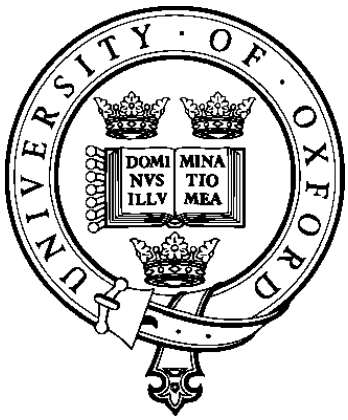


Diets in England: Change, Continuity and Regionality between the Iron Age and Domesday Book (700 B.C -1086 A.D.)

Sarah Marie Mallet
St Cross College
School of Archaeology
University of Oxford

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ABSTRACT

This thesis is both an investigation of subsistence trends in England over the *longue durée* and a review of the isotopic evidence currently available for English sites. One of the main aims of this study was to integrate all the isotopic legacy data available in England to provide the first fully contextualised database of its kind and examine isotopic patterns through different units of analyses – both chronologically and spatially.

The database includes human and non-human isotopic results and the thorough analysis of both sources of data revealed the dynamism of the isotopic signal; it is a reflection of subsistence strategies as a whole rather than simply dietary behaviour.

The main conclusion of this work posits the complexity of the relationship between the faunal and human data, with trends specific to each group. The main tendency in the data for all three main domesticates is one of depletion in ^{13}C between the Iron Age and the Early Medieval period and enrichment in ^{15}N in Roman Britain. The most distinctive pattern in the human data is a ^{13}C peak in the Roman period, and overall enrichment in ^{15}N from the Iron Age onwards, although comparisons with a cattle baseline reveal that the Roman humans display the smallest enrichment relative to the fauna. These results are explained by the evolution of landscapes and subsistence in Britain between the Iron Age and the 12th century, affecting both fauna and human.

Against these broad chronological trends, the data have been examined regionally to assess how much of the variation seen at the diachronic level can be nuanced by spatial patterns, which revealed a 'Hampshire' signal in both the fauna and the human data over time, although it might more appropriate to contextualise it as a 'Southern' signal. Indeed, since this thesis investigated data on a large scale both chronologically and geographically, it was also possible to examine units of analysis beyond traditional period or spatial boundaries, such as North/South, Coastal/Inland sites, and according to climate events, such as wetter/drier or warmer/colder periods, which again revealed the complexity of the both the faunal and human data, and of their relationship.

This study has, for the first time, brought together the bulk of dietary isotopes known in England today, and thus serves as an important stepping stone to better understanding ancient foodways.

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CHAPTER 1. INTRODUCTION

'Food brings the memory of the soil into our lives'
Roland Barthes, 1961. (trans. E. Forster, 1979)

If food carries within it the memory of the soil, then isotopes in the tissues of living organisms are a record of that memory. Food is an essential object of archaeological study: people in the past participated in a myriad of behaviours because of a myriad of factors, but one thing they all did was to eat.

This thesis investigates subsistence in England between the Iron Age and the Early Middle Ages through extensive analyses of legacy isotopic data. While this work draws on existing datasets, its purpose is not to repeat them or even to simply contextualise them. Rather, this study will integrate for the first time all existing datasets previously only examined individually. The aim is to investigate whether the trends and patterns identified at a micro-scale – whether by site or time period – exist over the *longue durée* and how regionality, climate or geography may or may not be pervasive factors in their variation. Stable isotope analysis is a powerful tool to examine the food ingested by individuals over the course of their lifetime and to reconstruct the environment in which it was produced. Therefore, it is not only the consumption of food that is studied here but rather subsistence in the widest sense from production to ingestion.

Through its prehistory and early history, England has seen many profound cultural changes, which were investigated by the English

Landscape and Identities project, of which this thesis forms a part. Language, religion and social organisation changed substantially over this period, both internally and as a result of the on-going arrivals and subsequent settlements of different groups of culturally distinct people. The central question this thesis seeks to answer is whether subsistence was transformed by these changes too or whether agricultural practices and dietary behaviours remained relatively stable even in times of change.

1.1 Scale of the project

1.1.1 Temporal range

Temporally, this thesis concentrates on the *longue durée* subsistence patterns in England between the Iron Age and the Early Medieval period (700 B.C. – 1200 A.D.) during which time Britain witnessed at least three archaeologically and historically distinct eras: the Iron Age, Roman Britain and the Early Medieval period.[1] Although some of these periods have traditionally been defined by absolute dates, it is probable that the reality of these cultural changes were different and a lot more fluid and gradual on the ground. For example, 43 A.D. marks the end of the Iron Age and the beginning of Roman Britain. However, contacts with Rome are attested much earlier than that, at least in the South East, and it is possible that the Late Iron Age has culturally more in common with the beginning of Roman Britain than it would have had with the Early Iron Age (Lodwick 2016). Similarly 410 A.D. marks the traditional end of Roman Britain after the

[1] While the English Landscape project is interested in changes and continuity from the middle Bronze Age onwards, it has proven difficult to find samples from before the Iron Age, with the exception of ten humans from the site of Wetwang Slack in East Yorkshire and scattered faunal values across the country (Jay 2005). The sample size is simply not large enough for the Bronze Age to be considered in this thesis.

Emperor Honorius 'sent letters to the cities of Britain, counselling them to be watchful of their own security' (Zosimus, *Nova Historia,* Book 6). However, accepting 410 A.D. as the absolute date for the end of Roman Britain may hide the realities of a Roman power waning and losing its influence long before this, or on the contrary, its resilience well after its historically defined end.

The names of some of these periods can also be problematic, especially in the later centuries, which tend to be named after the perceived dominant ethnicity, thus implying a sense of cultural homogeneity. The term 'Roman' and 'Anglo-Saxon' are therefore used here as chronological indicators, with an implied understanding that they do not accurately describe the complex mosaic of ethnicities of the people living in those periods.

1.1.2 Spatial range

Geographically, this thesis focuses on what is now modern England, through ninety-five sites that offer isotopic evidence. Of course, the term 'England' is anachronistic for most of the timeframe investigated here.[2] While 'Britain' might seem slightly more accurate, its modern meaning is somewhat at odds with the content of this thesis, which does not include data from either Wales or Scotland.[3] However, for simplicity's sake, both words and their respective adjectives 'English' and 'British' shall be used in this study when and where they are most appropriate. Within England,

[2] In two documents dated to 774, King Offa of Mercia styles himself '*rex totius Anglorum patriae',* which does seem to imply a conception of an English Kingdom as early as the 8th century but traditionally, its creation is dated to the 10th century, when Athelstan unified the different Anglo-Saxon kingdoms in 927 (Stenton 1973)

[3] Pytheas of Massilia is widely recognized as the Greek author to have named Britain (*Bretannikē)* through his travels. His original works are now lost, but some of his observations survive through the works of later authors, most notably the geographer Strabo. (*Geography,* I; 4,3).

twenty-three historical counties are represented within the database, although some have such a low sample count that their use for analyses has been marginal. Different geographical units of analyses will also be investigated to identify the possible factors determining how patterns of subsistence can be mapped.

In the first stages of research, it was thought that gaps in the data, either in chronology or geography could be filled with new data from unanalysed samples. However, the temporal and geographical distribution of these data is actually a good representation of the availability of the materials suited for sampling. Some soils simply do not preserve bones and in some cases it would have been practically impossible to obtain enough samples from regions under-represented in this dataset. It was also decided that there was no need to collect a marginal number of extra material from regions that were already over-represented. The results of this approach means that this thesis is both an in-depth analyses of *longue durée* trends and a general review of the isotopic work done in Britain in the past twenty years.

1.2. Research Questions

This synthesis of all the isotopic data from English sites will both reveal previously unseen patterns as well as test hypotheses put forward by previous studies. Because this work is on a larger scale – both temporally and geographically – than any of the investigations previously conducted on British material, it will allow for in-depth comparisons between and within periods. The major existing arguments and questions can be summarised as follows:

- Interest in Iron Age subsistence has often focused on identifying a 'native' tradition, with the population relying on less sophisticated diets than would later be available in Roman Britain (Jay 2005). However, the Iron Age isotopic signal displays complex patterns that must be understood in their own right and not only in opposition to the Roman data (Jay and Richards 2006; Redfern *et al.* 2008; Stevens *et al.* 2010).
- Previous studies have shown that the samples from the Roman period tended to display more enrichment in ^{13}C and ^{15}N (both in the faunal and human samples) than the Iron Age and the Early Medieval period (Müldner 2013) and this needs to be tested further.
- With the end of Roman administration, following a purported decrease in population as well as lower production rates and the decline of trade, agriculture in the Early Medieval period is likely to have been more localised to sustain self-sufficient households (Banham and Faith 2014, 39). Land re-organisation may have resulted in more grazing space for animals, which in turn would mean an increased dietary reliance on animal products (Banham and Faith 2014, 39). This also needs to be tested.

It is expected that there will be considerable variation within period boundaries. This may have been caused by the adapting nature of localities and identities both through time and space. Such aspects can be summarized in the following manner:

- Agricultural innovations in the Late Iron Age may have been more distinct than those that occurred between the Iron Age and the

Roman period (Jones 1981; Haselgrove 1995; Campbell 2000; Campbell 2008). Therefore, the different phases of the Iron Age must be compared against each other.

- After the Roman conquest, not all regions of Britain were equally influenced by Roman culture (Cunliffe 2005, 244, 349). It needs to be tested whether this would be sufficiently reflected in diets to create a visible regional pattern in the Roman data.
- The nature of Roman Britain changed over time from military settlements to local elites adopting a Roman lifestyle and this may also have affected local subsistence patterns (Allen and Smith 2016).
- The Anglo-Saxon *Adventus* in the 5th century was not a single event, but rather different waves of migrations of people from multiple localities (Härke 2011). As with the Roman data, it is necessary to assess how this affected the regionality of the Early Medieval dataset.
- The growing influence of Christianity through the Early Medieval period may also be a factor of change worth investigating. Since not all regions were converted at the same time, this may have caused increased regionality in diet (Rippon *et al.* 2015).

While chronology and regionality are important factors to consider, this study benefits from not being limited by the constraints of time and locality. Therefore, it is possible to consider other elements that may have influenced the isotopic distribution, such as physical and social geography. Such aspects can be explored in the following manners:

- Coastal, riverine and inland sites will be compared regardless of period or region, building on the previous analyses of Nitsch (2012) and Mayes and Beavan (2012).
- Urban and rural populations are likely to have had access to different foodstuff with cities acting as centres for the trade and distribution of imported goods, while farms and hamlets relied on more local production (Garnsey 1999, 56). It is therefore necessary to compare urban and rural populations, drawing on the previous analyses of Cummings (2008a), Chenery *et al.* (2011) and Cheung *et al.* (2011).
- Climate, whose influence on the isotopic results of plants has been determined (Farquhar *et al.* 1989, Stevens *et al*. 2006), needs to be considered, especially as climate fluctuations are well attested in Britain in the time span investigated here (Lamb 1981; Chiverell 2001; Barber *et al.* 2003; Charman *et al.* 2006; Charman 2010; Büntgen *et al.* 2011).
- The social aspects of identities also need to be examined. While isotopic differences according to sex, status or age have not been systematically shown at site level, some sites seem to display significant differences between such groups while do others not. This will be examined on a larger scale.

The final strand of investigation in this thesis concerns legacy data and the methodology that can be developed through approaching these questions. Relevant questions in this respect include:

- Are datasets from different laboratories comparable?
- Are datasets analysed in different years comparable?

- How is the quality of the data assessed?
- How much information about the samples is lost between excavation and the isotopic analyses?

1.3. Outline of the thesis

The remainder of the text is separated into eight chapters. Chapter 2 examines the scientific background to isotopic studies, with a specific focus on factors likely to influence the isotopic record in the English landscape. Chapter 3 reviews all the isotopic work done on English material in the past twenty-two years. It does not solely focus on dietary studies, but also considers investigations of mobility and animal management. This chapter also discusses known agricultural and dietary patterns, which reveals the availability and prevalence of different foods in the periods investigated. Finally, it briefly discusses some theoretical points relating to this thesis such as scale and landscape. Chapter 4 covers the methodology used to analyse the dataset as well as reviews questions of methodology that arise from integrating data from different sources. Chapter 5 assesses the distribution of the data and answers methodological questions about using meta-data. Preliminary statistical analyses are also addressed in this chapter.

The main part of the thesis will be covered in Chapters 6 to 8. Chapter 6 reviews the faunal results on different chronological and regional levels to identify trends between periods as well as within them, and how these are spatially distributed. Chapter 7 builds on Chapter 6 to analyse the human data in depth, using the same criteria as Chapter 6. Both chapters also go beyond chronology and regionality to investigate the data through different units of analyses, such as, for instance, dry and wet climatic

episodes or coastal and riverine sites. Chapter 8 discusses these results and examine them against different factors to assess areas of continuity or change and reveal subsistence patterns in England between the Iron Age and the Early Middle Ages. Finally, the conclusion (Chapter 9) will summarize the main arguments and findings of this work, as well as consider possible areas for future research.

CHAPTER 2. ISOTOPES ANALYSES: SCIENTIFIC BACKGROUND

In this chapter, both the principles of isotopic analyses and how they are used for palaeodietary reconstruction are addressed by investigating the biological processes behind the dietary signal. There are two levels of variation that must be taken into account. First, the environment and plant physiology will determine the isotopic signature of the plants at the base of the food chain and the factors at play must be identified. Secondly, dietary input influences the $\partial^{13}C$ and $\partial^{15}N$ values of the fauna and humans and must also be accounted for.

2.1 Isotopes

2.1.1 What are they?

Put simply, isotopes are varieties of atoms of the same element. Their nuclei contain the same number of both protons and electrons, but they have a different number of neutrons (Hoefs 2009, 1). Isotopes exist under two forms: stable and unstable (radioactive). Unstable isotopes decay gradually, while stable isotopes, which are the ones investigated here, have not been shown to disintegrate over time (Hoefs 2009, 1).

Isotopic compositions in the biosphere vary through different processes (Hoefs 2009, 93). In the case of stable isotopes, this process is called fractionation and is a result of various biological reactions (Hoefs 2009, 3). With the ratios of $^{13}C/^{12}C$ and $^{15}N/^{14}N$ investigated here, photosynthesis and environmental factors define the isotope signatures of the vegetation first, and when these are consumed by humans and fauna, the physical

processes of food assimilation add another level of fractionation (see specific references in this chapter).

Different types of foodstuff ingested by humans or animals will have different isotopic ratios and by measuring these ratios, it is possible to reconstruct the diet of an individual, as well as the environment in which the food was produced (Vogel and van der Merwe 1977; van der Merwe and Vogel 1978; Tauber 1981; Chisholm *et al.* 1982; Schoeninger *et al.*1983; Ambrose 1986; Schoeninger 1995).

Stable isotopic ratios of $^{13}C/^{12}C$ and $^{15}N/^{14}N$ are reported as ∂-values and units of 'parts per thousand' (per mil or ‰) relative to a standard. The formula to calculate ∂ values is shown below in (1).

$$\partial\ (‰) = (R_x/R_s\ -1) * 1000 \quad (1)$$

In this formula, R is the ratio of the heavy to light isotope (here $^{13}C/^{12}C$ and $^{15}N/^{14}N$), R*x* is the sample measured and R*s* is the standard of known composition. A positive ∂-value indicates that the sample is enriched relative to the standard, while a negative ∂-value indicates that the sample is depleted relative to the standard (Hoefs 2009, 8).

For the reconstruction of past diet, the ratios of $^{13}C/^{12}C$ and $^{15}N/^{14}N$ in bone collagen are the most common analyses undertaken. Nevertheless, recent years have seen studies of other isotopes, such as calcium, sulphur or hydrogen for example, and other bodily tissues, such as hair, skin, and bone apatite (O'Connell and Hedges 1999 a and b; Richards *et al.* 2003; Clementz *et al.* 2003; Privat *et al.* 2007; Reynard and Hedges 2008; Nehlich *et al.* 2010; Nehlich *et al.* 2011). A brief review of how stable isotope analyses have been used in archaeology will be presented in section 2.1.4.

2.1.2 Carbon

Carbon has two stable isotopes: ^{12}C (98.93 % of the natural isotopic abundance), and ^{13}C (1.07 % of the natural abundance; Hoefs 2009, 48). Carbon stable isotope ratios ($\partial^{13}C$) have traditionally been reported relative to the international standard of Peedee Belemnite (PDB), a limestone fossil from the Peedee formation in South Carolina. The ∂-value of the sample is calculated using equation (1) seen above (Hoefs 2009, 49).

It must be noted that the original material has now been entirely used and has been replaced by a substitute referred to as the Vienna-PDB (V-PDB). Because the PDB and the V-PDB are of marine origin, they are significantly enriched in ^{13}C. Most material will therefore appear depleted in $\partial^{13}C$ relative to the standard and display negative values (Gonfiantini *et al*. 1995, 15).

Carbon is primarily used to define the ecological environment of the samples investigated – both the conditions under which they grew (plants) and in which they fed (animals and humans). The main factors that influence carbon isotopic variation will be reviewed below in section 2.2.1

2.1.3 Nitrogen

Nitrogen, like carbon, has two stable isotopes: ^{14}N, which is the lighter (99.63 % of the natural abundance of nitrogen in the atmosphere) and the heavier isotope, ^{15}N (0.37%; Hoefs 2009, 54). To report nitrogen stable isotope ratios ($\partial^{15}N$), the accepted standard is atmospheric N_2, also referred to as AIR for Ambient Inhalable Reservoir. $\partial^{15}N$ ratios are also calculated with the same equation (1) shown above (Mariotti 1983; Hoefs 2009, 54) and they are used to assess the trophic levels of the food

consumer, that is where that consumer falls on the food chain. Because each step up the food results in added fractionation, $\partial^{15}N$ values of animal product consumers are higher than those of herbivores or vegetarians (Ambrose 1986; Ambrose 1991; Hedges 2003; Hedges and Reynard 2007). Therefore, one of the primary uses of $\partial^{15}N$ is to assess the amount of meat or other animal product, such as dairy, in an individual's diet (Ambrose 1986). The main factors that influence nitrogen isotopic ratios will be reviewed in section 2.2.2

2.1.4 Palaeodietary reconstructions in Archaeology

Stable isotope analysis was first used as a tool to reconstruct ancient diets in 1977, in a pioneering paper by Vogel and van der Merwe (Vogel and van der Merwe 1977). This first application of the method used the different ratios in the $\partial^{13}C$ isotopic composition of C_3 and C_4 plants to investigate the introduction of maize as a dietary staple in the United States (Vogel and van der Merwe 1977; van der Merwe and Vogel 1978). After this, stable isotope analyses were used to distinguish between terrestrial and marine diets in relation to the question of subsistence change during the Mesolithic-Neolithic transition in Denmark or in North Western Canada (Tauber 1981; Chisholm *et al.* 1982). These first studies were focused on identifying isotopically large dietary shifts, but as the method was developed, it became more widely used and has been applied to populations for which less striking dietary difference is expected, such as in the case of the data used in the present thesis. Indeed, while some significant variation is expected between different groups, neither a shift from C_3 to C_4 at the level of the general population, since C_4 was not

cultivated widely at the time, nor clearly distinct ecological niches are likely to be seen in the signal of the data pertaining to England between the Iron Age and the Early Medieval period.

2.1.5 Stable Isotope analyses of bones

The most commonly used materials in stable isotope analyses for palaeodietary reconstructions are bones and teeth. While any tissue such as hair, skin or red blood cells can be used, bones are the most likely to be preserved in European burial contexts (for a review of the different tissues, see O'Connell and Hedges 1999 a and b; O'Connell *et al.* 2001). In the dataset presented in this thesis, analyses were almost exclusively conducted on bone collagen (the organic phase of the bone) rather than apatite (inorganic phase of the bone) and with only a few measured from dentine samples (for a breakdown see Chapter 4). While carbonate in bone apatite may be a more accurate reflection of the whole diet compared to collagen, which is biased toward dietary protein (Ambrose and Norr 1993; Froehle *et al.* 2010), collagen is a more stable tissue, less prone to exchange with the burial environment (De Niro 1985; Hedges 2002; Collins *et al.* 2002; Jim *et al*. 2004; Mays and Beavan 2012). Dentine, on the other hand, is formed in childhood and does not experience turnover. Therefore, the $\partial^{13}C$ and the $\partial^{15}N$ values obtained from dentine are a reflection of childhood diets (Richards *et al.* 2002; Budd *et al.* 2004).

After this brief review of what is meant by carbon and nitrogen isotope analyses of bone collagen, it is worth investigating the factors behind isotopic variation, first at the environmental level and how they affect

plants, and then at the physiological level for the main actors of the biosphere.

2.2 Environmental factors of isotopic variation

Ecologists have identified different isotopic signatures in plants according to different photosynthetic pathways, as well as environmentally driven variation such as water-efficiency use, light, temperature, and altitude (O'Leary 1981; Stuiver and Braziunas 1987; Farquhar *et al.* 1989; Tieszen 1991; Korol *et al.* 1999; Amundson *et al.* 2003; Richards and Hedges 2003). These are then passed on to the consumers of these plants, allowing not only the reconstruction of their diet but also, at least to some extent, of their ecological environment. It is therefore crucial to review these factors, with a special focus on those that will be relevant in the context of the English landscape. Terrestrial, marine and freshwater ecosystems will all be considered.

2.2.1 Carbon in Terrestrial Ecosystem

2.2.1.1 Photosynthesis

Plants are the basis of virtually every terrestrial food chain. The isotopic signatures of the local vegetation are therefore crucial to consider to understand the variability of terrestrial food webs, as plant variation will be passed on to the consumer (Farquhar *et al.* 1989; O'Leary 1995). Terrestrial plants obtain their carbon through the fixation of atmospheric CO_2 during photosynthesis, which is when the fractionation of isotopes occurs (Tieszen 1991). Three photosynthetic pathways exist, each fixing carbon in a different way and each resulting in different isotope ranges for the plant's organic matter (Hoefs 2009, 52). Plants using the C_3 photosynthetic pathway

(sometimes referred to as the Calvin-Benson pathway) use ribulose biphosphate carboxylase to fix atmospheric CO_2 and the first compounds they form contain three carbon atoms (DeNiro 1987; van der Merwe 1982). C_3 plants grow in temperate areas with sufficient CO_2 and water and include all trees, most shrubs, root crops and most grasses from temperate Europe and North America. C_4 plants include mainly tropical grasses such as maize, sugar cane, sorghum and millet, none of which are native to Britain but some, like millet and sorghum were nonetheless present in Europe in the time periods investigated here, albeit in small quantities (van der Veen 2008). Finally, a small group of terrestrial plants use a third pathway, known as Crassulacean Acid Metabolism (CAM), which has the ability to switch between the C_3 and C_4 pathways. Their isotopic signatures are not well established and fall between the $\partial^{13}C$ values of C_3 or C_4 plants (van der Merwe 1982; Tieszen 1991; Farquhar *et al.* 1989). C_3-plants have an average $\partial^{13}C$ value of -26.5‰ with a range of -34 to -22‰ while C_4 plants have $\partial^{13}C$ averages around -12.5‰ but there is considerable variation (van der Merwe 1982; Tieszen 1991; Hoefs 2009, 52). They are intricately linked with the isotopic composition of atmospheric CO_2, which fluctuates on various spatial and temporal scales: seasonal, diurnal and nocturnal, latitudinal, regional and local (Hoefs 2009, 59). Climate, especially rainfall and exposure to sunlight, is a key variable that affects rates of photosynthesis and therefore isotopic fractionation (O'Leary 1981; Ambrose and De Niro 1987, 1989; Ambrose and Norr 1993; van Klinken 1994; Yakir and Israeli 1995; Saurer *et al*. 1995*;* Schleser *et al.* 1999; van Klinken *et al*. 2002; Amundson *et al.* 2003; Marshall *et al.* 2007). Altitude, too, has a significant effect, although considerable interspecies variation has been

observed (Marshall and Zhang 1994). Regional differences in plant $\partial^{13}C$ are linked to local growing conditions and as these can fluctuate even within the same environmental niche, there may be considerable differences, even between species in the same habitat (Farquhar *et al.* 1989; Tieszen 1991; Heaton 1999). Each of these factors will be addressed in the next sections.

2.2.1.2 Water availability

Many studies have shown the correlation between water availability and the $\partial^{13}C$ values of plants, whether in terms of relative atmospheric humidity, rainfall or plant transpiration (Farquhar *et al.* 1989; Korol *et al.* 1999; Stevens *et al.* 2006; Kohn 2010; Hartman and Danin 2010). There are many complex models that predict these factors and how they affect the open and closing of stomatal pores, photosynthesis and conductance (Farquhar *et al.* 1989). There is also a set of equations to predict the isotopic ratios under particular conditions (for a review, see Farquhar *et al.* 1989). While understanding these mechanisms is beyond the scope of this thesis, it is nonetheless important to note that variation in $\partial^{13}C$ values is likely due to the closing of the plant stomata in arid conditions to preserve water and therefore limit CO_2 diffusion and fractionation (O'Leary 1981; Farquhar *et al*. 1989; Korol 1999; Kohn 2010). In short, drier conditions, either caused by aridity or higher temperatures, will result in water evaporation (Kohn, 2010). To conserve its moisture, the plant will close its stomatal pores, thus reducing the exchanges between the plant and the atmosphere and reducing ^{13}C fractionation relative to atmospheric CO_2, resulting in higher $\partial^{13}C$ values for the plants in drier conditions (Farquhar 1982; Araus *et al.* 2002; Hartman and Danin 2010). Conversely, wetter conditions result in the

stomatal pores remaining open, and lower $\partial^{13}C$ values relative to the plants in drier conditions (Farquhar and Sharkey 1982; Araus *et al.* 2002). However, it remains uncertain how much variation can be expected. Turner *et al.* (2008) measured a 2‰ decrease per 1000ml of rain, but put this down to leaf morphology rather than a direct rainfall effect. In more recent years, the $\partial^{13}C$ values of plant has been used to investigate their growing conditions, and more specifically the water regimes under which these plants were managed (Araus *et al.* 2002; Wallace *et al.* 2013; Masi *et al.* 2014), which opens up fascinating possibilities to better reconstruct past agricultural systems. Because the dataset used here spans different climatic events, it is important to consider how periods of heavy rainfall would have affected the isotopic values at the base of the food chain and how this can be reflected in the human data.

2.2.1.3 Canopy Effect

The 'canopy effect', first observed by Vogel in 1978, describes how in forest ecosystems, leaf and plant $\partial^{13}C$ values are often depleted in relation to their 'altitude' in the forest (Vogel 1978). There are a number of mechanisms behind the canopy effect. Light and nutrient availability, as well as the mixing of CO_2 from the forest air with atmospheric CO_2, could cause the $\partial^{13}C$ values of plants or leaves growing close to the ground to become depleted (Vogel 1978, Farquhar *et al.* 1989; Buchmann *et al.* 1997). Rotting organic matter releases isotopically light CO_2 that becomes trapped under the forest canopy resulting in a vertical stratification of the $\partial^{13}C$ values of the air within the forest canopy (Vogel 1978; Brooks *et al.* 1997). Forest plants then take in the CO_2 creating a vertical gradient among

the leaf $\partial^{13}C$ values (typically 3-4 ‰) from the forest floor to the top of the canopy (Vogel 1978).

While C_3 grasses in an open habitat have a mean $\partial^{13}C$ average of -26.5‰ (Vogel 1978), $\partial^{13}C$ values as low -37‰ have been recorded from the Amazonian forest undergrowth (van der Merwe and Medina 1989; Buchmann *et al.* 1997). In a British forest context, an offset of ~5‰ has been shown between grasses grown under a forest canopy and in an open system, and a strong relationship between values depleted in ^{13}C and low light intensity has been demonstrated (Bonafini *et al.* 2013). Such difference between growing systems will affect the values of the fauna or humans consuming them and can therefore help to distinguish between potentially different animal management systems, with some species grazing in woodlands and others grazing in open pastures.

2.2.1.4 Light

As discussed in the paper by Bonafini *et al.* (2013), one of the causes of the canopy effect is thought to be light (or irradiance), but this is not without controversy due to the difficulty in assessing the direct effects of light levels on the isotopic composition of plants as opposed to other correlated environmental factors (Farquhar *et al.* 1989). However, while the first models of the canopy effect posited that a decrease in ^{13}C was due to plants breathing recycled CO_2, a correlation between increased light exposition and enrichment in ^{13}C was later linked to plant transpiration (Farquhar *et al.* 1989). Because shaded leaves are less susceptible to water loss, their stomatal pores are open, causing lower rates of diffusion (Farquhar *et al.* 1989). In other words, because there is less risk of water evaporation in the

shade, stomatal pores can remain open without the risk of water loss. This constant exchange with the environment (as opposed to when plants keep their pores closed) means there are diminished levels of diffusion and therefore greater ^{13}C fractionation resulting in lower $\partial^{13}C$ values.

2.2.1.5 Temperature

One of the challenges in assessing the environmental variations on the $\partial^{13}C$ values of plants is the difficulty in disentangling all these correlated factors from one another as shown above. This is particularly true in the case of temperature. Leavitt and Long (1992) showed a negative correlation between temperature and the $\partial^{13}C$ values of juniper trees, with high $\partial^{13}C$ values in the colder months and low $\partial^{13}C$ values in the warmer months. They concluded that these changes were not controlled by seasonal variation in $\partial^{13}C$ atmospheric values nor caused by water availability but by temperatures. However, later experiments in controlled environments failed to reproduce these results (O'Leary 1995). Again, this is important here as different cold and warm episodes are well attested within the periods investigated and the effects of fluctuating temperature must be taken into account as much as possible.

2.2.1.6 Salinity

The first studies on the effect of salinity and $\partial^{13}C$ showed little correlation between the two but a later study reported a decrease in $\partial^{13}C$ values with increased salinity both in field samples and in plants grown in controlled environments (O'Leary 1981). This was confirmed by another study by van Groeningen and van Kessel (2002), who concluded that salinity could predict up to 57% of the $\partial^{13}C$ variation. Again, it is not the mechanisms

that are necessarily important here, but rather that there could be a potential environmental difference between coastal and inland sites that must be accounted for.

2.2.1.7 Plants physiology

Different plant parts have $\partial^{13}C$ values that vary between 1 and 2‰ (Farquhar *et al.* 1989; O'Leary 1995), possibly due to the different biochemical components (e.g. carbohydrates, lipids, protein) from which they are formed and which can have different $\partial^{13}C$ isotope values (Lee-Thorpe *et al.* 1989; Heaton 1999). Plant parts can display varying carbon isotope signatures depending on the time of the year in which they grow and the seasonal environmental conditions (Heaton 1999). Thus leaves, seeds, and branches of a single plant can vary and display different isotopic signatures. Plant $\partial^{13}C$ values have also been reported to increase with age such as a 3‰ increase in $\partial^{13}C$ between seed and the mature plant due to higher rates of photosynthesis, stomatal conductance and transpiration (Donovan and Ehleringer, 1992). Typical natural variability in ^{13}C for a population containing a single species sampled at the same time and from the same area can approximately be between 0.8 to 1.5‰ (Heaton 1999). Difference in plant isotope values may also occur both within a single species and between species due to natural genetic variability resulting in varying responses to the same environmental parameters (Heaton 1999). Plants are at the base of the food chain and it is therefore important to understand the natural variation likely to occur. However, there is a strong argument that herbivores' ∂-values actually average the variation in individual plants, meaning that important

variation in the plant data will not necessarily result in important variation in the herbivore data. (Hedges *et al*. 2000; Stevens and Hedges 2004).

2.2.2 Nitrogen in Terrestrial Environment

2.2.2.1 Nitrogen assimilation

Terrestrial plants assimilate atmospheric nitrogen with the help of soil micro-organisms, which convert N_2 both from the atmosphere and from decaying organic matter into simple compounds (Hoefs 2009, 54). There are two different pathways of N-assimilation. Some plants such as legumes and clovers are N_2-fixers and acquire nitrogen directly from the atmosphere through symbiosis with specialised nitrogen-fixing bacteria (Fraser *et al*. 2011). Because these processes result in very little fractionation, typical $\partial^{15}N$ for N_2-fixers are close to atmospheric values, that is 0‰ (Hoefs 2009, 55).

Most of the terrestrial plants, however, are non-fixers and assimilate their nitrogen from the soil. The isotopic composition of soil nitrate, the chief nitrogen source for plants, is extremely variable since nitrification, or the production of soil nitrate, usually requires several chemical processes and the $\partial^{15}N$ ratios of soil nitrates are the result of several complex nitrification and de-nitrification processes (Spzak 2014). Plants can have $\partial^{15}N$ ratios between 2‰ and 10‰ depending on nitrogen sources in the soils, such as NH_4, NO_2 and NO_3 (Schoeninger and DeNiro 1984; Hoefs 2009, 55; Spzak 2014). They also vary according to the local nitrogen pool, which may contain hyper-localised sources such as animal excreta or decaying carcasses (Hoefs 2009, 55; Spzak 2014; Figure 2.1).

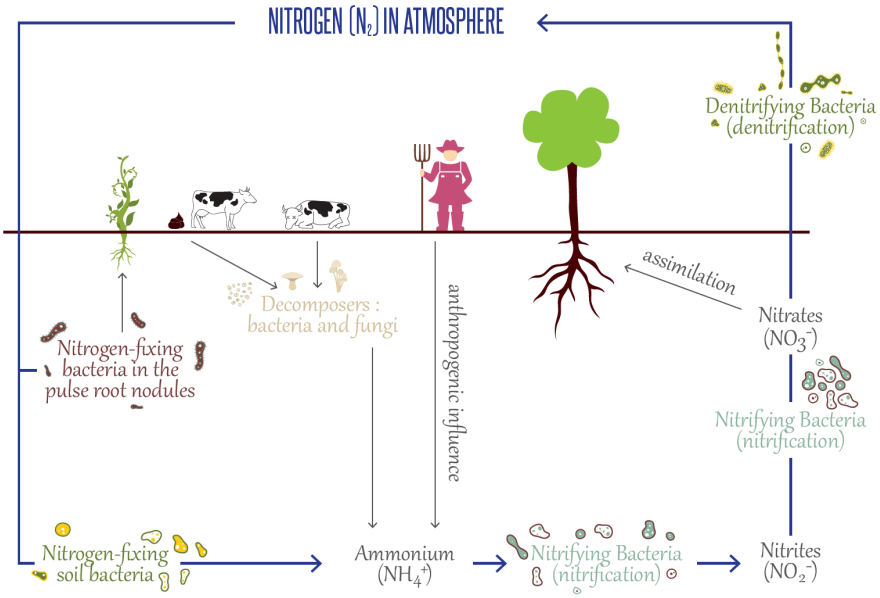


Figure 2.1. The cycle of nitrogen in nature. This is a simplified version; not taking into account the role of the ocean, intensive human activity or how different soils would react differently. (Illustration by Zoé Mallet).

The net fractionation of these reactions is dependent on soil properties and the presence or absence of certain micro-organisms (Ambrose 1991; Spzak 2014). Most of these factors change on a very small scale and the spatial variability of soil ∂^{15}N ratios can therefore be very large (Heaton 1987; Ambrose 1991; Hoefs 2009, 55). Physiological processes within the plants are also complex (Ambrose 1991). As with carbon, ∂^{15}N ratios may vary not only between and within plant species but also between different parts of the same plant. Shoots, for example, are sometimes enriched in ^{15}N in relation to roots (Ambrose 1991). Most often, however, the assumption is that plants are enriched in ^{15}N by the equivalent of one trophic level relative to AIR (+3‰; Hedges and Reynards 2007). The majority of domestic animals from archaeological contexts that have been subjected to isotopic analysis are herbivores (e.g., cattle, sheep, goats). Therefore, unlike omnivorous or

carnivorous species (e.g., dogs, pigs), the N isotopic compositions of herbivore tissues will be affected by biogeochemical processes in plant-soil systems. It is therefore important to consider how these systems may be different for animals kept under different conditions (e.g., stabling vs. free-ranging) or fed particular diets (e.g., agricultural by-products; for a review see Spzak 2014).

The influence of human activity on soil nitrification processes has been demonstrated in relation to climate change and soil pollution since the Industrial Revolution (for example Mulder *et al.* 2015). While these levels of industrialisation are unlikely to be met in the periods investigated here, it remains that human activity, and more specifically farming and animal husbandry, influence the soil nitrogen contents (Fraser *et al.* 2011). Of particular interest here is the application of manure, which has been shown to significantly raise the ∂^{15}N values of cereals (Bogaard *et al.* 2007; Fraser *et al.* 2011; Bogaard *et al.* 2013; Spzak 2014). To be able to assess patterns of manure application in the past would allow for a more in-depth understanding of agricultural techniques.

2.2.2.1 Canopy Effect

Bonafini *et al.* (2013) reported tentative evidence of a slight canopy effect in the ∂^{15}N values of grass, which was more depleted if grown in forested environments compared to the samples collected in the greenhouse. This is somewhat surprising as the accumulation of decaying organic debris on the forest floor would suggest an increase in ∂^{15}N values for plants grown in such conditions, although the processes of nitrogen cycling in forest are complex (Emmett *et al.* 1998; Vesterdal *et al.* 2008; Hamilton *et al.* 2009).

It is however possible that the grass grown in the greenhouse displayed higher $\partial^{15}N$ values due to the use of compost (Bonafini *et al.* 2013).

2.2.2.2 Water availability and heat stress

Many studies have reported a correlation between aridity and increased $\partial^{15}N$ values, which suggests that heat and aridity inhibit fixation of atmospheric N_2 into the soil and accelerate the volatilization of isotopically light ammonia (NH_3) making soils in hot and arid climates enriched in ^{15}N (Ambrose 1991; Schwartz and Schoeninger *et al*. 1991). A recent paper suggested an aridity 'threshold' at which point this effect is reversed (Wang *et al.* 2014). However, it must be acknowledged here that such levels of aridity are unlikely to be met in Britain but they might nonetheless be relevant to the dataset examined here, considering the possibility of migrants from drier climates. Drought and water stress can also affect the $\partial^{15}N$ ratios of animals, due to factors affecting urea excretion in response to water stress (Sealy *et al.* 1987; Ambrose 1991; Hare *et al*. 1991), resulting in ^{15}N-enriched values in the organism.

2.2.3 Carbon in Marine Ecosystems

The two major carbon reservoirs on Earth (terrestrial and marine) have different compositions (Hoefs 2009, 53). Because the material used for carbon calibration is of marine origin, marine carbon has $\partial^{13}C$ values close to 0‰, while atmospheric carbon has an average value of -7‰. This difference between atmospheric and marine carbon means that terrestrial and marine ecosystems can be differentiated through $\partial^{13}C$ isotopic ratios. This has been demonstrated by the seminal studies of Tauber (1981) and Chisholm *et al*. (1982) with regards to marine environments displaying

enriched $\partial^{13}C$ values compared to terrestrial ones. This difference is then passed on to the consumers of marine foodstuff, who will display higher $\partial^{13}C$ values compared to an individual feeding exclusively on foodstuffs from a terrestrial environment.

2.2.4 Nitrogen in Marine Environment

Nitrogen in oceans is derived from both the fixation of nitrogen in surface waters by algae and phytoplankton and from the deposition of organic matter from rivers or precipitation (Gruber 2004). The isotopic composition of the organic matter at the base of the food chain is dependent on the nitrogen source but also varies according to properties of the local aquatic cycle. This is one of the most complex processes in marine environments (Gruber 2008). Because de-nitrification processes favour the evaporation of the 'lighter' nitrogen isotope (^{14}N) from the water into the atmosphere, $\partial^{15}N$ values of marine organic matter are overall higher than those of atmospheric N_2 (Gruber 2004; Hoefs 2009, 56). Furthermore, because marine food chains comprise several more trophic levels than terrestrial eco-systems, marine animals usually display enriched $\partial^{15}N$ values compared to terrestrial organisms (Schoeninger and DeNiro 1984; Richards and Hedges 1999).

The consumption of fish has various implications – cultural and religious – for the periods investigated in this thesis, and it is important to be able to test whether or not populations, or indeed individuals, ate fish. Richards *et al*. (1998) showed it was the case for the population buried in Poundbury in Dorset and that it was correlated with status, but this needs to be tested further in this dataset.

2.2.5 Carbon in Freshwater Ecosystems

The isotope ecology of freshwater ecosystems is also quite complex, since carbon is derived from a range of sources, including atmospheric, aquatic and terrestrial ones, all with different isotopic values (Hoefs 2009, 153). The relative importance of each is dependent on numerous factors and can vary considerably within the same habitat (Hoefs 2009, 153). Because of the great diversity in the isotopic composition of aquatic plants and the complexity of freshwater food webs, the isotopic signatures of lake and riverine fish are extremely variable. Significant variations between species and within the same species have been reported (Jones and Waldron 2003). Jones and Waldron (2003) have shown a range of isotopic values for freshwater species that overlap with both terrestrial and marine systems, even within the same ecological niche, i.e. the same body of water. Migratory species spending part of their lifetime in the sea and part in freshwater environments must be considered separately. Their isotopic signatures are dependent on the eco-system they primarily feed in and may therefore resemble marine or freshwater fish as well as exhibit intermediate $\partial^{13}C$ values, which is why such species have been kept separately from either marine or freshwater species in the analyses here (McCarthy and Waldron 2000). Human values that do not show a clear terrestrial or marine dietary pattern are often thought to be caused by a diet predominantly based on freshwater fish. This interpretation is problematic on some levels, not least because fish bones are rarely recovered in large enough quantities to account for freshwater fish being an important part of the diet (Hedges and Reynard 2007). More recent studies have investigated the use of sulphur isotopes to differentiate types of freshwater resources in

the diet (Richards *et al.* 2003; Privat *et al.* 2007; Nehlich *et al.* 2010; 2011).

2.2.6 Nitrogen in freshwater environment

The length of aquatic food chains and the variability of nitrogen sources in lakes and rivers are the main factors of isotopic variation in freshwater systems (Hoefs 2007, 154). As with marine nitrogen cycles, the processes are complex, with many cycles of nitrification and de-nitrifications and it is difficult to predict the $\partial^{15}N$ values of freshwater organisms. Jones and Waldron (2003) have also shown that the range of nitrogen variation in freshwater species exceeds that of terrestrial and marine species.

