7±7.4
UB-6036	Castledyke South: grave 13	580,351	28.3±10.2	22.2±17.1	26.3±12.6	16.0±11.7	4.0±3.4	3.1±2.7	6.3±7.4
UB-6040	Castledyke South: grave 53	306,978	41.9±8.9	18.6±15.0	21.1±10.3	12.7±9.4	3.2±2.8	2.5±2.2	4.2±7.4
UB-6042	Castledyke	729,487	39.0±11.9	26.6±20.8	11.7±7.9	9.8±7.2	7.2±5.1	5.7±4.1	12.6±7.4

	South: grave 88								
UB-6039	Castledyke South: grave 94, skeleton 1452	661,828	39.3±11.7	26.1±20.5	13.2±8.5	10.7±7.7	6.0±4.4	4.8±3.6	10.5±7.4
UB-6035	Castledyke South: grave 96	216,055	35.3±8.1	15.8±12.9	31±11.6	13.3±10.6	2.6±2.4	2.0±1.9	2.1±7.4
UB-6034	Castledyke South: grave 120	384,391	45.3±9.8	21.3±17.0	15.2±8.8	11.0±8.0	4.0±3.3	3.2±2.6	6.3±7.4
UB-6037	Castledyke South: grave 134	592,480	40.6±11.3	25.1±19.8	13.6±8.6	10.8±7.8	5.5±4.1	4.3±3.3	9.5±7.4
UB-6041	Castledyke South: grave 182	356,068	53.1±9.2	20.2±15.8	8.1±5.7	6.9±5.2	6.5±4.5	5.1±3.6	10.5±7.4
UB-6038	Castledyke South: grave 183	347,127	44.1±9.4	20.0±16.0	17.7±9.5	11.9±8.6	3.6±3.0	2.8±2.4	5.3±7.4
UB-4964	Coddenham: grave 308	758,125	36.9±12.1	27.1±21.1	13.4±8.6	10.9±7.9	6.5±4.7	5.2±3.8	11.6±7.4
UB-6472	Dover Buckland: grave 222	592,357	44.7±10.2	22.8±17.6	8.4±6.0	7.3±5.5	9.4±6.1	7.5±4.9	15.8±7.4
UB-6472									
UB-6473	Dover Buckland: grave 250	884,452	36.5±11.6	26.4±20.2	9.9±7.0	8.6±6.4	10.3±6.7	8.3±5.4	17.9±7.5
UB-6474	Dover Buckland: grave 264	456,100	49.0±8.9	19.7±15.2	6.8±5.1	6.0±4.7	10.2±6.6	8.2±5.3	16.8±7.4
UB-6474									
UB-6475	Dover Buckland: grave 323	599,025	44.3±9.8	21.9±16.9	7.7±5.7	6.8±5.2	10.7±6.8	8.6±5.5	17.9±7.5
UB-6476	Dover	227,749	56.8±6.5	13.6±10.7	4.3±3.5	3.9±3.2	11.9±7.4	9.7±6.0	18.9±7.5

	Buckland: grave 339								
UB-4958	Dover Buckland: grave 375	287,342	54.9±7.2	15.4±12.0	5.0±3.9	4.5±3.6	11.2±7.0	9.0±5.7	17.9±7.5
UB-4959	Dover Buckland: grave 391A	630,127	42.5±11.2	25.0±19.5	10.4±7.2	8.8±6.5	7.3±5.1	5.8±4.1	12.6±7.5
UB-6477	Dover Buckland: grave 414	431,610	49.6±8.5	18.7±14.4	6.3±4.8	5.6±4.4	10.9±6.9	8.8±5.6	17.9±7.5
UB-4923	Edix Hill: grave 7	857,687	34.7±12.3	27.9±21.5	13.5±8.8	11.1±8.0	7.1±5.0	5.6±4.0	12.6±7.4
UB-4923									
UB-4508	Edix Hill: grave 12	802,855	38.3±11.6	26.3±20.3	10.2±7.2	8.8±6.6	9.1±6.0	7.3±4.9	15.8±7.4
UB-4709	Edix Hill: grave 14	786,124	35.9±12.1	27.4±21.2	13.8±8.9	11.2±8.1	6.5±4.7	5.2±3.8	11.6±7.4
UB-4509	Edix Hill: grave 33	639,219	42.7±11.0	24.7±19.2	9.8±6.9	8.4±6.3	8.0±5.4	6.3±4.4	13.7±7.4
UB-4510	Edix Hill: grave 48	481,426	46.1±10.6	23.4±18.4	11.3±7.4	9.2±6.7	5.6±4.2	4.4±3.3	9.5±7.4
UB-4922									
UB-4707	Edix Hill: grave 79	323,171	55.0±8.4	18.4±14.3	6.6±4.9	5.8±4.5	7.9±5.2	6.3±4.2	12.6±7.4
UB-4708	Edix Hill: grave 83	1,021,404	30.8±12.2	28.6±21.5	14.8±9.4	12.2±8.5	7.6±5.3	6.1±4.3	13.7±7.4
UB-4511	Edix Hill: grave 90	611,989	42.5±11.3	25.1±19.7	11.1±7.5	9.3±6.8	6.7±4.8	5.3±3.8	11.6±7.4
UB-4511									
UB-4512	Edix Hill: grave 91	958,945	32.7±12.3	28.5±21.6	13.7±8.9	11.4±8.1	7.6±5.3	6.1±4.3	13.7±7.4
UB-4976	Ford, Laverstock: barrow 2	381,038	52.3±9.1	20.2±15.7	7.6±5.5	6.6±5.0	7.4±5.0	5.9±4.0	11.6±7.4
UB-4920	Gally Hills (post	857,174	35.7±12.2	27.8±21.4	12.3±8.2	10.3±7.5	7.7±5.4	6.1±4.3	13.7±7.4

	PVA extraction)								
UB-6347	Lakenheath: ERL 104 4222	356,350	52.2±7.8	17.1±13.2	5.7±4.4	5.1±4.0	11.1±7.0	8.9±5.6	17.9±7.5
UB-4501	Lechlade: grave 14	752,418	39.9±11.1	25.0±19.3	9.3±6.6	8.1±6.1	9.8±6.4	7.9±5.2	16.8±7.4
UB-4984	Lechlade: grave 18	308,338	55.6±8.6	19.0±5.9	7.3±5.3	6.3±4.8	6.6±4.5	5.2±3.7	10.5±7.4
UB-4984									
UB-4683	Lechlade: grave 40	1,026,609	31.7±12.3	28.7±21.6	13.5±8.8	11.3±8.1	8.2±5.6	6.6±4.5	14.7±7.4
UB-4683									
UB-4983	Lechlade: grave 136	503,923	43.2±10.8	23.7±18.8	13.6±8.4	10.6±7.7	5.0±3.8	3.9±3.1	8.4±7.4
UB-4502	Lechlade: grave 138	324,071	54.6±8.0	17.5±13.6	6.0±4.6	5.3±4.2	9.2±5.9	7.3±4.8	14.7±7.4
UB-4503	Lechlade: grave 148	1,060,753	30.8±12.3	28.7±21.5	14.0±9.0	11.7±8.3	8.2±5.6	6.6±4.5	14.7±7.4
UB-4982	Lechlade: grave 155	485,279	44.2±10.7	23.5±18.6	13.1±8.2	10.3±7.4	5.0±3.8	4.0±3.1	8.4±7.4
UB-4505	Lechlade: grave 172/1	439,118	49.9±9.6	21.2±16.5	8.1±5.8	7.0±5.3	7.6±5.2	6.1±4.1	12.6±7.4
UB-4506	Lechlade: grave 172/2	304,198	55.1±7.6	16.6±12.9	5.6±4.3	5.0±3.9	9.8±6.3	7.9±5.1	15.8±7.4
UB-4504	Lechlade: grave 179	1,155,880	26.7±11.7	28.0±20.4	17.4±10.6	14.2±9.6	7.6±5.3	6.1±4.3	13.7±7.4
UB-4981	Lechlade: grave 183	133,813	65.4±6.0	12.2±9.8	4.0±3.2	3.5±3.0	8.2±5.4	6.6±4.3	12.6±7.4
UB-4507	Lechlade: grave 187	371,850	50.6±7.7	16.7±12.9	5.4±4.2	4.9±3.9	12.3±7.7	10.0±6.2	20.0±7.4
UB-4549	Marina Drive: grave C7	611,989	42.5±11.3	25.1±19.7	11.1±7.5	9.3±6.8	6.7±4.8	5.3±3.8	11.6±7.4
UB-4553	Marina Drive: grave D10	1,024,468	29.2±12.0	28.2±21.0	16.6±10.1	13.4±9.3	7±5.0	5.6±4.0	12.6±7.4
UB-4550	Marina Drive: grave E1	535,315	46.4±9.5	21.2±16.4	7.5±5.5	6.6±5.1	10.1±6.5	8.1±5.2	16.8±7.4

UB-4551	Marina Drive: grave E2	857,174	35.7±12.2	27.8±21.4	12.3±8.2	10.3±7.5	7.7±5.4	6.1±4.3	13.7±7.4
UB-4552	Marina Drive: grave E3	387,651	52.0±8.6	19.1±14.8	6.7±5.0	5.9±4.6	9.0±5.9	7.2±4.7	14.7±7.4
UB-4554	Marina Drive: grave F2	456,100	49.0±8.9	19.7±15.2	6.8±5.1	6.0±4.7	10.2±6.6	8.2±5.3	16.8±7.4
UB-4889	Melbourn: SK1293, SG69	499,126	47.7±9.9	22.0±17.1	8.3±6.0	7.2±5.5	8.2±5.5	6.5±4.4	13.7±7.4
UB-4890	Melbourn: SK1307 SG75	564,752	45.0±10.7	23.8±18.6	9.6±6.7	8.2±6.1	7.4±5.1	5.9±4.1	12.6±7.4
UB-4886	Melbourn: SK1204 SG77	224,947	57.5±6.6	13.8±10.8	4.4±3.5	3.9±3.3	11.3±7.1	9.1±5.7	17.9±7.4
UB-6345									
UB-4885	Melbourn: lnL1189 SG78	469,759	48.7±9.9	21.9±17.1	8.5±6.0	7.3±5.5	7.6±5.1	6.0±4.1	12.6±7.4
UB-4885									
UB-4884	Melbourn: SK1188 SG79	758,125	36.9±12.1	27.1±21.1	13.4±8.6	10.9±7.9	6.5±4.7	5.2±3.8	11.6±7.4
UB-4884									
UB-4882	Melbourn: SK1187 SG80	455,346	49.4±9.3	20.6±15.9	7.4±5.4	6.5±5.0	8.9±5.8	7.1±4.7	14.7±7.4
UB-4887	Melbourn: SK 1229 SG82	469,759	48.7±9.9	21.9±17.1	8.5±6.0	7.3±5.5	7.6±5.1	6.0±4.1	12.6±7.4
UB-4888	Melbourn: SK1271 SG89	409,086	51.2±9.3	20.5±16	7.7±5.6	6.7±5.1	7.7±5.2	6.1±4.2	12.6±7.4
UB-4883	Melbourn: SK1038, SG95	838,620	36.9±12.0	27.2±21.0	11.2±7.7	9.6±7.0	8.4±5.7	6.7±4.6	14.7±7.4
UB-6479	Mill Hill: grave 40	143,349	59.2±5.5	10.6±8.6	3.2±2.7	2.9±2.5	13.3±8.2	10.9±6.6	21.1±7.5
UB-4728	Mill Hill: grave 64	338,054	51.2±7.3	15.7±12.2	5.0±4.0	4.5±3.7	13.0±8.1	10.6±6.5	21.1±7.4
UB-4729	Mill Hill: grave 68	708,639	40.5±10.0	22.4±17.1	7.7±5.7	6.8±5.2	12.5±7.9	10.1±6.3	21.1±7.4
UB-4730	Mill Hill: grave 79	488,430	44.1±8.0	17.4±13.4	5.5±4.3	5.0±4.0	15.4±9.5	12.5±7.6	25.3±7.4
UB-4921	Mill Hill: grave	469,759	48.7±9.9	21.9±17.1	8.5±6.0	7.3±5.5	7.6±5.1	6.0±4.1	12.6±7.4