This brief review of the environmental effects on plant isotopic ratios was necessary to fully understand the role of environmental factors in the isotopic signal, which affect the plants then consumed by animals higher up the food chain. Dietary factors are considered in the next section.

2.3 Dietary factors of isotopic variation

2.3.1 Collagen Turnover

An important point to make in relation to collagen concerns rates of collagen turnover, which depend on various factors such as health, nutrition and levels of physical activity and therefore vary from one individual to another. Research done on femoral bone has shown that collagen turnover is not constant and varies with age (MacAnulty and Laurent 1987; Eyre *et al.* 1988; Hobson and Clark 1993; Sealy *et al*. 1995; Hedges *et al.* 2007; Lamb *et al*. 2014). The most relevant aspect here is

how replacement rates vary between different types of bone tissues, and hence how different bones may have different turnover rates. For example, collagen will renew faster in ribs than in long bones (Sealy *et al*. 1995; Hedges *et al.* 2007; Lamb *et al*. 2014) but feeding experiments have shown only a small difference of the order of 1‰ in the isotopic composition of skeletal elements in individuals that have been fed monotonous diets (DeNiro and Schoeninger 1983; Clark *et al.* 2017; Dauven *et al*. in press). The implications of this for this dataset will be addressed more fully in Chapter 4 and 5. Finally, it is also important to remember that the isotope ratios of bone collagen are not an instant snapshot of diets at the time of death, but rather are an average of the decade of life preceding death (Sealy *et al*. 1995; Hedges *et al.* 2007). This means that individuals who changed environments during their life course might show isotope values that do not reflect the 'local' values at the place of burial but rather isotopic values consistent with where they spent the decade prior to their death.

2.3.2 Collagen synthesis: different models

Isotopic fractionation of both carbon and nitrogen in collagen occur during the production of amino-acids and it is important to be aware of these processes insofar as possible as this what is understood by 'isotopic dietary signal'. Two models have been suggested for the assimilation of carbon into the body. In early isotopic studies, the linear mixing model was posited. It suggested that the carbon in bone collagen was 'scrambled', that is acquired from all sources of carbon in the diet (Ambrose and Norr 1993; Howland *et al*. 2003; Hedges 2006; Lee-Thorp 2008). However, feeding experiments in which the protein, carbohydrate and lipids could be

controlled and were distinguishable demonstrated that up to 90% of carbon in collagen derived from the protein contents of the diet and that when a non-essential amino acid is present in enough concentrations, it will be incorporated directly from the diet to the tissue rather than being synthesised again (Ambrose and Norr 1993; Tieszen and Fagre 1993; Schwarcz 2002). However, it is worth noting that in cases of protein insufficient diets, carbon will then indeed be scrambled from the whole diet, and that the amount of carbon routed from protein increases with the amount of protein in the diet (Jim *et al.* 2006; Codron *et al*. 2012). Again, however, a level of uncertainty remains over how applicable these findings are to humans and there is a debate over whether the carbon in collagen that does not come directly from protein comes from the carbohydrate component of the diet or the carbohydrate and lipids components of the diet (Schwarcz 2002; Nitsch 2012, 78).

Things are somewhat simpler in the case of nitrogen, because dietary protein is the only source of nitrogen for the body and will therefore be the sole contributor (Ambrose 1986; Ambrose 1991; Hedges and Reynard 2007).

These are crucial points to consider as they raise the question whether protein- rich food such as meat or fish might 'hide' the contribution of foodstuff with a lesser protein content, such as plants (Ambrose and Norr 1993; Ambrose *et al*. 1997; van Klinken *et al*. 2002; Hedges and Reynard 2007). Since protein-rich food have usually enriched ^{13}C and ^{15}N ratios due to their position on the food-chain, if they are favoured for $\partial^{13}C$ and $\partial^{15}N$ assimilation then there is possibility that overall higher $\partial^{13}C$ and $\partial^{15}N$ values reflect only the protein content of the diet rather than the whole diet,

thus 'hiding' less rich protein food under the signal of protein-rich food. Conversely, if carbon from carbohydrates is included in collagen, 'carbohydrate-poor' foodstuff (such as fish) can be masked by 'carbohydrate-rich' foodstuff (Craig *et al*. 2013).

2.3.3 $\Delta^{13}C_{Diet\text{-}Tissue}$ in herbivores

Plants are at the base of the food chain as they are consumed by herbivores and omnivores. Therefore, herbivore isotopic values are closely correlated with plant values: when animals consume the plants, the plants isotopic signatures are incorporated into the animals' tissues, with a slight offset due to metabolism. Feeding experiments have measured an increase between 2 and 5‰ between diet and the collagen of herbivores (DeNiro and Epstein 1978; Hare *et al.* 1991; Jim *et al.* 2004). This may be caused by variations in plant $\partial^{13}C$ values, feeding preferences or dietary quality, as well as through differences in the physiology between laboratory and non-laboratory animals (DeNiro and Epstein 1978; Tieszen *et al*. 1983; Schoeninger and DeNiro 1984; Lee-Thorp *et al*. 1989; Tieszen 1991; Ambrose and Norr 1993; Tieszen and Fagre 1993; Hedges and van Klinken 2000; Hedges 2003; Jim *et al.* 2006).

2.3.4 $\Delta^{13}C_{Diet\text{-}Tissue}$ in Omnivores and Carnivores

At the next level of the food chain, a differentiation between diet-tissue spacing and trophic level must be made. Because of the differences in ∂-values between collagen and muscle, which posits that muscles are ^{13}C-depleted compared to collagen, the offset between diet (the meat of herbivores) and the measured tissue (the collagen of carnivores) is actually larger than a comparison of the collagen values of both the eater and the

eaten would suggest (Lee-Thorpe *et al.* 1989). Therefore, there is a difference between diet-tissue spacing (of the order of ~4.5‰) and the trophic level (of the order of 1 or 2‰; Schoeninger 1985; Lee-Thorpe *et al*. 1989; Bocherens and Drucker 2003).

2.3.5 $\Delta^{15}N_{Diet\text{-}Tissue}$

Consumer tissues are systematically enriched in ^{15}N with each step up the food chain (DeNiro and Schoeninger 1983; Schoeninger and DeNiro 1984) meaning that herbivores will have $\partial^{15}N$ values higher than those of the plants they ate and carnivores will have $\partial^{15}N$ values higher than that of the herbivores they ate, while omnivorous species will have $\partial^{15}N$ ratios in between those of an obligate herbivore and an obligate carnivore. It is worth noting here that, because stable isotope analyses cannot distinguish between the consumption of primary (meat) and secondary (milk) animal products, vegetarian diets will still show an omnivorous $\partial^{15}N$ signature while vegan diets will have $\partial^{15}N$ ratios similar to that of an herbivore (Katzenberg and Krouse 1989; Minagawa 1992; O'Connell and Hedges 1999a). However, the mechanisms of ^{15}N trophic level enrichment are complex, and not readily understood for dietary reconstruction (Hedges and Reynard 2007; O'Connell *et al.* 2012). Controlled feeding experiments, the main way to measure ^{15}N trophic level enrichment, are limited to small laboratory species, and therefore some uncertainty remains about larger species, including humans (Nitsch 2012, 67). Most studies assume a trophic level increase between 3 and 5‰ but it has been argued that this leads to an overestimation of animal protein in the diets,

sometimes to even unrealistic levels (Hedges and Reynard 2007; O'Connell *et al.* 2012; Nitsch 2012, 68).

To more fully understand trophic level enrichment between species, it is important to understand the mechanisms of fractionation between diet and tissues. An average $\partial^{15}N$ trophic level increase between diet and tissue ($\Delta^{15}N_{diet\text{-}tissue}$) of 2 to 3‰ has been suggested (Post 2002; McCutchan *et al.* 2003; Vanderklift and Ponsard 2003; Robbins *et al.* 2005). Robbins specifically noted an enrichment of up to 5.8‰ but Hedges and Reynard (2007) dismissed the outliers as a possible 'nursing signal (see section 2.4.3.2; Nitsch 2012, 67). Control feeding experiments on pigs, whose digestive system might be closer to that of humans, have measured $\Delta^{15}N_{diet\text{-}collagen}$ between 2.2 and 6.1‰ (Hare *et al.* 1991; Howland *et al.* 2003), suggesting that a range of factors can possibly affect the enrichment in ^{15}N. Trophic levels between diets and tissues in humans can be measured using the hair of living subjects (Yoshinaga *et al* 1996; O'Connell and Hedges 1999a), from which the $\Delta^{15}N_{diet\text{-}collagen}$ can be inferred since the offset between human keratin and human collagen is known to be about 1‰ (O'Connell and Hedges 1999b; Hedges and Reynard 2007; Nitsch 2012, 67). Hedges and Reynard (2007), accepting a human $\Delta^{15}N_{diet\text{-}hair}$ of 4-5‰, calculated the $\Delta^{15}N_{diet\text{-}collagen}$ to be 5-6‰. Understanding the offset between diet and tissue is crucial to dietary reconstruction, especially for assessing the level of animal protein in the diet (Hedges and Reynard 2007; O'Connell *et al.* 2012).

These considerations are also complicated by question of protein quality, as Ambrose (1991) observed that low protein diets can display higher $\partial^{15}N$ signatures but controlled feeding experiment seem to demonstrate that

high-protein diets usually results in larger $\Delta^{15}N_{diet\text{-}tissue}$ fractionation (Pearson *et al.* 2003; Sponheimer *et al.* 2003). For example, Sponheimer *et al.* (2003) measured that herbivores fed on a 19% protein diet had $\Delta^{15}N_{diet\text{-}tissue}$ on average 2.3‰ higher than those on a 9% protein diet. These differences varied across species in term of magnitude, but the increase was consistent across them all (Sponheimer *et al.* 2003). However, other studies showed the opposite, that is that either the relationship between the protein contents of the diets and $\Delta^{15}N_{diet\text{-}tissue}$ was negative (Robbins *et al.* 2005) or not significant (McCutchan *et al* 2003). The causes behind the possible enrichment noted by Sponheimer could be due to the change in the amount of nitrogen excreted in either faeces or urine for low and high protein diets, which will be discussed further in case of protein-stressed situations below in section 2.4.2.

2.3.6 Baselines

It is a common practice in isotopic studies to compare human isotope signatures to faunal ones, the animal providing a baseline against which to calculate diet or trophic position (Casey and Post 2011). For dietary studies, the interpretation of $t\partial^{13}C$ and $\partial^{15}N$ data relies upon a thorough understanding of the range and variation in isotopic compositions of the foodstuff that may have been consumed, which is complicated since the majority of ecosystems have multiple food sources, which have distinct $\partial^{13}C$ and $\partial^{15}N$ isotopic signatures even if they are at the same trophic level in the same ecosystem (Casey and Post 2011). This difference must be accounted for when calculating diet or trophic position using stable isotopic method and is particularly important when comparing animals from different

regions or different times, as is the case here (Casey 2008; Casey and Post 2011). Not taking this variation into consideration can cause erroneous estimations of diet or trophic level, especially for organisms with mixed diets (Casey and Post 2011). There are two ways to construct a baseline: (1) by directly measuring $\partial^{13}C$ and $\partial^{15}N$ signatures of plants as a primary food source (Aurioles-Gamboa *et al*. 2009; Casey and Post 2011); and (2) by measuring the $\partial^{13}C$ and $\partial^{15}N$ signatures of a proxy species, here cattle (Cabana and Rasmussen 1996; Post 2002; Casey and Post 2011). Good proxy taxa are close to the primary food source, and derive as much of their energy as possible from it, and integrate nutrients into their tissues over time scales comparable to secondary consumers of interest, here the humans (Cabana and Rasmussen 1996; Vander Zanden *et al*. 1999; Post 2002). In short, animals with restricted dietary needs, such as herbivores, feeding in a similar environment to the human (the secondary consumers of interest here), can be used as control group.

2.4 Physiological Factors

2.4.1.Difference between species

2.4.1.1 Carbon

In general, diet-tissue offsets appear to be relatively constant across species, indicating that there is no physiological difference in carbon assimilation between species. Also important to consider is the question whether the production of isotopically light methane in the guts of herbivores, and especially ruminants, has a significant effect on carbon. This is particularly important in archaeological studies relying on cattle and sheep for environmental baselines (on ruminants, see Cerling and Harris

1999). However, the effects of rumination on collagen composition have been argued to be negligible (Hedges, 2003).

2.4.1.2 Nitrogen

Contrary to carbon, there seems to be physiological difference between species in nitrogen assimilation. Vanderklift and Ponsard (2003) found that the form in which nitrogen is excreted during deamination, i.e. the process by which amino acids are broken down when there is an excess of protein intake affects the ∂^{15}N values of bone collagen. The amino group is removed from the amino acid and converted to ammonia: the excretion of ammonia happens differently according to species: fish excrete the ammonia directly while birds convert it to uric acid and vertebrates convert it to urea (Vanderlift and Ponsard 2003). The chemical reaction increases in complexity from ammonia to urea, and each extra step introduces extra fractionation. Physiological differences in the digestive anatomy of ruminants and non-ruminants have also been discussed as a reason for herbivore ∂^{15}N variation (Sealy *et al*. 1987; van Klinken *et al*. 2002).

2.4.2 Nutritional Stresses and quality of diets

2.4.2.1 Carbon

While some isotopic enrichment of body tissues under nutritional stress has been noted in the case of ∂^{15}N ratios (see below, section 2.4.2.2), there is no definite evidence in the case of carbon. Some experimental studies have reported a 'starvation effect' for carbon (Olive *et al*. 2003), while others failed to observe any change of the carbon isotopic data of fasting individuals (Hobson *et al*. 1993). However, it is worth noting that Olive *et al.* (2003)'s experimental study was conducted on marine worms while

those of Hobson *et al.* (1993) was conducted on birds and the physiological differences between these species may be a factor in these results. A study on the hair of anorexic patients did reveal a correlation between Body-Mass Index and $\partial^{13}C$ ratios (Mekota *et al.* 2006). In the case of compact bone studies, Beaumont and Montgomery (2015) demonstrated evidence of nutritional stress by comparing dentine and ribs $\partial^{13}C$ and $\partial^{15}N$ measurements of inmates during the Great Irish Famine in the 19th century, suggesting new avenues to assess the quality of the diets of individuals who may otherwise appear healthy because death was too quick for the body to produce a bone marker, such as in the case of malnutrition (Wood *et al*. 1992; Beaumont and Montgomery 2015).

2.4.2.2. Nitrogen

In the case of starvation, the body must recycle nitrogen and since it will continue to excrete the lighter ^{14}N isotope, the tissues' nitrogen will become enriched in ^{15}N (Hobson *et al.* 1993; McCutchan *et al.* 2003; Fuller *et al.* 2005). This ^{15}N-enrichment has been shown in vertebrates and invertebrates as the result of starvation or low-protein diet (Hobson *et al*. 1993; Webb *et al*. 1998; Olive *et al*. 2003; Mekota *et al.* 2006; McCue and Pollock 2008). For humans, it has been shown in tissues with a short turnover, such as hair (Fuller *et al.* 2005) and Beaumont and Montgomery (2016) have used comparisons of dentine and bone collagen to show protein stress in slow turnover tissues in human, opening up the possibility of assessing period of starvation and famine through the study of bone collagen.

2.4.3 Sex and Age

2.4.3.1 Carbon

It is important to consider whether similar diets have different isotopic signatures depending on a consumer's age or sex in order to assess whether physiological differences exist. DeNiro and Schoeninger (1983) demonstrated that there were no significant differences between the sexes in a population of minks raised on the same diet. Other modern field studies failed to find a correlation between $\partial^{13}C$ values with sex or age (Minagawa 1992; Schwarcz and Schoeninger 1991).

The 'nursing effect' is well attested in $\partial^{15}N$ values of infants and it is important to consider whether it would affect $\partial^{13}C$ signatures too (for the nursing effect in the nitrogen isotope, see section 2.4.3.2). In their pioneering paper, Fogel *et al*. (1989) did not observe enrichment in ^{13}C in the fingernails of breast-feeding infants compared to their mothers. However, a clinical study on infants and their mothers showed a $\partial^{13}C$ trophic level effect of about 1‰ in fingernail and hair protein between the breast-fed babies and their mother, but not in the formula-fed infants, suggesting that a nursing effect also exist for carbon (Fuller *et al*. 2006a). This is confirmed by a more recent paper by Nitsch *et al.* (2011), which noted elevation of 1-2‰ in $\partial^{13}C$ values of infants compared to the adults' $\partial^{13}C$ signatures.

2.4.3.2 Nitrogen

As was the case with carbon, no physiological difference between males and females is expected in the $\partial^{15}N$ values (Schwarcz and Schoeninger 1991; Vanderklift and Ponsard, 2003). Nevertheless, Fuller *et al*. (2004)

reported a 0.5 - 1.0‰ decrease in ^{15}N in the hair of pregnant females during pregnancy, as ^{15}N is conserved for the foetus instead of being excreted (Fuller *et al*. 2004). The effect has only been measured in a tissue with high turnover and it remains debatable whether it would be visible in bone collagen (Nitsch *et al.* 2010). There is evidence that the bone is formed slightly faster than usual during pregnancy and lactation (Fuller *et al*. 2004). However, if pregnancies indeed had a lasting impact on the $\partial^{15}N$ values of bone collagen of females, significant variation between male and female population would be systematically observed, which is not the case (Fuller *et al*. 2004; Nitsch *et al.* 2010). There is therefore no evidence for the physiological differences in males and females and any variation in $\partial^{15}N$ values should thus be interpreted as evidence of dietary behaviour.

The most significant systematic physiological variation of tissue $\partial^{15}N$ values with age is the 'nursing effect' – a specific form of trophic level (Ambrose 2002). By drinking breast-milk, infants are effectively feeding off their mothers' and Fogel *et al.* (1989) noted that nursing human and animals display $\partial^{15}N$ ratios that are enriched compared to their mothers by about one trophic level. After nursing, the child loses this signal enriched in ^{13}C and ^{15}N, usually between 1 and 2 years of age (Fuller *et al*. 2006a and b, Nitsch *et al.* 2011; Jay *et al.* 2013). However, it must be noted that using bone collage to investigated weaning will result in crude age estimate do to the slow tissue turnover.

2.4.4 Health

2.4.4.1 Carbon

The few available studies on isotopic responses to pathological conditions affecting bone report no changes in the $\partial^{13}C$ values between healthy and sick individuals (White and Armelagos 1997; Katzenberg and Lovell 1999).

2.4.4.2 Nitrogen

The effects of pathological change on the nitrogen isotopic composition of bone of collagen are not well known. Katzenberg and Lovell (1999) observed both N-variation of up to 1‰ on the same bones if healthy and damaged fragments were measured. White and Armelagos (1997) report significantly higher $\partial^{15}N$ ratios in the bone collagen of a group of female Nubian mummies diagnosed with osteopenia but high protein diets can predispose people to this disease and it is therefore uncertain whether the high $\partial^{15}N$ ratios are a result of diets or pathology.

2.5 Summary

This review of the causes of isotopic variation in the tissues of organism is not exhaustive and could certainly be extended considerably. However, some environmental effects would be irrelevant in the context of this study and have therefore not been included. What have been shown here are the factors most likely to have influenced humans and fauna in the context of England in the timeframe investigated by this project as well as considerations of health and physiology. Maybe one of the most interesting of these factors is the soil nitrification process and specifically how

agricultural practices can alter such processes in measureable ways. Factors linked to climate may also need to be accounted for as Northern Europe between 700 B.C and 1200 A.D. was affected by cycles of climatic deterioration and amelioration, which are likely to have had an effect on the isotopic values of the environment (Büntgen *et al.* 2011; further references about climate variation in section 4.2.5). Some factors of physical geography are also likely to be relevant, such as the difference between terrestrial and marine/riverine environments and whether these differences are visible in the dataset will be assessed and investigated in this thesis.

CHAPTER 3. WHY DO WE EAT AND WHAT DID THEY EAT?

Food matters in two fundamental ways: one nutritional and one cultural. It guarantees the basic functioning of life forms and its acquisition is the primary concern for all animals including humans. But beyond the need to fulfil the biological imperative of nutrition, humans use food 'not only [as] a collection of products that can be used for statistical or nutritional studies. It is also, and at the same time, a system of communication, a body of images, a protocol of usages, situation and behaviour' (Barthes 1961; trans. E. Forster 1979).

This chapter focuses on the research background of this thesis, approaching it from both biological and cultural viewpoints. It will first outline the project of which this thesis is a part of and explain how it fits within that project. Then, the theoretical framework in which isotopic research is conducted will also be addressed. Finally, all the previous isotopic work done on material from English sites, which have been extensively used here, will be reviewed.

3. 1 The English Landscape and Identities Project

This thesis forms part of the English Landscape and Identities project, which has analysed change and continuity in the English landscape from the Middle Bronze Age (c. 1500 B.C.) to the Domesday survey (c. 1086 A.D.). A five-year project, funded by the European Research Council (ERC) at the University Oxford, it has combined an extensive amount of existing artefactual and mapping data from English Heritage's National

Mapping Programme (NMP), the Portable Antiquities Scheme (PAS), the Archaeological Data Service (ADS) and various county Historic Environment Records (HERs). The joint analyses of archaeological features and the English landscape had never been undertaken so extensively before and it is expected that it will shed new lights on the development of both the English landscape and the identities of the people who inhabited it, while also revealing patterns in modern archaeological practices (Gosden *et al.* in prep.)

The methodology of this thesis is similar to that of the English Landscape and Identities project, as it also integrates legacy data in order to offer a synthesis of the large amount of bio-archaeological information that has not yet been collated in one place. Indeed, sources for these data include articles published between 1998 and 2014, doctoral theses, site reports and the ADS. Therefore, this work draws on many previous separate analyses and its objectives include offering an up to date (at the time of writing) synthesis of data from disparate sources.

3.2. Food and the Landscape

Many cultural and symbolic values are placed on food, from the ingredients used in its preparation, to modes of cooking it, to how it is served, and the social contexts in which it is consumed (Barthes 1961; Bourdieu 1979; Gumerman 1997). Biologically speaking, the human species is omnivorous even though, at both the individual and group levels, there may be a genetic predisposition not to be able to digest certain foodstuffs, such as in the cases of food allergies or lactose intolerance in

some populations (Malmström *et al.* 2010). However, for simplicity's sake, it is assumed here that most foods valued and/or excluded are treated in this manner for cultural reasons rather than biological ones. Food is therefore both a nutritional imperative and a complex ideological symbol, making it a valuable and productive object of study.

It is important to note that the study of two facets of food – nutritional and cultural – require the examination of different types of evidence and have seldom been undertaken together in the past, although recent years have seen more of an effort toward the integration of these spheres.

Archaeological investigations of food ways and isotopic analyses of archaeological remains were both pioneered in 1977. James Deetz published one of the first studies of past food behaviour in his *In Small Things Forgotten* (1977, 49-61) the same year Vogel and van der Merwe published the first reconstruction of past diets using stable isotope analyses, looking at maize cultivation in New York State (Vogel and van der Merwe 1997). That timely coincidence could have sparked a discussion between the humanistic and scientific branch of food studies and led to a joint effort to examine past diets, but that was not to be the case. Archaeologists paid little interest to patterns of food consumption until the 1990s, despite anthropologists developing ever more complex approaches to the subject (Parker-Pearson 2003). This thesis is not the place to cover over hundred years of the social anthropology of food, but a brief overview is nevertheless necessary to at least understand some of the theoretical background in which these isotopic analyses were undertaken.

The very first anthropological studies of subsistence were concerned with the role of food as a socialising factor in the Andaman Islands (Radcliffe-Brown 1922) and its role in the formation of social relationships among the Bantu (Richards 1932). Both these works were firmly grounded in functionalism with food behaviours understood as the primary social construct in a society (Radcliffe-Brown 1922; Richards 1932). Thirty years later, Levi-Strauss' seminal work *Mythologiques* reframed the debate as a question of 'nature vs. culture', and divided food into 'uncooked' and 'cooked' (Levi-Strauss 1968). Others after him developed systems of opposition between 'pure' and 'impure' (Douglas 1966), 'new' and 'old' (Leach 1999) or 'local' and 'foreign' (Earle 2010).

More recent approaches have used food with the aim to understand social identities (Meadows 1994; Cool 2006; Twiss 2007; van der Veen 2007; Frantzen 2014). The utilisation of food as a symbol of identity is well established – and does not need to be debated here. The relationship between food, self and bodies has been observed since Classical Greece and Rome when authors would underline the otherness of foreigners by disparaging – among other things – the food they consumed, using cooking as a reflection of group identity (Garnsey 1999, 65). The impact of food on the body, as well as its perceived power, was also well recognised. The most prominent theory related to diet in the past was without doubt the concept of humours or elemental thinking that started with Plato and Hippocrates (5th-4th century B.C.) and was then further developed by Galen (1st century A.D.; Jones *et al*. 2016). It conceived that all physical matter was composed of the four elements (Water, Earth, Fire and Air) and that each element was

associated with certain qualities linked to the four humours: blood, yellow bile, black bile and phlegm (Jones *et al.* 2016). They were not fixed and could be found in different quantities in different individuals according to personal character, sex or age and they would fluctuate through the life of an individual (Jones *et al.* 2016). More relevant to this discussion, they were especially influenced by the consumption of different foods. Hippocratic and Galenic dietary theories became highly prominent and their influence can still be perceived as late as the 16th century in the anguish of Europeans encountering foreign foodstuff on an unprecedented scale when they colonised the Americas (Jones *et al.* 2016; Earle 2010). Columbus explained to the Spanish court that the very first European settlers in America were falling to sickness because of the lack of European food, and he believed that everyone would be restored to health as soon as 'the food we are accustomed to in Spain' would be made available (Earle 2010). Similarly, most settlers were worried that 'Indian food would give them Indian bodies' (Earle 2010).

However, isotopic analyses can only investigate one fraction of the food question, being that of what was actually ingested. Indeed, the means of preparation are outside the sphere of investigation of this thesis. While some chemical analyses can distinguish how the food had been cooked, either the manner (boiled, grilled or smoked for example) or the recipe (presence and absence of salt or spices), this is cannot be done with stable isotope analyses of bone collagen. Neither can it distinguish between different types of the same food, for example different grains, or even between primary and secondary animal products (meat or milk for

instance; Katzenberg and Krouse 1989; O'Connell and Hedges 2009; O'Connell and Lawler 2009, 118; O'Connell and Wilson 2011, 317). These are important factors as they may have been crucial to cultural distinctions but they cannot be considered in the interpretative framework of this thesis.

But while this 'cooking caveat' is important, it must nonetheless be remembered that isotopic analysis is still a powerful tool to assess the diets of individuals. Thanks to isotopic investigation, it is possible to assess individual diets within a group on a variety of criteria (such as sex, age, status, or burial position). Besides, while preparation and serving are important and worthy object of study in their own right, consumption is also equally important as an engagement with the world, 'allowing whole landscapes to be incorporated into the human body in a single bite' (Sykes 2011).

While most of the first isotopic studies investigated human diet and then mobility, recent years have seen a growing interest in the isotopic values of flora and fauna, as they begin to be considered as agents in their own right. Therefore, the following part of this chapter will consider the relationship between animals and the landscape.

3.2.1 Flora and Fauna

Interest in animals and plants as agents, rather than as economic or symbolic products is a somewhat more recent development of isotopic studies (Sykes 2011; Lightfoot and Stevens 2012; Stevens *et al.* 2013b; van der Veen 2014b). It is crucial to consider animal remains beyond their final resting place and acknowledge that each of these animals had a 'back-

story, or biography, of human interrelationships of varying duration and purpose' (Sykes 2011). Indeed, animals were not static in the landscape (Britton *et al.* 2009; Viner *et al.* 2010). It must be kept in mind that an animal buried at a given site might not be *from* that site, as it might not have been born and disposed of in the same place and repeatedly fed within the same limited environment. There is indeed ample evidence of animals moving within the landscape, whether on a large scale such the introduction of a new species such as chicken or deer (Sykes 2011; 2012) or on a much smaller scale, such as herds driven around the landscape to maximise their seasonal feeding (Schweissing *et al.* 2003; Towers *et al*. 2014). The notion of 'local' fauna is therefore one that must be used cautiously.

However, this does not mean that animal baselines might therefore not be a good proxy for the local environment (see Chapter 2, section 2.3.6). Indeed, to display signatures so wide as to be unusable as a local baseline, animals would have had to constantly move, which is not a realistic assumption (Stevens *et al.* 2013b). It is nonetheless important to underline that animals are agents in their own right and their isotopic signature might reveal important patterns of subsistence. As such, the faunal data will be analysed separately from, and before, the human group. Indeed, the focus of this thesis will not solely be on the relationship between the humans and their environment, but will favour a more holistic approach encompassing plants, fauna and humans.

3.3 Scale and Resolution

An important point to make here concerns issues of scale. Indeed, previous isotopic analyses – regardless of the number of samples measured – have usually focused on either small-scale units of analysis, such as the population of a site or very large-scale units, comparing the populations of one settlement across long-period of time or different population from wide geographical areas. It must be noted here that 'large-' and 'small-scale' are used to respectively describe large areas or long portions of time and small areas or short portions of time.

The advantage of a small-scale analysis is that the variables are, if not exactly the same, similar enough for the investigation to be free from considerations of geology, climate or the geographical proximity of certain resources. At the other end of the spectrum, large-scale analyses, such as long term dietary trends in one place (Müldner 2005; Müldner and Richards 2007a and b; Hamilton 2016) or dietary trends across a wide geographical area (Hedges *et al.* 2013) allow to some for factors of variation to be accounted for and measured.

This thesis' approach is somewhat different in that it attempts to correlate different scales altogether. Indeed, the temporal scale here is large – 2.5 millennia – and the effects of climate variation, the expansion or collapse of trade routes, or cultural factors can be measured. However, the geographical scale is neither small enough to be dismissed, nor large enough for these variations to be easy to measure. Because of this, it was the chronological trends that were primarily analysed, and against these *longue durée* patterns, the smaller and more nuanced regional ones were

compared. While it was simple enough to divide the dataset into large-scale periods based on traditional period boundaries, it nonetheless raised some questions. For instance, considering that early and late Roman Britain may have greatly differed from one another, it is worth wondering whether it is judicious to group all of the samples dated between 43 A.D. and 410 A.D. as 'Roman' without more distinction; there might well have been more in common between a 5th-century Roman and a 5th-century Saxon than a 1st-century and a 5th-century Roman. However, trying to break the Roman dataset into smaller chronological units would have resulted in the analysis being a mere repetition of the original works from which this thesis draws. It is an equally delicate matter to account for regional variation, mainly because geographical units are not necessarily coherent from one period to another. Questions of identity are likely to have been tied to different scales of locality and time. Senses of belonging to a household, a village, a region or a political entity would have depended on external pressures and internal understanding of self and may have fluctuated over the course of an individual's life, making it difficult for the modern analyst to define a relevant scale. Besides, difficulties in assessing identity on the basis of archaeological evidence, and specifically on the basis of scientific techniques have been raised elsewhere (Leach *et al.* 2010) and are certainly issues considered in this work, specifically in relation to scale and resolution. Therefore, a balance must be found between large- and small-scale and high- and low-resolution analyses. Indeed, there is not necessarily a correct scale at which to look at these data, because there is not one level of resolution that would resolve all the

chronological and spatial challenges. Instead there are different levels of analysis that can help answer different questions, with each answer adding to the understanding of each subtle trend. Having accepted that 1st- and 5th-century Romans might be different from one another, it is also important to recognise that they both lived in a world where Roman culture was the dominant one. Thus, a broad chronological scale can be as revealing as a smaller one accounting for seasonal changes in an individual's life, depending on the investigated subject. The French historian Braudel theorized the '*dialectique de la durée*' which described how 'different kinds of histories operat[e] at different timescales' (Braudel 1987; Rippon *et al.* 2015, 113). Braudel posited that short-term political and military events occur against a backdrop of medium-term social and economic circumstances, which in turn exist within the context of the *longue durée* (Rippon *et al*. 2015, 113). A '*dialectique de l'espace*' can be similarly theorized, in which hyper-localised events (such as happening in a household or a community) exist within a larger space (such as a region), this larger space itself also a part of a bigger whole (such as a political territory). In short, the actions of a Cornish family in 375 A.D. exist at the same time within the context of their household, their community, Cornwall, Roman Britain and the Roman Empire. Therefore, instead of trying to resolve this question by finding the 'correct' scale of analysis, this work will therefore investigate the data on different, complementary scales.

3.4. Food availability

3.4.1 Iron Age

'Their customs are in some respects like those of the Celt, in other aspect simpler and more barbaric. As results, some of them, through their want of skill do not make cheese though they have no shortage of milk. They are also unskilled in horticulture or farming in general'

Strabo, 1st century B.C – 1st century A.D; IV, 5.12

Despite Strabo's disparaging comments on the state of late Iron Age agriculture, evidence points to a complex system of consumer and producer sites involved in a network of redistribution (van der Veen and Jones 2006; van der Veen and Jones 2007; Stevens *et al*. 2013a and b). The dominant model of consumer sites vs. producer sites is important to consider when conducting isotopic studies, since, if the food is produced in the same environment for different populations, then any significant difference between them might be caused by dietary choices rather than environmental factors. By looking at data from sites on different regional scales, some near each other, others far away, it will therefore be possible to test the regional limit of this model.

The remains of cattle, sheep and pigs dominate faunal assemblages from Iron Age sites. Sheep are particularly ubiquitous, to the extent that the Iron Age is sometimes described as the 'Sheep Age' (Hambleton 2008). It is striking that wild resources, both terrestrial and maritime, are much rarer. Hill suggested that wild animals had a symbolic significance and, as such, were not a dietary staple and that their consumption was strictly regulated and reserved for certain occasions (Hill 1995; Sykes 2011). In the case of aquatic resources, the fishbone evidence suggest that aquatic resources

were not consumed in the Iron Age, or at least not consumed in quantity large enough to show in the archaeological record (Dobney and Ervynck 2007), which has been confirmed by the isotopic record to some extent (Jay 2008). The exploitation of dairy has been demonstrated by residue analyses, but it is impossible at this stage to confirm whether or not dairy was turned into cheese (Copley *et al.* 2003).

Arable farming was dominated by two crops: spelt wheat and barley, both hulled rather than free-threshing. Emmer wheat, bread wheat, rye and oats were also cultivated locally, as well as peas and beans (van der Veen 2014a; Treasure *et al*. 2016a and b), although these were more likely to be minor crops. However, because of their unique isotopic signature, it is important for pulses to be considered thoroughly in this thesis.

3.4.2 Roman Britain

Upon 'becoming Roman', Britain entered into a highly mobile network where people, animal and supplies were not as tightly bound by locality as they may have been in the Iron Age. Evidence for the arrival of new people, new animals (Sykes 2011) and new plants are abundant (Lodwick 2016; van der Veen 2014a). While there were many innovations in the Roman period, like the import of new foods, such as millet and coriander, what is the most striking is that, while agriculture intensified, there was actually little difference between the staple crops of the Iron Age and the Roman period (van der Veen 2014a). Therefore, a difference in the isotopic profiles of fauna and humans between these two periods may be due to a change in farming practices rather than diets.

Of course, this is not to say that the Romans did not also innovate agriculturally in Britain, as they introduced and developed horticulture, i.e. the cultivation of fruits, vegetables and spices, on a local scale (Lodwick 2016; van der Veen 2014a; van der Veen and Hill 2008). While the introduction of these new foodstuff is often seen as a mark of Romanisation, it has in fact been shown that these would have been already been present at elite sites in the Late Iron Age (Lodwick 2016). The same is true of condiments: while they certainly became more ubiquitous in Roman Britain, there is nonetheless evidence that they were indeed present in Iron Age Britain (Lodwick 2014; Livarda and van der Veen 2008). Therefore, it may be more correct to see Roman Britain as a period in which existing trends became intensified, rather than there being a wholesale change from the Iron Age.

The main aspect in which Roman Britain differs from the Iron Age, however, is in the composition of its faunal assemblages. While sheep dominated in the Iron Age, cattle became the main species of the Roman period (Maltby 1998; 2014). Another difference concerns the presence of fish bones and oyster shells at different sites, regardless of their proximity to the coast, suggesting a consumption of aquatic resources apparently absent from the Iron Age (Müldner 2013; Locker 2007). Particularly noteworthy here is Richards *et al*.' s (1998) analyses of the data from Poundbury, which link the consumption of aquatic resources in the Roman period to social status.

Finally, a brief consideration of urbanism is necessary. Not unlike the question of producer/consumer sites in the Iron Age, there is a debate on

how urban centres would have sustained themselves and how much they depended on rural producers (Bowman and Wilson 2013). Again, this is important in relation to isotopic studies because it can be tested through the systematic investigation of the differences between rural and urban settlements, which will be done here.

3.4.3 Early Medieval Britain

'The Romans […] left the island, destitute as it was of wine and oil, and returned to Italy'

Gildas, *De Excidio,* 1.7.

In his famous, if somewhat inaccurate account of post-Roman Britain, the British monk Gildas lamented the loss of wine and oil after the Romans departed (although it is unclear in the narrative if this refers to the actual end of the Roman rule or another event; *De Excidio* 1.7). Regardless of Gildas' accuracy as an historical witness, this image of Britain left almost destitute after the Roman period is one that has prevailed in modern scholarship (Rippon *et al.* 2015, 3, 4). Evidence for an economic depression is indeed well attested: woodlands expanded, population numbers dropped and trade with the Continent was interrupted (Rippon *et al.* 2015, 7, 9; Hamerow 2012, 144). The perceived landscape of the Early Medieval period is one that favoured animal husbandry over crop management (Banham and Faith 2014, 39). Because of this shift towards a more animal based economy, it is also assumed that Early Medieval diets were richer in meat compared to Roman ones (Banham and Faith 2014, 39). However, while it is certainly true that the Early Medieval period was

less intensively farmed than the Roman Period, there is nonetheless much evidence for rich agricultural traditions.

The Anglo-Saxons grew many species of wheat, such as einkorn (*Triticum monococcum)* and emmer (*Triticum dicoccum*), which had already been grown in the Iron Age, and spelt (*Triticum Spelta*; Banham and Faith 2014; 22), which had been grown in the Roman period. Wheat comes in two species: free threshing and hulled and while the hulled kind was dominant in Britain before the Roman period, the Anglo-Saxons seem to have preferred the free-threshing variety. Conversely, however, in the case of barley, the hulled kind was dominant. In prehistory (and today), free-threshing barley has been favoured when it was the dominant crop and a major human dietary staple (Banham and Faith 2014, 26). This would seem to indicate that barley was either not a dominant crop in Early Medieval England or not important for human consumption, but it is nonetheless abundant in the earlier Anglo-Saxon periods before it was replaced (Banham and Faith 2014, 26). The current model of agricultural development in the period suggests that bread wheat replaced hulled barley in the 8th century, but McKerracher makes a convincing argument that this is not the case and posits that rye and oats became more important regionally (McKerracher 2016). Today, hulled cereals are grown for brewing or animal fodder and it is often assumed it would have been the same in the past, meaning that barley could have been grown *en masse* to meet demands for animal fodder and/or for the making of beer (Hamerow 2012, 149; Banham and Faith 2014, 26).

It is also worth noting that hulled cereals had been predominant in Britain prior to the Anglo-Saxon period (Banham and Faith 2014, 26). Therefore, the shift to free-threshing cereals represents an important stage in agricultural practices in England and directly undermines the idea that there were no agricultural innovations in Britain during the early Middle Ages (Banham and Faith 2014; 25).

In term of livestock, cattle, sheep and pigs often appear in the written records (as well as horses, Banham and Faith 2014, 75). Because the population was less dense in the Early Medieval period than it had been in Roman Britain, it is often argued that there was more land available for livestock to graze on and that they required little to no management, leading to an increase in animal numbers with a drive to produce a surplus (Crabtree 2010; Banham and Faith 2014, 39). Over time, regional specialism appeared, with some regions focusing on sheep and others on cattle. For example, looking at the will of Aethelgifu, a noble Saxon woman of the late 9th century A.D. (or maybe the early 10th century A.D.), it is obvious from the resources she distributes from her different estates across southern England that some regions specialised in sheep while others seem to have favoured cattle (Whitelock and Rodd 1968). There is little evidence for the consumption of wild resources (Holmes 2015) but there is a 'fish event horizon' c. 1000 A.D. when zooarchaeological evidence suggests a change in the scale of marine fish consumption, even before the expansion of the North Sea medieval fisheries in Orkney, but also in the South of England (Barrett *et al.* 2004; Barrett *et al.* 2011; Reynolds 2016).

The archaeological record shows evidence for both continuity and innovation in agricultural practices between all three periods, although it could be argued that the main difference is one of scale of production rather than one of food availability, with distinct foodstuff only available to certain members of the population.

3.5. Previous Research

The following section reviews previous isotopic analyses conducted on materials from English sites. This section is divided chronologically and addresses previous stable isotope analyses of the data examined in this thesis. While only dietary data are considered in this work, a review of mobility and health studies will also be undertaken as these yield interesting insights in the dietary behaviours and the daily life of past population. Each section has been divided into three categories: (i) analyses of human and faunal remains; (ii) specific populations/practices based on studies investigating one aspect of a population or specific dietary behaviour; and (iii) non carbon and nitrogen studies, which focus on questions other than diet through the use of different isotopes. Because not all periods contains studies of all four categories, these sub-sections have been marked out with bullet points to avoid non-sequential numbered section titles.

3.5.1 Multi-Period Analyses

- ***Human and Faunal studies***

The first multi-period study of interest here is the thesis of Gundula Müldner (2005), who investigated diachronic changes in the city of York

between Roman Britain and the 19th century and two published papers from this work (Müldner and Richards, 2007a and b). The second paper focused specifically on the later Middle Ages and is therefore outside the investigative frame of this work. She investigated a total of 311 humans and 145 faunal remains from six different sites, including the ones not used here. She noted some trends between the different periods, such as an increase in $\partial^{15}N$ values in both the Roman and the later Medieval periods. Some individuals are identified as migrants due to their unusual isotopic signatures, an idea she revisited in a 2013 paper. Overall, she noted some elevated $\partial^{15}N$ values with terrestrial carbon, as well as elevated $\partial^{13}C$ consistent with consumption of aquatic foodstuff being a significant part of diets both in Roman and Early Medieval Britain.