	81								
UB-4731	Mill Hill: grave 93	737,694	40.3±10.8	24.3±18.6	8.8±6.3	7.7±5.8	10.5±6.8	8.4±5.4	17.9±7.4
UB-4732	Mill Hill: grave 94	619,692	43.4±9.7	21.8±16.8	7.6±5.6	6.7±5.1	11.3±7.2	9.1±5.8	18.9±7.4
UB-4733	Mill Hill: grave 95	707,106	41.2±10.8	24.3±18.7	8.9±6.4	7.8±5.9	9.9±6.4	7.9±5.2	16.8±7.4
UB-4734	Mill Hill: grave 105C	564,752	45.0±10.7	23.8±18.6	9.6±6.7	8.2±6.1	7.4±5.1	5.9±4.1	12.6±7.4
UB-4961	St Peter's Tip: grave 8	377,900	49.9±7.6	16.5±12.8	5.3±4.2	4.8±3.8	13±8.1	10.5±6.5	21.1±7.4
UB-4930	St Peter's Tip: grave 42	11,233	66.4±3.2	4.3±3.9	1.1±1.2	1.0±1.1	14.6±9.1	12.7±7.3	24.2±7.4
UB-6346									
UB-4925	St Peter's Tip: grave 68	726,834	39.7±9.9	22.2±17.0	7.5±5.6	6.7±5.2	13.2±8.2	10.6±6.6	22.1±7.4
UB-4925									
UB-6032	St Peter's Tip, grave 73A	230,678	57.8±8.3	18.1±14.4	9.1±6.1	7.3±5.5	4.3±3.3	3.3±2.7	6.3±7.4
UB-4924	St Peter's Tip: grave 113	120,261	61.2±5.2	10.0±8.2	3.0±2.6	2.7±2.4	12.6±7.8	10.4±6.3	20±7.4
UB-6534									
UB-4929	St Peter's Tip: grave 194	674,522	42.1±10.8	24.3±18.8	9.1±6.5	7.9±5.9	9.3±6.1	7.4±4.9	15.8±7.4
UB-4962	St Peter's Tip: grave 196	346,849	53.0±7.9	17.2±13.4	5.8±4.4	5.2±4.1	10.4±6.6	8.4±5.3	16.8±7.4
UB-4963	St Peter's Tip: grave 208	471,428	48.2±8.8	19.5±15.1	6.7±5.0	5.9±4.6	10.9±6.9	8.7±5.6	17.9±7.4
UB-4926	St Peter's Tip: grave 212	889,238	35.9±12.0	27.4±21.0	11.0±7.6	9.5±7.0	9.0±6.0	7.2±4.8	15.8±7.4
UB-4928	St Peter's Tip: grave 250	526,789	46.8±9.9	22.1±17.1	8.1±5.9	7.1±5.4	8.8±5.8	7.0±4.7	14.7±7.4
UB-4927	St Peter's Tip: grave 263	443,519	48.8±8.4	18.6±14.3	6.2±4.7	5.6±4.4	11.6±7.3	9.3±5.9	18.9±7.4
UB-4927									
UB-4931	St Peter's Tip:	592,357	44.7±10.2	22.8±17.6	8.4±6.0	7.3±5.5	9.4±6.1	7.5±4.9	15.8±7.4

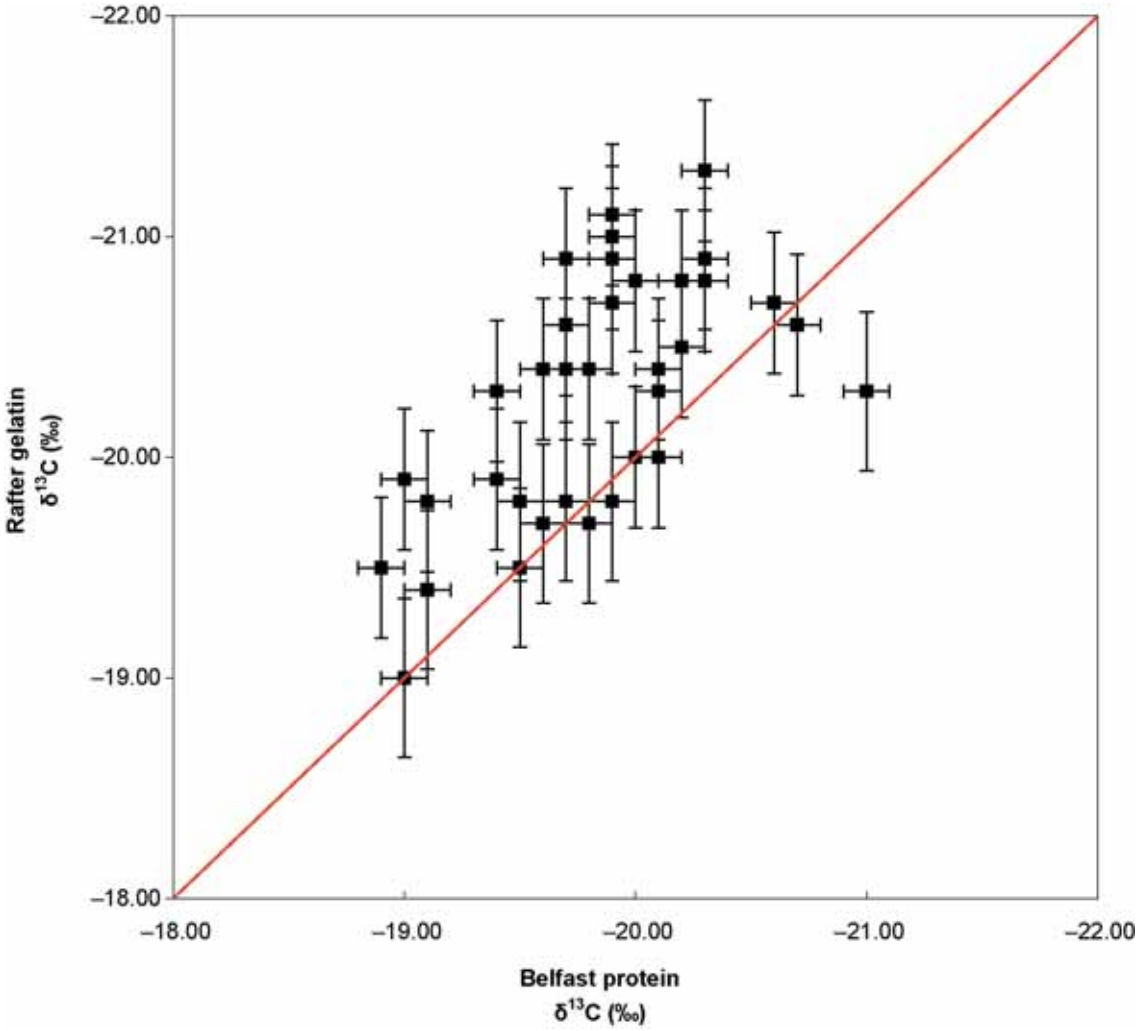
	grave 318								
UB-6478	St Peter's Tip: grave 360	954,538	33.6±12.3	28.3±21.6	12.6±8.4	10.6±7.6	8.3±5.7	6.6±4.5	14.7±7.5
UB-6033	West Heslerton, grave 113	568,906	35.9±10.9	23.7±18.7	19.1±10.5	13.4±9.6	4.4±3.6	3.5±2.9	7.4±7.4
UB-4706	West Heslerton: 002BA 00536	313,197	54.3±7.6	16.4±12.8	5.4±4.2	4.9±3.9	10.5±6.6	8.4±5.3	16.8±7.4
UB-4705	West Heslerton: 002BA 00606	351,066	53.8±8.7	19.1±14.9	7.0±5.2	6.1±4.7	7.8±5.2	6.2±4.2	12.6±7.4
UB-4985	Westgarth Gardens: grave 11	232,369	58.8±8.2	17.9±14.1	8.0±5.5	6.6±5.0	4.9±3.6	3.8±2.9	7.4±7.4
UB-4836	Westgarth Gardens: grave 27	512,649	46.9±9.1	20.3±15.7	7.0±5.2	6.2±4.8	10.8±6.9	8.7±5.5	17.9±7.5
UB-4682	Westgarth Gardens: grave 66	662,629	42.5±10.5	23.5±18.1	8.6±6.2	7.5±5.7	9.9±6.5	8.0±5.2	16.8±7.5