Another multi-period study is that of Lightfoot *et al.* (2009), who reported the results of stable isotopic analyses conducted on animal and human bones from the Neolithic to the Medieval period and recovered from the site of Yarnton, Oxfordshire. All of the data fell within the expected isotopic ranges for the European Holocene, but both faunal and human $\partial^{15}N$ values were higher than at other British sites (Lightfoot *et al.* 2009). Within the faunal data, pigs were shown to be more omnivorous than ruminants, although not strictly so. Dogs were also close to humans, which is often the case as they can be fed on the leftovers from human food. The authors also noted an increase in $\partial^{15}N$ for the faunal values between the Iron Age and the Roman period, but could not conclude whether it was due to a change in environmental conditions or due to changes in agricultural

practices. No age or sex distinctions were revealed, except for infants with a higher $\partial^{15}N$ signal reflecting breastfeeding practices.

The other multi-period paper that needs reviewing here is Stevens *et al.* (2012), which investigated human and faunal remains recovered from the Eton College Rowing Course in Buckinghamshire to examine changes in diet from the Neolithic to the Roman period. As with Lightfoot *et al.* (2009) the human isotope values pointed to a diet based on C_3 terrestrial resources in all periods. Stevens noted more variation in $\partial^{13}C$ values over time but not in the $\partial^{15}N$ values. However, because the faunal sample was poorly distributed between periods, they could not assess whether the pattern was due to environmental factors or dietary ones.

These works on a large diachronic scale hint at possible trends – more significant variation in $\partial^{13}C$ values than in $\partial^{15}N$ values and enriched in ^{15}N values in both the fauna and the humans in the Roman period – that will need to be investigated on a larger geographical scale.

- ***Non-dietary studies***

Montgomery *et al.* (2005) conducted a small preliminary study of lead and strontium isotopes in tooth enamel, of Iron Age (n= 2), and Early Anglo-Saxon (n= 32) skeletons to investigate the presence of migrants in the cemetery of West Heslerton in North Yorkshire. Strontium data imply the presence of two groups: one of "local" and one of "nonlocal" origin, but results were only tentative.

3.5.2 Iron Age

- ***Human and faunal***

One of the main sources of data for the Iron Age is the thesis of Mandy Jay (20005). The data from these works were also published elsewhere (Jay and Richards 2006; 2007; Jay 2008a; Jay *et al*. 2013). In her doctoral work, Jay analysed samples from nine cemeteries in Britain (England and Scotland) for a general overview of Iron Age diets. She conducted site-by-site analyses of both human and faunal data, as well as inter-regional comparisons. Overall, her conclusions are that the Iron Age population had a C_3-based terrestrial diet, with little variation between the different human groups. She noted a high $\Delta^{15}N$ offset between her human samples and the herbivore baseline, which she attributed to the consumption of either omnivorous or young animals since the results are not consistent with marine food consumption. Her results were later published in two different papers (Jay and Richards 2006 and 2007). She then further examined these populations, and investigated breastfeeding practices (Jay 2008a) and high-status burial (Jay et al. 2013).

Another Iron Age site of interest is the site of Glastonbury Lake Village in Somerset. What is particularly interesting about the site is the recovery of fish and bird bones, suggesting that they were part of the inhabitants' diets. Since the evidence for the consumption of aquatic resources in the Iron Age was scarce for other sites, isotopic analyses of both faunal and human remains were undertaken by Jay (2008b), to test the hypothesis whether fish were consumed at Glastonbury Lake Village. However, no consumption of aquatic foodstuff was shown in the results.

Stevens *et al*. (2010) conducted isotopic analyses on Iron Age human and animal bones recovered from pits within the hillfort at Danebury. Once again, the results are consistent with a C_3-terrestrial diet and do not differ from results at other Iron Age sites. Stevens *et al.* (2010) noted a large $\Delta^{15}N$ offset, which was interpreted as evidence of the significant amount of protein consumed, although they did not rule out that plants were an important component of the diets either. Maybe the most interesting conclusion of this paper concerns the wide range of the faunal isotopic signatures. Stevens *et al.* investigated this further in two paper published in 2013, which are discussed below.

A few years later, as a follow up to the previous paper, Stevens *et al.* (2013a) measured the $\partial^{13}C$ and $\partial^{15}N$ isotopic ratios of 40 humans from Suddern Farm and compared this information to the faunal data from the previous study of the remains from Danebury (Stevens *et al.* 2010). They showed that despite the considerable variation in the faunal isotope data, the adult humans from both sites had similar isotopic signatures. This might indicates that these people might have had similar access to dietary resources, which would support other evidence for the interdependence of sites with regard to their farming practices, as predicted by the consumer/producer sites model. However, considering the complex systems at play that underline isotopic signatures, this cannot be understood as definite evidence that they indeed fed from the same ecological niche.

Lightfoot and Stevens (2012) have conducted the only isotopic analyses on British archaeobotanical remains. Their paper reports the results of carbon

and nitrogen isotope analyses performed on charred barley and wheat grains recovered from pits within the Iron Age hillfort at Danebury. The results suggest that the cereals found at the hillfort came from different environmental contexts. Crucially, they show that the $\partial^{15}N$ values of grains and herbivores were virtually the same, which has serious implications for palaeodietary reconstruction models.

Finally, Stevens *et al.* (2013b) conducted isotopic analysis of 357 animals from five sites in the Danebury Environs (Suddern Farm, Nettlebank Copse, Houghton Down, New Buildings, Bury Hill) to investigate faunal variability in the Iron Age. In a 2010 paper, it was hypothesised that the animals at Danebury – which showed large intra-population variability– were raised in different ecological zones before being brought to the hillfort. The 2013 paper proposed a quite different explanation for the observed faunal isotopic variation, which confirms the complexity of faunal isotopic variation and the likelihood that while their diets were simple the environment in which they fed was not.

- ***Studies of specific human group or specific practices.***

In 2008, Jay *et al.* investigated infants and young children from the cemetery of Wetwang Slack in East Yorkshire (2008a). The aim of the study was to investigate breastfeeding and nursing practices. The data were compared to completely different sites, from 19th-century Canada and Medieval Britain. Results suggested that the Iron Age children population did not display strong evidence of being breastfed, which may suggest that the practice was limited at the time. This is quite interesting when contrasted to Fuller *et al.* (2006b)'s studies, which showed evidence for the

breastfeeding of infants in the Roman period, maybe suggesting that the practice evolved over time in Britain.

In 2013, Jay *et al.* conducted a multi-isotope analysis of seven chariot burials from Wetwang, Garton Station and Kirkburn. With the exception of one individual from Kirkburn, there was no evidence for a foreign origin for these people. In terms of diet, however, a subtle difference can be seen between them and the rest of the population, which Jay *et al.* interpreted as evidence of patterns of land-use and ecological niche.

- ***Non dietary studies***

Peck (2013) investigated health during the Iron Age in East Yorkshire by collecting bio-archaeological data from two Middle Iron Age cemeteries. He determined social status from animal offerings, grave goods and body orientation using Parker-Person's methodology. More interesting in relation to diet is the similar degree of dental wear as well as the similar frequency of carious lesions and dental abscesses suggestive of similar diets between the groups, which is also supported by the isotopic analyses as they have been reviewed so far.

3.5.3 Roman

- ***Human and faunal studies***

Richards *et al.* (1998)'s investigation of Poundbury was the earliest isotopic study done on Romano-British materials and it investigated the cemetery of Poundbury in Dorset, comparing different types of burials depending on the material of the coffins and the types of burial. This study was notable for showing a difference in diets in regards to status, with evidence of increased marine foods consumption for the individuals buried

in wealthier graves. This study, however, did not include faunal data and issues of calibration were raised afterwards (see Jay 2005, 176). However, this study remains important for showing the first isotopic evidence for consumption of marine foodstuffs in Roman Britain.

Cummings (2008a), investigated 383 humans and 126 faunal remains from seven locations – some being represented by more than one cemetery – from all over Roman Britain both in her thesis (2008a) and in a published paper (2008b). Cummings compared her results with known written evidence of food to estimate how much these diets matched that of the 'ideal Roman diets'. Her results showed differences between towns and rural settlements as well as differences over time. Again, while most of her samples fell into the range for C_3-terrestrial diets, some of the ^{15}N offsets between the baseline and the humans were particularly large.

The next paper discussed here is a regional investigation of diets in Dorset, conducted by Redfern *et al.* (2008). The purpose of this study was to test whether the Romanisation of diets would have resulted in more variation compared to Iron Age diets. Their conclusion was that there was a distinct enrichment in both isotopes, but there is no strong indication of fish consumption in the Roman data. Maybe more interesting is the trends that show more enriched $\partial^{13}C$ values in the female data compared to the males, but no explanation is offered.

The next paper concerns the investigation of a catastrophic event, with the analyses of human remains from a pit from the 2nd century A.D. in Gloucester, as well as contemporary faunal remains. Chenery *et al.* (2010) showed no difference in $\partial^{13}C$ and $\partial^{15}N$ values between the individuals in

the pit, maybe the victims of an epidemic and the rest of the British population. This is not surprising as the isotope values of bone collagen are unlikely to be affected by sudden, short-term change. An interesting conclusion of this paper, however, was that oxygen and strontium analyses revealed that the people buried in the pit had varied geographical origins, with evidence for people from Britain and from outside Britain (Chenery *et al.* 2010).

Following this study of an urban population, Chenery *et al.* (2011) investigated how more rural populations may have differed from urban ones. They conducted multi-isotope analyses (carbon, nitrogen, strontium and oxygen) on the bones of forty-two individuals from Catterick, a *colonia* settlement in Yorkshire. This revealed that the population of urban centres were a lot more diverse than rural ones, both in terms of diet and origin.

Gloucester attracted more interest in another study by Cheung *et al.* in 2011. This time, the focus was on the differences between rural and urban settlements, and a significant difference in stable isotope ratios were discovered between the samples from Gloucester and the rural sites (Horcott Quarry and Cotswold Community), suggesting the urban population might have consumed slightly more marine or freshwater resources than people living in rural communities. This was interpreted as evidence of more Romanised urban centres compared to rural settlements. This dichotomy between rural and urban is particularly interesting and needs to be tested across the dataset to assess if this was specific to Gloucestershire or more generalised to the Roman data.

Müldner reviewed all of these trends in Roman diets in 2013. Her conclusions were that diets improved between the Iron Age and Roman Britain and confirmed the possible difference between rural and urban settlements. Of particular relevance here, Müldner noted a relatively large enrichment in ^{13}C by over 2‰ in between the faunal baseline and the human values in the Roman period, which was closer to 1‰ in the Iron Age, which suggests an increase in fish consumption in the Roman period compared to the Iron Age.

Bonsall and Pickard (2015) combined analyses of carbon and nitrogen stable isotopes and dental pathology to reconstruct diet in a population from late Roman Winchester. The aim of the study was to establish a more holistic approach to urban diets in Roman Britain. Mean $\partial^{13}C$ and $\partial^{15}N$ values suggested a diet based largely on terrestrial C_3 resources and comparison with a faunal baseline indicated that animal products from domesticates also contributed to the bulk of dietary protein. The evidence from dental pathology pointed to a diet rich in carbohydrate. Considered together, the isotopic and dental pathology data suggested a predominantly plant-based diet, with moderate consumption of meat and/or secondary products.

- ***Studies of specific human group or specific practices.***

Müldner *et al.* (2011) investigated an exceptional cemetery in York where excavations at Driffield Terrace revealed an extremely unusual series of Romano-British burials. All the individuals were males, and more than half of the individuals showed signs of decapitation, with a high incidence of other *peri*- and *ante*-mortem trauma. In order to examine the identity of

these individuals, multi-isotopic analyses were conducted on both bone collagen and dentine, as well as tooth enamel. The results showed that these individuals had significantly more diverse origins than in other known cemeteries of Roman York. The origins of these individuals has been the subject of more scholarship, most notably Montgomery *et al* (2011) and Martiniano *et al.* (2016). Two individuals displayed highly enriched $\partial^{13}C$ values, suggesting a diet containing a significant proportion of C_4 plant-based protein. These were the first such isotope values observed in Britain from any archaeological time-period at Müldner's time of writing, but another individual with bone collagen values consistent with a C_4 based diet was unearthed in Kent and was been discussed in Pollard *et al.* (2011).

Pollard *et al*. (2011) investigated a large boundary ditch of Iron Age origin that contained both Iron Age and Roman inhumations, adjacent to a Roman cemetery. Bone collagen isotopic analysis of eleven skeletons of Iron Age and Roman date gave a typical C_3 terrestrial signal, except for one individual with a value significantly enriched in ^{13}C, similar to that reported by Müldner *et al.* (2011). Subsequent $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ measurements on the dental enamel of this individual were not consistent with a foreign origin and indicated instead that this individual was likely indigenous to Britain (Pollard *et al.* 2011). Pollard *et al.* suggest that either C_4 plants were available for consumption in Late Roman Britain or that the use of oxygen and strontium as a marker of mobility is not as accurate as previously thought. However, once again considering the complex processes of isotopic signal, it is also possible that this individual is

showing a 'foreign' signal, albeit from a place with similar strontium and oxygen baselines.

Redfern *et al*. (2012) did a regional study on the effect of Romanisation on sub-adults in Dorset. While a sample of 200 sub-adults was examined for dental health and specific metabolic diseases, only twenty-nine individuals were selected for $\partial^{13}C$ and $\partial^{15}N$ isotope analysis. Again, increased consumption of marine foods in the Romano-British period was indicated by enrichment in ^{13}C in the samples from the Roman period. They suggested that these changes are connected to the introduction of urban living, Romanised diets and population migration, which confirmed their earlier paper (Redfern *et al.* 2010).

Madgwick *et al.* (2013) conducted a multi-isotopes analyse of a deer population in Roman Britain. The results were wide-ranging but suggested that deer, or deer's body parts were maybe traded over long distance, and that some of the animals possible grazed over salt marshes.

- ***Non-dietary studies***

Both Evans *et al.* (2006) and Eckardt *et al.* (2009) conducted strontium ($^{87}Sr/^{86}Sr$) and oxygen ($\partial^{18}O$) isotope analyses on tooth enamel sampled from individuals from the site of Lankhills, Winchester. Results show that a significant number of individuals had a foreign origin, maybe from the Hungarian Basin and the Southern Mediterranean. However, individuals with the same origins were not necessarily buried according to the same funerary practices, indicating that ethnicity might not have necessarily been deemed to be relevant in death.

Because of the difficulty of identifying a diet drawing on freshwater fish in the isotopic record, Nehlich e*t al.* (2011) investigated the application of sulphur isotope ratios ($\partial^{34}S$) in combination with carbon and nitrogen on archaeological human and faunal remains from Roman sites in Oxfordshire. Humans (n= 83), terrestrial animals (n= 11), and freshwater fish (n= 5) were analysed for their isotope values from four locations in the Thames Valley, and a broad range of $\partial^{34}S$ values were found. Fish values, however, were clustered and systematically depleted. While Nehlich *et al.* interpreted the broad range of variation in the sulphur data as evidence of more diverse diets in Roman Britain, the $\partial^{34}S$ ranges are too large to be usefully applied to the study of diet.

3.5.4 Early Medieval

- ***Human and Faunal studies***

Privat *et al.* (2002) investigated human and faunal bones from the Early Anglo-Saxon cemetery site at Wally Corner, Berinsfield, Oxfordshire, and analysed dietary patterns within sub-groups determined by sex, age, and grave goods, as well as possible household groupings. They identified dietary variation based on grave wealth, as well as a significant difference in diet between males under and over the age of 30. It is usually hypothesized that lower status burials would display $\partial^{15}N$ isotopic values that are less enriched since meat consumption is considered to be a marker of a 'wealthier' diet. However, the Wally Corner data showed the exact opposite: it was the individuals in the poorer graves that had the highest $\partial^{15}N$ values. The authors suggested this could be explained by the

consumption of pork, since pigs are omnivorous animals with overall higher ∂^{15}N values than the herbivore baseline against which the humans were compared.

Bradley Hull completed his thesis at the University of Oxford in 2007 and investigated a large faunal and human dataset, containing 570 animal samples and 226 human ones from 16 different sites from Anglo-Saxon England. He thoroughly examined the relationship between burial contexts and isotopic values to investigate 'social diets'. Again, his data showed a wide ^{15}N offset between the faunal and humans. His results showed some interesting patterns, although they had a tendency not to be systematic, i.e. some sites would show that females had lower ∂^{15}N values than males, while other sites would show the opposite. His conclusions regarding the fauna were that differences between species, region and sites could be explained by agricultural practices and access to resources and possibly the climate (Hull 2007, 230). His findings were synthesized in Hull and O'Connell (2011).

O'Connell and Lawler (2009) conducted the isotopic analyses of the cemetery at Bloodmoor Hill, Carlton Colville in Suffolk. Seventeen human samples and twenty mammalian ones were collected. The results suggested that the humans relied on C_3-diets with little reliance on marine produce, similar to other data from the same period (Berinsfield and Butler's Field). However, they noted a significant difference in the carbon isotopic values of all three sites, with both the faunal and human data in Bloodmoor Hill slightly lower than in the other two sites (O'Connell and Lawler 2009, 320). They also recorded that the nitrogen isotopic values of data from

Bloodmoor Hill had a smaller range than the data from Berinsfield and Butler's Field. Neither significant difference between males or females nor correlation between diet and wealth were revealed.

O'Connell and Wilson (2011) conducted the isotopic analyses of the Anglo-Saxon cemetery at Butler's Field, Lechlade, Gloucestershire. 115 human samples, but no faunal samples, were collected. Again, evidence points to a C_3 diet, with a possible contribution of freshwater fish. While the data are slightly enriched relative to the faunal baseline (the fauna used as a baseline in this study come from Berinsfield, Privat *et al.* 2002; O'Connell and Wilson 2011, 121). The nitrogen isotopic values indicate reliance on animal protein, whether in the form of meat or cheese for all the population, but some individuals were even more elevated compared to the baseline (+6‰) possibly suggesting the consumption of freshwater fish, or omnivorous animals such as foxes, dogs or pigs (O'Connell and Wilson 2011, 122, 123). However the lack of animal baseline from the site itself prevents from forming any more specific conclusions. Difference due to age were noted, with males between 30-35 displaying ^{15}N-enriched values compared to the other males, with a possible increased status for males this age, who had more access to omnivore meat and freshwater species (O'Connell and Wilson 2011, 127). No other difference based on wealth or gender was detected.

Mays and Beavan (2012) investigated whether protein sources in human diets in early Anglo-Saxon England (5^{th}-7^{th} century A.D.) varied with geographic location, or with respect to age or sex. To do this, they conducted stable isotope analyses of carbon and nitrogen in the bone

collagen of seventy-six adult skeletons from a total of eighteen different cemeteries located in inland, riverine and coastal environments. To limit the effect of status on diet, they decided to only analyse the remains from high-status graves. The results suggest that protein sources varied little according to geographic location and that terrestrial foods dominated at all locations. However, they noted slightly elevated ∂-values in both isotopes in skeletons from coastal and riverine locations, which may indicate that communities in these settlements made greater use of marine and freshwater resources. Although this is an interesting conclusion, the lack of a faunal baseline should caution one to be careful when interpreting these results – it is indeed reasonable to assume that the elevated values in coastal and riverine settlements were possibly due to environmental rather than dietary factors, an hypothesis that cannot be tested in the absence of animal data.

- ***Specific Population Studies and specific practices***

McPherson (2005) investigated breastfeeding practices using a juvenile population of various ages from Medieval Lincolnshire. As has been the case with many of the studies described here, she found no specific difference in diets between the different groups, except for the physiological effects of breastfeeding in babies. She also noted the diverse origins of the buried populations.

On the same subject, Fuller *at al.* 2006b investigated breastfeeding and nursing practices in Late/Sub-Roman Britain by measuring the $\partial^{13}C$ and $\partial^{15}N$ values in juvenile and adult skeletons from the cemetery of Queenford Farm, Dorchester-on-Thames, Oxfordshire. After the age of

two, the $\partial^{15}N$ values were shown to gradually decline, indicating complete cessation of breastfeeding by three to four years. The $\partial^{13}C$ results are similar in the different adults groups, but females show a small but significantly lower mean average $\partial^{15}N$ value compared to males. This is explained by either the physiological differences between sexes, or by a cultural division in male and female diets regarding the consumption of animal/fish protein.

Considering the burial of elite, it is worth considering the burials at Ely, some of them containing rich grave material (Lucy *et al.* 2009). There does not appear to be significant dietary differences between the richer graves and the rest of the population. By comparing the human data to faunal remains from Berinsfield (Privat *et al.* 2002), Bloodmoor Hill (O'Connell and Lawler 2009), and Westgarth Gardens (Hull 2008; Hull and O'Connell 2011), they conclude to a possible freshwater fish contribution to the diet (Lucy *et al.* 2009). The $\partial^{18}O$ might suggest that the population at Ely is not local, possibly of a foreign origin, but the authors remain cautious in that interpretation.

Pollard *et al.* (2012) investigated a mass burial of mostly young adult males with severe *peri*-mortem blade trauma uncovered in St John's College, in Oxford. It has been suggested that these burials may have been related to the St Brice's Day Massacre in Oxford on 13th November AD 1002, but radiocarbon analyses dated the burial to the tenth century. Multi-isotopic study of the bone collagen ($\partial^{13}C$ and $\partial^{18}N$) and dental enamel ($\partial^{13}C$, $\partial^{18}O$ and $^{87}Sr/^{86}Sr$) were undertaken to assess the origin of these individuals. Bone collagen suggests a diet more similar to other Scandinavian

populations than that of local groups, and the enamel isotopes point towards a Scandinavian rather than a lowland English origin.

Another Anglo-Saxon population investigated here is the Raunds Furnell population, in Northamptonshire (Haydock *et al* .2013). The paper focuses on the weaning age of infants, and compare it with other published data. It reveals a change a change in weaning practices over time, and links these changes to population growth in the Anglo-Saxon period.

Finally, another paper investigating the presence of Danes in Britain in the Early Medieval period provided data for this thesis (Buckberry *et al.* 2014). They undertook both osteological and isotopic analysis for burials from Masham, which were typical of the later Anglo-Saxon period and included males, females and children. Unlike the skeletons from St John's College in Oxford, none of the skeletons revealed interpersonal violence. The isotopic analyses of carbon and nitrogen suggest that no marine component to the diet, although the authors point out that this does not necessarily mean that there were no Scandinavians settlers amongst the population investigated. Strontium and oxygen analyses, however, revealed that some of these individuals might have indeed migrated from possibly Scotland, Norway, Denmark or Sweden (Buckberry *et al.* 2014).

- ***Non dietary studies***

Bayliss *et al.* (2004) dated human bone collagen using radiocarbon dating and Bayesian analyses and in conjunction with this conducted some carbon and nitrogen isotopic analyses to investigate the potential effect of diets, specifically high carbon diets, on radiocarbon dating (Bayliss *et al.* 2004).

Finally, Hughes *et al.* (2014) investigated another population (n= 19) from Berinsfield in Oxfordshire to test different hypotheses about the transition from Roman Britain to Anglo-Saxon England. They used strontium and oxygen isotopic ratios in tooth enamel to identify immigrants in the burial population and assess their proportions. The oxygen and strontium isotopic results indicated a local origin for most of the individuals, save for one with a significantly depleted $\partial^{18}O$ value, potentially indicative of Continental origin. However, due to issues of equifinality, there results should be taken cautiously.

3.6. Summary of the key trends

From this review of the isotopic work done in England in the past twenty years, it is obvious that three patterns stand out at all sites and for all periods. For example, all researchers note ^{15}N-enriched human values compared to an herbivore baseline, but without a clear marine carbon signal for some populations. Evidence for fish consumption from the Roman period has also been noted. All these studies also identified enrichment in ^{13}C and ^{15}N for the humans in the Roman period, with probable differences between rural and urban settlements. When considering the Roman data with a *longue durée* perspective, it seems that Roman Britain was strikingly different compared to the Iron Age and the Early Middle Ages. Finally, a lack of systematic patterns between the different human groups is also reported.

This thesis will build on these studies by systematically investigating all the trends identified by previous researchers on a much larger scale. It will

be tested whether trends seen at different sites or in specific regions can be understood as pan-English patterns or if on the contrary, they are hyper-localised.

CHAPTER 4. METHODOLOGY

Because this thesis examines data from the Iron Age to the Early Medieval period across a variety of regions, a range of methodological questions were raised and are addressed in this chapter. As seen in Chapter 2, isotopic variation is caused by both environmental and dietary factors and cannot be compared as if the values obtained were an absolute indication of diet. Equal isotopic values for two different individuals cannot be interpreted as meaning that they consumed the same food, no more than different isotopic values indicate different diets. Besides, environment is a defining factor in isotopic ratios and must be considered at all times. This is a point crucial to the research conducted here since to assess the *longue durée* changes and continuity in diets over a long period of time, one must examine data from different environments. Simply comparing isotopic values side by side without taking into account a range of variables creates an inaccurate picture: $\partial^{13}C$ or $\partial^{15}N$ values close to the overall mean averages in the Roman period may be considered high in an Iron Age context. Therefore, it is important to devise a model that accounts for the environmental factors independent from dietary practices and allows for the comparison of relative values, which will be done by creating faunal baselines acting as control groups (See Chapter 2, section 2.3.6). Human values will then be compared to this baseline and to each other in order to assess their variability both against the environment and within their investigated group. The scale of these analyses will depend on how the tested group is defined, whether by period or by region, or by any other parameters, such

as age and sex, the nature of the sites, the geographical environment or other factors.

The first section of this chapter will cover the construction of the dataset and the distribution of the data. The methodology for the analyses will be discussed in the second section, while the final part will address specific concerns of using legacy data.

4. 1. Dataset and database

4.1.1. Construction of the dataset

The primary aim of this thesis is to assess dietary trends in England between the Iron Age and the Early Medieval period through isotopic analyses. At first it was assumed that the dataset would be a compilation of isotopic analyses done on new samples as well as legacy data. However, it soon became evident when collecting the data that the dataset thus created would be on a very large scale and would be the first compilation of its kind for the periods considered. None of these legacy datasets had been systematically compared and the research for this thesis raised a number of questions as to how isotopic data are produced and used, and how data from different sources can be integrated. Therefore, it was decided to use only pre-existing data and that this work should be understood as both an assessment of diets in England between 700 B.C. – 1200 A.D. but also as a review of the state of isotopic research in English archaeology at the time of writing. The studies from which the dataset has been constructed were conducted between 1998 and 2013, in laboratories across the world as seen in Table 4.1. Due to the time constraints of writing a DPhil thesis, it was decided not

to gather data published after 2013.[1] There are 3629 isotopic values used in this thesis, both human (n= 2127) and faunal (n= 1502). The samples come from 95 different sites. Some of these are different cemeteries within the same city (for example in Gloucester and York), others are burials attached to a settlement. The dataset in this thesis is roughly balanced between unpublished (n=1619) and published (n=2010) materials thus creating the most comprehensive isotopic dataset between the Iron Age and the Early Medieval period at the time of writing.

4.1.2 Data gathering

The question of how to collect and organise the data has been a prominent one during the creation of this dataset. The datasets used could not simply be 'copied and pasted'. In the case of datasets used more than once (Müldner 2005; Müldner and Richards 2007a; Jay 2005; Jay and Richards 2006 and 2007; Cummings 2008a; Chenery *et al.* 2011; Cheung *et al.* 2011), particular care was taken to avoid duplicating the values by checking the sample numbers. The same applied in cases where some remains might have been sampled more than once so one individual would not become multiple people though inattention. If different tissues were measured for the same individual (for example dentine and bone collagen), bone collagen was preferred. Finally, in cases when analyses were reported in different works, for example a dataset used in a thesis and different publication

[1] However, it is worth noting that some data were overlooked and only came to my attention after the dataset had been assembled. Most of these papers were integrated to the revised version while two others were not, as it was decided that they did not fit a gap. The data not used were the supplementary human data from the Railway Cemetery from Müldner, 2013 (the supplementary faunal from the paper was added) and from Ridgeway *et al*. 2013, as there were no other human group from London to allow for larger scale comparison. Jay (2008)'s study of Glastonbury Lake Village has also not been integrated to the dataset.

(Müldner 2005; Müldner and Richards 2007a; Jay 2005; Jay and Richards 2006 and 2007), it was the original publication that was preferred for reference.

4.1.3 Database and data archive

One of the purposes of this thesis has been the creation of a database. It was compiled manually in Microsoft Excel (v.14.4.1). It contains 19 fields, relevant to the investigation conducted here. It has been organised according to species but can be re-organised depending on the interest of the person researching it. For example of the database, see Table A.1 in Appendix I. The full database is available on the CD included in this thesis.

4.2. Methodology

4.2.1 Analyses of carbon and nitrogen

For the first level of analyses, the isotopic results were shown on an x/y scatter plot, with $\partial^{13}C$ values represented on the x-axis and $\partial^{15}N$ values on the y-axis, as is the convention in isotopic studies. Because of the size of the dataset, and the different range of data for each different period, it was not always possible to keep the graphs on the same scale and therefore immediately comparable to one another. On each graph, the vertical line (green) represents the $\partial^{13}C$ mean average of the broad period and the horizontal line (red) the $\partial^{15}N$ mean average. The dotted vertical and horizontal lines show the respective $\partial^{13}C$ and $\partial^{15}N$ standard deviation (1σ). This was done to facilitate the visualisation of the data and allow for more

immediate comparisons between different groups in relation to their mean average.

4.2.2 Faunal baseline and offsets

As was shown in Chapter 2, isotopic values are like a chain, in which each level is linked and builds upon the next. Photosynthesis and the environmental background (atmosphere, sunlight, climate) are the starting point and the human values are the end point of interest here, several steps away from the start. Therefore, to understand these human values, it is important to analyse comprehensively the links that come before them. For obvious reasons, plants would be the ideal candidates to recreate the past isotopic environmental landscapes (Nitsch 2012, 124; Spzak *et al*. 2013). However, isotopic analyses of plants have yet to be undertaken systematically for British samples. The only site for which there are isotopic archaeobotanical data that can be used here is Danebury (n= 34; Lightfoot and Stevens 2012; further data will be published in Lodwick *in prep.*). Therefore, local herbivores have been used as a proxy for environmental values instead, as is usually done in the absence of plant data, under the assumption they reflect the $\partial^{13}C$ and $\partial^{15}N$ mean averages that would have been available to humans at the time (See Chapter 2, section 2.3.6). While Chapter 2 discussed the possibility of large variation in the plant isotopic data, it was also established that measurements on bone collagen of herbivores will average that variation over the time taken to form the collagen (month to year) in the proportion of that time spent feeding on plants from various habitats with different plant values (Bump *et al*. 2007).

Indeed, using herbivores as a faunal baseline is a solid method to understand the human values and fauna can act as control groups to compare the different populations analysed. However, some uncertainty must be recognised. First, it must be stated that the relationship between human and faunal isotopic values is far from straightforward. Plant $\partial^{13}C$ and $\partial^{15}N$ available to the fauna might not be the same as the plant $\partial^{13}C$ and $\partial^{15}N$ available to humans (Hedges and Reynards 2007). This may be because animals and human feed on different parts of the plants such as stalks or leaves, with different $\partial^{13}C$ values, as shown in Chapter 2 (Fraser *et al.* 2011). Animals could also have grazed in unmanaged parts of the landscape while humans would have drawn their food from cultivated crops, so factors like manure or closed/opened environment (forest canopy vs. pasture) can affect the isotopic profile of both humans and animals in different ways (Hedges and Reynards 2007; Bogaard *et al.* 2007; Fraser *et al.* 2011). The profile of animals slaughtered is also important: younger animals may retain a nursing signal, which would raise the $\partial^{13}C$ and $\partial^{15}N$ averages of the baseline. Another important caveat is whether animals are inherently local to the site from which they have been recovered. Indeed, using fauna as a proxy for the local environment is done under the assumption that animals were immobile in the landscape and that the mere presence of a faunal assemblage at a site is enough to accept that the isotopic signal of said assemblage is representative of local environmental values. However, the possibility that animals were traded and exchanged over longer distances than previously envisaged cannot be ignored (see above, 2.1). Evidence of cattle movement has indeed been showed in the Roman Period through

strontium isotope analyses and suggests that the animals could be driven over distance of 70 km (Minniti *et al*. 2014; see section 3.2). Since this thesis considers wider geographical areas and broader trends, it raises the question of whether the notion of 'local' could be extended to a whole region, for example whether one faunal assemblage from Hampshire can be considered to be representative of all the surrounding areas. But recent research has shown that this should not the case, as there can be significant variations between sites of the same region (Stevens *et al.* 2013b).

This uncertainty in the relationship between the faunal baseline and the human values makes the relationship difficult to assess and the choice of which samples to include in the so-called faunal baseline for a site can raise many problems. Choosing an appropriate faunal assemblage from a nearby site might also introduce an error; a problem encountered by Mundee (2010) in her analyses of Medieval Spanish diets. The issue in this dataset compiled for this thesis is that not all human groups have a local baseline against which to be compared. Even if 'local' could be extended to 'regional', the very small faunal numbers in some regions would have resulted in a weak baseline of only three or four samples in some cases, as well as the exclusion of entire human groups from the analyses, if there were no regional fauna contemporary with the human data. The question of sample size in relation to the baseline must also be addressed. Pearson and Grove (2013) used simulation based on the sheep data from Çatalhöyük to model sample size effect. They demonstrated that sample numbers above 40 did not improve the accuracy of estimating the mean. Maybe more relevant here, they also estimated that in sample sizes smaller than eight, each extra

measurement could have a large effect on the estimation of the mean, depending on the variation in the population. Since this work's focus is on legacy data, decisions about sample size were not concerned about how many measurements should be obtained for site/region/sub-period, but rather, on how many measurements were needed for the trends observed in the dataset to be considered reasonably solid. This is particularly important in the case of baselines – if mean estimates are inaccurate for sample sizes below 8, then a baseline should contain at least that many samples. Furthermore, in the case of small sample size (8<), for example when the data are separated into smaller units of analyses (i.e. sub-periods), results will be considered tentative and they will be interpreted with caution.

Taking all this into account, it was therefore decided that all the cattle from the broad archaeological period would act as a baseline from the different human groups, i.e. all the Iron Age cattle would serve a baseline for the all Iron Age humans and so on. There are issues with this approach, not least that there are groups of cattle significantly different from other groups of cattle in the same period, for example in the case of regional difference. This will be addressed thoroughly in the next two chapters, which will statistically assess which samples can be pooled together for the baseline and which are too different. Traditionally, faunal baselines are constructed using both the cattle and the sheep averages while pigs are excluded because they are too omnivorous to provide a reliable environmental proxy (see for example Jay and Richards 2007). Here, however, the baseline consists only of cattle since there is a statistical difference between cattle and sheep in the different periods (see Chapter 6 for details) and it is therefore argued that

this is significant enough for cattle and sheep not to be treated as one similar 'herbivore species'. Indeed, these animals have different needs and physiology. For example, cattle need access to water a few times a day while sheep do not. This might lead to a management system where cattle are kept in the wetlands while sheep are sent grazing in the uplands, which might explain these slight differences in isotopic values (Hull 2007, 230; Bird *et al.* 1994). Ideally, the human data would be systematically compared to three different baselines representing all three main domestic species, similar to what Hedges *et al.* (2013) did for the Neolithic but due to constraints of space in a doctoral thesis, this was not done here. Cattle were chosen as the 'main' baseline' for the simple reason that they were the best distributed of the faunal data over both chronological periods and regions. This echoes Hamilton's (2016, 75) comments in her thesis reflecting that the best data available are often for cattle, maybe due to the better survival of cattle bones (Hamilton 2016, 75).[1] The cattle values were therefore averaged for each period to provide the baseline, and each human value was compared against these cattle averages to create offset values, reported as $\Delta^{13}C_{human\text{-}cattle}$ or $\Delta^{15}N_{human\text{-}cattle}$. Human values were not averaged to avoid creating additional errors (Casey and Post 2011) in the transformed data but also to retain its subtleties: averaging some 3500 data points (for the human and main herbivore groups) into a dozen mean averages would have defeated the point of this work. These Δ-values represent how much the human data vary from a control group and allow for more in-depth comparisons.

[1] There are actually more sheep in the data set (sheep n= 508, cattle n = 443).

4.2.3 Chronological analyses

For simplicity's sake, the traditional chronological divisions followed by archaeologists and historians as well as the traditional names for the three main periods investigated within the scope of the English Landscape project have been maintained: the Iron Age, Roman Britain and the Early Medieval period. The main challenge in assessing the chronological variation in the dataset is that some of the samples were not precisely dated. The reason for this lack of dating might be due to the lack or loss of information about the samples. It must be remembered that the data presented here comes from samples that were excavated over many decades, and that the techniques and methods of the discipline have greatly evolved. Some of the data, and this is particularly true of the faunal data, were not recorded on site plan or attributed to a phase in the site stratigraphy (see Jay 2005, for example). As a result, these particular samples cannot be dated precisely and this unfortunately cannot be resolved. It is also worth noting that the samples have been dated by a range of techniques with varying degrees of precision and accuracy. That was not much of a problem for the broad chronological trends as most of the samples were clearly dated to one period with the exception of some samples from two sites – one dated to the Late Iron Age/Roman transition (Yarnton) and one dated to the Roman/Post-Roman transition (Queenford). To be able to investigate isotopic variations at a more refined chronological level, it was decided to divide the broad period into sub-periods, insofar as the dating of the samples in the dataset allowed it. The Iron Age was therefore divided into the Early Iron Age (600 B.C.-400 B.C), Middle Iron Age (400 B.C – 100 B.C.), Late Iron Age (100 B.C -

50 B.C) and, in some cases for the fauna, Latest Iron Age (50 B.C. – 43 A.D.). Some of the Late Iron Age samples also had to be grouped with the Romans, since samples from that particular sub-period were usually roughly dated to the 1st century A.D, while some of the Roman samples are considered to be Early Roman (43 A.D to 100 A.D). The distinction between Late Iron Age/Early Roman and Early Roman might feel superfluous, but it was necessary to acknowledge that some of the earliest Roman samples might, in fact, belong to the Iron Age. The whole period between 100 A.D. and 300 A.D. is simply labelled as Mid-Roman. Some samples within this period are more precisely dated, but the vast majority was recorded as 'Roman' in the original reports without any more precision. Finally, the last century of Roman administration in Britain, between 300 A.D. and 410 A.D, will be analysed as 'Late Roman'. There is even more variation in the dating of the Early Medieval samples, which reflects the different dating techniques used. However, four sub-periods can be distinguished: post-Roman between 400 A.D and 500 A.D, Early Anglo-Saxon between 450 and 700 A.D, Early Anglo-Saxon/Mid-Saxon between 450 and 800 A.D. Middle-Saxon between 700 and 900 A.D., Late Saxon between 900 A.D. and 1000 A.D and finally, the Late Saxon/Norman period, between 900 A.D and 1200 A.D. 1200 A.D is later than the endpoint of the time-frame investigated by the English Landscape project but many data are dated to a range that starts before 1086 A.D and ends after this date. It was decided that these data should be also be included to the dataset. The data from Wharram Percy, on the other hand, were excluded because they were not precisely dated between the 10th and the 16th centuries (Richards *et*

al. 2002). Some of these sub-periods overlap, and they have been kept separate for clarity's sake.

Diachronic trends will be analysed both on large and short scale. Large scale is defined here as the archaeological period as traditionally understood, i.e. Iron Age, Roman Britain or Early Medieval. Small scale corresponds to internal sub-periods within them (see Chapter 5 for distribution of the data) Addressing issues of change and continuity on both scales will allow for an understanding of subsistence both at the macro and the micro-scale. Chronology is used here as the 'main' unit of analyses as it is the broadest category, containing the most data. For the sub-period analyses, only sub-periods for which there are more than two sites **and** eight samples will be included in the analyses, to avoid confusing 'sub-period' with site identity.

4.2.4 Regional analyses

Twenty-two English historical counties are represented in the database, although some have such a low sample count that their use for analyses has been marginal. It is acknowledged that modern regional borders are not likely to be a relevant representation of the past landscapes of England. However, considering how much regional borders varied, sometimes even within the same time period, it seems reasonable to use modern ones as the common unit of analyses between the different periods considered, at least to understand broad patterns. Nevertheless, when deemed appropriate, regional comparisons have also been made between the geographical divisions of a particular time-period, for example *Britannia Prima* and *Britannia Secunda* in Roman Britain. It is also important to address how some geographical units have been defined here. The question of locality

has been addressed briefly in the discussion of the faunal baseline in section 4.2.2 of this Chapter, but it is also relevant to human isotopic values. Often, an individual with a different isotopic signal compared to the rest of their group is interpreted as a potential migrant but this idea of a migrant needs to be clearly defined. It could mean anything from an individual non-local to the settlement where they were buried to someone born outside England. Here, the use of the word 'migrant' will be strictly limited to people who may have been born outside England. The issue of locality is a difficult one as it is intimately tied to the question of identity, which is likely to be have been fluid and operating on different scales, surely linked with perceptions of gender and/or age, among many other intersectional facets, and would have varied over time. 'Geographical identity' would have operated on many different scales, almost too many to fathom and to take into account in this thesis (see section 3.3). Because one of the main points of this work is to go beyond site-by-site analyses, it is important to define geographical units above the site level but on a level that still allows for small-scale variations to show. It is also important to take the nature and environment of the site into account. Indeed, regionality is here understood to mean more than the mere location of the samples within England. Factors of physical and social geography will also be considered and are discussed below. One of the first points to address is sites distribution within a region as it raises the obvious question of how many sites are needed to represent a region. Indeed, some of these regions might have a lot of data, but only from one site and it is important not to confuse 'regional identity' with 'site identity'.

It has been decided here that for a region to be considered significant, it will need to contain more than two sites **and** more than 8 samples.

4.2.5 Criteria other than 'Archaeological Period' and 'Region' used for analyses

The following variables will be tested in this thesis to assess the factors of variability in the data: (1) social organisation; (2) climate; (3) physical geography; and (4) social geography. These are defined in this section, while distribution of the data following these parameters will be addressed in Chapter 5. It must be noted here that the only faunal groups analysed through these parameters are the cattle, as there was simply not enough space to investigate all three main domesticates. Again, the reason for choosing cattle was because there were the best distributed of the faunal data.

4.2.5.1 Social organisation

a. Sex

It is necessary to investigate how patterns of social organisation may have influenced dietary behaviour. Indeed, in at least two of the periods examined here, there is historical evidence suggesting dietary differences between males and females. Roman medical texts, for example, suggested that women should eat very little and avoid meat (Garnsey 1999, 102-103) and Early Medieval women might have suffered from poor nutrition (Bullough and Campbell 1980; Pearson 1997). In relation to isotopes, sex-based differences in diets have been noted in previous studies but the lack of systematic differences in these patterns has also been underlined (Hull 2007, 302). In short, there is not a clear pattern of gender-based differences in the

isotopic signatures of males and females, but there are some significant differences that need to be investigated further. In the next chapter, the distribution of the sexed remains in the data will be discussed, before the discussion of the isotopic analyses of the human group in Chapter 7.

b. Age

Age attribution faces similar problems. Indeed, age might be even a little bit more difficult to assess than sex: although it is accepted that gender may have been constructed differently in the Roman or Medieval periods, biological sex can still be used as a variable which can be categorised. It is impossible to assign a definite age to remains and as such, they are usually assigned to a range. What these age ranges meant is likely to have been fluid, with 'adulthood' and 'old age' for example having different meaning not only in different periods but maybe in different regions, and possibly also within the same society according to social status. For example, while status might increase with age in the higher ranks of society, it might have been the opposite in the lower levels of society where an individual's worth might have been determined by his/her ability to contribute to the community (Williams 1951).

The following age categories were used when the information was available: infant (0–4 years), juvenile (5–12), sub-adult (13–18), young adult (19–25), middle adult (26–44) and mature adult (45+ years). While there is a known physiological effect between breastfeeding infants and older humans, it is also worth investigating whether age-base dietary difference exists between the different groups, as has been demonstrated elsewhere (Turner *et al.* 2007).

4.2.5.2 Climate

Looking at multi-period data from different region allows for *longue durée* factors beyond chronology and regionality to be assessed. It is believed here that one of the most pervasive factors may be large-scale climatic variation. This was touched upon by Hull (2007, 230, 231) and can be tested here. By climate, what is meant here is both precipitation and temperature (For a review of how these affect isotopic variation, see Chapter 2). Indeed, the time frame under study was not only a period of important cultural changes, but also a period of climate change, for which there is abundant evidence (see Figure 4.1).

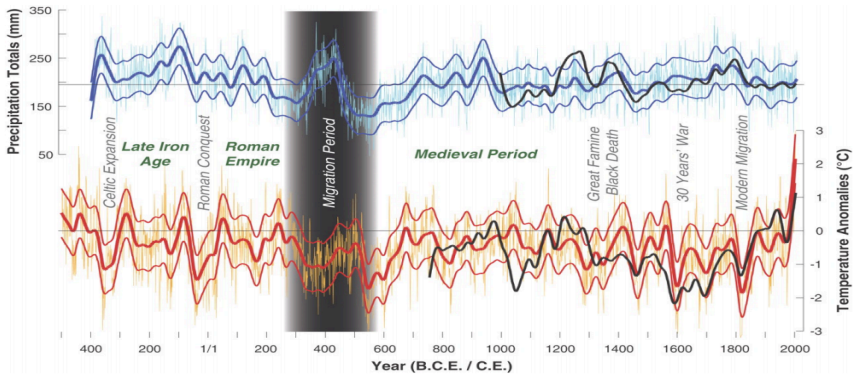


Figure 4.1 Reconstruction of summer temperatures (June to August, red lines) and April to June precipitation changes in Europe in the last 2500 years, calculated from regional oak chronologies. Figure from Büntgen *et al.* 2011.

Table 4.1. Wet phases identified by proxies, after Charman *et al.* (2010).

Wet Phase	Bog Oak	Peatland	Fluvial	Speleothem	Sand/Dune
660-810 A.D.	Y	Y	Y	?	
280-580 A.D.	Y	Y	Y	Y	Y
50 B.C. -80 A.D.	Y	Y	Y	Y	
310 B.C. -190 B.C.	Y	Y	Y	?	
620 B.C. -510 B.C.	Y	Y	Y		
820 B.C. - 770 B.C.		Y	Y		
1110 B.C. - 920 B.C.	Y	Y		Y	
1600 B.C. – 1350 B.C.	Y	Y	Y	Y	

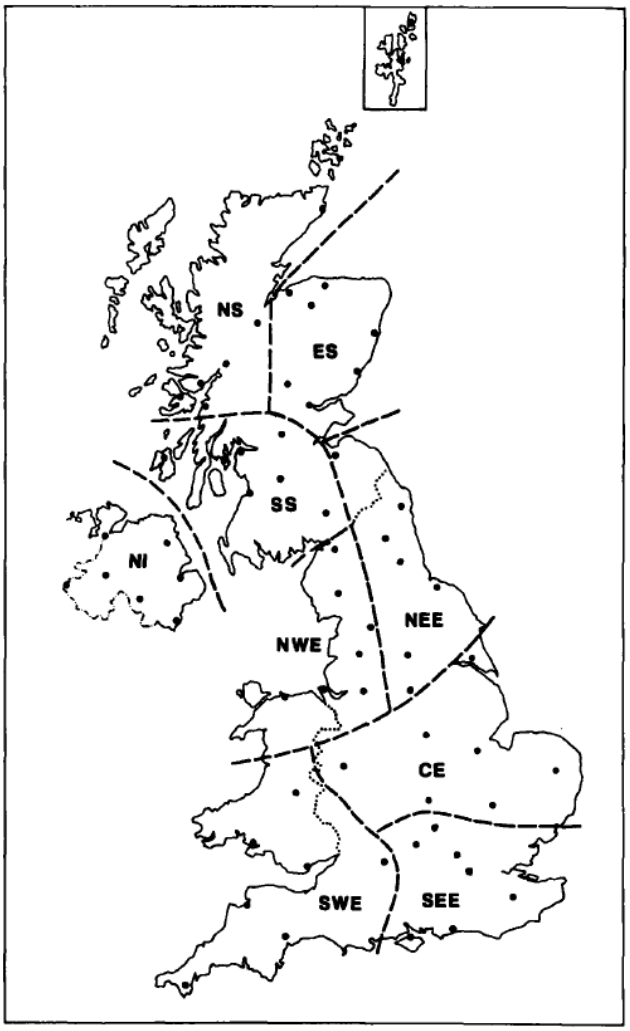
While the Iron Age is often seen as a 'cold' period, Figure 4.1 shows that it was not especially colder than the other periods, except for a dip in temperature c. 400 B.C (Lamb 1984). It started getting gradually warmer until 200 B.C., which is traditionally taken as the start date of the Roman Warm Period, which lasted until 400 A.D. (Barber *et al.* 2003; Büntgen *et al* 2011; Chen *et al.* 2011; Wang *et al.* 2012). It was a period of relatively warm and stable climate for Europe, although Figure 4.1 shows a decrease in temperature from the 3rd century onwards. Büntgen *et al* (2011) also showed increased variation from 250 A.D, which lasted until the 7th century, as well as an overall decrease in temperature and increase in precipitation, which is particularly visible in the Migration Period (450 A.D. – 650 A.D; Figure 4.1). Documentary evidence also report decreases in temperature after 500 A.D. (Randsborg, 1991; McCormick *et al*. 2007). After this period of climate deterioration, both precipitation and temperatures increased again, to reach levels similar to the Roman Warm Period around the 9th century (Pfister *et al.* 1998; Bradley *et al.* 2003), which lasted until the 14th century (Büntgen *et al.* 2011). It is important to note here that Mean Annual

Precipitation (MAP) and Mean Annual Temperature (MAT) are not necessarily correlated and must be assessed separately. Table 4.1 shows the different wet events in the periods of interested here. The reasons behind these climatic changes, be it the North Atlantic Oscillation (Chen *et al.* 2011), or volcanic eruption (Larsen *et al.* 2008), as well as their political consequences (patterns of settlements changes are often linked to the climate, see Cheyette 2008), are all closely linked to issues examined in this thesis, as climate change would have affected both subsistence procurement strategies and the isotopic values of the environmental baselines. Due to the nature of the dataset assembled here, it will be possible to test variation between broad periods of climatic changes and assess their impact on the data.

a. Precipitation

Based on the data from Table 4.1, populations that fall within 'dry' and 'wet' episodes have been identified in the dataset in both the human and the faunal data, and will be systematically examined against one another. For simplicity's sake, sites for which the chronology is not precise enough to fall clearly into one of those periods have been excluded from these specific analyses.

b. Climatic Region



Map 4.1. Regions of coherent precipitation in Britain, from Gregory *et al.* 1991.

Gregory *et al*. (1991) mapped nine regions of coherent modern precipitation variability in Great Britain (see Map 4.1). Whether modern precipitation values are a good predictor of past precipitation is debatable but it is nonetheless crucial to consider that rainfall would have also varied regionally in the past. Even if the precipitation values of Gregory *et al.* (1991) are unlikely to be accurate for the past in an absolute sense, they nonetheless give a sense of how regional precipitation may have varied

regionally and indeed, it is the variation that is of interest here, rather than the absolute value of mean annual precipitation.

c. Temperature

Temperature is also an important factor to investigate. As with precipitation, mean annual temperature (MAT) will be assessed on the basis of the available palaeoclimatic data. Sites for which the chronology is not precise enough to fall clearly into one of those periods have been excluded from these analyses.

4.2.5.3 Physical geography

While Chapter 2 reviewed a range of environmental factors influencing isotopic signatures, the most relevant one in the context of these data might be the location of the site in relation to the sea or rivers. Here, a coastal and/or riverine site is defined as a site no more than 1000 meters from either the sea or a major river (the Severn, the Thames, the Tyne and the Ouse). The definition of a coastal site is somewhat contentious. Fischer *et al*. (2007) define a coastal site as a site lying immediately on the contemporaneous beach (<100 metres from the sea). Perry and Glasgow (2015) suggest equally strict criteria and consider a site to be coastal when less than 400 metres from the sea. Erlandson (2016) argues that 400 metres is too short a distance and that coastal sites can be defined as sites less than 1000 metres from the sea. At the other end of the spectrum, some archaeological studies have considered 10 kilometres to be reasonable distance to describe a site as 'coastal' (Nitsch 2012, 90; Mayes and Beavan 2012). The difficulty here is whether one wants to measure the physical effects of the sea on the isotopic signatures of the faunal and human groups,

or whether it is human behaviour that is of concern. It is likely that any environmental effects will be limited to sites in physical proximity to the sea, therefore fairly close to the coast, even when taking into account equinox high tides and sea-spray. But beyond the physicality of these effects, it is of course important to consider how proximity to rivers and the sea would have affected resources availability as well, either for human consumption or for agriculture purposes (Madgwick *et al.* 2013; Britton *et al.* 2008; Balasse *et al.* 2005). Dietary behaviours are however likely to have been too complex to be reduced to a simple equation of proximity = consumption. Talking all these considerations into account, it was decided that a coastal site would be defined as a site less than 1000 meters from the modern coast. It is understood here that coastlines are not fixed in time (Erlandson 2015) and that therefore some sites, which may have been considered costal in the Iron Age might now be classified as inland, but modelling the British coastline throughout the Holocene was outside in the parameters of this thesis (for research on the subject, see Shennan and Horton 2002; Horton and Shennan 2009).

4.5.2.4 Social geography

a. Urban/Rural

Previous studies have investigated the difference between rural and urban sites in the Roman period and have shown a systematic difference between them, which has been interpreted as the status of towns as centre of trades with more readily available foodstuffs from different origins (Cummings 2008a; Chenery *et al.* 2010; Cheung *et al.* 2012). Here, all the data from large urban centres in the Roman period (Cirencester, Winchester,

Gloucester and York) will be compared to smaller towns and rural settlements, to assess whether urbanisation is a good predictor of isotopic variation or if other factors are at play (such as sub-period, regions and/or climate). These cities have been chosen here on the hypothesis that urban trends will be magnified in larger towns and that therefore a difference is more likely to be visible and statistically significant. The question of subsistence and urbanisation in Roman Britain is a complex one, that should be investigated more fully by taking into account town size, networks, and demography, but there is simply not enough space here to do this in depth. The comparison between the urban and rural data presented in this thesis is done on a broad scale to assess the urban/rural pattern already noted by other researchers more generally, i.e. to possibly identify 'rural' and 'urban' identities.

b. North/South

Throughout all three periods investigated, it can be argued that the 'North' and the 'South' have distinct identities. In the Iron Age for example, the South was in contact with the continent as shown by archaeological evidence of trade (Lodwick 2014) and direct observations made by Julius Caesar of regular contacts between the Britons and the Veneti in Armorica (Caesar, *The Gallic War,* III:9). Similarly, the Roman conquest happened in two phases resulting in two different provinces, *Britannia Prima* in the south and *Britannia Secunda* in the north, with the latter maybe less integrated into the Roman Empire than the former (Dark 1994). In the Early Medieval period, Britain became more fragmented again with the establishment of the Anglo-Saxon kingdoms (Harrington and Welch 2014),

but the division between the south and the north still persisted, first through religion. Southern kingdoms such as Wessex or Kent followed the rites of Roman Christianity under the leadership of Canterbury, when the Northern Kingdom (Bernicia and Deira, later to be united as Northumbria) followed the rite of Irish Christianity under the patronage of the abbots of Iona (Ireland 2015). Later, in the 9th century, the division became cultural with the establishment of the Danelaw in the north, effectively splitting Britain in two between 'Anglo-Saxons' and 'Danes' (Buckberry *et al.* 2014). Here, it was decided that the 'North' would include Lincolnshire, Northumberland and Yorkshire, while the 'South' would include the rest of the regions investigated here.

4.2.6 Statistics.

4.2.6.1 Simple modelling

Comparisons of complex data must be backed up by statistical analyses to assess the viability of the trends investigated. This is done by calculating the probability of finding the observed results if the null hypothesis is true, which is reported as the *p-value*. All statistical analyses in this thesis were conducted through the free software R for statistical computing and graphics (https://www.r-project.org).

For the primary level of analyses, it was the Analysis of Variance (ANOVA) that was favoured because the ANOVA is considered robust, even in the case of unequal sample sizes or abnormal distribution (Field *et al.* 2012, 412). The most common command in the computer programme R for ANOVAs is 'aov' and was the main command used to run these analyses. However, the one parameter that must be respected for ANOVAs

is homogeneity of variance, otherwise the results might not be meaningful (Field *et al.* 2012, 412). Therefore, prior to performing the ANOVA on the data, homogeneity of variance was assessed using the Levene Test ('levene.test'). If the assumption of equal variance was rejected, then an ANOVA using the 'oneway.test' command in the R programme was conducted, as this particular function is built to handle unequal variances and automatically applies a Welch correction to the data (Field *et al.* 2012, 412).

Because the 'aov' test only returns an indication of significance in the data but does not recognize which groups may be different, it is then necessary to conduct a post-hoc test. Here, Tukey's HSD test was preferably used to allow for the identification of these groups. However, while the 'oneway.test' is limited in the same way that its output does not identify the particular groups displaying significant differences, in this case, there are no post-hoc tests designed to further analyse the results. Therefore the 'pairwise.comparison' function using t-tests was conducted but this method is not perfect because comparisons of multiple groups in pairs increase the likelihood of Type-1 error (that is a 'false positive'). Some methods have been designed to adjust the *p-values* and therefore to limit the error rate, and the Bonferroni method was used here to adjust the *p-values*.

Another important test conducted in this thesis is the Cohen D test to measure effect size. It was conducted in R, using the 'cohen.d' function, from the 'effsize' package. 'Effect size' is used to measure the scale of the difference between two groups rather than only statistical significance, which can be affected by sample size (Sullivan and Feinn 2012). Indeed,

when testing large sample numbers, as is the case with some of the data presented here, a statistical test will almost always demonstrate a significant difference, unless the effect size is exactly zero (Sullivan and Feinn 2012). To avoid reporting a significant, but ultimately meaningless, difference, the Cohen D test was run every time differences between two groups were found to be statistically significant. The results of the Cohen D test are classified as follows: 1) small (d=0.2); 2) medium (d=0.5); 3) large (d=0.8); 4) very Large (d >1.3; Sullivan and Feinn 2012). While the Cohen D test results are not integrated to the statistical tables presented in this work, they are discussed in the text where relevant, particularly in the case of small or very large differences.

Finally, another test used on these data is Pearson's Correlation Coefficient (*r)*. As with all other statistical analyses in this thesis, it was run in R, using the 'cor.test' default function. Pearson's r is a measure of the relationship of two variables, here the ∂^{13}C and ∂^{15}N values of individuals. The value of the correlation can be between -1, indicating a strong negative correlation (i.e. if the first variable increases then the second variable decreases), to 1, indicating a strong positive correlation (i.e. if the first variable increases then the second variable increases too). The strength of the direct relationship between the variables is measured as follow: 1) small: $r \leq 0.35$; 2) moderate: $0.36 \leq r \geq 0.67$; 3) strong: $0.68 \leq r \geq 0.89$; 4) very strong $r \geq 0.90$ (Taylor 1990).

4.2.6.2 Multivariate modelling

The full complexity of the dataset cannot be assessed solely through simple statistical models. The dataset includes 3629 pairs of measurement of ∂^{13}C

and $\partial^{15}N$ values from 20 species at 95 sites, over 3 archaeological periods, sometimes divided in 17 sub-periods and over 22 regions. The hierarchical structure of the data, namely the fact that individual data points are 'nested' within sites, within regions, and within 2 levels of time periods must be considered. Indeed, while the focus of this thesis was removed from site to site analyses on purpose, it could not be ignored that individuals from one site were more likely to be similar to each other than to individuals from another site. Similarly, individuals from the same sub-periods or regions might be more similar to one another. This nested data structure means that the assumption of independence needed for the ANOVA is not respected (Peugh 2009). The example often given to illustrate this point describes how the test results of students from the same school are more likely to be correlated because they share the same environment (Peugh 2009; Borenstein *et al*. 2010). Testing a nested dataset with ANOVA would results with Type I errors, and biased parameter estimates (Peugh 2009).

Furthermore, as will be shown in more depth in the next chapter, the data distribution is unbalanced, with samples ranging from 0 to 1000 per species/region/period, which also must be accounted for. Similar concerns are raised in the theses of Nitsch (2012), Budd (2015) and Hamilton (2016) and the methodological approach used here draws heavily on those works.

As such, in order to test for the statistical significance of isotopic ratios differences through time and between different regions, the dataset was analysed using a mixed multi-level model, also using the R programming language. Multi-level models with $\partial^{13}C$ or $\partial^{15}N$ values as the first level and site as the second level were therefore run using the 'lme4' package (Bates

et al. 2017). The 'lsmeans' and 'multcomp' packages (Hothorn *et al* 2013*;* Lenth 2017) were used to conduct pairwise comparisons. Linear mixed-effect models do not require the data to be balanced or normally distributed but the residual models from model fitting should be normally distributed and it could be a problem if variances differ systematically (Peugh 2009).

There are two main models for multilevel modelling: the fixed-effect model and the random-effects model (Borenstein *et al*. 2010). Fixed-effects assume that the conditions in which the results are observed are identical – in the example of the school above, it would mean that all students have been taught by the same teacher, from the same textbooks and so on. Random-effects are used when groups of studies are incorporated, but while it is assumed that they are similar enough to be synthesised, they are not identical and some variables must be contained. The model used here was the Restricted Maximum Likelihood (REML), which accounts for the nested distribution by controlling for the site level variation and assessing significance independently from site level factors.

Different random-effects and fixed-effect factors will be used for the different analyses. For example, the analyses of the cattle data between the different broad periods, have been tested by two models: one integrating regions as a random effect (to assess whether diachronic trends are significant independently from regional distribution) and as a fixed-effect (to assess the interplay of chronology and region on the data). For the human data, age and sex will be integrated as random-effects, as the female/male and age groups distribution of the data might affect the overall

results: for example if a sub-region/region contains more neonates than another, it might affect the statistical results.

Finally, for the broader environmental analyses, broad periods/sub-periods, regions and the different variables NOT measured will be contained as random-effects (for example, to disentangle the effects of temperatures and precipitation from one another). This will be explored further in the next chapter, in which an example of the scripts used and the R programme output will be discussed. Due to reasons of space, not all the models used will be discussed in the light of which random/fixed effects have been chosen and why, but the results will be presented in such way to make it clear how the models were constructed. The scripts for the cattle data can be consulted in Appendix III. There is no space to include the scripts for all the analyses conducted, but the scripts for the cattle data can be used as a template to reproduce these models.

In all the analyses 'site' was considered a random effect, while chronology, region and climatic, geographical and social factors were included as explanatory variables in the different models. Each species (human, cattle, sheep and pig) was analysed separately. While it might be argued that the 'Site' variable could represent both the 'Region' and 'Archaeological Period' variables, it was taken into account here that data may be more similar within the same time period/region independently from site level variations, and that 'intermediate' levels might need to be contained too. Therefore, models including factors such as chronology and/or regions used as random effects were also tested: for example, when assessing the role of precipitation as an explanatory variable, the model was written to take into

account not only site distribution, but also chronological distribution (i.e. acknowledging that data from the same sub-period/region might be more similar to each other and biasing the result). The different models were then tested using the 'anova' test in R (despite the name, this test is an not an ANOVA as usually understood; Hamilton 2016, 96). The output of this command is the AIC number, which allow to assess which model is the better fit, and the significance at which it is the better fit (Akaike 1973; Snipes and Taylor 2014).

In lme4, *p-values* are not reported because it is uncertain how they should be calculated (Hamilton 2016, 96). While some analysts prefer to report the t-values, the 'lsmeans' package and function allows to transform the *t-values* into *p-values* for each of the groups compared and was systematically used here. An example of the mixed effect models, with both scripts and outputs will be shown and discussed in Chapter 5.

Results are reported as significant if $p \leq 0.05$ but some suggestive trends ($0.05 < p < 0.1$) are also discussed.

4.3 Legacy Data Questions and Methodology

Collecting legacy data is a staple of isotopic studies. When the material is not available to a researcher, for example in the case of faunal data to create environmental baselines, it is common to use previously published or unpublished material (for example, Cheung *et al.* 2011 uses faunal baselines from 2008; Beavan and Mays 2012 uses faunal baselines from Müldner 2007). However, collecting legacy data and comparing it to one's dataset is based on the assumption that all isotopic data are of equal quality. Controls

are well established for the actual isotopic analyses and only the values passing these criteria have been included in this thesis. However, other factors need to be assessed to establish the accuracy and/or precision of a specific dataset against another dataset when produced in another laboratory or at a different time. Indeed, machine calibration or procedures may vary from one study to another, resulting in variations above the standard error. It is therefore crucial to look at how the dataset was created and understand the source material from which the analyses originated.

4.3.1 Inter-Laboratory difference

One of the first factors to consider is whether different equipment would affect the results. However, it is problematic to do a direct comparison here: as no directly comparable units (i.e. same species in the same period) has been analysed by all the laboratories. Therefore, it would be nearly impossible to ascertain whether any variation observed would be due to a difference in laboratory procedures or actual chronological or regional variation. This particular issue has been addressed specifically by Jay in her thesis (2005). Jay sent pilot samples to be analysed commercially at Iso-Analytical Ltd (Jay 2005, 167, 168). These analyses were performed using a Europa Scientific GEO 20/20 isotope ratio mass spectrometer coupled to an ANCA-GSL elemental analyser, while the same sample was analysed using the Finnigan mass spectrometer at the University of Bradford (Jay 2005, 167). Iso-Analytical Ltd used Bovine Liver Standard (NBS 1577a) as the reference material in their analysis for both carbon and nitrogen (Jay 2005, 167), while Bradford used methionine as the reference material (Jay 2005, 167). Jay ran the comparison between the Europa and

Finnigan equipment in three different ways and overall the replication differences between the machines were found not to be outside the replication standard deviation within the machines (Jay 2005, 168). So while some differences must be expected in terms of both accuracy and precision when comparing data across different equipment and using different references, they are not significant enough to prevent comparative analyses (Jay 2005, 168). Related to the question of machine is the question of sample preparations and how different procedures might have an impact on the isotope measured. Søreide *et al* (2006) and Mateo *et al*'s (2008) considered the following factors: acid-washing, distilled water rinsing, sample type (whole individuals or pieces of soft tissues), lipid content, and gut contents, revealing overall large and highly significant effects of acidification for both $\delta^{13}C$ values (up to 0.9‰ decrease) and $\delta^{15}N$ values (up to 2.1‰ decrease in whole individual samples, and up to 1.1‰ increase in tissue samples). Related to sample preparation, one must also consider that techniques (and not just machines) might also change over time. Again, Jay (2005, 175) reports a personal communication from Richards about calibration of standards found to be problematic at Oxford in 1998 for the Poundbury study, which directly affect some of the data used for this thesis.

More recently, Pestle *et al.* (2014) conducted an inter-laboratory experiment to assess what they termed the Minimal Meaningful Difference, which is the level of variation expected between different laboratories. They suggest an average $\partial^{13}C$ value of 0.6‰ for bone collagen and an average $\partial^{15}N$ value of 0.9‰ for bone collagen to account for laboratory variations. Along with

Jay's results, these small differences indicate that datasets produced in different laboratories are perfectly comparable, but that nonetheless, small isotopic variations between them should not be over-interpreted. It is important to raise these issues of data quality and more can certainly be done in the future about addressing them. Nevertheless, the context of this thesis difference between laboratories, be it to do with equipment or practices, will not make a significant different to the results.

4.4 Summary

This chapter reviewed issues of methodology when comparing legacy data on a large scale. The two main methodological approaches will be the uses of cattle baselines against which to compare the human, as well as complex statistical modelling taking into account the nested structure of the data. Different paths of investigations have been identified both in the human and the faunal data and will be addressed in Chapter 6 and 7, while the distribution of the data between different units of analyses (e.g. dry/wet, geographical, chronological) and the basic statistics underlining it will be addressed in the next chapter.

CHAPTER 5. DATA CHARACTER

This chapter aims to review the characteristics of the data used in this thesis. It will explore the distribution of these data at the different levels chosen as criteria for the analyses (see Chapter 4, section 4.2.5), as well as present basic statistical testing for the broader scale analyses at the core of this work. Indeed, it is necessary to investigate and test the trends that underlie these data before pooling it all together. An example of the more complex multivariate modelling will also be given. Finally, this chapter will also address issues specific to legacy data, such how these data have been produced, when and under what conditions the samples were excavated, and how they were dated. All these issues are understood here as the 'character' of the data.

5.1 Chronological Distribution of the faunal and human data

Because some of the data are often only dated within a large range, it was challenging to organise the whole dataset with accurate and precise chronological resolution. However, while some of the samples are not absolutely dated, it is still possible to organise them in a relative sequence to look at the broad patterns of diets in England. Figure 5.1 and Figure 5.2 show how both the faunal (Figure. 5.1) and human (Figure. 5.2) data are distributed in all three broad periods. It is immediately obvious that the data are not well balanced between species and period, with humans in both the Roman and Early Medieval periods counting more than double the number

of faunal samples, while in the Iron Age, it is the fauna which is present in greater number, with three times more faunal samples than human ones.

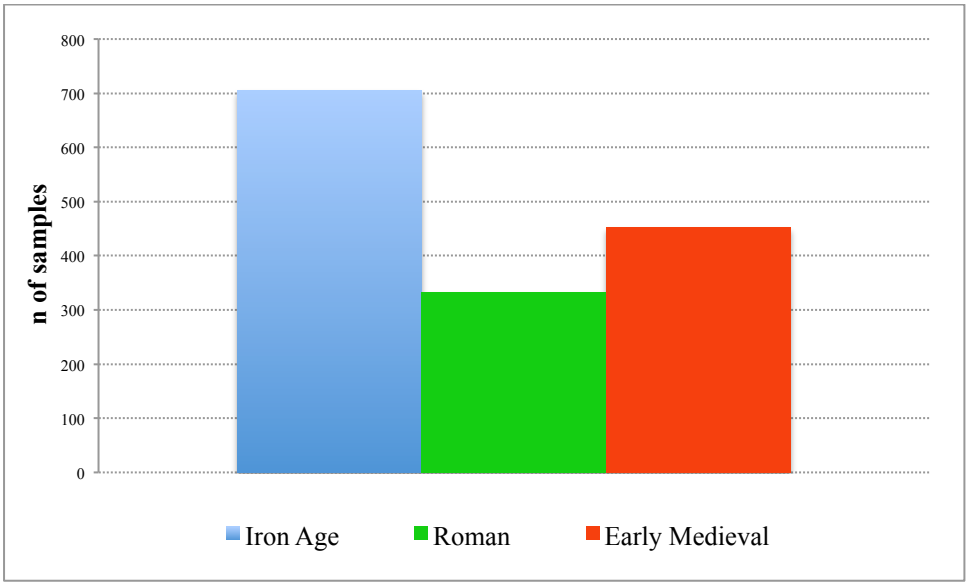


Figure 5.1. Sample distribution of all the faunal data by time period (Iron Age n=705, Roman Britain n=336, Early Medieval n=461, total n= 1502).

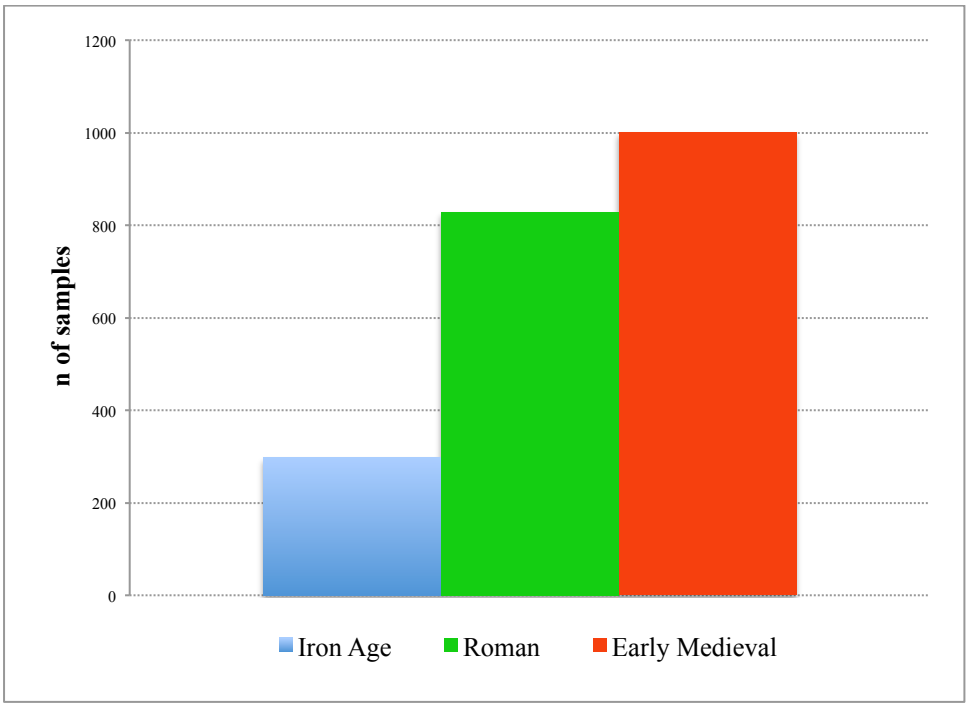


Figure 5.2. Sample distribution of all the human data by time period (Iron Age n=298, Roman Britain n=829, Early Medieval n=1000), total n= 2127).

Figures 5.3 and 5.4 below show the distribution of these same data according to the more refined chronology discussed in Chapter 4 (section 4.2.3). Again, it shows that the data are not well distributed between sub-periods, with the 'Middle Roman' and the 'Early Anglo-Saxon' containing an overwhelming number of samples for the human data (Figure 5.4). The faunal data are also fairly unbalanced (Figure 5.3). However, at the exception of the Late Iron Age/Roman for the fauna and the Latest Iron Age for the humans, all sub-period contains more than 8 samples, the lower limit for significant sample size (see section 4.2.2).

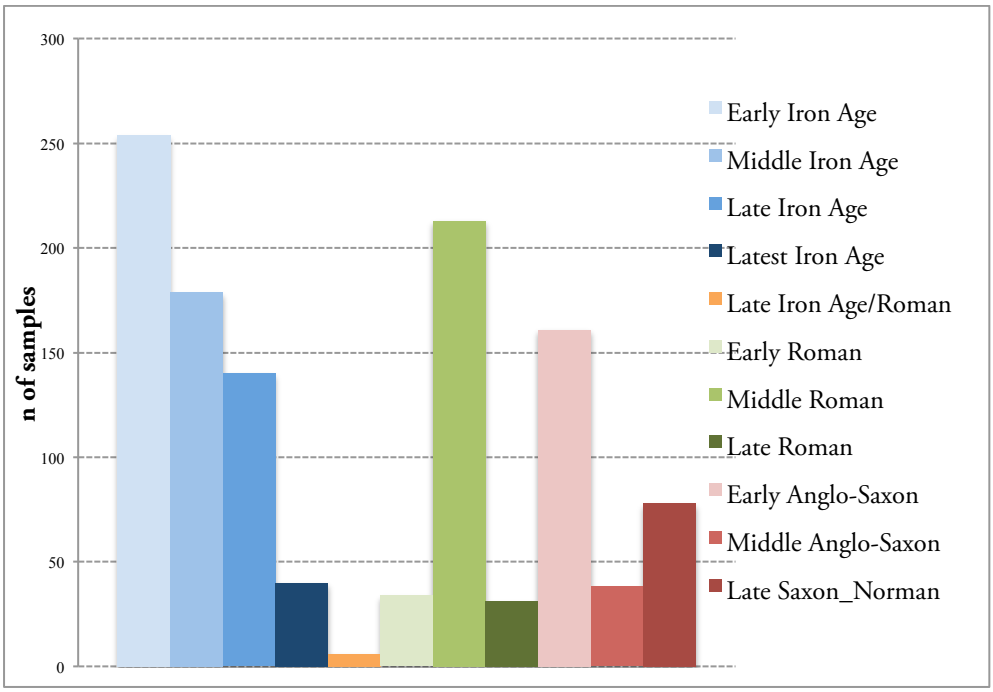


Figure 5.3. Sample distribution of all the faunal data by sub-period (Early Iron Age n=254, Middle Iron Age n=179, Late Iron Age n=140, Latest Iron Age n=40, Late Iron Age/Roman n=6, Early Roman n=34, Middle Roman n=213, Late Roman n=31, Early Anglo-Saxon n=161, Middle Anglo-Saxon n=38, Late Saxon_Norman n=78. Samples dated less precisely, i.e. dated only to a broad period ('Iron Age' n=92, 'Roman'n=49, 'Anglo-Saxon' n=184) have been excluded.

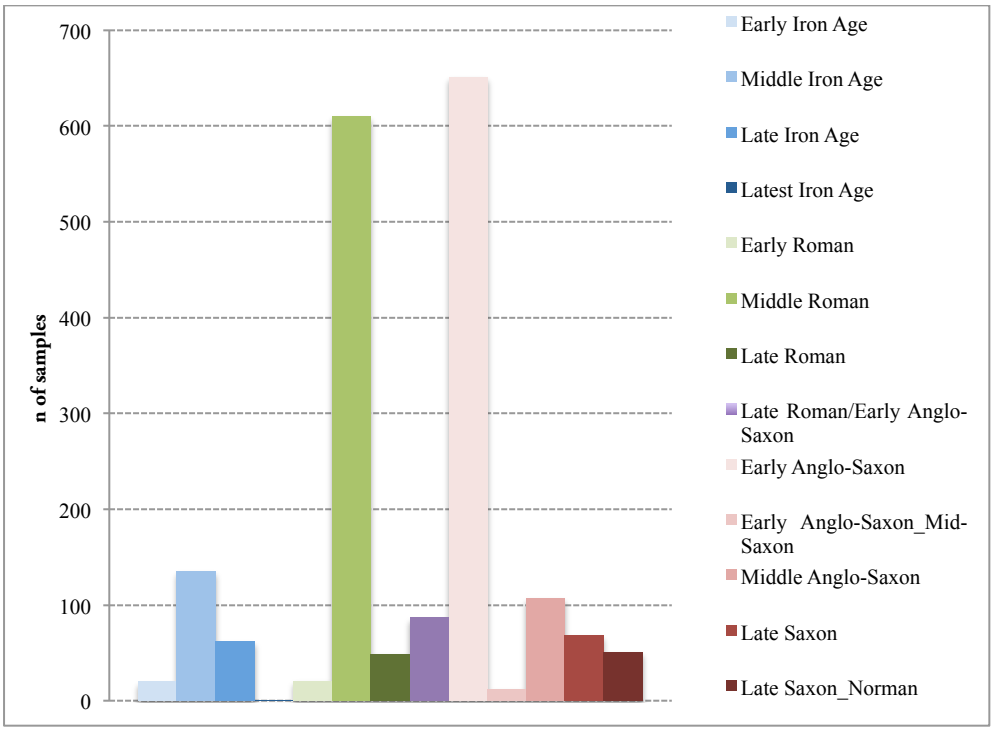
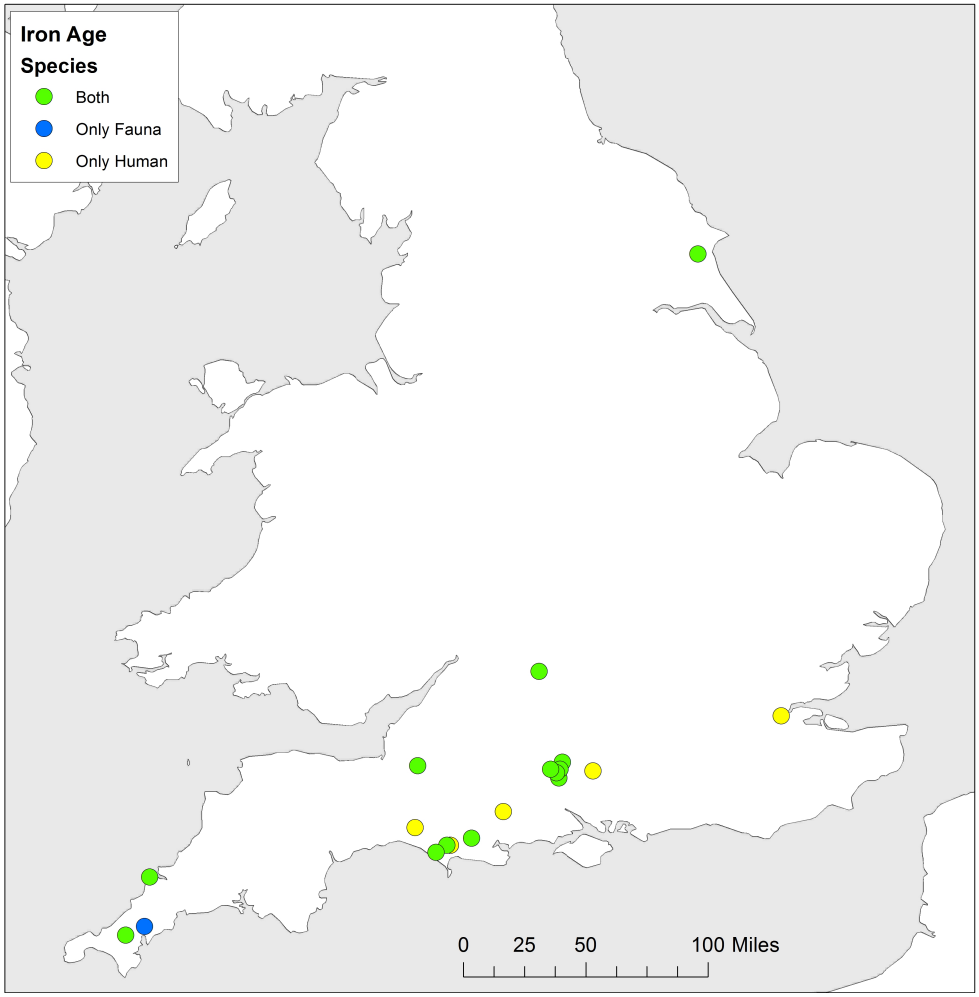


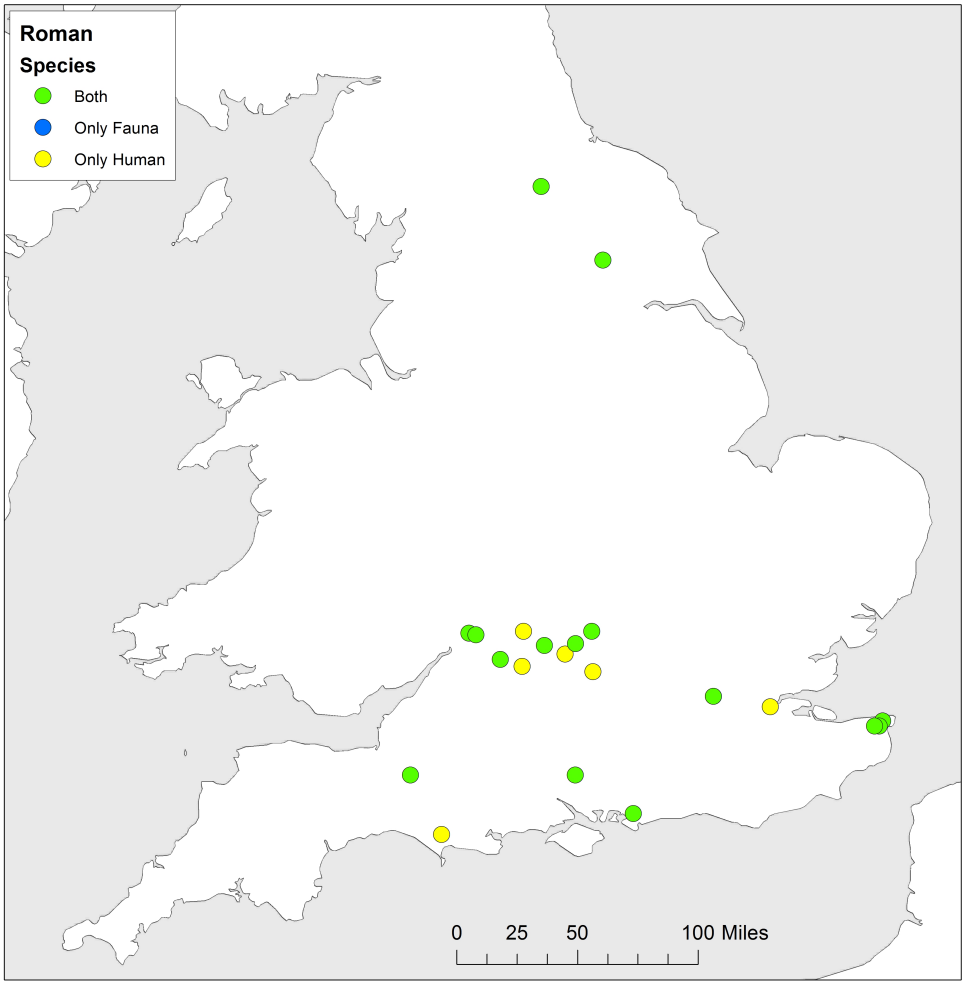
Figure 5.4. Sample distribution of all the human data by sub- period. (Early Iron Age n=20, Middle Iron Age n=135, Late Iron Age n=62, Latest Iron Age n=1, Early Roman n=21, Middle Roman n=610, Late Roman n=49, Late Roman/Early Anglo-Saxon n=87, Early Anglo-Saxon n=651, Early Anglo-Saxon/Mid-Saxon n=12 Middle Anglo-Saxon n=107, Late Saxon n=68 , Late Saxon_Norman n=51. Samples dated less precisely, i.e. dated only to a broad period ('Iron Age' n=79, 'Roman' n=61, 'Anglo-Saxon' n=111) have been excluded.