*Table 8: Summary statistics for $\delta^{13}C$ (‰); IQR, interquartile range; Mann-Whitney test used to test for sex differences in $\delta^{13}C$ at each location; *, two identical values hence no IQR calculated*

	Males			Females			All adults			Mann-Whitney test	
Location	N	Median	IQR	N	Median	IQR	N	Median	IQR	Z	p
Inland	17	–20.2	0.4	25	–20.3	0.3	42	–20.3	0.3	0.79	0.43
Riverine	2	–20.5	-*	6	–21.0	0.9	8	–20.7	0.7	0.67	0.50
Coastal	19	–19.8	0.5	7	–19.8	0.2	26	–19.8	0.4	0.26	0.79

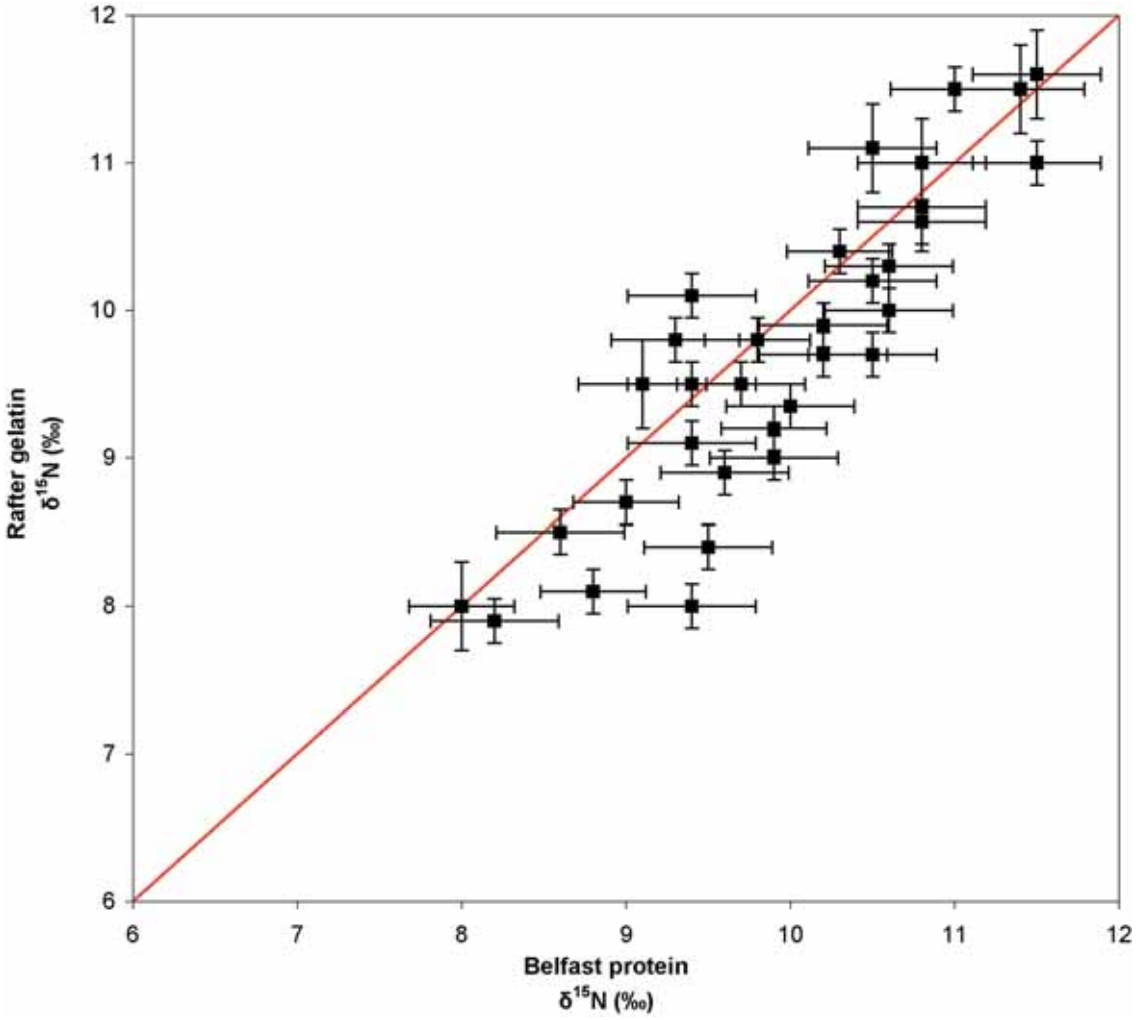
Table 9: Summary statistics for $\delta^{15}N$ (‰); t-test used to test for sex differences in $\delta^{15}N$ at each location

	Males			Females			All adults			t-test	
Location	N	Mean	SD	N	Mean	SD	N	Mean	SD	t	p
Inland	17	9.5	0.7	25	9.5	0.9	42	9.5	0.8	0.10	0.92
Riverine	2	9.5	0.8	6	10.6	0.6	8	10.3	0.8	1.64	0.30
Coastal	19	9.6	0.6	7	9.7	0.5	26	9.6	0.6	0.37	0.72