5.2 Regional Distribution of the human and faunal data

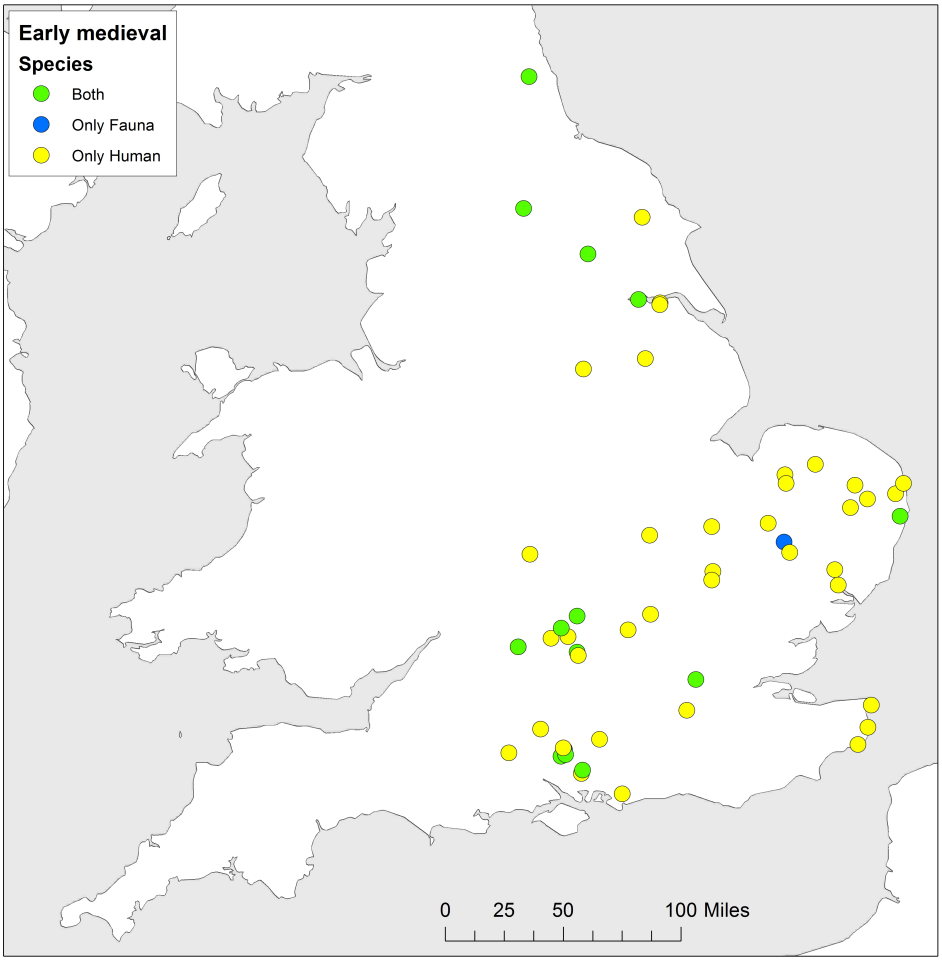
Regionally, these data do not cover the whole country, as they are biased toward the South Coast, Yorkshire, and the Southern Central region, with East Anglia as less prominent group despite good representations in the Early Medieval period (Map 5.1, 5.2 and 5.3).



Map 5.1. Geographical distribution of the human and faunal samples in the Iron Age. The sites and number of samples per site can be found in Appendix I.2, Tables 1.2.1 and 1.2.2.



Map 5.2. Geographical distribution of the human and faunal samples in Roman Britain. The sites and number of samples per site can be found in Appendix I.2, Tables 1.2.1 and 1.2.2.



Map 5.3. Geographical distribution of the human and faunal samples in Early Medieval Britain. The sites and number of samples per site can be found in Appendix I.2, Tables 1.2.1 and 1.2.2.

The reasons for this distribution are more likely to be the result of modern archaeology practices than actual patterns of life in the past (Gosden *et al.*in prep). It is nonetheless necessary to cover what this means for the analyses here. First, it must be acknowledged that this dataset does not cover the whole of England. However, should similar isotopic trends be systematically repeated across various landscapes there will be a strong case to hypothesise that these trends may be representative of the whole country. On the contrary, should it be established that the isotopic patterns differ from one region to another for reasons other than environmental factors, the

existence of dietary regional variations between the different regions present here could be the basis on which on to investigate further regional variation as more samples are analysed in the future.

5.3 Distribution of the different species

5.3.1 Overview of the faunal data.

With the exception of the Iron Age, the human data clearly dominate the isotopic record. There are indeed many sites, and sometime entire regions, for which faunal remains were not analysed (see Table A1.2.1 in Appendixes II.2). While the data contain a variety of domesticated and wild species, the three main domesticates (cattle, sheep and pig) are the ones of interest here. It is acknowledged that wild species may be a better proxy for the natural environment but they are simply not present in numbers large enough to be useful for the analyses at this stage. Therefore, the focus is on the domesticate ones, with the understanding that their isotopic values represent an environment that is to some extent managed. Out of the 1502 faunal data investigated here, the species present in larger number are sheep (n= 508), cattle (n = 443) and then pig (n = 286) followed by deer, horse, dog, fowl, wild animals and aquatic species. Large ungulates (sheep, cattle, pig) survive well in sampled archaeological contexts and constitute nearly all of the excavated faunal material for all the periods considered (Hamilton 2016, 75) As discussed in Chapter 3, these were undoubtedly the most common species, yet their predominance in the archaeological record is also due to issues of recovery and preservation. Accordingly, the contribution to the diet of smaller animals, whose bones would not have been preserved,

might have been underestimated when getting archaeozoological data for individual food species because of their relatively low number (Sykes *et al*. in press). It should also be noted here that that these numbers reflect the number sampled and analysed for isotopes rather than the MNI at any given site or for any given period. However, these numbers do nonetheless reflect something of the proportion of animals present at each site. If sheep bones are more numerous in the archaeological sample, then it stands to reason that they should also be numerous in the isotopic data too.

The focus of this thesis, however, will be on constructing robust cattle baselines, and as such, the relatively slow number of small and/or wild animals will not be a problem. In the Iron Age, the most represented species are sheep, as was expected considering the dominance of the sheep in the archaeozoological record (Hambleton 2008). Cattle and pig are the second most numerous species, but it must be noted at the while cattle might be slightly less numerous than sheep, they might have dominated diets due to their meat weight. Horses are also present in fairly large numbers, and there is evidence that their meat was consumed, at least in the Upper Thames Valley, although there appears to be a correlation between types of settlements (enclose or unclosed) and horse bone presence (Figure 5.5; for more details on horses, see Stansbie 2017, 358-359).

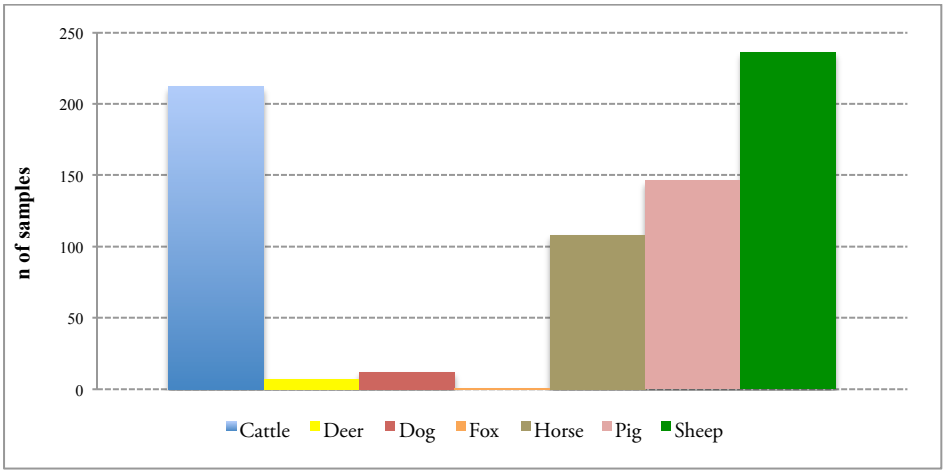


Figure 5.5. Distribution of the faunal data according to species in the Iron Age (Cattle n=206, Deer n=7, Dog =n12, Fox n=1, Horse n=108, Pig n=141, Sheep n=230).

While the shift from sheep to cattle dominated assemblages happens in the Roman period, it is not particularly striking here with only marginally more cattle than sheep (Figure 5.6; see also section 3.5.2) Again, the three main species represented are the three main domesticates.

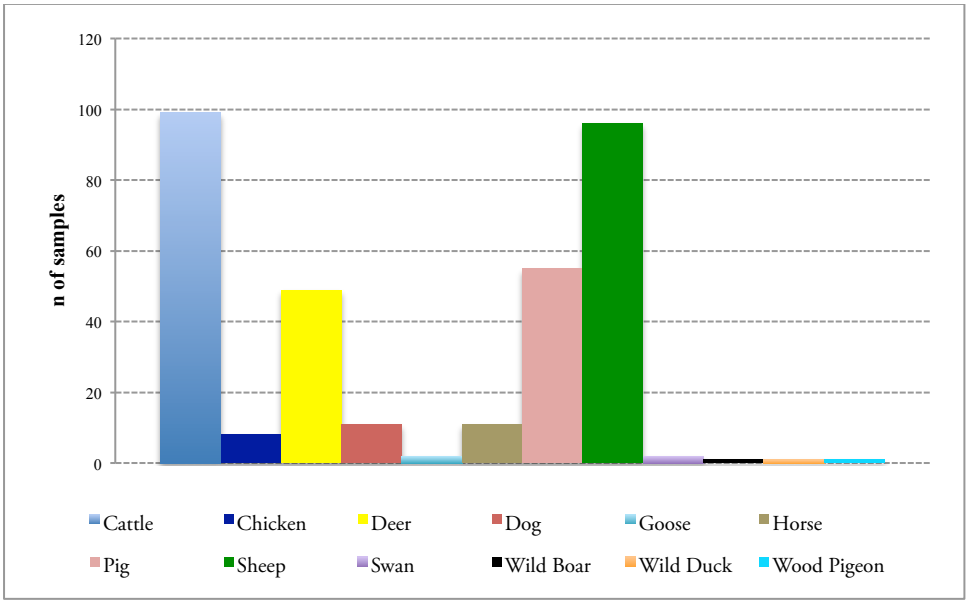


Figure 5.6. Distribution of the faunal data according to species in the Roman period (Cattle n=99, Chicken n=8, Deer n=49, Dog n=11, Goose n=2, Horse n=11, Pig n=55, Sheep n=96, Swan n=2, Wild Boar n=1, Wild Duck n=1, Wood Pigeon n=1).

Figure 5.7 shows that the medieval dataset is dominated by cattle, sheep and pig. Again, this is not surprising as these three species are both more easily recovered in archaeological context and their importance in the past is well attested (see Chapter 3). Sheep are the most represented species (n= 182), before cattle (n= 135) and pigs (n= 90). An interesting addition compared to the faunal dataset discussed above is the presence of aquatic fauna (eel n= 5; salmon n= 6; herring n= 5; these have been grouped in the graph below under 'Freshwater Fish' and 'Marine Fish').

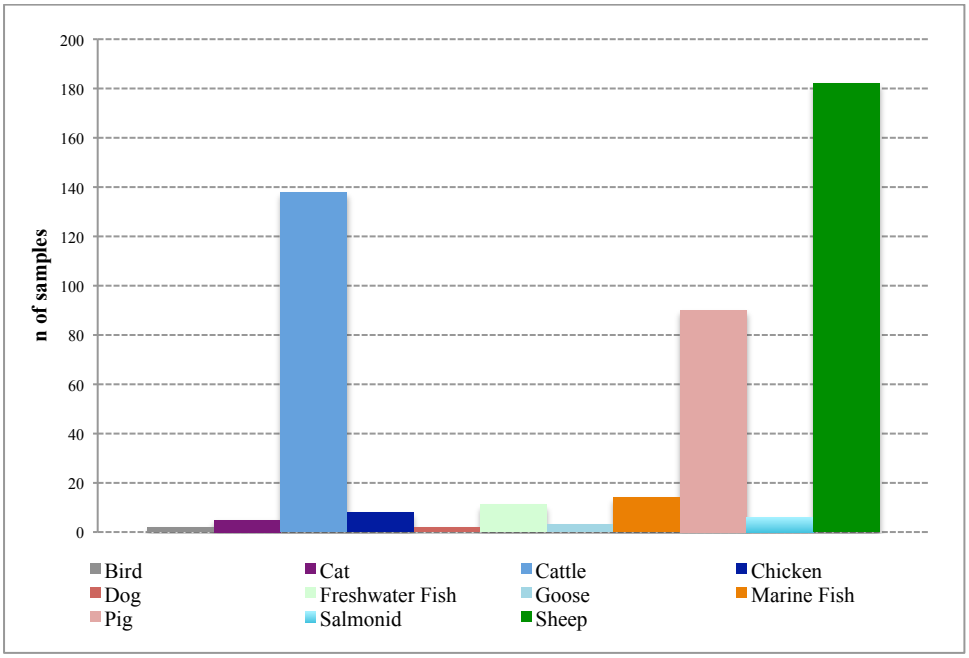


Figure 5.7. Distribution of the faunal data according to species in the Early Medieval period (Bird n=2, Cat n=5, Cattle n=138, Chicken n=8, Dog n=2, Freshwater fish n=11, Goose n=3, Marine Fish n=14, Pig n=90, Salmonid n=6, Sheep n=182).

5.4. Data distribution following criteria other than time period and region

This section briefly reviews the number of samples for the different units of analyses investigated in this thesis for both the fauna used as baseline (here cattle) and the human. This will show how the data are balanced between different regions and broad periods

5.4.1. Social organisation.

5.4.1.1 Sex

The primary use of isotopes is to measure the diets of individuals. Therefore, it is common to collect as much information as possible about each individual sample as it is particularly important to investigate the potential roles of sex, age or status in the diet of a population. In this dataset, however, this information is far from complete. Not all the adult population have been attributed a sex (Female n= 487 [+28 uncertain but likely females]; male n= 602 [+ 29 uncertain but likely male]; sex unknown n= 989; Figure 5.8). It must however been noted here that Cummings (2008a) did analyse dietary differences between males and females but she did not include sex in her data tables. So while the proportion of sexed skeleton is higher when taking into account Cummings' data (Female = 642, Male =802, unknown = 684), because 'sex' cannot be attributed to specific samples in her dataset, they are counted as 'unknown' (Cummings, 2008a).

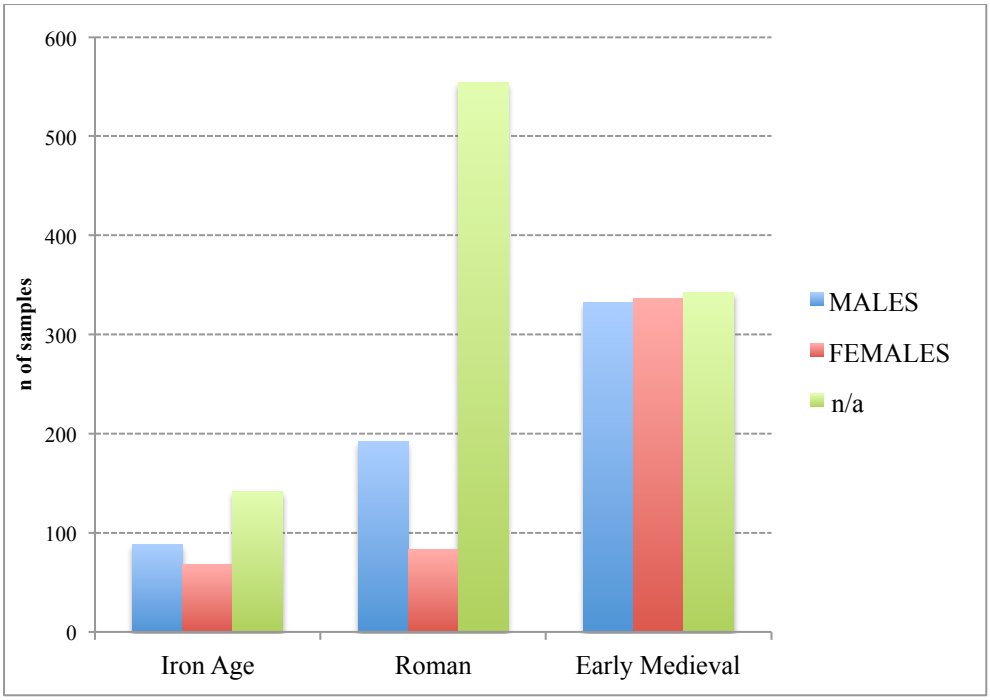


Figure 5.8. Distribution of the data according to sex in the three broad periods (Iron Age Females n=68, males n= 88 n/a n=142, Roman females n=83, males n=192, n/a n=554, Early Medieval females n=332, males n=336, n/a n=342).

5.4.1.2 Age

As discussed in Chapter 4, the age ranges present in the dataset here are infants (0-3), juveniles (4-15), young adults (16-25), mature adults (26-50), older adults (50+) and adults for remains with no specific markers. Specific distribution within periods is shown below (Figure 5.9).

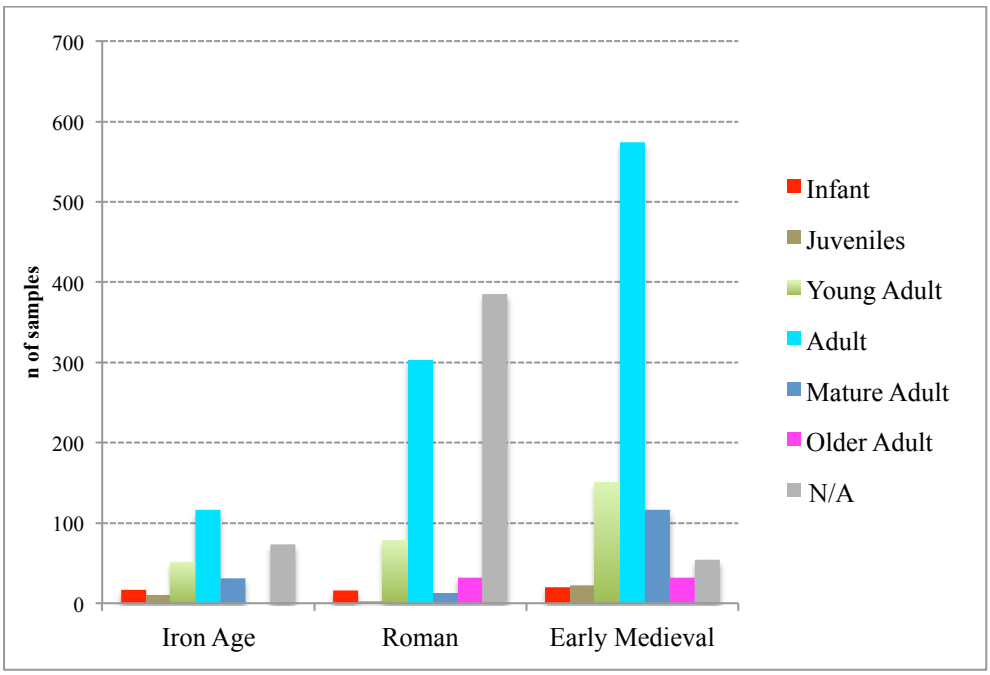


Figure 5.9. Distribution of the data according to sex in the three broad periods (IA Infants n=17, juveniles n=10, young adult n=51, adults n=116, mature adults n=31, n/a n=73; R Infants n=16, juveniles n=2, young adult n=78, adults n=303, mature adult n=13, older adult n=32, n/a n=385; EM Infants n=20, juveniles n=22, young adult n=150, adults n=574, mature adults n=116, older adult n=32, n/a n=54)

5.4.2 Climate

The following section addresses the distribution of the data according to different the climatic events, as defined Chapter 4, section 4.2.5. Specific distribution of the data in these broad categories, within sites, sub-periods and regions, will be reported in Chapters 6 and 7.

5.4.2.1. Precipitation

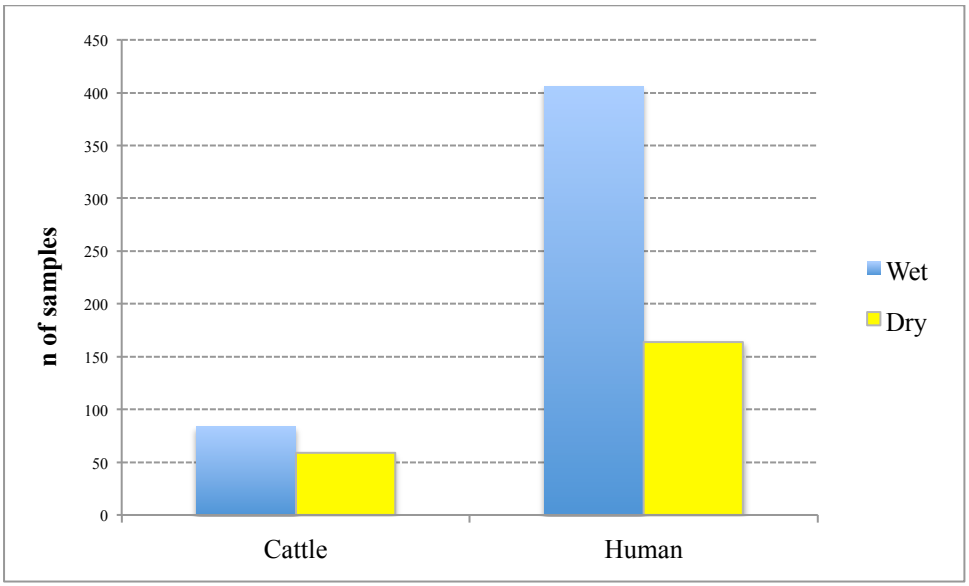
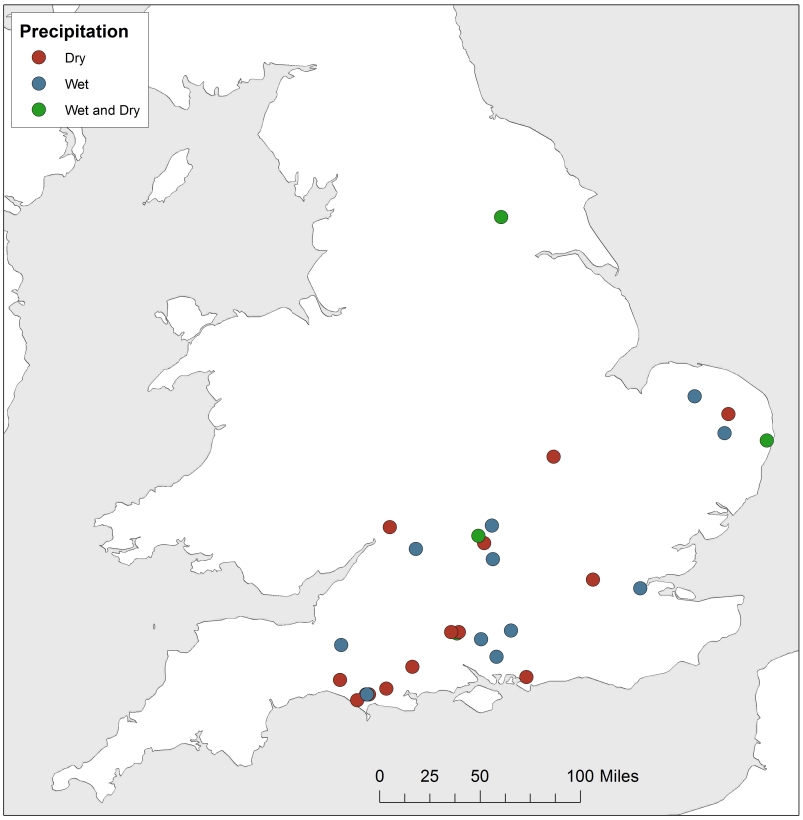


Figure 5.10. Distribution of the data according to wet and dry episodes (cattle n=84, dry n=59; human wet n=406, dry n=164).



Map 5.4. Site distribution according to wet and dry episodes for both the human and cattle data.

5.4.2.2. Regions of coherent precipitation

Because precipitation were likely not homogenous in the country, the data have been divided according to region of coherent precipitation, after Gregory *et al.* (1991). Distribution of the data in all three periods is shown below in Figures 5.11 to 5.13.

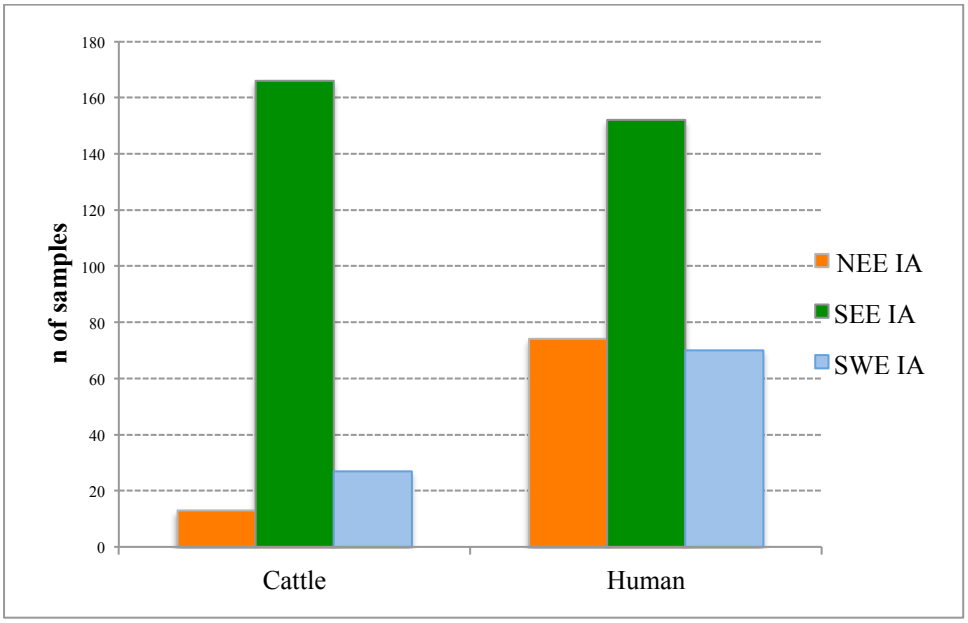


Figure 5.11. Distribution of the data according to the different regions of coherent precipitation in the Iron Age. (Cattle NEE (North East of England) n= 13, SEE (South East of England) n=166, SWE (South West of England) n=27; Human NEE n= 74, SEE n=152, SWE n=70.)

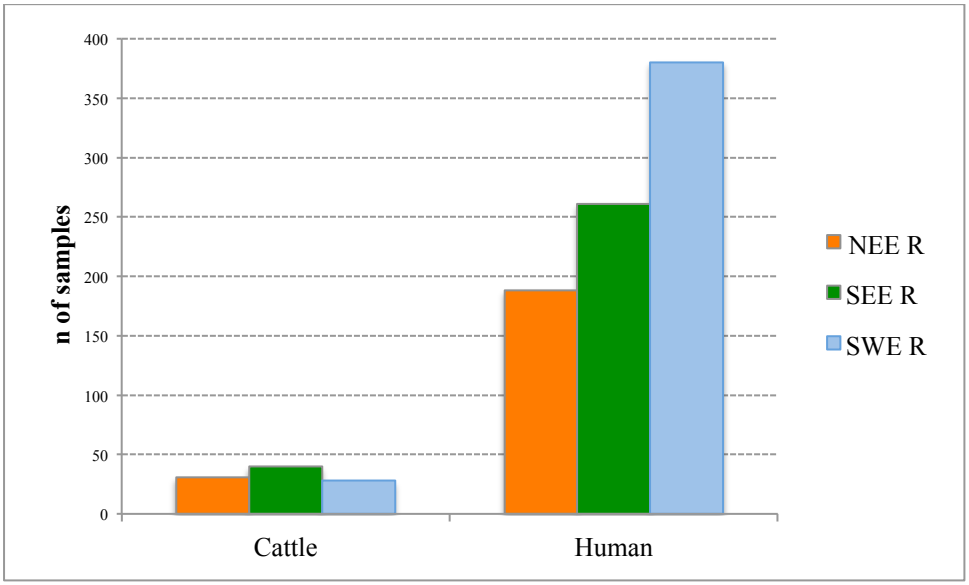


Figure 5.12. Distribution of the data according to the different regions of coherent precipitation in Roman Britain. (Cattle NEE (North East of England) n= 31, SEE (South East of England) n=40, SWE (South West of England) n=28; Human NEE n= 188, SEE n=261, SWE n=380.)

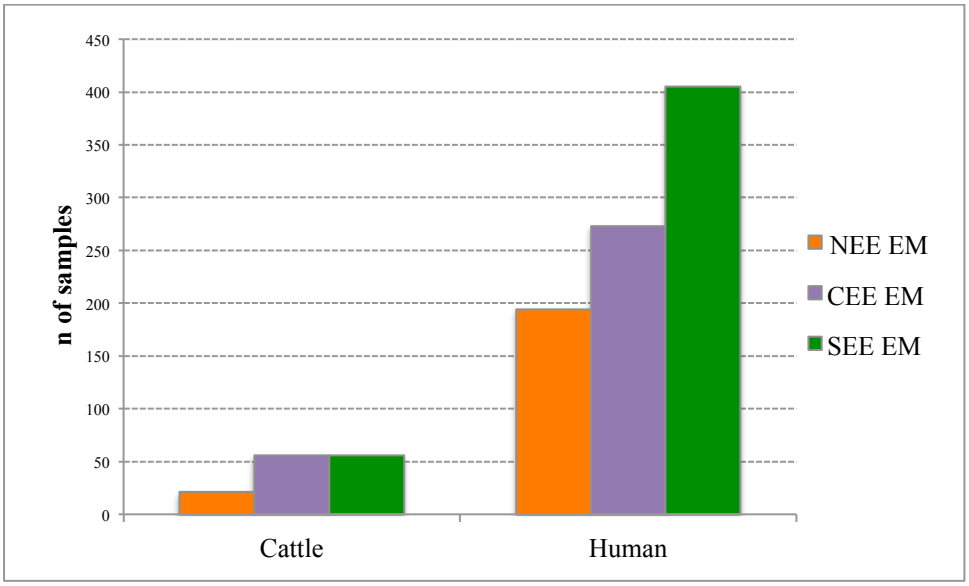
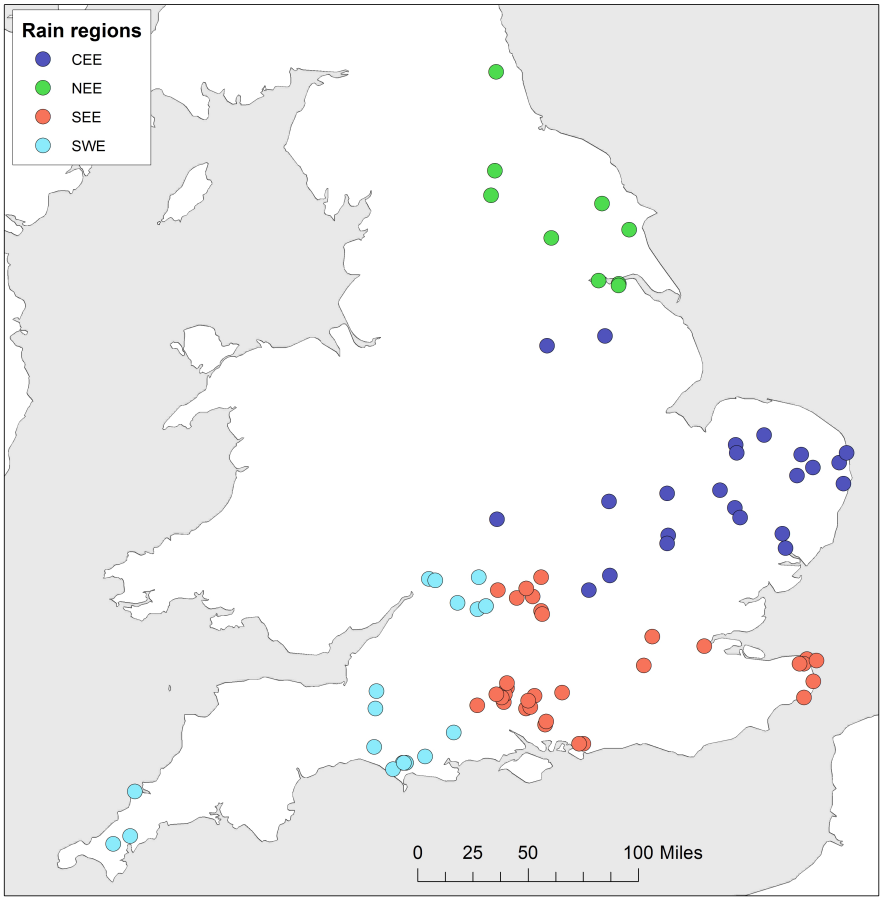


Figure 5.13. Distribution of the data according to the different regions of coherent precipitation in Early Medieval Britain. (Cattle CEE (Central England) n= 56, NEE (South East of England) n=21, SEE (South West of England) n=56; Human CEE n= 273, NEE n=194, SEE n=405.)



Map 5.5. Site distribution for cattle and human according to region of coherent precipitation for all periods.

5.4.2.3 Temperature

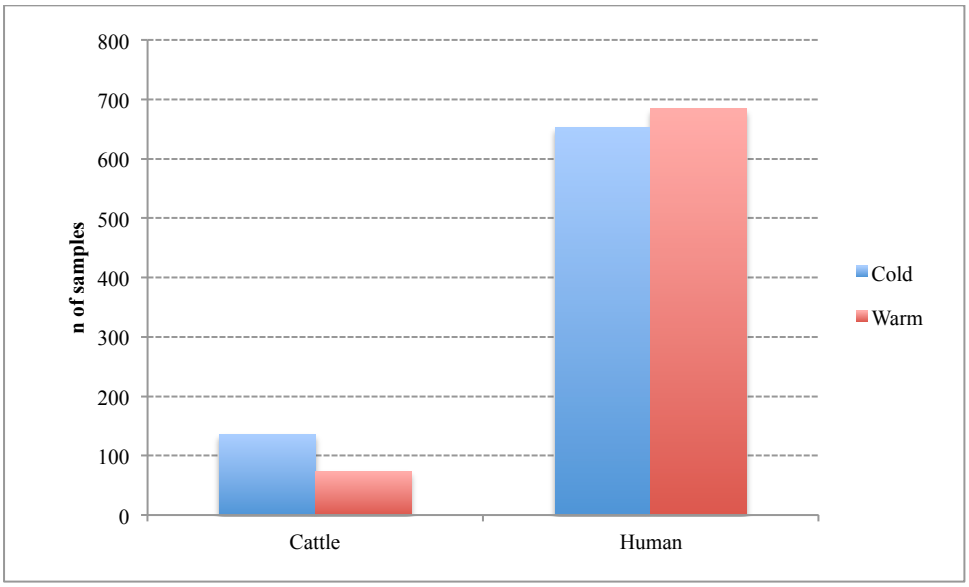
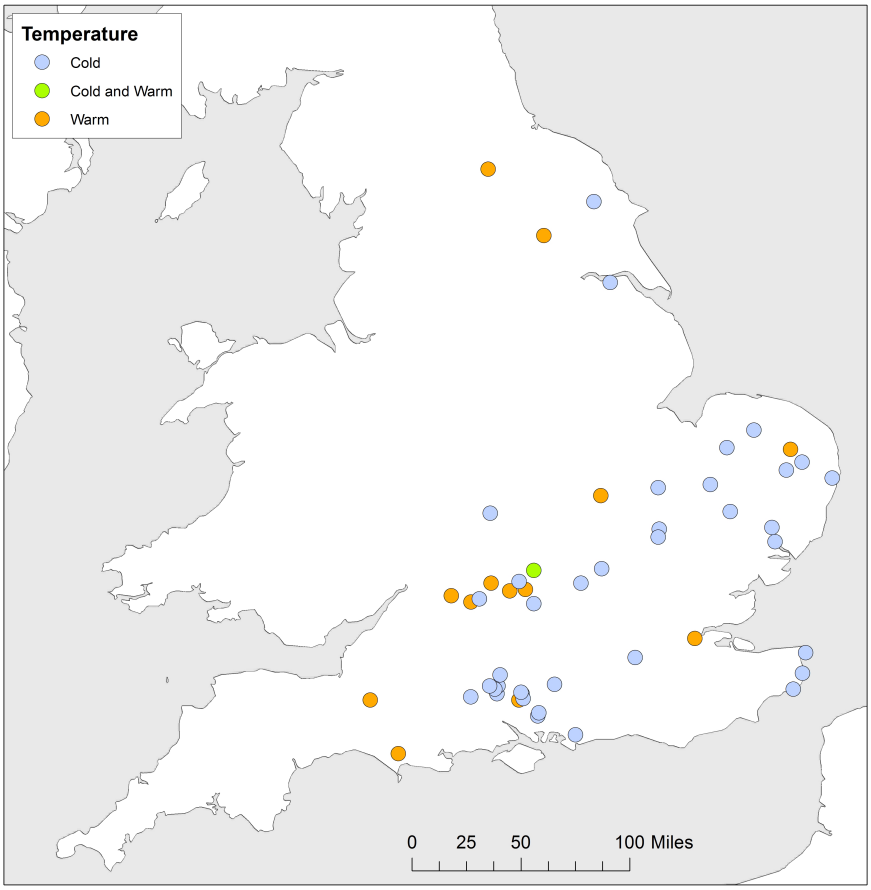


Figure 5.14. Distribution of the data according to warm and cold episodes. (Cattle cold n=136, warm n=73; Human cold n=653, warm n=684).



Map 5.6. Site distribution for the cattle and human data according to cold and warm periods for all periods.

5.4.3 Physical Geography

This section addresses distribution of the data according to aspects of physical geography that are relevant to the analyses in this thesis. Specific regional and sub-period distribution will be addressed in Chapters 6 and 7.

5.4.3.1 Coastal/Inland

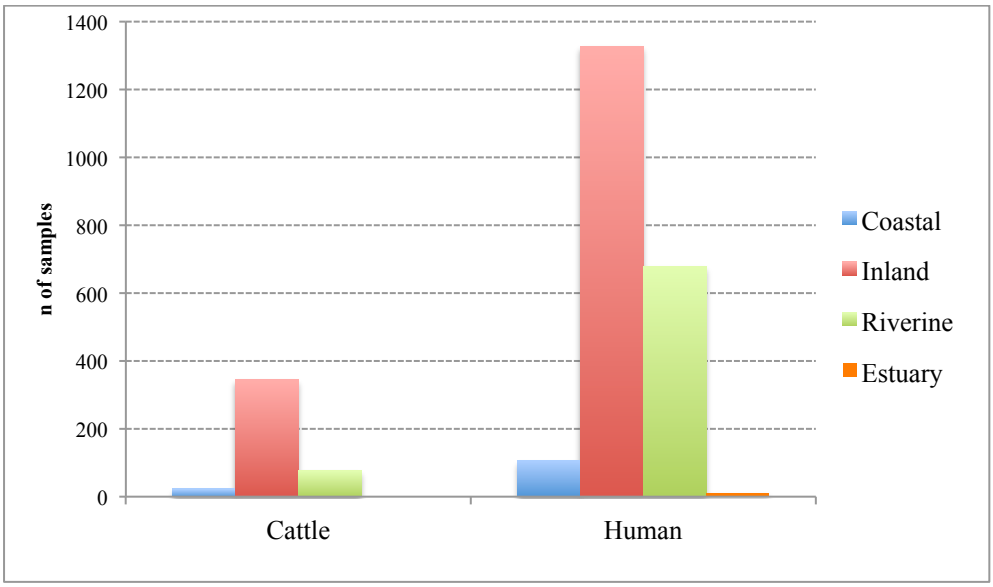


Figure 5.15. Distribution of the data according to proximity to the coast. (Cattle coastal n=23, inland n=344, riverine n=76; Human coastal n=106, inland n=1328, riverine n=679, estuary n=12).

5.4.3.2. North/South

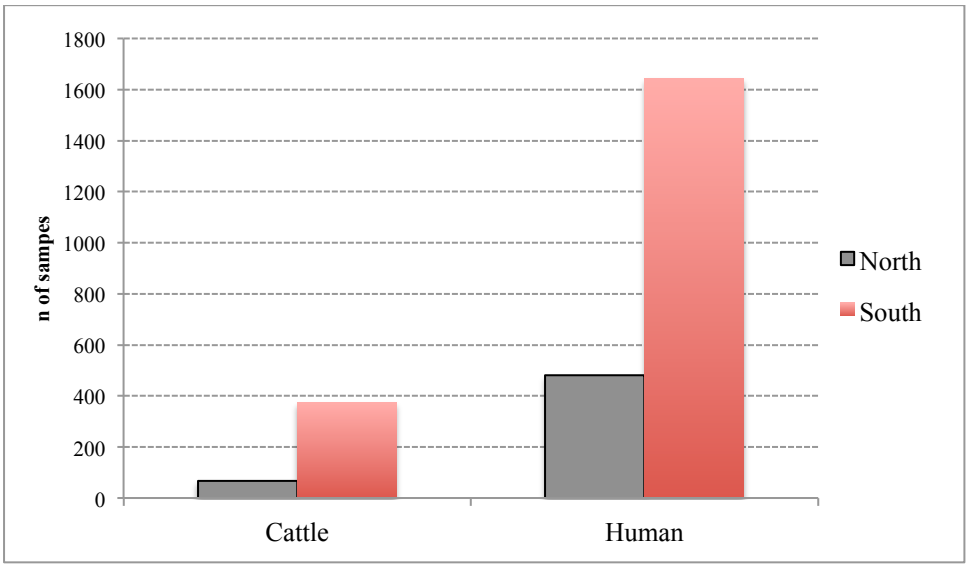
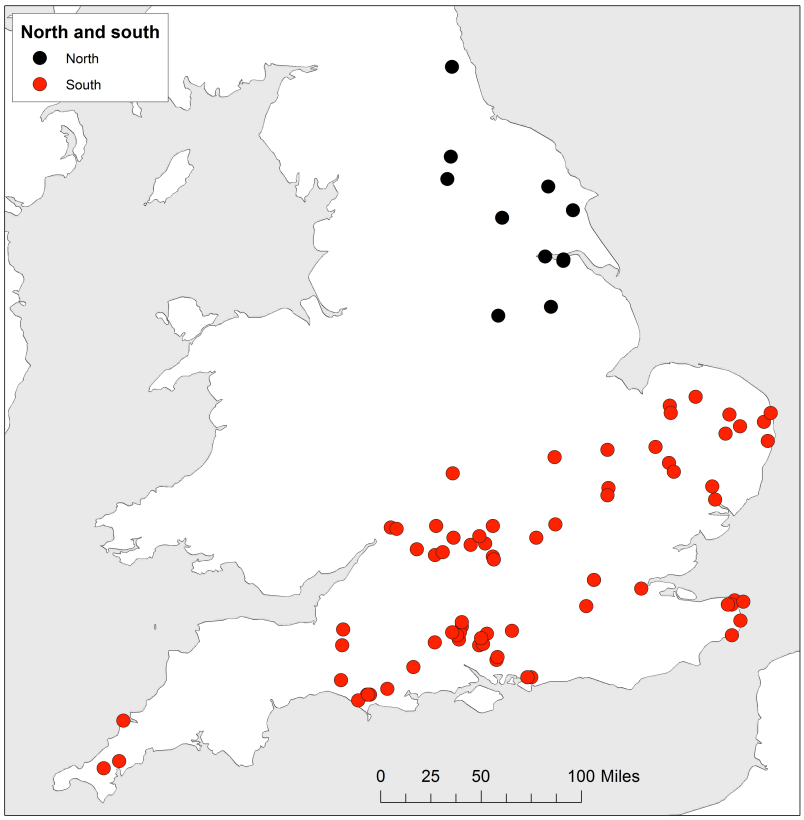


Figure 5.16. Distribution of the data according to latitude (North and South of the Humber. Cattle north n=68, south n=375; Human north n=480, south n=1645).



Map 5.7. Distribution of the human and cattle data between North and South.

This section, as well as Figures 5.1 to 5.16, and Maps 5.4 to 5.7, have shown how the data are distributed and how unbalanced they are between the different units chosen for analyses. Indeed, not only the ratio fauna to human is widely different in most cases, but also the sample count between same species groups between units is also unbalanced. A small number of the data from over-represented regions/units/sub-period could have been randomly selected to the re-establish the balance with under-represented units, but it was decided that the strength of these analyses lay in the fact that all these data were analysed together. Therefore it was decided that it would be better to use a statistical model that would take into account both the different sample sizes and the uneven, nested distribution of the data, as was discussed in Chapter 4. An example of this will be discussed below in Section 5.6.3

5.5 Considerations on the use of meta-data

The dataset used in this thesis is not homogenous. It is a composite of different datasets from different sources. The original datasets have been collected following different procedures, from different sites, from different archaeological traditions, each of these giving the data particular characteristics that need to be understood. Four points that may affect the interpretation of isotopic analyses stand out: (1) differences caused by bone variation due to growth and turnover rates and which might affect a composite dataset compiled from measurement on different types of bones; (2) loss of information between excavation and sampling; (3) the aims and standards of field techniques and of the eventual publication; (4) differential focus on either normal or unusual populations.

5.5.1 Differences in bones

A question raised in Chapter 4 concerns the tissues sampled. In order to limit variations, the data collected here come from measurements mainly done on bone collagen. However, bone collagen ratios might be dependent on rates of bone tissue replacement in the human body, resulting in a different signal depending on which bone was sampled (see above, Chapter 2, and also Dauven *et al.* in press). It seems impossible to establish a protocol imposing a specific bone for analyses since preservation and curatorial preferences are the first and foremost factors in the choice of the bone sampled (Jørkov *et al*., 2009). De Niro and Schoeninger addressed this issue as early as 1983 by measuring different bones of the same rabbits. They concluded that only small variations existed and expected them not to exceed 1 per mil for human bone collagen collected from different bones (De Niro and Schoeniger 1983). More recently, Olsen *et al.* (2014) and Dauven *et al.* (in press) tested this hypothesis more thoroughly and found the greatest variation to be between ribs and vertebrae with a maximum difference of 0.40‰ and 0.83‰ for carbon and nitrogen respectively, which is less than the 1‰ value suggested by DeNiro and Schoeniger (1983). When sampling other tissues, albeit tissues not readily available to archaeologists and maybe not relevant here, Dauven *et al.* (in press), found a range of measurements as wide as 1.24‰ for the carbon isotopic values and 0.69‰ for the nitrogen isotopic values (Dauven *et al*. in press). However, by restricting the measurement to the femur and ribs, the range drops to 0.30‰ for the carbon isotopic values and 0.26‰ for the nitrogen isotopic values. Ranges of measurements for the same bone (a rib) were found to be

0.18‰ for the carbon isotopic values and 0.55‰ for the nitrogen isotopic values by Olsen *et al.* (2014), while Dauven *et al* found slightly higher rates of variation (0.50‰ and 0.67‰ for carbon and nitrogen respectively).

Overall, the range measured seems to fall below what was suggested by DeNiro and Schoeniger, even in more modern experiments. Jay also considered this issue in her thesis and measured the variations in her own dataset, using eight different individuals (two from Hampshire and six from East Yorkshire) and processing samples of both rib and cortical long bone (Jay 2005, 169). The range of absolute differences between cortical long bones and ribs in these individuals is 0.0 to 0.5‰ for both ^{13}C and ^{15}N measurement, with an average of 0.2‰ for the carbon isotopic values and 0.3‰ for the nitrogen isotopic values and a standard deviation of 0.2‰ for both (Jay 2005, 169). There is no particular pattern to be seen in these differences in terms of the direction of variation, which is confirmed by more recent findings of Dauven *et al*. (in press). It must be noted that the experiments done are presumably under conditions of more or less homogeneous diets and that the differences between different bones will be larger if diets are changing over the medium term.

Because this dataset has been collated from pre-existing studies, it is not possible to re-test the samples to assess potential bone variations for the same individual and across the whole dataset, measurements come from different bones, most notably ribs and femora as shown in Figure 5.17.

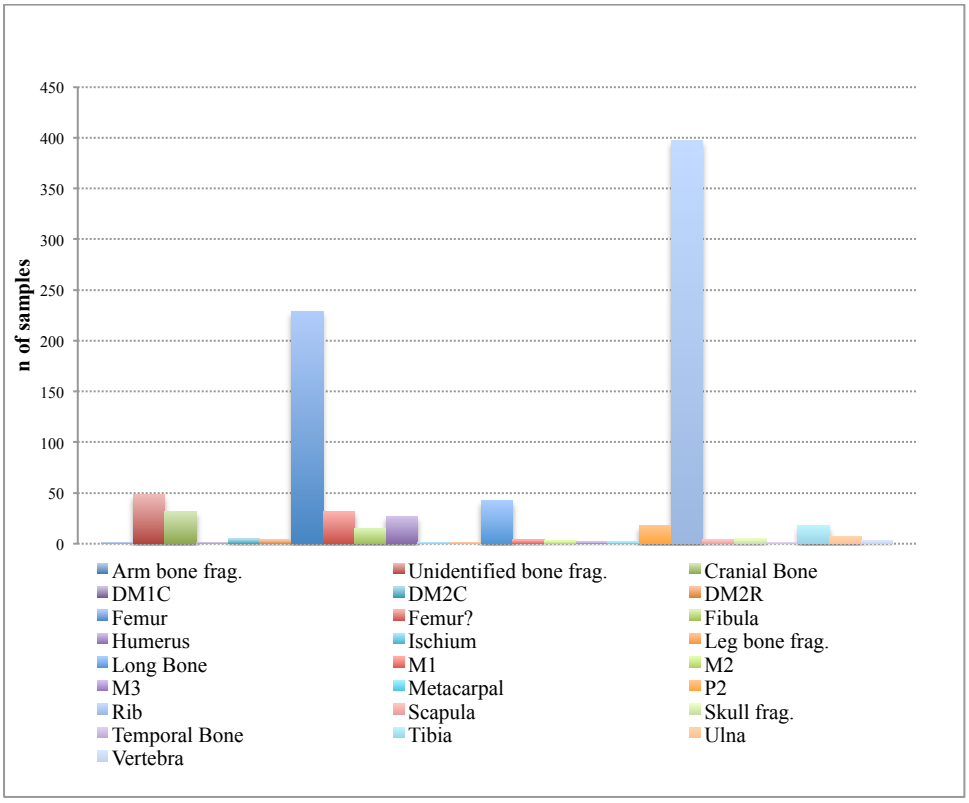


Figure 5.17. Distribution of the different bones that were sampled in the original analyses.

5.5.2 Loss of information and misidentification of samples

There is often a long time span between the moment of excavation and the sampling of the material for isotopic analyses. In this particular dataset, it ranges from two years (Winchester excavated in 2006 by Oxford Archaeology and analysed by Cummings (2008a, 46) to sixty-six years (Trevelgue Head in Cornwall excavated in 1939 and analysed by Jay, 2005; 50). This is even a conservative estimate, based on the assumption that the sampled remains were uncovered in the latest phase of excavation when more precise information was unavailable. This will not affect the final isotopic ratio as ^{13}C and ^{15}N remain inert in the bone (see Chapter 2) but it is nonetheless important to be aware of the complications that these delays can cause, most notably the loss of contextual information. The lack of

excavation reports can result, for example, in samples being imprecisely dated if there is no contextual information about the phase of the site to which the materials belong. However, because of the large spread of data, it has nonetheless been possible to establish a good relative chronology within the dataset.

Another aspect that must be commented upon is possibility of samples being misidentified (confusion between species) or younger animals recorded as adults, which can explain some of the variation in the fauna, in particular samples enriched compared the mean average.

5.5.3 Different techniques and aims

This thesis assesses information from ninety-five sites excavated between 1900 and 2006. The quality of excavation, recording and reporting are as various as the number of authors or sites. Some sites were excavated over decades of thorough excavation campaigns (such as Danebury, see Cunliffe 1995), while some were excavated in less than ideal rescue conditions (such as Yarnton, Hey and Bell 1997; Hey and Bell 1999; Hey 2004), Meanwhile, others were excavated by 'local enthusiasts' (Dent 1984; Darvill *et al*. 1986).

Furthermore, not all the materials have been published, or even reported in the grey literature. Some sites have been published partially with focus on one particular element of the site (like Wetwang-Garton Slack and its chariot burial, see Dent 1985), while others have not been published at all. Therefore, slightly different categories of archaeological information can be shown at one site but not others. This discrepancy is due to a lack of

available information; relevant pieces of archaeological data were simply not there in many cases.

5.5.4 Unusual populations

Whether the populations sampled here are representative of English diets between the Iron Age and the Early Medieval period is an important question of this thesis. The exclusion of certain populations – most notably individuals who were cremated – and the inclusion of populations deviating from the norm either from the way they were buried (Danebury, see Stevens *et al.* 2010) or the way they died (3DT/6DT in York, see Müldner *et al.* 2011), must be acknowledged. The cultural and environmental factors behind the isotopic ratios analysed are complex and the dietary behaviours of the many groups that inhabited England can only be fully understood if their own cultural peculiarities are recognised and established.

Although there are some issues in the way the data are distributed, whether to do with the under-representation of some regions or the over-representation of certain periods, there are sufficient data for an analysis of the broader trends and patterns to be sustainable. Differences between laboratories and skeletal elements have been shown to be insignificant enough in effect on the interpretation of the overall dietary isotopic signal. It is important to be aware that different analyses can cause a small variation in signal to avoid over-interpreting weak results, but there are enough strong patterns outside of the range of analytical variation that it is not necessary to develop a model taking into them into account. Although there are certainly challenges to analysing such a large dataset using solely legacy data, which have been produced in different conditions, these do not hinder the

achievement of a workable, solid comparison of diets across time and space. Obviously small variations of less than one per mil should not be over-interpreted, but even when solely looking at all the variations over that one per mil limit, there are numerous visible trends, both at the chronological level and the regional one, that have been identified and analysed in the following chapters.

5.6 Basic statistics

The data analysed here are pooled from different studies, across a variety of sites and regions. While the aim of this study is to analyse these data beyond their site characteristics, it cannot be ignored that 'site identities' are at the core of this dataset and this must be acknowledged and integrated to the analyses. Furthermore, some measures of tendency (such as mean averages and outliers) must be properly defined and identified in order to allow for workable comparisons between the different sub-groups investigated here. Finally, this section also applies the statistical method underlined in Chapter 4 to the data used here.

5.6.1 Median and mean averages

In all analyses and plots presented here, the mean is used as the measure of central tendency. The median might also be appropriate, since the median is less affected by outliers than the mean. In the data presented here, however, the difference between the mean and the median isotope value is very small, between 0 and 0.1‰ for the carbon isotopic data and between 0 and 0.3‰ for the nitrogen isotopic data for data from the main species groups in the broad period (Table 5.1).

Table 5.1. Comparison between the median and the mean average data for the four main species in the three broad archaeological periods.

Species	Median $\partial^{13}C$	Mean $\partial^{13}C$	Median $\partial^{15}N$	Mean $\partial^{15}N$	n
Cattle IA	-21.5	-21.6 ± 0.40	4.2	4.5 ± 1.48	206
Sheep IA	-21.3	-21.3 ± 0.45	4.5	4.8 ± 1.27	230
Pig IA	-21.4	-21.3 ± 0.48	6.7	6.8 ± 1.15	141
Human IA	-20.2	-20.2 ± 0.41	9.4	9.4 ± 1.15	298
Cattle R	-21.7	-21.7 ± 0.37	6	6.1 ± 1.45	99
Sheep R	-21.5	-21.5 ± 0.45	5.9	6.1 ± 1.62	96
Pig R	-21.5	-21.4 ± 0.64	7.1	7.1 ± 1.66	55
Human R	-19.7	-19.7 ± 0.68	10.2	10.1 ± 1.23	829
Cattle EM	-21.8	-21.8 ± 0.68	5.05	5.1 ± 1.19	138
Sheep EM	-21.5	-21.5 ± 0.65	5.4	5.4 ± 1.32	182
Pig EM	-21.5	-21.4 ± 0.53	6.9	7.0 ± 1.76	90
Human EM	-20.1	-20.1 ± 0.52	9.9	10.1 ± 1.37	1000

5.6.2. Outliers

As with most numerical data, it is common in isotopic studies to identify outliers in order to recognise which individuals might have a radically different diet than the rest of the groups. Outliers are defined here as samples either below or above 3 times the standard deviation compared the to mean (Leys *et al.* 2013). There is some debate whether this is the best way to assess outliers, as the mean and standard deviation are sensitive to outliers and using the absolute variation around the median has been suggested as a more robust method (Leys *et al.* 2013). However, considering how close the mean and median are in the data used here, it was decided that the 'traditional' method to detect outliers was satisfactory. Table 5.2 gives the limits outside of which a data point would be considered an outlier for each broad periods and each main species. For example, in the case of Early Medieval humans, a data point with a $\partial^{13}C$ value below -21.7‰ or above -18.5‰ will be considered an outlier.

Table 5.2. Lower and upper limits of the range within 3 standard deviations from the mean for the four main species in the three broad archaeological periods. Data point outside of these ranges will be considered outliers.

	$\partial^{13}C$ -3σ	Mean $\partial^{13}C$	$\partial^{13}C$ + 3σ	$\partial^{15}N$ - 3σ	Mean $\partial^{15}N$	$\partial^{15}N$ +3σ
Cattle IA	**-22.7**	-21.6 ± 0.40	**-20.3**	**0.0**	4.5 ± 1.48	**8.9**
Sheep IA	**-22.6**	-21.3 ± 0.45	**-19.9**	**0.9**	4.8 ± 1.27	**8.6**
Pig IA	**-19.8**	-21.3 ± 0.48	**-22.7**	**3.3**	6.8 ± 1.15	**10.2**
Human IA	**-21.5**	-20.2 ± 0.41	**-19.0**	**6.0**	9.4 ± 1.15	**12.9**
Cattle R	**-22.8**	-21.7 ± 0.37	**-20.5**	**1.7**	6.1 ± 1.45	**10.4**
Sheep R	**-22.9**	-21.5 ± 0.45	**-20.2**	**1.2**	6.1 ± 1.62	**10.9**
Pig R	**-23.3**	-21.4 ± 0.64	**-19.5**	**2.1**	7.1 ± 1.66	**12.1**
Human R	**-21.8**	-19.7 ± 0.68	**-17.6**	**6.5**	10.1 ± 1.23	**13.8**
Cattle EM	**-23.9**	-21.8 ± 0.68	**-19.8**	**1.6**	5.1 ± 1.19	**8.7**
Sheep EM	**-23.5**	-21.5 ± 0.65	**-19.6**	**1.4**	5.4 ± 1.32	**9.4**
Pig EM	**-23.0**	-21.4 ± 0.53	**-19.8**	**1.7**	7.0 ± 1.76	**12.3**
Human EM	**-21.7**	-20.1 ± 0.52	**-18.5**	**5.9**	10.1 ± 1.37	**14.2**

5.6.3 Differences at the site level

While repeating site analyses is not the aim of this thesis, it is necessary to address the site distribution of the data. As described above and in Chapter 4, the data are fairly unbalanced between regions and species and this must be rigorously addressed before pooling the data for the main analyses, which will be presented in Chapter 6 to 8.

In Appendix II, the results of the comparative ANOVAs for each site in each time period for each species are represented (Tables A2.1.1to A2.1.3.4 in Appendixes II).

One of the first difficulties is that not one site is consistently different from the others, i.e. not one site is different to all the other sites in either time period or species. Furthermore, statistical difference is not consistent between isotopes and not all sites differ from one another for both isotopes.

It was initially thought that should a site be consistently different from the others, i.e. if it was significantly different to more than three other sites, it would be removed from the data, as to avoid just 'lumping' everything together. However, this soon proved to be too complex as the sites used for ^{13}C and ^{15}N analyses would have been different from each other. More problematic here, it also meant that large subsets of the data would have been removed from the general analyses. Therefore, it was decided to use a statistical model that took into account the site structure of the data to analyse the larger population group by integrating the site as a 'random effect' in the statistical analyses (see Chapter 4, also Searle, Casella and McCulloch 1992), an example of which is given below.

5.6.4 Multi-levels modelling

To illustrate what multi-level modelling in R means, an example of both script and output is given below, in which the statistical differences in the horse data are calculated in different ways. Table 5.3 shows how the horse dataset is distributed between sites, sub-period and regions.

Table 5.3. Full horse dataset, as will be used as an example for multivariate analyses.

Site	Region	Sub_Period	n of samples
Bury Hill	Hampshire	Iron Age	16
Gloucester	Gloucestershire	Mid-Roman	2
Houghton Down	Hampshire	Early Iron Age	7
Nettlebank Copse	Hampshire	Early Iron Age, Late Iron Age	18
New Buildings	Hampshire	Early Iron Age	13
Suddern Farm	Hampshire	Iron Age, Early Iron Age, Late Iron Age, Latest Iron Age	26
Trevelgue Head	Cornwall	Middle Iron Age	2
Wetwang Garton-Slack	Yorkshire	Middle Iron Age	16
Yarnton	Oxfordshire	Middle Iron Age, Late Iron Age, Late Iron Age/Roman, Roman, Early Roman, Late Roman	18

```
Setwd("~/Desktop/R2D2")
Horse <- read.csv("H.csv", header = T)
###### SITE DIFFERENCE
### Levene Test
leveneTest(Horse$d13C, Horse$Site)
leveneTest(Horse$d15N, Horse$Site)
```

Figure 5.18. R script to load the data into the programme and test homogeneity of variance using the Levene Test.

The first two lines set up the working directory and load the data into the R programme, here a csv file called 'H.csv', which contains the horse dataset. The first test conducted is the Levene test to assess the homogeneity of variance in the data between sites (Figure 5.18). The output below (Figure 5.19) is what is generated for the Levene Test, showing that homogeneity of

variance is not respected for the carbon isotopic data (p = 0.02) but is for the nitrogen isotopic data (p=0.647).

```
> ### Levene Test
> leveneTest(Horse$d13C, Horse$Site) #### Homogoneity of variance is not respected
Levene's Test for Homogeneity of Variance (center = median)
       Df F value  Pr(>F)
group   8  2.4522 0.01762 *
      109
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
> leveneTest(Horse$d15N, Horse$Site)
Levene's Test for Homogeneity of Variance (center = median)
       Df F value Pr(>F)
group   8  0.7496 0.6476
      109
>
```

Figure 5.19. Output of the Levene Test in the R programme. Here it shows that homogeneity of variance is not respected for the carbon isotopic data (p = 0.01) but is for the nitrogen isotopic data (p=0.647).

Figure 5.20 shows the script for the ANOVA tests between the sites, with a WELCH correction applied for the carbon isotopic data. ‘Tukey HSD’ is the post-hoc tested used here, to assess which groups are different.

```
#### ANOVA with Welch Correction for ∂13C
oneway.test(Horse$d13C~Horse$Site)
###### ANOVA for ∂15N
HorseN <-aov(Horse$d15N~Horse$Site)
summary(HorseN)
TukeyHSD(HorseN)
```

Figure 5.20. Script for the ANOVA test in the R programme. The ‘oneway.test’ automatically applies a Welch correction when homogeneity of variance is not respected.

The ANOVA generate the output below (Figure 5.21, which shows only a suggestive difference between sites in for the horse carbon isotopic data but a significant difference in the nitrogen isotopic data. The output of the Tukey HSD is not shown here for reason of space and reveals that there are significant differences between Trevelgue Head and Bury Hill, and Yarnton and all the other sites. For reasons of space, only the differences in the nitrogen isotopic data will be discussed in this section.

```
> oneway.test(Horse$d13C~Horse$Site)  ### no significant difference

        One-way analysis of means (not assuming equal variances)

data:  Horse$d13C and Horse$Site
F = 2.6946, num df = 8.000, denom df = 11.278, p-value = 0.06341

> HorseN <-aov(Horse$d15N~Horse$Site)
> summary(HorseN) #### significant difference (p=0.00)
             Df Sum Sq Mean Sq F value   Pr(>F)
Horse$Site    8  92.47  11.558   7.847 2.77e-08 ***
Residuals   109 160.55   1.473
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure 5.21. Output of the ANOVA tests, showing significant difference between sites in the nitrogen isotopic data and only moderately significant in the carbon isotopic data.

The statistical differences between sub-periods were tested in the same manner, first with the Levene test and ANOVAs, which showed no significance difference in the carbon isotopic data and statistical differences between the following groups in the nitrogen isotopic data: Early Roman and Early Iron Age (p= 0.000), Late Roman-Early Iron Age (p=0.000), Iron Age-Early Roman (p=0.000), Late Iron Age-Early Roman (p= 0.000), Latest Iron Age-Early Roman (p=0.002), Middle Iron Age-Early Roman (p=0.000), Late Roman-Iron Age (p=0.001), Middle Iron Age-Late Iron Age (p=0.021), Roman-Late Iron Age (p=0.013), Latest Iron Age-Late Roman (p=0.009), Middle Iron Age-Late Roman (p=0.000). However,

these results do not take into account the site structure of the data and it is possible that they are biased by site-level factors. Therefore, another model was tested, the script for which is shown below.

```
####### Linear Regression Model integrating 'Site' as
a random effect and Sub_Period as a fixed variable
####∂13c
multihorse1    <-    lmer(d13C    ~    Sub_Period    +
(1|Horse$Site), Horse)
summary(multihorse1)
### posthoc test
lsmeans(multihorse1,pairwise~Sub_Period, data= Horse)
summary(glht(multihorse1,linfct   =   mcp(Sub_Period   =
"Tukey")), test = adjusted("bonferroni"))
####d15N
multihorse2    <-    lmer(d15N    ~    Sub_Period    +
(1|Horse$Site), Horse)
summary(multihorse2)
###posthoc test
lsmeans(multihorse2,pairwise~Sub_Period, data= Horse)
summary(glht(multihorse2,linfct   =   mcp(Sub_Period   =
"Tukey")), test = adjusted("bonferroni"))
```

Figure 5.22. R script for the restricted linear regression model used for the horse dataset.

Figure 5.22 shows the script for the restricted linear regression model ('lmer'), and the model formula is $\partial^{13}C$ (##∂13C) and $\partial^{15}N$ (##∂15N) values compared by sub-periods, with the site as grouping factor ('random effect'). Then, both 'lsmeans' and the 'glht' command transform the *t-values* output from the 'lmer4' models in *p-values* and allows for pairwise comparisons (with a Bonferroni correction), showing which sub-period groups differ from another significantly. This script results in the outputs below (Figure 5.23, 5.24).

```
> ####∂13c
> multihorse1 <- lmer(d13C ~ Sub_Period + (1|Horse$Site), Horse)
> summary(multihorse1)
Linear mixed model fit by REML ['lmerMod']
Formula: d13C ~ Sub_Period + (1 | Horse$Site)
   Data: Horse

REML criterion at convergence: 140.9

Scaled residuals:
    Min      1Q  Median      3Q     Max
-3.7972 -0.4648 -0.0286  0.5965  3.1027

Random effects:
 Groups     Name        Variance Std.Dev.
 Horse$Site (Intercept) 0.02505  0.1583
 Residual               0.17665  0.4203
Number of obs: 118, groups:  Horse$Site, 9

Fixed effects:
                           Estimate Std. Error t value
(Intercept)              -22.26967    0.09830 -226.55
Sub_PeriodEarly Roman      0.03034    0.32701    0.09
Sub_PeriodIron Age         0.03429    0.14193    0.24
Sub_PeriodLate Iron Age    0.17954    0.13878    1.29
Sub_PeriodLate Roman      -0.09466    0.25054   -0.38
Sub_PeriodLatest Iron Age  0.24006    0.26764    0.90
Sub_PeriodLIA/Roman       -0.06966    0.44188   -0.16
Sub_PeriodMid-Roman        0.26967    0.35077    0.77
Sub_PeriodMiddle Iron Age  0.09590    0.19246    0.50
Sub_PeriodMiddle-Iron Age -0.08966    0.23225   -0.39
Sub_PeriodRoman            0.53034    0.44188    1.20
```

Figure 5.23 Output summary of the restricted linear mixed model for the horse carbon isotopic data.

```
> ####d15N
> multihorse2 <- lmer(d15N ~ Sub_Period + (1|Horse$Site), Horse)
> summary(multihorse2)
Linear mixed model fit by REML ['lmerMod']
Formula: d15N ~ Sub_Period + (1 | Horse$Site)
   Data: Horse

REML criterion at convergence: 354.9

Scaled residuals:
    Min      1Q  Median      3Q     Max
-1.7519 -0.7242 -0.1569  0.6407  2.8230

Random effects:
 Groups     Name        Variance Std.Dev.
 Horse$Site (Intercept) 0.2098   0.458
 Residual               1.3005   1.140
Number of obs: 118, groups:  Horse$Site, 9

Fixed effects:
                           Estimate Std. Error t value
(Intercept)                 4.22917    0.27530  15.362
Sub_PeriodEarly Roman       3.61475    0.89141   4.055
Sub_PeriodIron Age          0.35618    0.39211   0.908
Sub_PeriodLate Iron Age    -0.51372    0.37846  -1.357
Sub_PeriodLate Roman        2.48975    0.68519   3.634
Sub_PeriodLatest Iron Age -0.11399    0.72846  -0.156
Sub_PeriodLIA/Roman         0.06475    1.20204   0.054
Sub_PeriodMid-Roman         1.72083    0.96739   1.779
Sub_PeriodMiddle Iron Age   0.02801    0.54154   0.052
Sub_PeriodMiddle-Iron Age   1.00475    0.63597   1.580
Sub_PeriodRoman             3.36475    1.20204   2.799
```

Figure 5.24 Output summary of the restricted linear mixed model for the horse nitrogen isotopic data.

The first three lines describes how the model was fitted (REML), repeat the model formula: carbon/nitrogen by sub-period, i.e. fixed effect, with site as grouping factor, i.e. 'random effect" and the name of the file. The value of the REML criterion at convergence, when it is minimum was 140.9 for carbon and 354.9 for nitrogen. This is the deviance, or -2xlog-likelihood (Hamilton 2016, 96). The scaled-residuals data give an idea of the distribution of the residuals, which are examined in more detail when checking the model. Here the median is close to 0 and the values for first and third quartiles are similar, albeit not identical, so the distribution is somewhat symmetrical around 0 as would be expected for normally distributed data, which means the model is appropriate (Hamilton, 2016, 96)

The intercept is the mean average of the reference group, which is the group that is first alphabetically, so here it is the 'Early Iron Age'. While, when reading the output, it might have felt more 'instinctive' to have the periods organised chronologically, it would have required changing the names of the periods, needlessly complicating the dataset. The 'estimate Std' column indicates how much the other groups vary from the intercept: here, the Early Roman horse data have $\partial^{13}C$ values on average 0.03‰ more elevated than the Early Iron Age data, and this difference is not significant ($t < 2$, Figure 5.23), while the Early Roman horse data have $\partial^{15}N$ values on average 3.6‰ more elevated than the Early Iron Age horse data, and this difference is significant ($t > 2$, Figure 5.24). The 'lsmeans' test confirms that there is no significant difference in the $\partial^{13}C$ values of the horses when analysed by sub-period, but significant difference in the $\partial^{15}N$ data between the Early Iron Age and Early Roman period independent from site level differences, but for reasons of space the full output cannot be shown here. When compared to the ANOVA results (see Table 5.4), it is immediately obvious that not taking the site variable into account resulted in many more Type I error (false positive) between sub-periods

Table 5.4. Comparison of the p-values generated by the ANOVA and REML test for the horse data by sub-period. The Bonferroni method was used for post-hoc corrections.

Sub_Period	ANOVA	REML
Early Roman-Early Iron Age	**0.000**	**0.012**
Late Roman-Early Iron Age	0.000	0.063
Iron Age-Early Roman	0.000	0.095
Late Iron Age-Early Roman	**0.000**	**0.004**
Latest Iron Age-Early Roman	0.002	0.103
Middle-Iron Age-Early Roman	**0.001**	**0.047**
Late Roman- Iron Age	0.001	0.424
Middle Iron Age-Late Iron Age	0.021	0.847
Roman-Late Iron Age	0.015	0.122
Latest Iron Age-Late Roman	0.009	0.415
Middle Iron Age -Late Roman	0.003	0.283
Late Roman-Late Iron Age	**0.000**	**0.020**

However, since the data are distributed over different regions, the variable 'region' also needs to be tested. Therefore, two other models were tested. First, one that included 'Region' as a random effect, i.e. to check whether the regional distribution of the data affected the 'sub-period' results, and one that included 'Region' as a fixed effect (Figure 5.25).

```
####### Linear Regression Model integrating 'Site'
and 'Region' as random effects and Sub_Period a
fixed variable
####∂13c
multihorse3 <- lmer(d13C ~ Sub_Period + (1|Region)
+ (1|Site), Horse)
summary(multihorse3)
### posthoc test
lsmeans(multihorse3,pairwise~Sub_Period, data=
Horse)
####d15N
multihorse4 <- lmer(d15N ~ Sub_Period + (1|Region)
+ (1|Site), Horse)
summary(multihorse4)
###posthoc test
lsmeans(multihorse4,pairwise~Sub_Period, data=
Horse)
```

Figure 5.25. Linear Model integrating both 'site' and 'region as random effects, and sub-period as a fixed variable.

Table 5.5 shows the results of the model with 'Region' as random affect, and when compared to the results with only 'Site' as a random effect, it is clear that only the difference between the Early Roman and the Early Iron Age, and the Early Roman and Late Iron horses remain significant. The other two sub-periods for which there was a difference in the simpler model, the Early Iron age and the Middle Iron Age and the Late Roman and the Late Iron Age, are now only moderately significant ($0.05 < p < 0.10$), suggesting that factors at the regional level are important.

Table 5.5. Comparisons of the *p-value* between the two different models for the $\partial^{15}N$ values of the horses data.

Sub_Period	REML with Site as 'Random Effect'	REML with Site and Region as 'Random Effect'
Early Roman-Early Iron Age	**0.012**	**0.049**
Late Roman-Early Iron Age	0.063	0.978
Iron Age-Early Roman	0.095	0.237
Late Iron Age-Early Roman	**0.004**	**0.018**
Latest Iron Age-Early Roman	0.103	0.205
Middle-Iron Age-Early Roman	**0.047**	0.090
Late Roman- Iron Age	0.424	0.724
Middle Iron Age-Late Iron Age	0.847	0.984
Roman-Late Iron Age	0.122	0.215
Latest Iron Age-Late Roman	0.415	0.415
Middle Iron Age -Late Roman	0.283	0.626
Late Roman-Late Iron Age	**0.020**	0.100

Then, of course, it is necessary to wonder whether 'Region' might be a more important variable than 'Sub-Period', for which one can reverse the model by integrating 'Region' as the fixed variable, the script for which is below (Figure 5.26).

```
####### Linear Regression Model integrating 'Site'
as a random effect and Region as a fixed variable
####∂13c
multihorse7 <- lmer(d13C ~ Region + (1|Site), Horse)
summary(multihorse7)
### posthoc test
lsmeans(multihorse7,pairwise~Region, data= Horse)
####d15N
multihorse8 <- lmer(d15N ~ Region + (1|Site), Horse)
summary(multihorse8)
###posthoc test
lsmeans(multihorse8,pairwise~Region , data= Horse)
```

Figure 5.26. Linear Model integrating 'site' as a random effect and 'region' as a fixed variable.

Once again, the model was also tested through a simple ANOVA, against which the linear regression model is compared (Table 5.6). As was the case when assessing the 'Sub-Period' variation, no significant difference was apparent in the $\partial^{13}C$ data so only the $\partial^{15}N$ results are discussed below.

Table 5.6. Comparisons of the p-values generated by the ANOVA and REML test between regions for the $\partial^{15}N$ values of the horse data. The Bonferroni method was used for post-hoc corrections.

Region	ANOVA	REML
Gloucestershire -Cornwall	0.771	0.812
Hampshire - Cornwall	0.991	0.994
Oxfordshire - Cornwall	0.300	0.455
Yorkshire -Cornwall	0.996	0.997
Hampshire-Gloucestershire	0.236	0.339
Oxfordshire-Gloucestershire	0.995	0.997
Yorkshire -Gloucestershire	0.323	0.475
Oxfordshire -Hampshire	**0.000**	**0.078**
Yorkshire - Hampshire	0.999	0.999
Yorkshire Oxfordshire	**0.000**	0.165

As was the case with the 'sub-period' variable, there is less variation in the data if the site distribution is taken into account (Table 5.6). Now, it is also worth considering if the 'sub-period' distribution of the data affects the regional results. Thus, 'sub-period' was integrated as a random effect (Figure 5.27).

```
####### Linear Regression Model integrating 'Site'
and 'Sub_Period' as a random effects and Region as a
fixed variable
####∂13c
multihorse9 <- lmer(d13C ~ Region + (1|Sub_Period)+
(1|Site), Horse)
summary(multihorse9)
### posthoc test
lsmeans(multihorse9,pairwise~Region, data= Horse)
####d15N
multihorse9 <- lmer(d15N ~ Region + (1|Sub_Period)
+(1|Site), Horse)
summary(multihorse9)
###posthoc test
lsmeans(multihorse9,pairwise~Region , data= Horse)
```

Figure 5.27. Linear Model integrating 'site' and 'sub-period' as random effect and 'region' as a fixed variable.

As seen in Table 5.7, the results are not significant between the regional groups if the 'Sub-period' variable is integrated to the model, suggesting that the moderate significant difference between Oxfordshire and Gloucestershire was likely the result of chronological factors.

Table 5.7. Comparison of the p-values of the different models for the $\partial^{15}N$ values of the horse data, with either 'site' or 'site' and 'Sub-period' as random effect.

Region	REML with only site as 'Random Effect'	REML with site and sub-period as 'Random Effect'
Gloucestershire -Cornwall	0.812	0.960
Hampshire - Cornwall	0.994	0.992
Oxfordshire - Cornwall	0.455	0.698
Yorkshire -Cornwall	0.997	0.997
Hampshire-Gloucestershire	0.339	0.735
Oxfordshire-Gloucestershire	0.997	0.998
Yorkshire -Gloucestershire	0.475	0.852
Oxfordshire -Hampshire	**0.078**	0.135
Yorkshire - Hampshire	0.999	0.999
Yorkshire Oxfordshire	0.165	0.314

The last model to test is one that takes both Region and Sub-Period into account to assess the variation within both of these combined variables, i.e. whether horses in Late Iron Cornwall are different from horses in Roman Gloucestershire. The script is shown below (Figure 5.28).

```
####### Linear Regression Model integrating 'Site'
as a random effect and Sub_Period and Region as a
fixed variables
####∂13c
multihorse5 <- lmer(d13C ~ Sub_Period + Region +
(1|Site), Horse)
summary(multihorse5)
### posthoc test
lsmeans(multihorse5,pairwise~Sub_Period + Region,
data= Horse)
####d15N
multihorse6 <- lmer(d15N ~ Sub_Period + Region +
(1|Site), Horse)
summary(multihorse6)
###posthoc test
lsmeans(multihorse6,pairwise~Sub_Period + Region ,
data= Horse)
```

Figure 5.28. Linear Model integrating 'site' as a random effect and 'region' and 'sub-period' as a fixed variable.

This reveals no significant difference in either isotope at both the Regional and Sub-period levels. Now, five different models for the $\partial^{15}N$ results have been tested, all with slightly different results indicating a complex interplay between different variables. To test which one is the best model can done using the 'anova' function in 'lme4'. The models can only be compared two by two (Bates *et al.* 2017). The table below summarise the models tested (Table 5.8)

Table 5.8. Summary of the different models tested for the horse dataset.

Model Name	Random Effect	Fixed Effects
Multihorse2	Site	Sub_Period
Multihorse4	Site, Region	Sub_Period
Multihorse6	Site	Sub_Period, Region
Multihorse8	Site	Region
Multihorse10	Site, Sub-Period	Region

All models are then tested two by two, using the 'anova' function, the script for which and output are shown below (Figure 5.29).