Number of comparisons = 40
Average difference = 0.44
Average standard deviation in the difference = 1.70
Weighted mean difference = 0.49 ± 0.27
Standard deviation (=square root of sample variance) = 0.44
k = Standard deviation/Average standard deviation in difference = 0.26

Figure 1: offsets between $\delta^{13}C$ values measured in New Zealand on the protein extracted for dating by Queen's University, Belfast and the $\delta^{13}C$ values measured in New Zealand on gelatin extracted from the same skeletons



Number of comparisons = 40
Average difference = –0.23
Average standard deviation in the difference = 1.56
Weighted mean difference = –0.22 ± 0.25
Standard deviation (=square root of sample variance) = 0.51
k = Standard deviation/Average standard deviation in difference = 0.32

Figure 2: offsets between $\delta^{15}N$ values measured in New Zealand on the protein extracted for dating by Queen's University, Belfast and the $\delta^{15}N$ values measured in New Zealand on gelatin extracted from the same skeletons

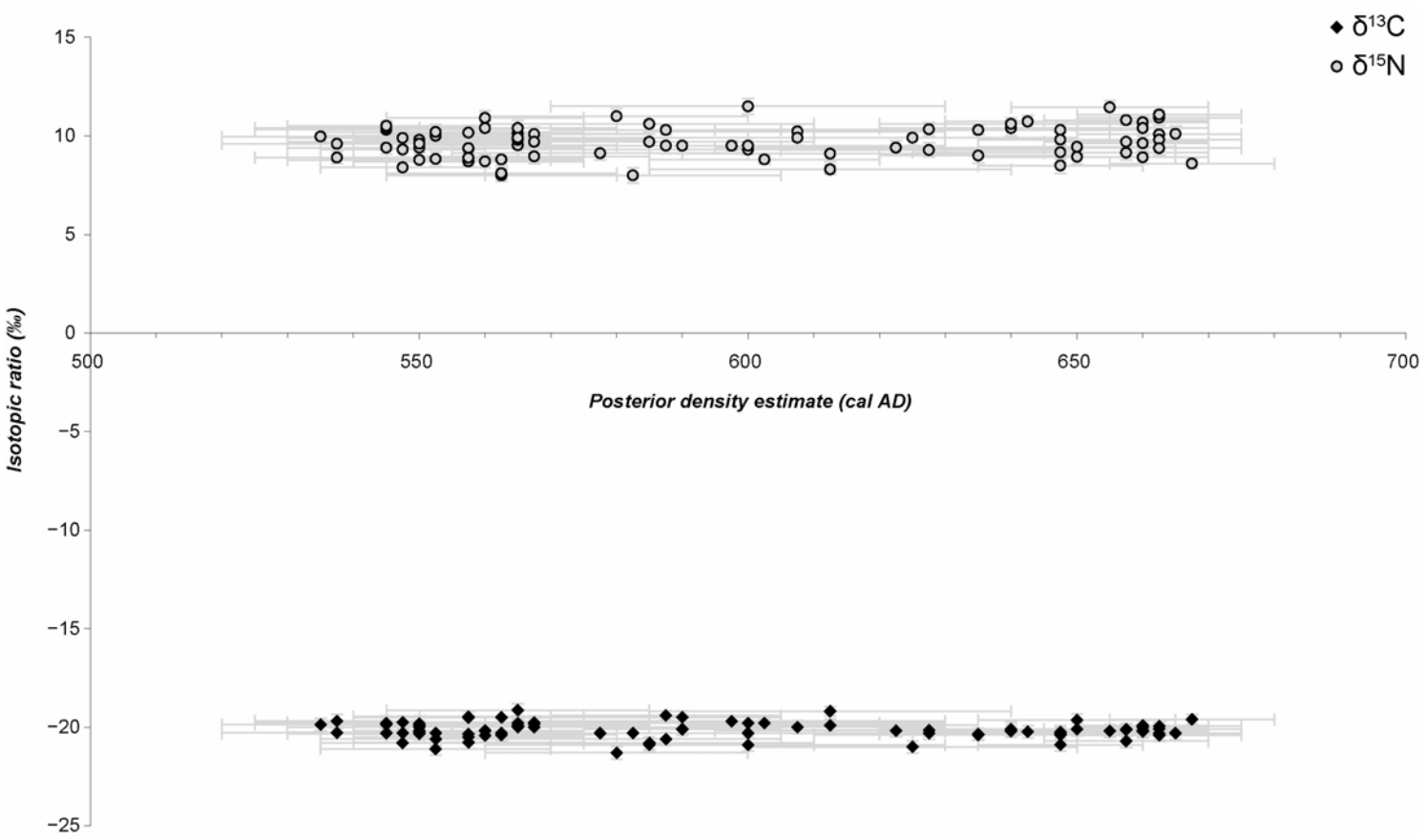


Figure 3: Variation in $\delta^{13}C$ and $\delta^{15}N$ for Anglo Saxons through time (95% probability highest probability density for each burial from the models defined by Bayliss et al 2013 (a), fig 6.52 and Bayliss et al 2013 (b), fig 7.65). Anglo Saxons of all periods have a fairly consistent range of $\delta^{13}C$ values of between –21.3‰ and –19.1‰, and $\delta^{15}N$ values of between +8.0‰ and +11.5‰

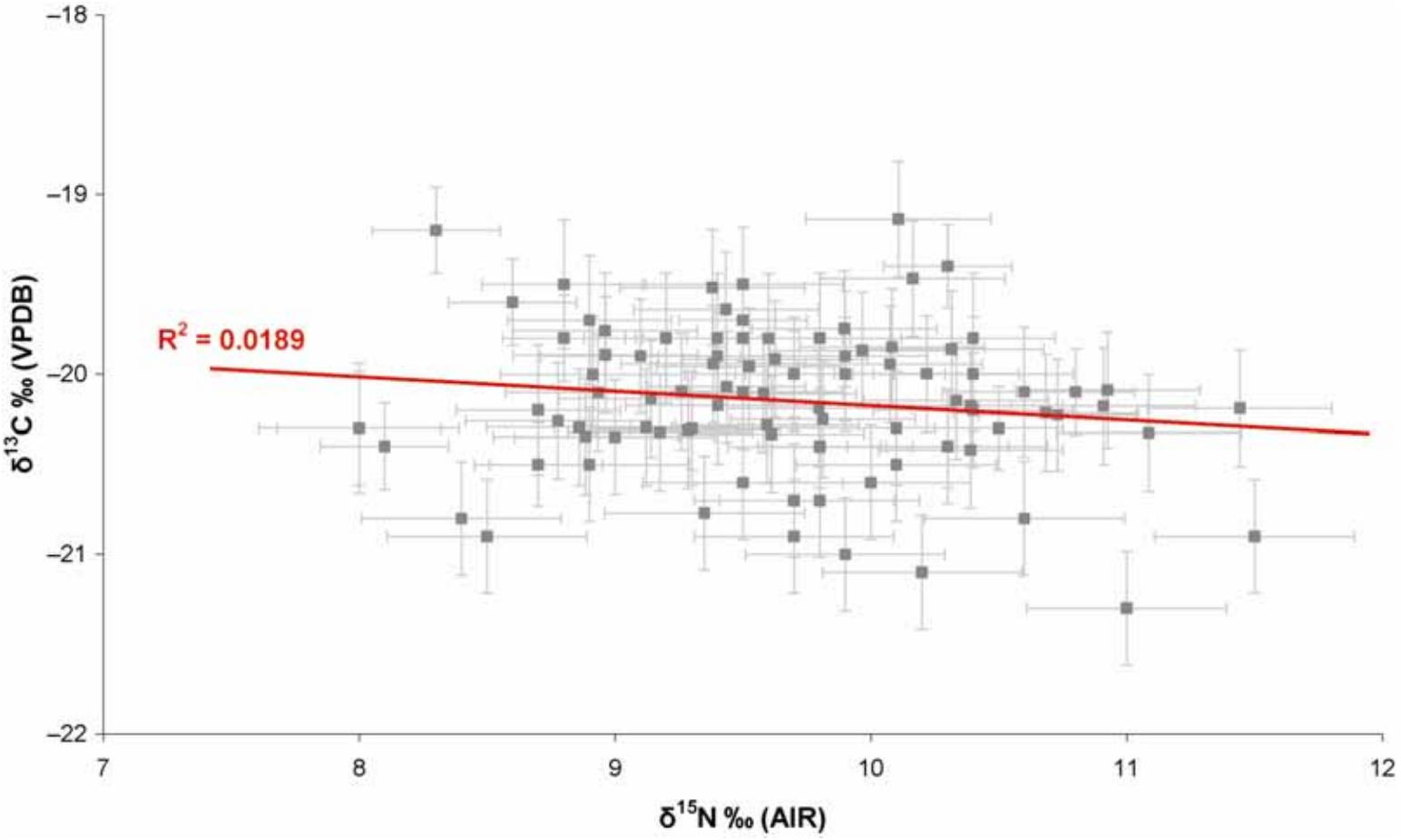


Figure 4: $\delta^{13}C$ and $\delta^{15}N$ for all Anglo Saxons show no relationship of enriched nitrogen with enriched carbon, which would be characteristic of marine inputs to diet

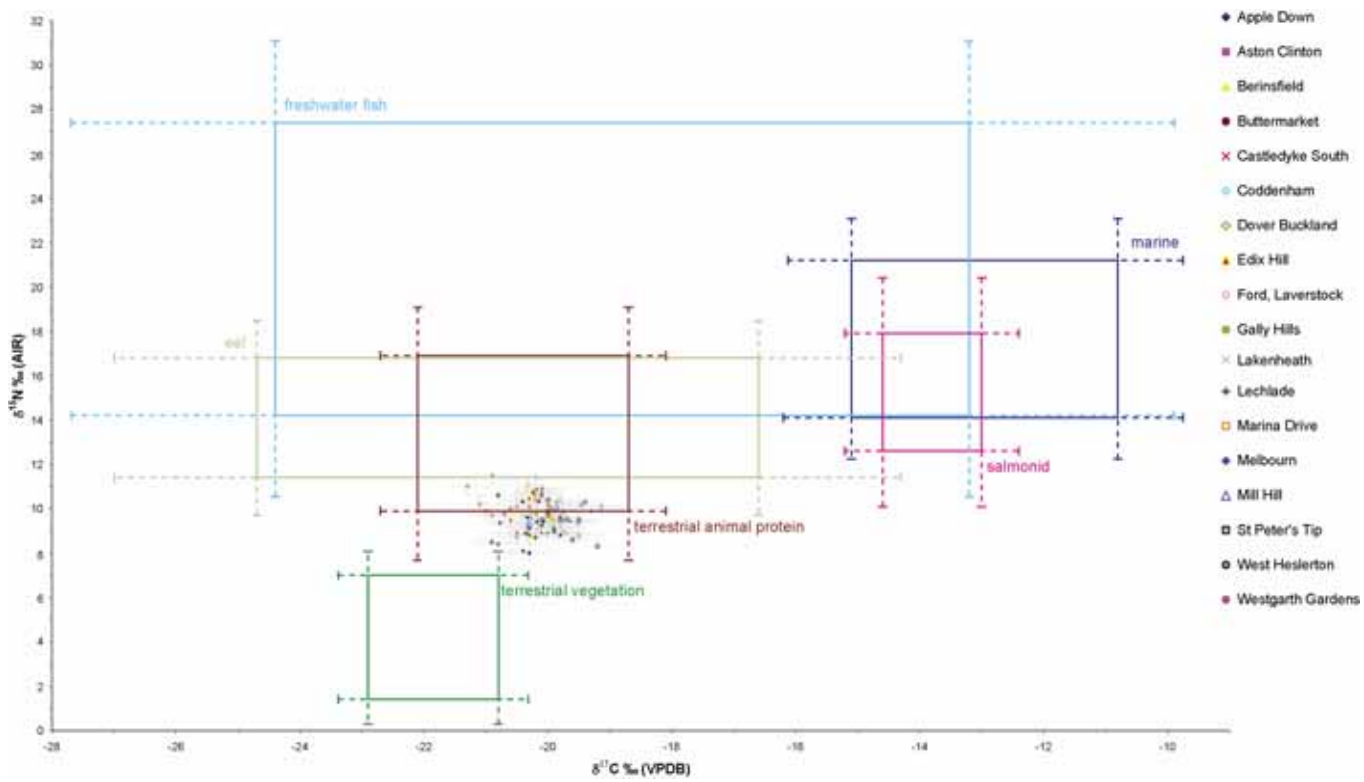


Figure 5. Stable isotope values for all Anglo Saxons fit well within parameters for a mainly terrestrial animal protein diet. The boxes are created from graphing minimum and maximum stable isotope values of $\delta^{13}C$ and $\delta^{15}N$ for ancient food sources (vegetarian, terrestrial animal protein, eel, freshwater fish, and marine fish) plus a trophic enrichment of 1‰ for $\delta^{13}C$ and 4‰ $\delta^{15}N$, on published values for British sites (Richards et al 2006; Jay and Richards 2006; Müldner 2005; Müldner and Richards 2005; Privat et al 2002; Birchall 2002; O'Connell and Lawler 2009) Error bars on boxes from Std Dev on mean $\delta^{13}C$ and $\delta 1^{5}N$ value for each food type; errors on Anglo Saxon isotope values from the analysis error for $\delta^{13}C$ and $\delta^{15}N$