```
> anova(multihorse2, multihorse4)
refitting model(s) with ML (instead of REML)
Data: Horse
Models:
multihorse2: d15N ~ Sub_Period + (1 | Site)
multihorse4: d15N ~ Sub_Period + (1 | Region) + (1 | Site)
            Df    AIC    BIC  logLik deviance Chisq Chi Df Pr(>Chisq)
multihorse2 12 389.41 422.66 -182.71   365.41
multihorse4 13 391.41 427.43 -182.71   365.41     0      1          1
```

Figure 5.29. Output of the 'anova' test, allowing to assess which is the best model. Here, multihorse2 has a lower AIC but it is not a significantly better model (p=1)

The first line, in blue, is the command for the test. Since it is preferable (and more conservative) to compare model fits obtained using a maximum likelihood rather than a restricted maximum likelihood, the models are refitted accordingly, which is the second line of the shown above, in red (Hamilton 2016, 96). The name of the data file and the formulas for the fitted models are then listed. The table give the degrees of freedom (Df) for each model and various indicators of model fit AIC (Akaike Information Criterion), BIC (Schwarz Bayesian Information Criterion), log-likelihood, and deviance calculated as 2xlog-likelihood. AIC is used as an indicator of best model, by choosing those with the AIC number closer to zero (Akaike 1973; Snipes and Taylor 2014). Here, it is model 'Multihorse2' which is better, although not significantly so ($p = 1$). The different models are then tested against one another, two by two and the results are shown in Table 5.9. There is no significant difference when region is added as a random effect when measuring sub-period (Multihorse2 and Multihorse4), or when sub-period is added as a random effect when measuring region (Multihorse8 and Multihorse10). However, the best-fit model is Multihorse6, which uses both region and sub-periods as fixed variables and sites as random effects. Overall, the models with 'sub-period' as a fixed effect (Mutlihorse2, Multihorse4 and Multihorse6) are a better fit than the models with region as a fixed effect (Multhorse8 and Multihorse10). To summarise, using ANOVAs to compare the horse data between either sub-period or region, and not taking the site structure of the data into consideration resulted in Type I error (see Table 5.4). The more restrictive model is not always the best fit, as was shown in the case of Multihorse2 and Multihorse4, due to

risk of 'over fit'. These statistical tests have shown that sub-period was a somewhat significant factor in the isotopic variation of the horse data in either the Iron Age or the Roman period, but region was maybe less so.

Table 5.9. Comparison between the different models. The best model is Multihorse6, integrating both sub-period and region as fixed variables and site as a random variable.

Model	**AIC**		***P-value***
Multihorse2 vs. Multihorse4	Multihorse2: **389.41**	Multihorse4: 391.41	1
Multihorse2 vs. Multihorse6	Multihorse2: 389.41	Multihorse6: **386.71**	**0.033**
Multihorse2 vs. Multihorse8	Multihorse2: **389.41**	Multihorse8: 395.45	**0.006**
Multihorse2 vs. Multihorse10	Multihorse2: **389.41**	Multihorse10: 396.41	**0.004**
Multihorse4 vs. Multihorse6	Multihorse4: 391.41	Multihorse6: **386.71**	**0.012**
Multihorse4 vs. Multihorse8	Multihorse4: **391.41**	Multihorse8: 395.45	**0.013**
Multihorse4 vs. Multihorse10	Multihorse4: **391.41**	Multihorse10: 396.41	**0.010**
Multihorse6 vs. Multihorse8	Multihorse6: **386.71**	Multihorse8: 395.45	**0.001**
Multihorse6 vs. Multihorse10	Multihorse6: **386.71**	Multihorse10: 396.41	**0.001**
Multihorse8 vs. Multihorse10	Multihorse8: **395.45**	Multihorse10: 396.41	0.307

Due to reasons of space, it is not possible to show the results from all the models tested in Chapter 6 and 7, but all factors have been systematically tested both as fixed and random effects and all the results presented in this thesis are the results from the best-fit model, unless otherwise stated. If different parameters resulted in a change in significance between different groups, this will be noted and discussed.

Results are reported as significant where $p < 0.05$ but some suggestive results ($0.1 > p > 0.05$) are also discussed. In case of significant difference, the effect size is also measured with the 'cohen.d' test, as discussed in section 4.2.6.1.

5.7 Summary

This chapter has shown the distribution of the data, and highlighted how it is unbalanced between broad archaeological period and/or region, as well as between units of analysis beyond chronology or regionality. However, multivariate modelling with both fixed and random effects is robust in the case of unbalanced, hierarchic data and can be applied here to support the observations, which will be made in the next three chapters.

CHAPTER 6. RESULTS OF THE FAUNAL ANALYSES

This chapter will examine the faunal data in depth to identify what isotopic patterns can shed light on the question of subsistence. The faunal data are investigated before the human data because they will be used as a control group against which to compare the human groups and therefore variation within the faunal data must be thoroughly understood first. There are three strands of analyses presented here (1) the data will be analysed both in its wider chronological context, that is within its archaeological period, and between sub-periods to investigate diachronic trends in the *longue durée;* (2) the data will then be examined regionally within periods and across periods to assess how much change and continuity there is between regions; and (3) patterns across both time and space will be addressed: climate, physical geography and social geography will be examined as variation factors. These in-depth analyses of the faunal data will allow for a thorough understanding of both the environmental background and animal management practices, and will allow for the construction of a solid baseline against which to compare the human data in the following chapter.

6.1. Iron Age

Table 6.1 shows a summary of the Iron Age data that will be discussed below. It contains 705 values (cattle n= 206, sheep n= 230, pig n= 141 horse n= 109, dog n= 12 deer n= 7, fox n= 1). The human values (n =298) will be discussed in the next chapter.

Table 6.1. Summary of the faunal data in the Iron Age.

	Average $\partial^{13}C$ ‰	Average $\partial^{15}N$ ‰	min $\partial^{13}C$ ‰	max $\partial^{13}C$ ‰	range $\partial^{13}C$ ‰	min $\partial^{15}N$ ‰	max $\partial^{15}N$ ‰	range $\partial^{15}N$ ‰	n=
Cattle	-21.6 ± 0.40	4.5 ± 1.49	-22.8	-20.6	2.2	1.5	9.6	8.1	206
Sheep	-21.3 ± 0.45	4.8 ± 1.24	-22.8	-20.0	2.8	2.6	10.3	7.7	230
Pig	-21.3 ± 0.48	6.8 ± 1.15	-22.4	-19.9	2.5	3.9	9.9	6.0	141
Horse	-22.2 ± 0.45	4.2 ± 1.20	-24.0	-20.8	3.2	1.7	7.2	5.5	109
Dog	-20.4 ± 0.63	7.9 ± 1.17	-21.8	-19.4	2.4	5.3	9.3	4.0	12
Deer	-21.6 ± 0.55	5.5 ± 0.70	-22.2	-20.9	1.3	4.7	6.4	1.7	7

6.1.1 Faunal isotopic results

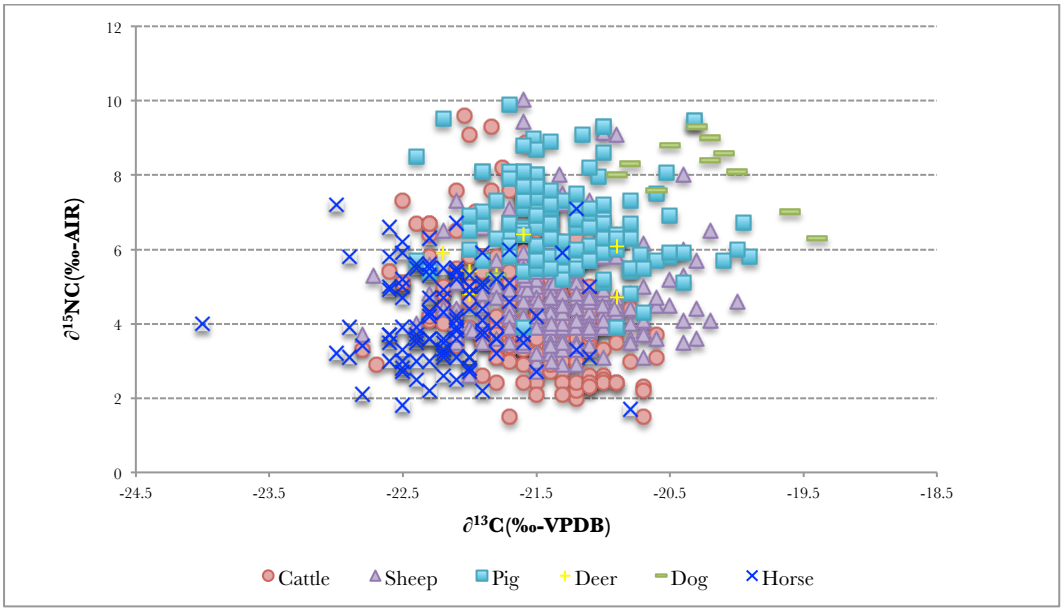


Figure 6.1. Isotopic results of the faunal data in the Iron Age Cattle n=206, Deer n=7, Dog n=12 , Horse n=108, Pig n=141, Sheep n=230).

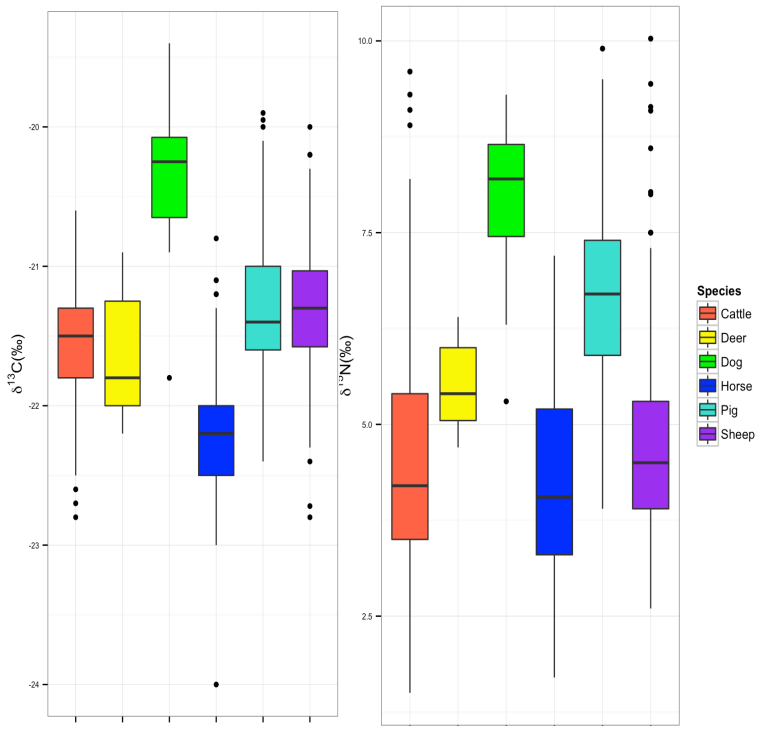


Figure 6.2 Boxplot comparison of isotopic results of the faunal data in the Iron Age (Cattle n=206, Deer n=7, Dog =n12, Horse n=108, Pig n=141, Sheep n=230).

As seen in Figures 6.1 and 6.2, the mean average $\partial^{13}C$ and $\partial^{15}N$ values for cattle in the Iron Age are -21.6 ± 0.40‰ and 4.45 ± 1.49‰. Both $\partial^{13}C$ and $\partial^{15}N$ mean averages are similar for sheep: -21.3 ± 0.45‰ and 4.8 ± 1.24‰. Although the $\partial^{13}C$ mean average for pig is similar to that of cattle and sheep with -21.3 ± 0.48‰, the $\partial^{15}N$ mean average is noticeably higher: 6.8 ± 1.15‰. Horses display depleted $\partial^{13}C$ and $\partial^{15}N$ mean average values compared to the rest of the fauna ($\partial^{13}C$ = -22.2 ± 0.45‰; $\partial^{15}N$ = 4.2 ±1.20‰), while the dogs are on average ^{13}C and ^{15}N-enriched ($\partial^{13}C$ = -20.4 ± 0.63‰; $\partial^{15}N$= 7.9 ± 1.17‰). The dogs are relatively ^{15}N-depleted overall for omnivorous animals (see Chapter 2 for average isotopic values on the food chain) but it is because this average has been lowered down by the ^{15}N-depleted value (5.3‰) of a single sample. When this value is removed, the

dogs' ∂^{15}N average raises to 8.1 ± 0.88‰. All of the domestic data displays a negative correlation between ∂^{13}C and ∂^{15}N (see Table 6.2). This is unusual and will be addressed in section 8.2.4.1 of Chapters 8.

Table 6.2. Results of Pearson's correlation (r) between ∂^{13}C and ∂^{15}N for the faunal data in the Iron Age.

Species	Pearson's *r*	*p-value*	*n*
Cattle	**-0.41**	**0.00**	206
Sheep	**-0.40**	**0.00**	230
Pig	**-0.20**	**0.02**	141
Horse	-0.10	0.29	108
Deer	0.00	0.98	7

Before the ANOVA test was performed, homogeneity of variance was tested using a Levene Test, which showed that the assumption of homogeneity of variance was respected between the herbivores (the dogs were excluded from analyses) for the carbon but not for the nitrogen isotopic data. Therefore, a Welch correction was applied to analyse the ∂^{15}N values of the Iron Age fauna. ANOVA testing showed significant difference in the data in both isotopes (see Table 6.3). However, the ANOVA test does not take into account the hierarchical structure of the data, which means the results could be dependent on site level effects. Therefore, a multi-level model, as described in Chapters 4 and 5, was also applied, especially since differences between sites have been shown to be significant in some cases (see Appendixes II for sites differences). The comparison between the

ANOVA and the restricted linear mixed modelling (REML) are shown in Table 6.3

Interestingly, while the absolute value of *p* might differ between the different tests, statistical differences are confirmed suggesting that the differences between species are significant independently of site-level, regional or chronological factors. However, the multi-level model picked up a significant difference between the pig and deer's nitrogen isotopic values, which was not visible in the ANOVA, indicating that the site structure of the data may have hidden significant differences between the groups. Overall, the pigs appear to have the most significantly different ∂^{15}N values to the rest of the other species. This difference between the species is likely to be the result of the pigs' reliance on more omnivorous diets compared to. the strictly herbivore diet of the other animals. Cattle appear to have the most different ∂^{13}C values. This does not seem to be because of a ruminant/non-ruminant difference since there are no systematic patterns between these groups, so this is more likely to be the result of the environmental niches in which these animals fed.

Table 6.3. Results of the statistical comparisons for the herbivores data in the Iron Age. Values in bold indicate statistical significance. While p-values might differ between both models, the significant differences do not change between the same faunal groups, suggesting that the site variations did not cause a Type I error in the ANOVA. It is worth noting, however, that the multivariate model picked up a significant difference between the pigs and deer's ∂^{15}N values, suggesting that site-level variation hid a significant difference between both these faunal groups. The results remained significant between the same groups regardless of whether 'Region' and 'Sub-Period' were integrated as fixed or random effects.

SPECIES	*Anova + Tukey Hsd*	*Anova (with applied Welch correction) + pairwise t-test (p adjusted with the Bonferroni method)*	*Multi-Level Model With Sites As Random Effect And 'Species' And 'Region' As Fixed Effects.*	
	p-value (∂^{13}C)	*p-value* (∂^{15}N)	*p-value* (∂^{13}C)	*p-value* (∂^{15}N)
Deer-Cattle	0.994	0.365	0.772	0.683
Horse-Cattle	**<0.000**	1	**<0.001**	0.336
Pig-Cattle	**<0.000**	**<0.000**	**<0.001**	**<0.000**
Sheep-Cattle	**<0.000**	0.194	**<0.001**	0.238
Horse-Deer	**0.011**	0.133	**<0.001**	0.329
Pig-Deer	0.305	0.142	0.982	**0.003**
Sheep-Deer	0.317	1	0.993	0.924
Pig-Horse	**<0.000**	**<0.000**	**<0.001**	**<0.000**
Sheep-Horse	**<0.000**	**0.009**	**<0.001**	**0.005**
Sheep-Pig	0.999	**<0.000**	0.992	**<0.000**

6.1.2 Diachronic trends within the Iron Age

To look at variation within the Iron Age, the cattle and sheep data were chosen as they were well represented in all the sub-periods investigated (see section 4.2.3). Some samples are problematic in that they are only dated to the 'Iron Age', without further dating precision but they have nonetheless been integrated here. The distribution of the data is addressed in Tables 6.4 and 6.7.

6.1.2.1. Cattle

Table 6.4. Distribution of the Iron Age cattle data in different sub-periods, according to number of sites, number of samples and regions.

Sub-Period	n of sites	n of samples	Region	Sites
Iron Age	3	14	Gloucestershire, Hampshire	Danebury, Lechlade, Suddern Farm
Early Iron Age	6	69	Hampshire	Danebury, Houghton Down, Nettlebank Copse, New Buildings, Suddern Farm, Yarnton
Middle Iron Age	6	53	Cornwall, Hampshire, Yorkshire	Harlyn Bay, Suddern Farm, Trethellan Farm, Trevelgue Head, Wetwang Garton-Slack, Winnal Down
Late Iron Age	5	49	Dorset, Hampshire, Oxfordshire	Danebury, Fordington Bottom, Nettlebank Copse, Suddern Farm, Yarnton
Latest Iron Age	2	16	Hampshire	Danebury, Suddern Farm.

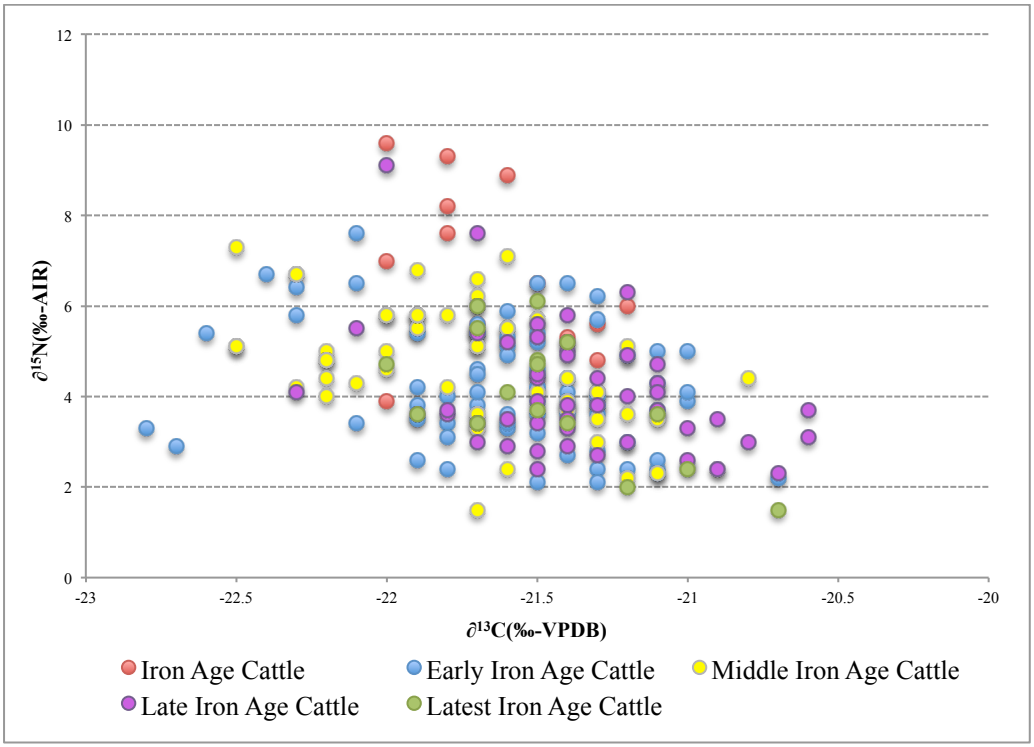


Figure 6.3. Chronological evolution of the Iron Age cattle data (Iron Age n= 14, Early Iron Age n = 69, Middle Iron Age n= 53, Late Iron Age = 49, Latest Iron Age = 16).

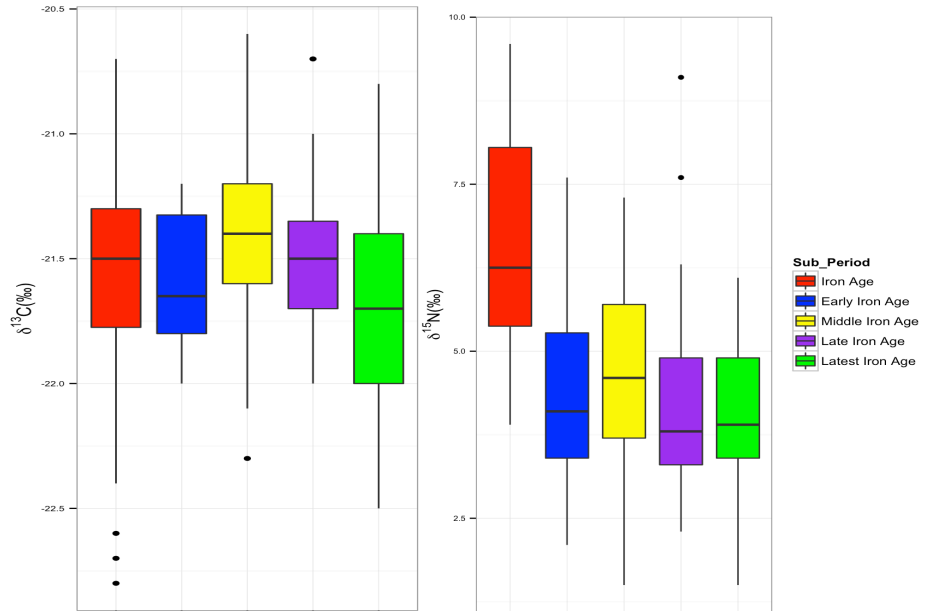


Figure 6.4 Boxplot comparisons of the chronological evolution of the Iron Age cattle data (Iron Age n= 14, Early Iron Age n = 69, Middle Iron Age n= 53, Late Iron Age = 49, Latest Iron Age = 16).

Figures 6.3 and 6.4 show that the less well-dated samples appear more different than the better dated samples. The high ∂^{15}N values of the 'Iron Age' all come from the site of Lechlade and are possibly due to the presence of juvenile animals in the data. While there are some enriched ^{15}N samples in the sheep data of the same sub-period (see section 6.1.2.2), it is nowhere near as high as it is in the cattle data, suggesting that this is not an environmental effect but something from the animal themselves, and the most likely explanation is the presence of young animals in the data.

It was shown in section 6.1.1 that there was an overall moderate correlation between high ∂^{15}N and low ∂^{13}C in the Iron Age cattle data. Looking at the sub-period shows that it fluctuates over time, but remains significantly

negative in all four sub-periods, except for the Latest Iron Age, for which the correlation is only moderately significant. (Table 6.5).

Table 6.5. Results of Pearson's correlation (r) between $\partial^{13}C$ and $\partial^{15}N$ for the cattle data in the Iron Age sub-periods.

Sub_Period	Pearson's *r*	*p values*	*n*
Early Iron Age	**-0.29**	**0.009**	69
Middle Iron Age	**-0.53**	**0.000**	53
Late Iron Age	**-0.39**	**0.004**	49
Latest Iron Age	-0.63	0.080	16

This is a very unusual profile for fauna. This may be due to the water regime under which the plants the animals grazed on, grew. Depleted $\partial^{13}C$ values are indeed predicted in wetter environments. This might also possibly be due to the changing landscapes of the Iron Age in which they fed, with more reliance in open pasture in the later periods (see section 2.2.1.3; this will be discussed further in section 8.2.4.1). Another explanation for the negative correlations observed for the cattle and sheep may be due to the influence in the dataset of animals grazing on the Chalk, since this would be more open, and hence grass would be expected to be slightly enriched in ^{13}C; and there is a well-attested ^{15}N depletion in plants on the Chalk (see Hamilton 2016; Schulting *et al*. 2019).

The $\partial^{15}N$ values are widely spread, maybe due to the presence of young animals, or the different feeding environment for these animals. However, none of the sub-period investigated significantly differ from one another (Table 6.6).

Table 6.6. Results of the statistical comparisons for the cattle data when comparing sub-periods in the Iron Age. Values in bold indicate statistical significance. The results remained significant between the same groups regardless of whether 'Region' and 'Sub-Period' were integrated as fixed or random effects

	Multi-Level Model With 'Sites' As Random Effect And 'Sub-Period' And 'Region' As Fixed Effects	
	p-value ($\partial^{13}C$)	*p-value* ($\partial^{15}N$)
Iron Age-Early Iron Age	0.999	0.096
Iron Age-Middle Iron Age	0.997	0.224
Iron Age-Late Iron Age	0.943	0.182
Iron Age-Latest Iron Age	0.985	0.278
Early Iron Age-Middle Iron Age	0.999	0.992
Early Iron Age-Late Iron Age	0.211	0.946
Early Iron Age-Latest Iron Age	0.772	0.972
Middle Iron Age-Late Iron Age	0.479	1
Middle Iron Age-Latest Iron Age	0.776	0.999
Late Iron Age-Latest Iron Age	0.998	1

6.1.2.2 Sheep

Table 6.7. Distribution of the Iron Age sheep data in different sub-periods, according to number of sites, number of samples and regions.

Sub-Period	n of sites	n of samples	Region	Sites
Iron Age	3	36	Gloucestershire, Hampshire	Danebury, Lechlade, Suddern Farm
Early Iron Age	6	85	Hampshire	Danebury, Houghton Down, Nettlebank Copse, New Buildings, Suddern Farm, Yarnton
Middle Iron Age	4	44	Cornwall, Hampshire, Yorkshire	Harlyn Bay, Suddern Farm, Trethellan Farm, Trevelgue Head, Wetwang Garton-Slack, Winnal Down
Late Iron Age	6	48	Dorset, Hampshire, Oxfordshire	Danebury, Fordington Bottom, Nettlebank Copse, Suddern Farm, Yarnton
Latest Iron Age	2	17	Hampshire	Danebury, Suddern Farm.

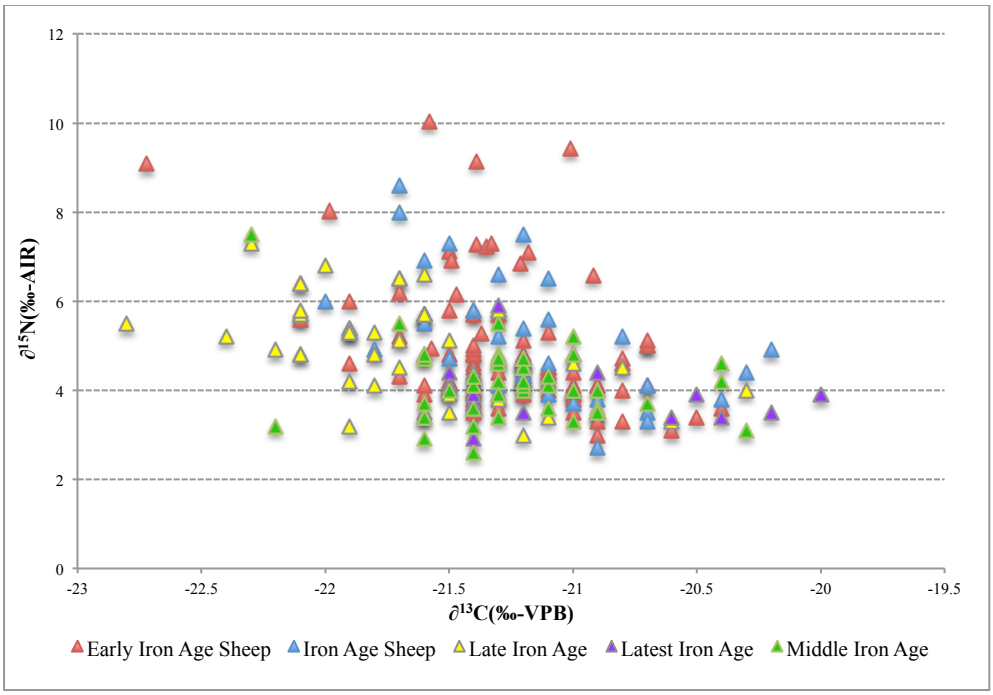


Figure 6.5. Chronological evolution of the Iron Age sheep data (Iron Age n= 36, Early Iron Age n = 85, Middle Iron Age n= 44, Late Iron Age = 48, Latest Iron Age = 17).

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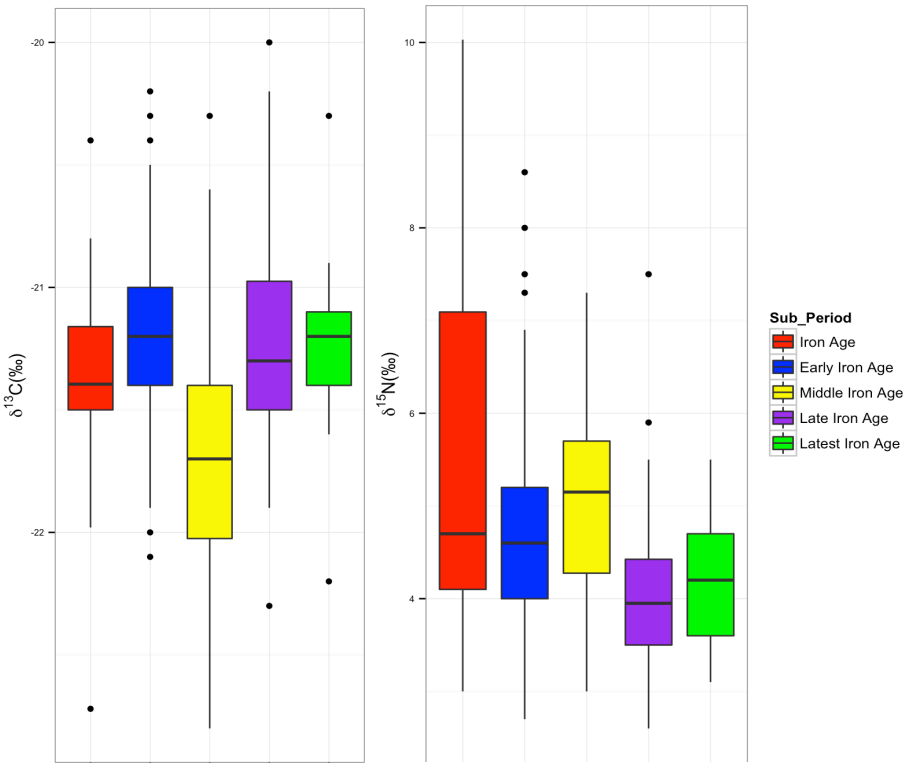


Figure 6.6. Boxplot distribution of the ∂^{13}C (left) and ∂^{15}N (right) values of the sheep in the different sub-periods within the Iron Age. (Iron Age n= 36, Early Iron Age n = 85, Middle Iron Age n= 44, Late Iron Age = 48, Latest Iron Age = 17).

Compared to the cattle data, the less well-dated samples are not as enriched as the better dated ones (Figures 6.5 and 6.6). The Middle Iron Age looks to be the most different to the other sub-periods but this is not supported by multivariate testing (Table 6.8). Indeed, the statistical results show that this difference is likely regionally driven. If 'Region' is not integrated to the model, the results are significant, but they are not when region is treated as a random effect, i.e. these variation are not independent from regional level factors. More significant is the difference in the ∂^{15}N values between the sheep from the Early Iron Age compared to the sheep from the Late Iron Age.

Table 6.8. . Statistics for the sheep data when comparing sub-periods. Values in bold indicate statistical significance. *If 'Region' was excluded from the model, the sheep data from Middle Iron Age were statistically different the Early Iron Age (p=0.005), the Late Iron Age (p=0.009) and the Latest Iron Age (p= 0.033). Statistical analyses suggest that these differences may therefore be driven by the site/regional distribution of the data.

	Multi-Level Model With Sites And Region As Random Effect and 'Sub-Period' as fixed effect.	
	p-value **(∂^{13}C)**	***p-value*** **(∂^{15}N)**
Iron Age-Early Iron Age	0.923	0.408
Iron Age-Middle Iron Age	0.448	0.999
Iron Age-Late Iron Age	0.925	0.925
Iron Age-Latest Iron Age	0.990	1.00
Early Iron Age-Middle Iron Age	0.107*	0.767
Early Iron Age-Late Iron Age	1.000	**0.018**
Early Iron Age-Latest Iron Age	0.998	0.534
Middle Iron Age-Late Iron Age	0.127*	0.878
Middle Iron Age-Latest Iron Age	0.264*	0.999
Late Iron Age-Latest Iron Age	0.998	0.885

As with the cattle, there is a strong negative correlation in the data. The correlation is more pronounced in the earlier sub-periods but becomes progressively less pronounced through time, as was the case with the cattle data (Tables 6.5 and 6.9). This could be the result of changing environments for the domesticated fauna with an increasing reliance on open pastures for sheep in the later periods, compared to animals browsing from woodland floors in the earlier periods, which is consistent with know patterns of woodland clearance at the time (Hamilton 2016, 130). This could also be linked to the water regimes of the plants, at least for the carbon isotopic values.

Table 6.9. Results of Pearson's correlation (r) between $\partial^{13}C$ and $\partial^{15}N$ for the sheep data in the Iron Age sub-periods.

Sub_Period	Pearson's *r*	p values	n
Early Iron Age	-0.47	**0.000**	85
Middle Iron Age	-0.56	**0.000**	44
Late Iron Age	-0.25	0.081	48
Latest Iron Age	-0.04	0.860	17

6.1.3 Regional trends within the Iron Age

While the diachronic analyses have been the primary focus of analyses so far, the regional distribution of the data cannot be ignored and must be addressed, as it might explain some of the variation examined here. The regions that will be examined here, however, will only be the regions for which there are more than two sites as was described in section 4.2.4. In the case of the Iron Age, this means that only Cornwall and Hampshire will be discussed here.

6.1.3.1 Cornwall