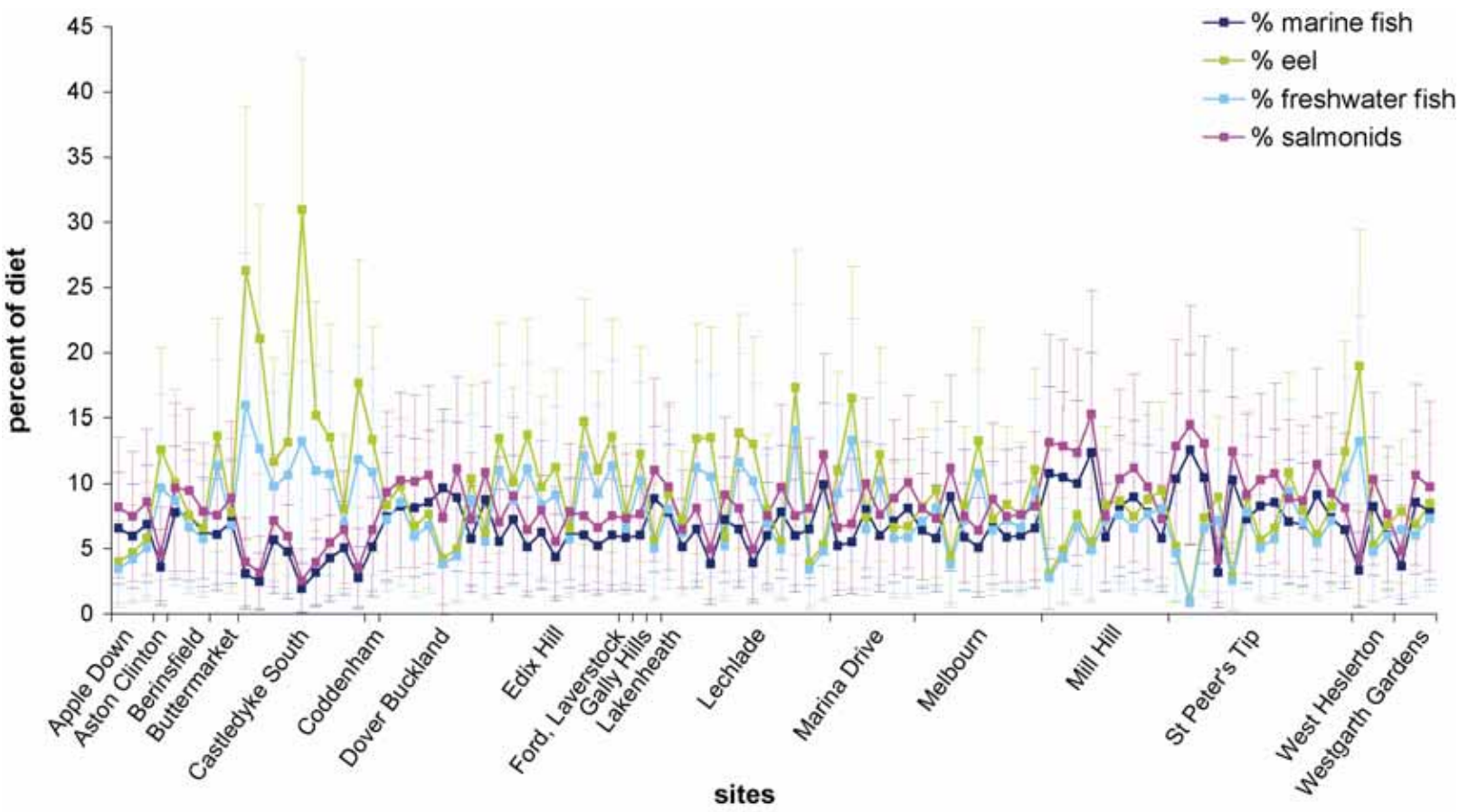


Figure 6: Comparing the percentages of non-marine and marine fish at sites. Each point represents an individual skeleton, also illustrating the intra-site variation of percent non-marine fish

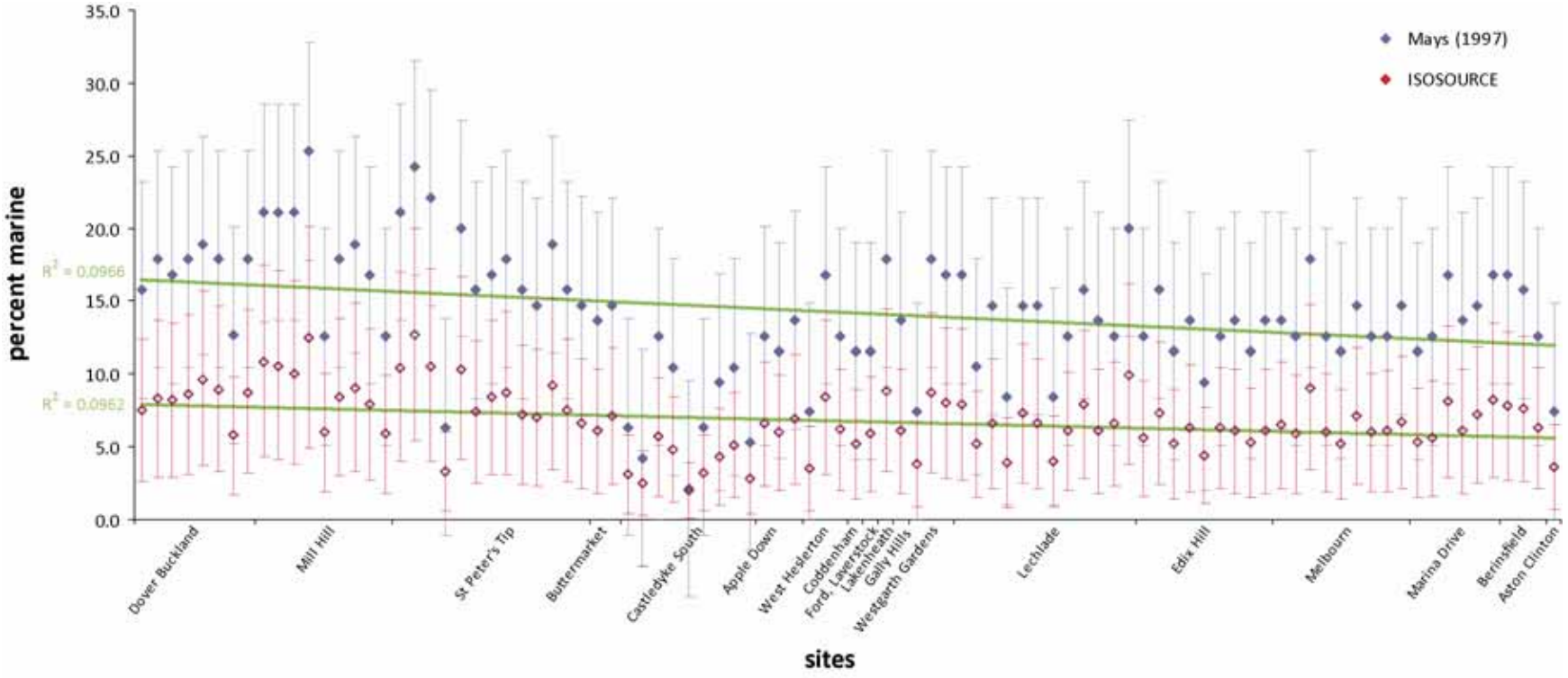


Figure 7: Comparison of marine percent in diet calculated from ISOSOURCE (Phillips and Gregg 2003), and by $\delta^{13}C$ by back calculation of $\delta^{13}C$ (Mays 1997). Sites are ordered from left to right by closest (0km) and farthest (115km) from the sea. R^2 of the linear trend for ISOSOURCE and Mays 1997 calculations show that while Mays 1997 returns higher estimates of percentage marine, overall trend of the two methods are similar

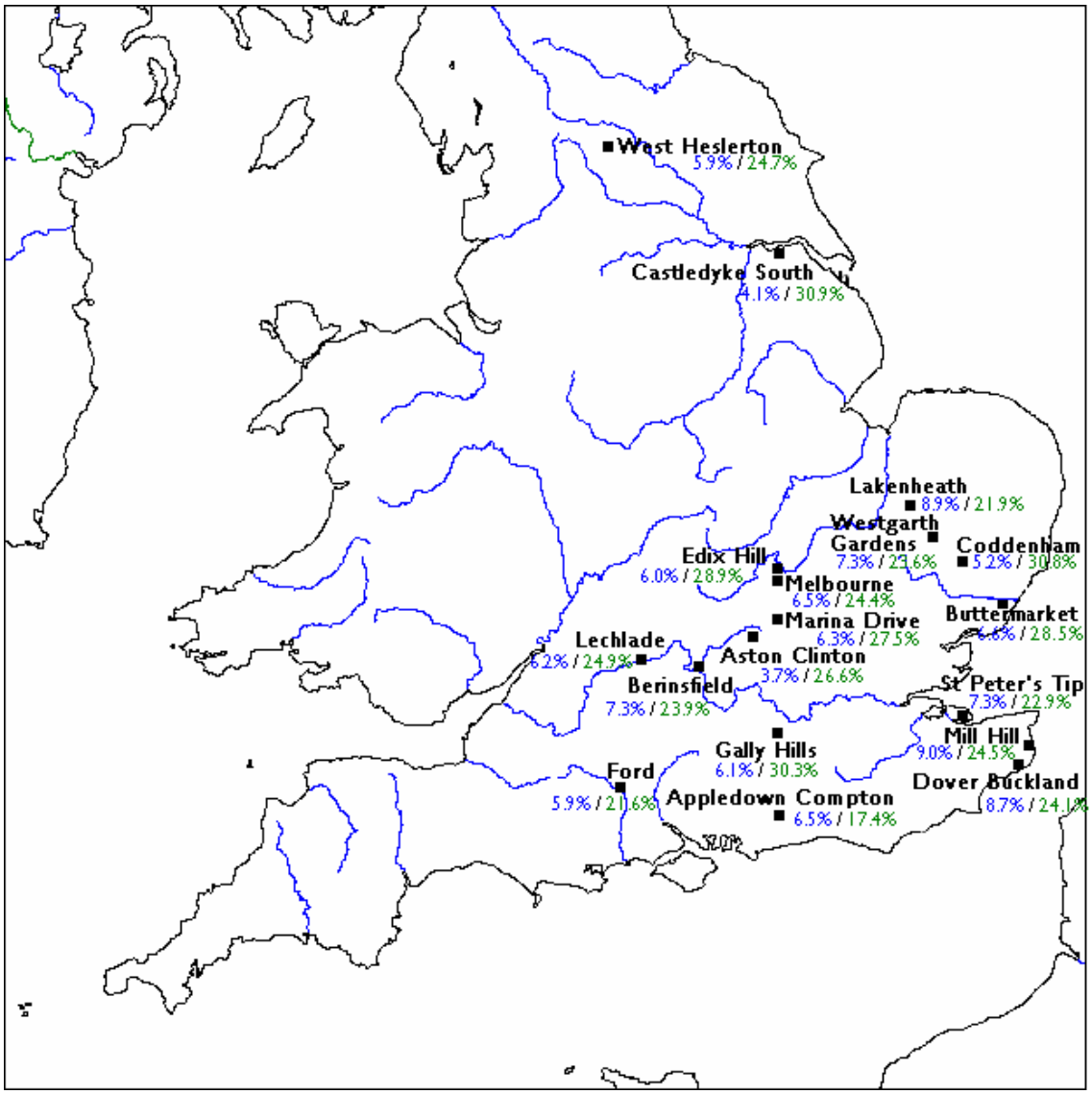


Figure 8: Geographic distribution of percent marine / percent non-marine fish, as calculated from ISOSOURCE

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