Table 6.10. Summary of the data for Cornwall. The data come from three sites (Trevelgue Head n = 29, Harlyn Bay n=3 , Trethellan Farm n=23).

	Average $\partial^{13}C$(‰)	Average $\partial^{15}N$(‰)	min $\partial^{13}C$ ‰	max $\partial^{13}C$ ‰	range $\partial^{13}C$‰	min $\partial^{15}N$‰	max $\partial^{15}N$ ‰	range $\partial^{15}N$ ‰	n=
Cattle	-21.9±0.31	5.6 ± 0.57	-22.5	-21.5	1.0	2.0	7.3	5.3	16
Sheep	-21.8±0.28	5.7± 0.51	-22.4	-21.3	1.1	4.8	6.5	1.7	16
Pig	-21.5 ± 0.41	7.0 ± 1.3	-22.4	-20.8	1.6	5.5	9.3	3.8	17

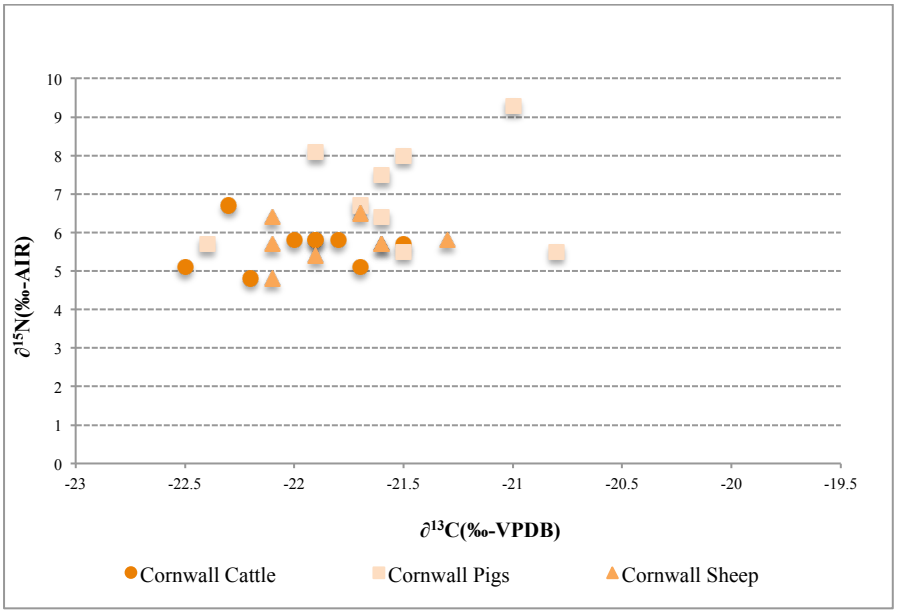


Figure 6.7. Results of the Cornish faunal data in the Iron Age (Cattle n= 16, Sheep n = 16, Pig n = 17)

The Cornish faunal ranges from -22.5‰ to -20.8‰ with small ranges for each species observed: cattle's $\partial^{13}C$ values range from -22.5‰ to -21.5‰, sheep's $\partial^{13}C$ values range from -22.1‰ to -21.3‰ and pig's $\partial^{13}C$ values range from -22.4‰ to -20.8‰. On average, though, cattle still have the lowest $\partial^{13}C$ values (-21.9 ± 0.31‰). The sheep average is virtually equal to the cattle average (21.8 ± 0.28‰), while the pig average is slightly higher (21.5 ± 0.41‰; Figure 6.7; Table 6.10).

The $\partial^{15}N$ values range from 4.8‰ to 9.3‰. The largest variation within a species is found among pigs (5.5‰ to 9.3‰), whose $\partial^{15}N$ average is also higher than the average of the herbivores (7.0 ±1.30‰). Cattle and sheep have similar $\partial^{15}N$ values on average (respectively 5.6 ± 0.57‰ and 5.7 ± 0.51‰). Both the $\partial^{13}C$ and $\partial^{15}N$ values are within the standard deviation range of the overall average for the Iron Age. The question whether coastal sites would display enriched values has been raised, and on the basis of the Cornish Iron Age data, which is slightly elevated compared to the Iron Age

averages of the three main species, it seems that it is a possibility. This will be explored further in section 6.6.4

6.1.3.2 Hampshire

Table 6.11. Summary of the faunal data for Hampshire. The data come from seven sites (Bury Hill n=16, Danebury n=126, Houghton Down =52, Nettlebank Copse=125, New Buildings n =55, Suddern Farm n = 106, Winnall Down n = 24).

	Average $\partial^{13}C$(‰)	Average $\partial^{15}N$(‰)	min $\partial^{13}C$ ‰	max $\partial^{13}C$ ‰	range $\partial^{13}C$ ‰	min $\partial^{15}N$ ‰	max $\partial^{15}N$‰	range $\partial^{15}N$ ‰	n=
Cattle	-21.5 ± 0.35	4.0 ± 1.22	-22.8	-20.6	2.2	1.5	7.6	6.1	159
Sheep	-21.2 ± 0.39	4.3± 0.76	-22.4	-20.0	2.4	2.6	6.6	4	169
Pig	-21.2 ± 0.41	6.5 ± 0.91	-22.0	-19.9	2.1	3.9	9.9	6	86

Sheep (n=169) and cattle (n=159) dominate the faunal record for Hampshire (Figure 7.2). However, as mentioned in Chapter 4, this distribution only represents the number of samples analysed, rather than the actual animal distribution in Hampshire in the Iron Age. It is nonetheless worth noting that this predominance of sheep reflects the overall pattern of Iron Age faunal distribution (Stevens *et al.* 2010).

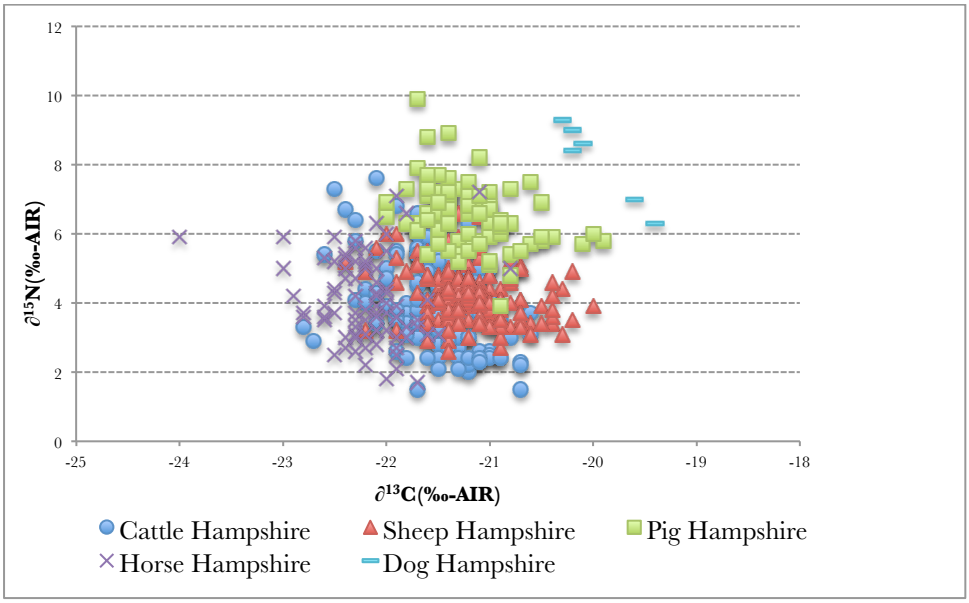


Figure 6.8. Results of the Hampshire faunal data in the Iron Age (Cattle n= 159, Sheep n = 169, Pig n = 86)

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The $\partial^{13}C$ values ranges for the faunal data between -22.8‰ to -19.9‰ with similar ranges for each species observed: $\partial^{13}C$ values range from -22.8‰ to -20.6‰ for cattle , from -22.4‰ to -20.0‰ for sheep -22.0‰ to -19.9‰ for pigs.. On average though, cattle have the lowest $\partial^{13}C$ values (-21.5 ± 0.35‰), while sheep and pigs have similar averages (respectively -21.2 ± 0.39‰ and -21.2 ± 0.41‰), which is very similar to the overall Iron Age averages for all three species (see Table 6.11; Figure 6.8).

There is a lot more variation among the $\partial^{15}N$ values, which range from 1.5‰ to 9.9‰. The largest variation within a species is found in cattle (1.5‰ to 7.6‰), whose mean average is also slightly higher than sheep, although the difference is small and should not be over interpreted (4.0 ± 1.22‰ for cattle and 4.3 ± 0.70‰ for sheep, with values ranging from 2.6‰ to 6.6‰). The highest average is found for the pigs with 6.5 ± 0.91‰ (with values ranging between 3.9‰ to 9.9‰). All three species are below the

overall Iron Age ∂^{15}N average (Figure 6.8; see Table 6.1) a pattern that will be discussed more fully in section 6.1.4 and 6.5.1.

6.1.4 Regional comparisons

6.1.4.1 Cattle

The cattle data are dominated by the data from Hampshire (n=159) to the point that some of the patterns observed could accurately be described as a 'Hampshire' signal rather an Iron Age one. For example, it is obvious in Figure 6.9 that the negative correlation in the data is mostly driven by the Hampshire data (see Table 6.12).

Table 6.12. Results of Pearson's correlation (r) between ∂^{13}C and ∂^{15}N for the cattle data between regions in the Iron Age.

Region	Pearson's *r*	*p values*	*n*
Cornwall	0.02	0.935	159
Hampshire	-0.39	0.000	16

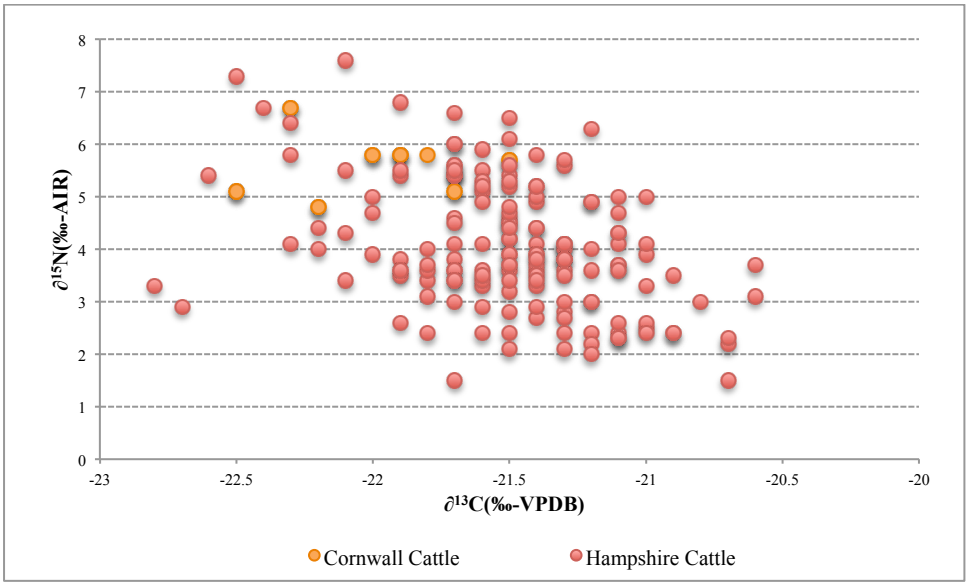


Figure 6.9 Comparison of the Iron Age cattle data by region (Hampshire n= 159, Cornwall =16).

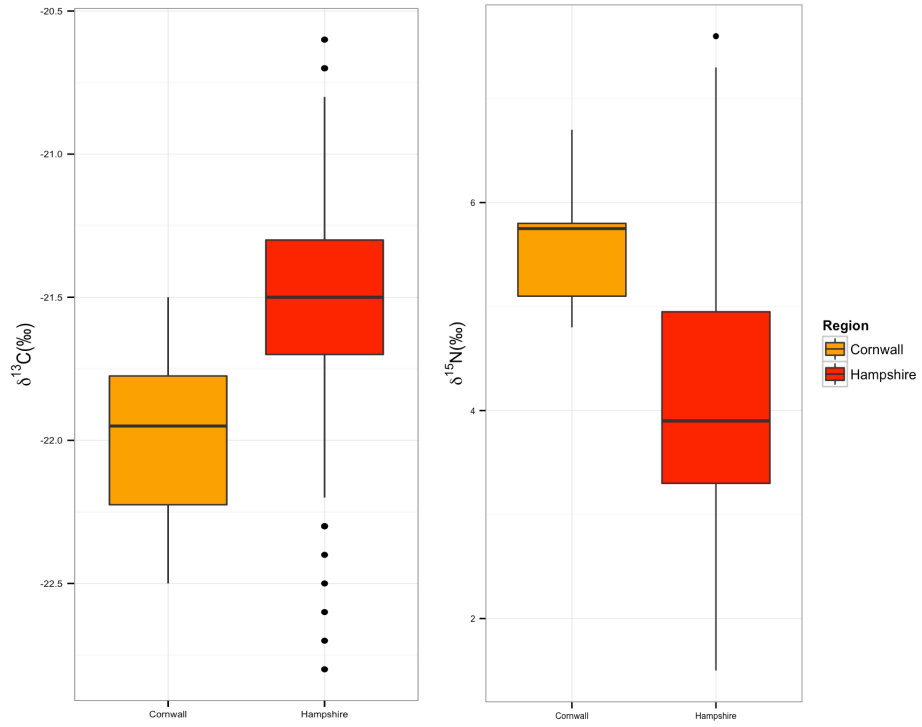


Figure 6.10. Boxplot comparison of the Iron Age cattle data by region (Hampshire n= 159, Cornwall =16).

Table 6.13 Results of the statistical analyses for the cattle data when comparing regions. Values in bold indicate statistical significance. The results were not affected if 'sub-period' was integrated as a random or fixed effect.

Region	Multi-Level Model With 'Sites' And 'Sub-Period' As Random Effects and 'Region' as fixed effects	
	p-value ($\partial^{13}C$)	*p-value* ($\partial^{15}N$)
Cornwall - Hampshire	0.120	**0.031**

Unsurprisingly, Hampshire is the most different from the other regions, which is confirmed by an effect size test (Figure 6.9, 6.10; Table 6.13). Using the function 'cohen.d' in the R programme shows that the difference is large (Hampshire/Cornwall: 1.30). This raises an important question about the baselines, which will be used in the next chapter, and whether baselines from the Iron Age are not going to be biased because of the Hampshire data. Removing the cattle Hampshire data from the Iron Age data would mean that the largest cattle dataset (n=159) of the Iron Age is not used in the baseline, but sample size studies have suggested that using the most samples is not necessarily the best practice (Pearson and Grove 2013). The difference in $\partial^{15}N$ average of all the Iron Age cattle with or without the Hampshire data is ±1.36‰. While keeping the Hampshire data might result in $\Delta^{15}N_{human\text{-}cattle}$ offsets that are artificially elevated, removing them might on the contrary results in offsets that are too low. Considering that 1.36‰ is a value below one ^{15}N trophic level, it was decided to keep the Hampshire cattle data in the Iron Age baseline, but to exercise caution when analysing the results in Chapter 7.

6.1.4.2 Sheep

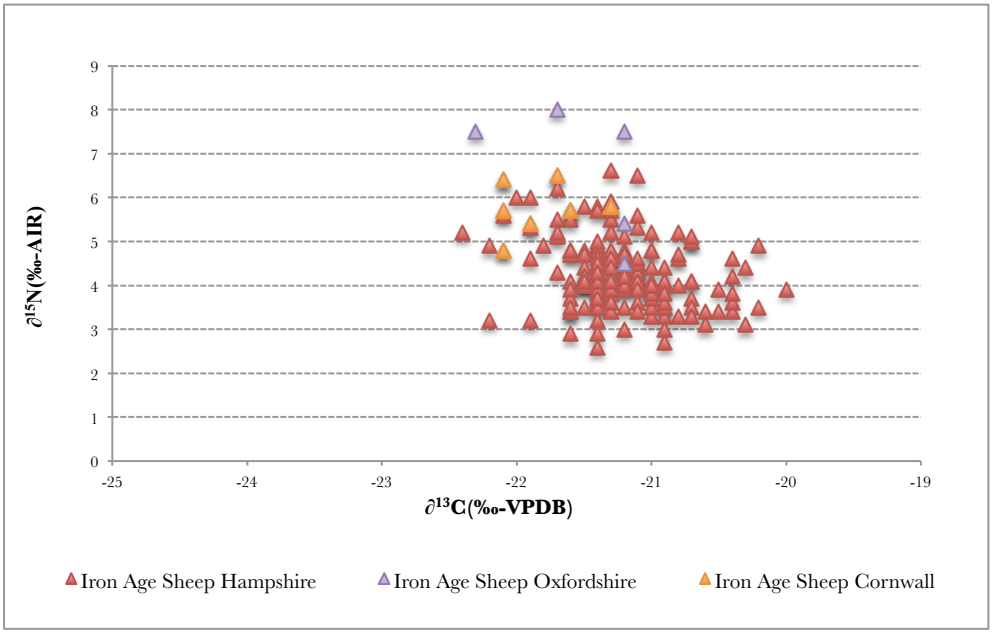


Figure 6.11. Comparison of the Iron Age sheep data by regions (Hampshire n= 196, Cornwall =16).

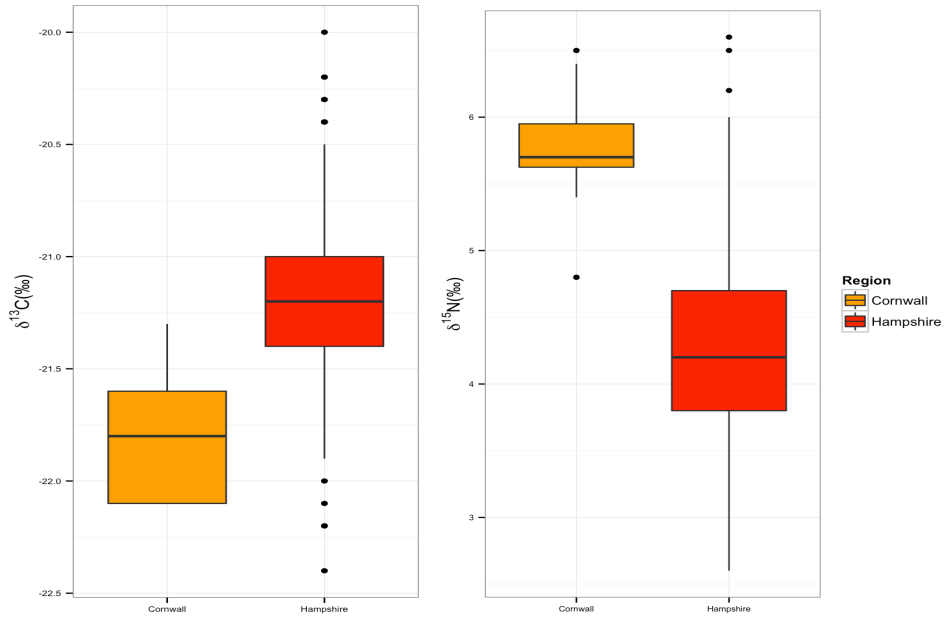


Figure 6.12 Boxplot Comparison of the Iron Age sheep data by regions (Hampshire n= 196, Cornwall =16).

Table 6.14. Statistical results for the sheep data when comparing sub-period. Values in bold indicate statistical significance. The results were not affected if 'sub-period' was integrated as a random or fixed effect.

Region	*Multi-Level Model With 'Sites' As Random Effect, And 'Region' And 'Sub-Period' As Fixed Effects.*	
	p-value ($\partial^{13}C$)	*p-value* ($\partial^{15}N$)
Cornwall - Hampshire	0.863	**0.001**

As was the case in the cattle data, the Hampshire sheep have significantly lower $\partial^{15}N$ signatures compared to the data from Cornwall (Figures 6.11, 6.12, Table 6.14) This is less of an issue in the case of sheep, as they are not used for the baseline, but it is interesting all the same as it points at either a possible environmental difference in Hampshire compared to Cornwall. It could be possibly be due to the fact that the Cornish sites are coastal sites (see Chapter 2). This will be explored further in section 6.6.4 of this Chapter.

6.1.4.3. Pig

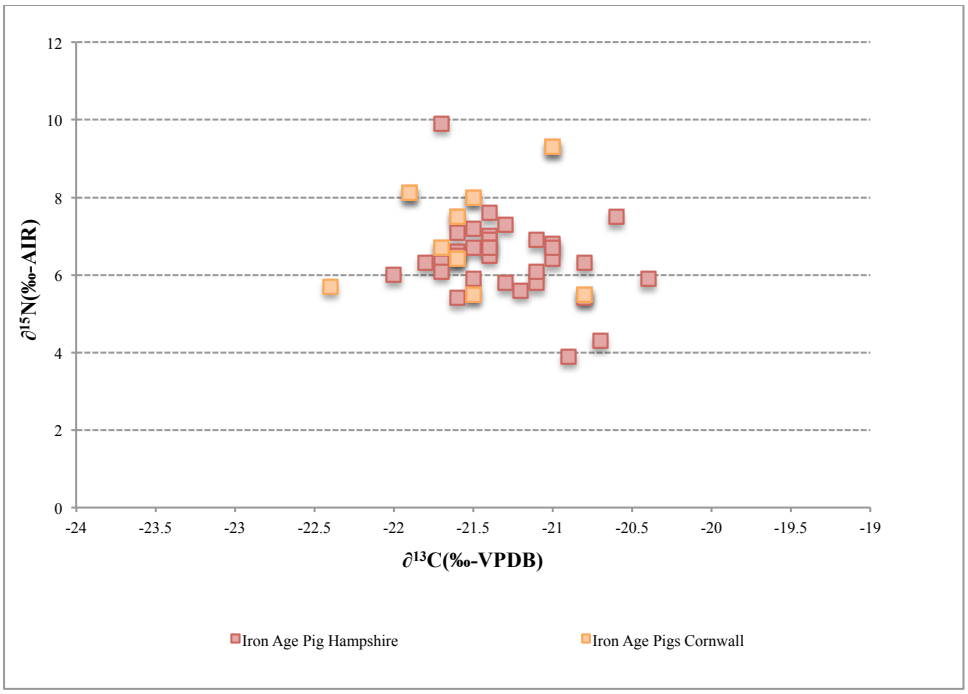


Figure 6.13. Comparison of the Iron Age pig data by region (Hampshire n= 86, Cornwall =17).

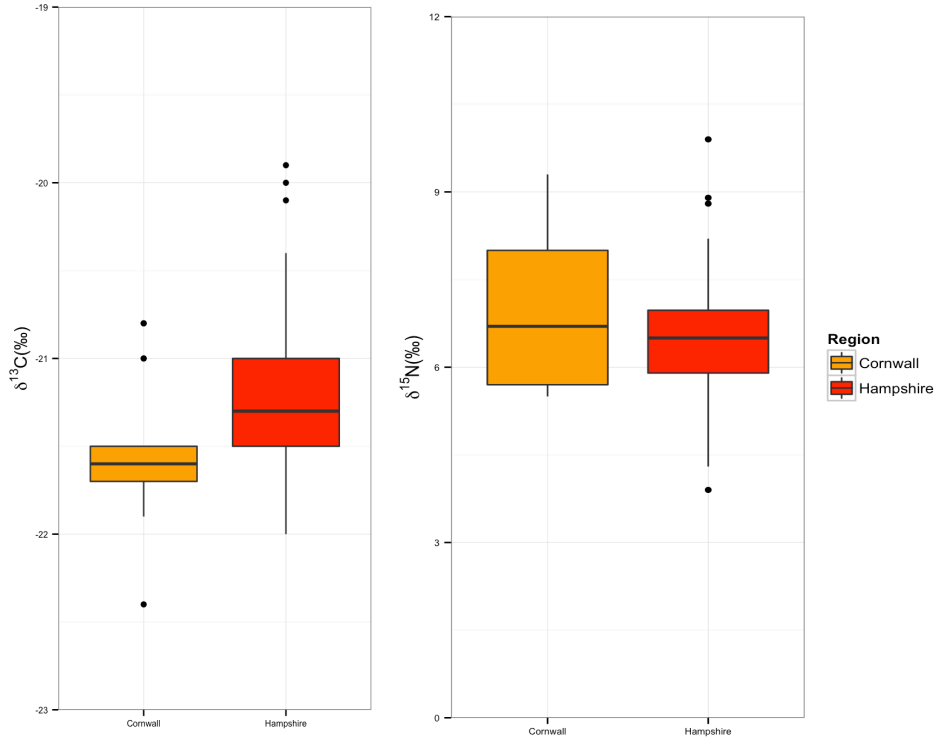


Figure 6.14. Boxplot comparison of the Iron Age pig data by region (Hampshire n= 86, Cornwall =17).

Table 6.15. Statistical differences between the pig data from Hampshire and Cornwall. The results were not affected if 'sub-period' was integrated as a random or fixed effect.

Region	**Multi-Level Model With 'Sites' As Random Effect and Region as a Fixed Effect**	
	P-value (∂^{13}C)	*P-value* (∂^{15}N)
Cornwall - Hampshire	0.235	0.436

Contrary to both the cattle and sheep data, the pig data do not display any significant difference between both regions tested here (Table 6.15). While this could rule out an environmental effect for the differences witnessed in the other domestic animals, as pigs would also have been affected should the environment be a defining factor, it is difficult to be definitive. Due to

their omnivorous diets, pigs are a lot more versatile than sheep or cattle, and this might interfere with an environmental signal. Indeed, it worth noting that while the pigs' $\partial^{15}N$ average is a bit higher in Cornwall than it is in Hampshire, the pigs' $\partial^{15}N$ average in Hampshire is more elevated compared to the cattle (Figure 6.13; Figure 6.14; $\Delta^{15}N_{pig\text{-}cattle}$ in Cornwall: 1.4‰, $\Delta^{15}N_{pig\text{-}cattle}$ in Hampshire: 2.5‰) suggesting that pigs were possibly kept on a more omnivorous diet in Hampshire than in Cornwall making it difficult to generalise about an environmental signal. This will be explored further in section 6.5.2. The Iron Age cattle and sheep seem to have had similar diets, albeit drawn from different parts of the environment in each region, and likely reflecting different environmental constraints between regions.

6.1.5 Preliminary discussion of the Iron Age faunal data

The most striking aspect of the Iron Age faunal data is the negative correlation between the $\partial^{13}C$ and $\partial^{15}N$ values as this is an unusual profile for fauna. However, this influenced by the large Hampshire dataset and it might be premature to see this as a characteristic of the Iron Age faunal data and might be rather something particular to Hampshire. Multivariate statistics reveal that the most significant patterns here might be regional rather than temporal, since there are no differences between the Iron Age sub-periods in either the cattle or sheep data, at the exception of a difference between Early Iron Age and Late Iron Age sheep. However, since only two regions have been analysed here, these results can only be seen as tentative.

6.2. Roman Britain

Table 6.16 shows the summary of the Roman faunal data. Species for which there was only one sample have been excluded (wild pigeon, wild boar and swan).

Table 6.16. Summary statistics of the Roman faunal data.

	Average $\partial^{13}C$‰	Average $\partial^{15}N$‰	min $\partial^{13}C$ ‰	max $\partial^{13}C$ ‰	range $\partial^{13}C$ ‰	min $\partial^{15}N$‰	max $\partial^{15}N$ ‰	range $\partial^{15}N$ ‰	n
Cattle	-21.7 ± 0.37	6.1 ± 1.46	-22.7	-20.6	2.1	2.4	10.4	10	99
Chicken	-20.9 ± 0.81	9.5 ± 1.88	-22.6	-19.9	2.7	6.5	12.9	6.4	8
Deer	-21.8 ± 0.62	6.3 ± 1.27	-23	-20	3	2.2	10.1	7.9	49
Dog	-20.2 ± 0.19	10.3 ± 0.94	-20.5	-20	0.5	9.40	12.40	3	11
Horse	-20.3 ± 0.33	7.0 ± 1.38	-22.8	-21.7	1.1	4.7	9.5	4.8	11
Sheep	-21.5 ± 0.45	6.1 ± 1.62	-22.8	-19.9	2.9	2.2	10.5	8.3	96
Pig	-21.4 ± 0.64	7.1 ± 1.66	-22.8	-20.1	2.7	4.2	11	6.8	55

6.2.1 Faunal isotopic results

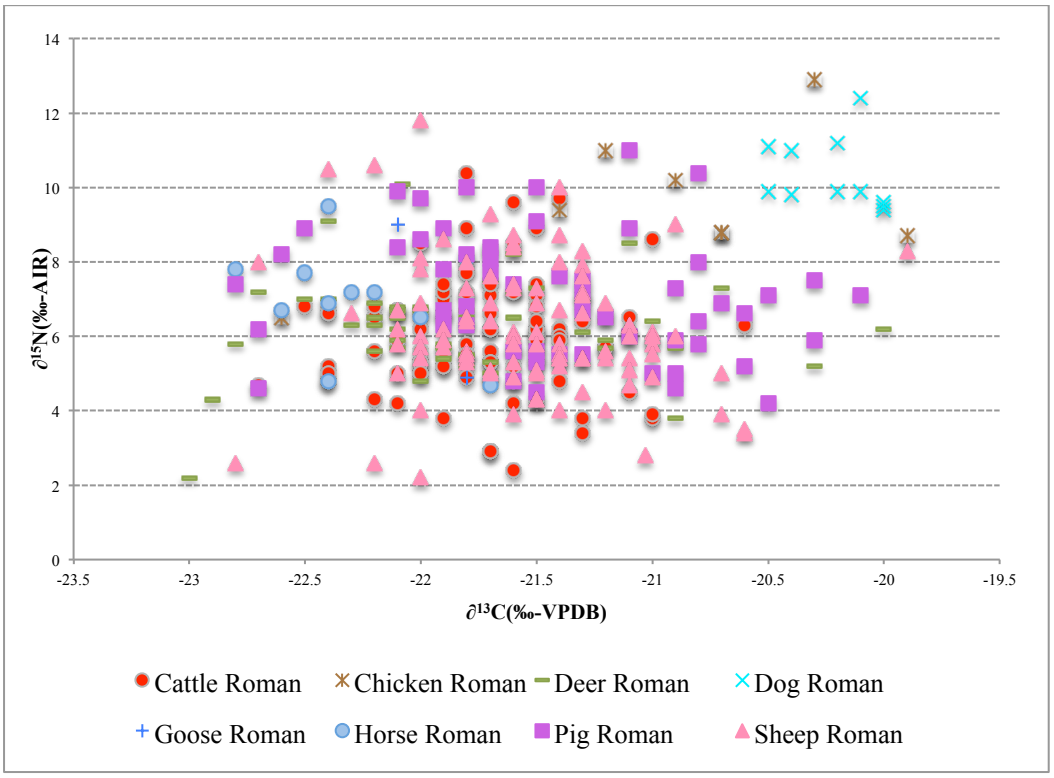


Figure 6.15. Isotopic results of the faunal data by species in Roman Britain (Cattle n=99, Chicken n=8, Deer n=49, Dog n=11, Goose n=2, Horse n=11, Pig n=55, Sheep n=96, Swan n=2, Wild Boar n=1, Wild Duck n=1, Wood Pigeon n=1).

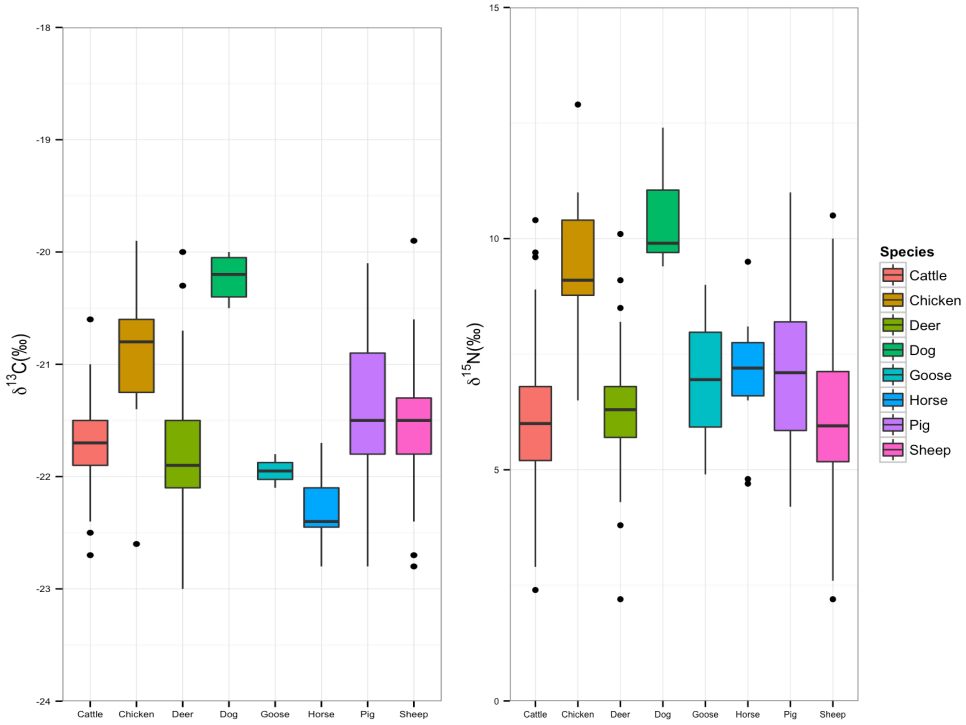


Figure 6.16. Boxplot comparisons of the isotopic results of the faunal data by species in Roman Britain (Cattle n=99, Chicken n=8, Deer n=49, Dog n=11, Goose n=2, Horse n=11, Pig n=55, Sheep n=96, Swan n=2, Wild Boar n=1, Wild Duck n=1, Wood Pigeon n=1).

Cattle display the following mean averages $\partial^{13}C$ = -21.7 ± 0.37‰, $\partial^{15}N$ = 6.1 ± 1.46‰. Sheep are very similar to cattle with the following isotopic results: $\partial^{13}C$ = -21.5 ± 0.45‰; $\partial^{15}N$ = 6.1 ± 1.62‰, while pigs have similar $\partial^{13}C$ values to the rest of the herbivores (-21.41 ± 0.62‰) but enriched $\partial^{15}N$ signatures (7.10 ± 1.67‰; Figures 6.15 and 6.16).

The dataset also contains horses and chicken in a number high enough to warrant inclusion on the graph. Chicken diets can be very varied and quite omnivorous. They can feed on kitchen scraps, grains or insects, and as a results, their $\partial^{13}C$ and $\partial^{15}N$ values can be relatively elevated compared to the rest of the terrestrial fauna, like it is here ($\partial^{13}C$: -20.96 ± 0.81‰, $\partial^{15}N$: 9.53 ± 1.88‰). Because of the wide range of foodstuff their diets can be drawn from, they are not particularly useful for the creation of a baseline but it is important to consider since they were consumed by humans. The Roman faunal data differ from the Iron Age faunal in two ways: (1) they display higher $\partial^{15}N$ averages for all species (Tables 6.1, 6.16); (2) there is no correlation between the carbon and nitrogen isotopic values of the data, except for a small suggestive negative correlation in the pig data (Table 6.17), which might an indication that they fed in parts of the landscape that remained more similar to the Iron Age landscapes.

Table 6.17. Results of Pearson's correlation (r) between $\partial^{13}C$ and $\partial^{15}N$ for the domesticated data in Roman Britain.

Species	Pearson's *r*	*p-value*	*n*
Cattle	0.01	0.897	99
Sheep	-0.08	0.433	96
Pig	**-0.22**	**0.090**	55
Horse	-0.30	0.35	11
Deer	0.04	0.77	49

There are less significant differences between species in the Roman periods than there were in the Iron Age, but this might be due to the different sample sizes and distribution of the data in both periods (Table 6.18). In Roman Britain, the nitrogen isotopic values of the pigs differ from those of the cattle and sheep, and the carbon isotopic values of cattle and pigs also differ significantly. Horses display significantly lower $\partial^{13}C$ averages to the rest of the domesticate herbivores. This might be due to horses not being ruminant, although previous studies have shown that this should not have affected the results (Hedges *et al.* 2003). Further, Britton *et al.* (2012) argued against a physiological effect to explain the difference in the horse data. This could possibly be due to horses grazing in a different landscape to the other species (Figure 6.15).

Table 6.18. Results of the statistical comparisons for the herbivores data in Roman Britain. Values in bold indicate statistical significance. While p-values might differ between both models, the significant differences do not change between the same faunal groups, suggesting that the site variations did not cause a Type I error in the ANOVA. It is worth noting, however, that the multivariate model picked up a significant difference between the pigs and sheep's ∂^{15}N values, suggesting that site-level variation hid a significant difference between both these faunal groups

SPECIES	*ANOVA + TUKEY HSD*		Multi-Level Model With Sites As Random Effect And 'Species' And 'Region' As Fixed Effects	
	p-value (∂^{13}C)	*p-value* (∂^{15}N)	*p-value* (∂^{13}C)	*p-value* (∂^{15}N)
Deer-Cattle	1.000	0.981	1.000	0.999
Horse-Cattle	**0.008**	0.007	**0.007**	0.999
Pig-Cattle	**0.016**	**0.013**	**0.001**	**0.000**
Sheep-Cattle	0.324	0.183	0.153	0.999
Horse-Deer	0.088	0.061	0.192	0.996
Pig-Deer	**0.004**	0.056	0.371	0.144
Sheep-Deer	0.079	0.998	0.921	0.998
Pig-Horse	**0.000**	**0.000**	**0.001**	0.617
Sheep-Horse	**0.000**	**0.000**	**0.001**	0.999
Sheep-Pig	1.000	0.897	0.372	**0.007**

6.2.2 Diachronic trends within the Roman period

As was done for the Iron Age, cattle and sheep were chosen to analyse the diachronic trends in the Roman periods in the next two sections. Distribution of the data is in Tables 6.19 and 6.21.

6.2.2.1 Cattle

Table 6.19. Distribution of the cattle data between the different sub-periods, by sites, number of samples and regions in Roman Britain.

Sub-Period	n of sites	n of samples	Region	Sites
Roman	3	18	Oxfordshire, Yorkshire	6 Driffield Terrace (York), Blossom Street (York), Yarnton
Early Roman	3	12	Yorkshire, Gloucestershire, Oxfordshire	Blossom Street (York), Hucclecote, Yarnton
Middle Roman	7	56	Gloucestershire, Hampshire, Oxfordshire, Yorkshire	Asthall, Bradley Hill, Catterick, Cirencester, Gloucester, Winchester, York
Late Roman	2	13	Oxfordshire	Alchester, Yarnton

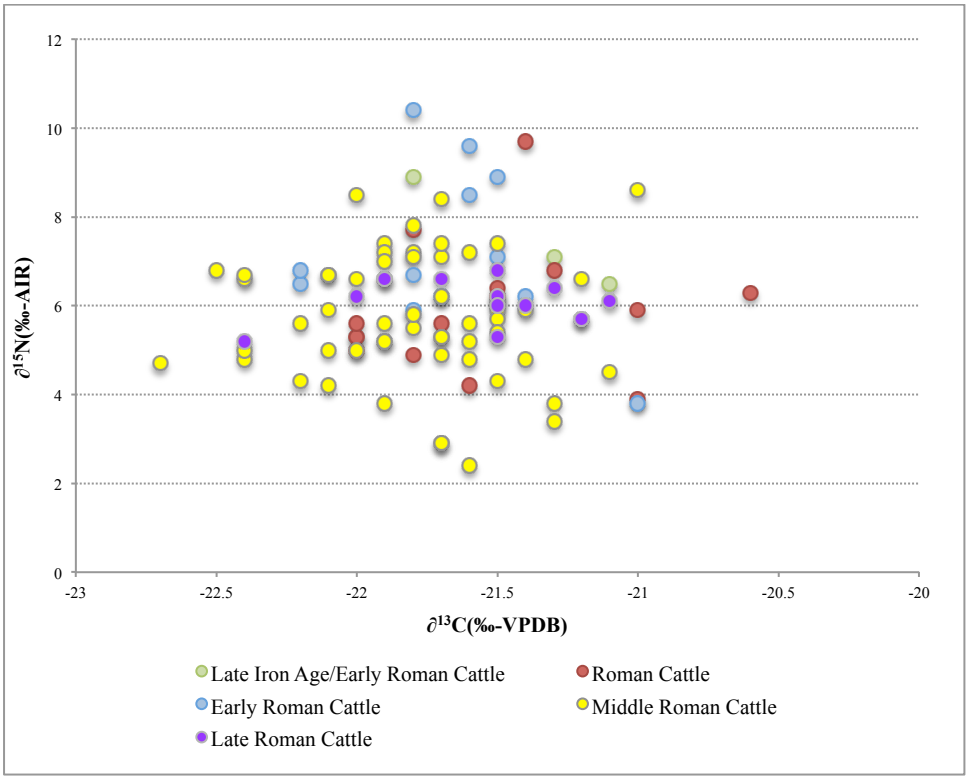


Figure 6.17. Chronological evolution of the Roman cattle data (Roman n= 18, Early Roman n = 12, Middle Roman n= 56, Late Roman = 13).

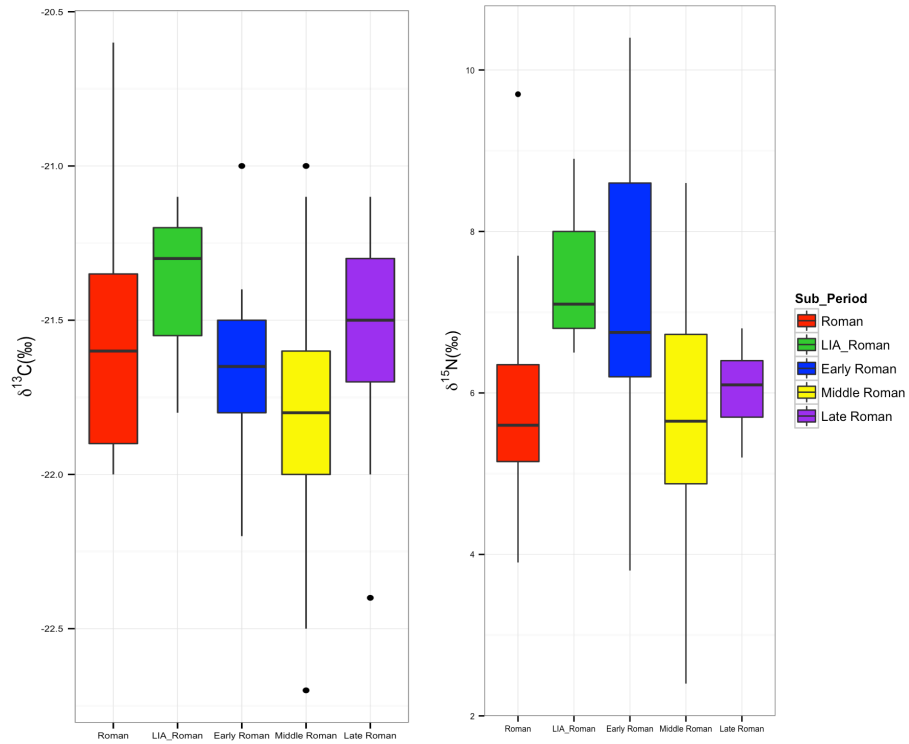


Figure 6.18. Boxplot comparison of the chronological evolution of the $\partial^{13}C$ (left) and $\partial^{15}N$ (right) values of the cattle in the different sub-periods within the Iron Age (Roman n= 18, Early Roman n = 12, Middle Roman n= 56, Late Roman = 13).

It is immediately striking that the Late Iron Age/Early Roman (green data points) data plot much higher than the later periods (Figures 6.17, 6.18). This is rather surprising as the development of agriculture (and the associated enrichment in ^{13}C and ^{15}N) were expected to have taken effect later in the period. It is also noticeable that both $\partial^{13}C$ and $\partial^{15}N$ averages are lower in the Middle Roman period than they are in the Early Roman or Late Roman periods but statistical analyses reveal that it is not significantly different, except for a suggestive difference between the nitrogen isotopic values of the Early and Middle Roman cattle (Table 6.20).

Table 6.20. Statistical results for the cattle data when comparing sub-periods. Values in bold indicate statistical significance. The results remained significant between the same groups regardless of whether 'Region' and 'Sub-Period' were integrated as fixed or random effects.

Sub_Period	**Multi-Level Model With 'Sites' As Random Effect And 'Sub-Period' And 'Region' As Fixed Effects.**	
	p-value ($\partial^{13}C$)	*p-value* ($\partial^{15}N$)
Early Roman - Roman	0.694	0.496
Middle Roman - Roman	0.110	0.602
Late Roman -Roman	0.972	0.764
Early Roman - Middle Roman	0.726	0.066
Early Roman- Late Roman	0.941	0.130
Middle Roman - Late Roman	0.358	1.000

6.2.2.2 Sheep

Table 6.21. Distrubtion of the sheep data between the different sub-periods, by sites, number of samples and regions in Roman Britain.

Sub-Period	n of sites	n of samples	Region	Sites
Roman	3	21	Oxfordshire, Yorkshire	6 Driffield Terrace (York), Blossom Street (York), Yarnton
Early Roman	3	8	Yorkshire, Gloucestershire, Oxfordshire	Blossom Street (York), Hucclecote, Yarnton
Middle Roman	7	56	Gloucestershire, Hampshire, Oxfordshire, Yorkshire	Asthall, Bradley Hill, Catterick, Cirencester, Gloucester, Winchester, York
Late Roman	2	8	Oxfordshire	Alchester, Yarnton

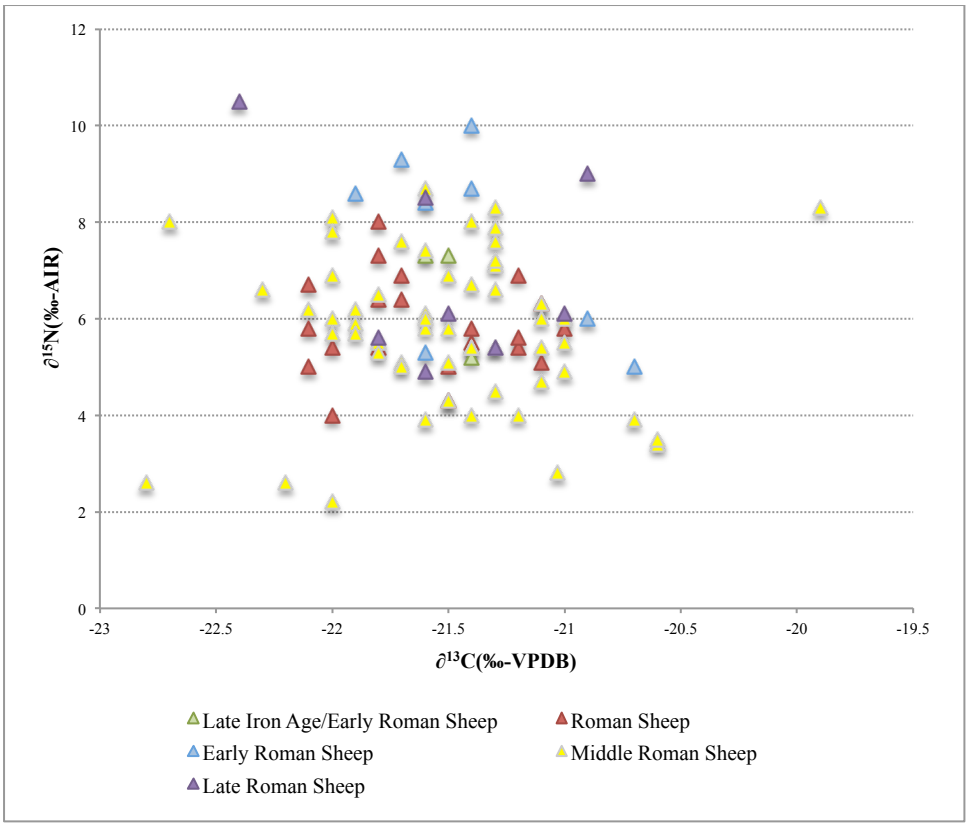


Figure 6.19. Chronological evolution of the Roman sheep data (Roman n= 21, Early Roman n = 8, Middle Roman n= 56, Late Roman = 8)

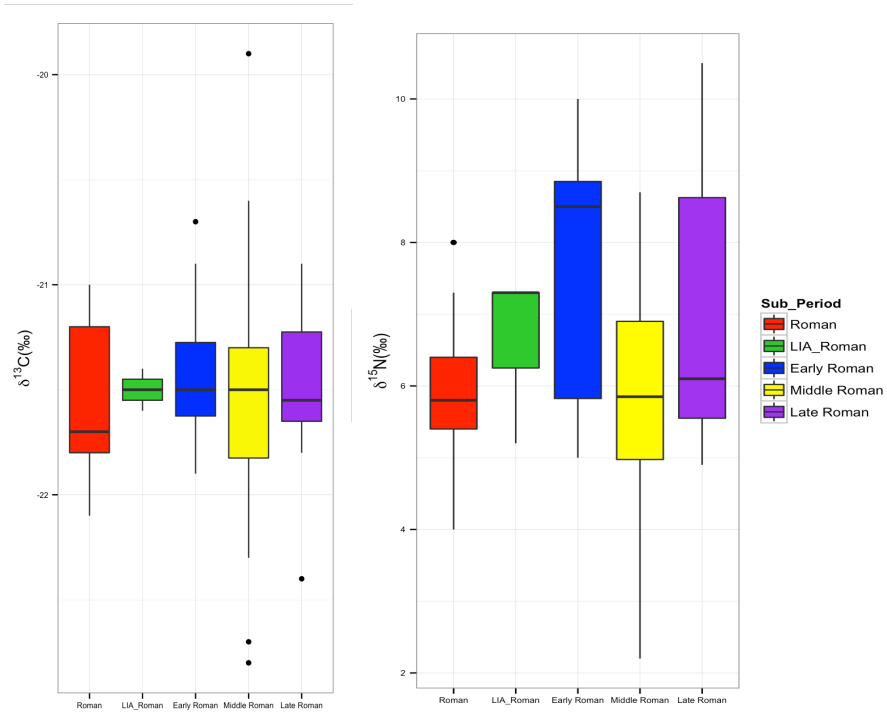


Figure 6.20. Boxplot distribution of the ∂^{13}C (left) and ∂^{15}N (right) values of the sheep in the different sub-periods within the Iron Age (Roman n= 21, Early Roman n = 8, Middle Roman n= 56, Late Roman = 8)

Figures 6.19 and 6.20 show the spread of the sheep data in the Roman period, but no clear pattern emerges. The Early Roman data are somewhat enriched in ^{15}N compared to the other sub-periods but Table 6.22 shows that this is dependent on factors at the site level and therefore not conclusive as a diachronic pattern.

Table 6.22. Statistical results for the sheep data when comparing sub-periods. Values in bold indicate statistical significance. Out of the 14 models tested (7 for each isotopes), the best-fit one was 'Region' and 'Sub-Period' as fixed effects and 'SITE' as random effect. However, the results remained significant between the same groups regardless of whether 'Region' and 'Sub-Period' were integrated as fixed or random effects.

Sub_Period	Multi-Level Model With 'Sites' As Random Effect, And 'Sub-Period' And 'Region' As Fixed Effects	
	p-value (∂^{13}C)	*p-value* (∂^{15}N)
Early Roman - Roman	0.911	0.209
Middle Roman - Roman	0.974	1.000
Late Roman -Roman	0.994	0.995
Early Roman - Middle Roman	0.983	0.156
Early Roman- Late Roman	0.994	0.413
Middle Roman - Late Roman	1.000	0.983

6.2.3 Regional trends within Roman Britain

The data for the Roman period come from six different counties. The dataset is biased towards the South – with the North only represented by Yorkshire. Because of the constraints of the analyses decided (see Chapter 4), only Gloucester, Oxfordshire, Yorkshire are analysed here.

6.2.3.1 Gloucestershire

Table 6.23. Summary of the Gloucestershire data in the Roman period (data from Cirencester n=28, Gloucester n= 15, Hucclecote n= 8)

	Average ∂^{13}C(‰)	Average ∂^{15}N(‰)	min ∂^{13}C ‰	max ∂^{13}C ‰	range ∂^{13}C ‰	min ∂^{15}N ‰	max ∂^{15}N ‰	range ∂^{15}N ‰	n=
Cattle	-21.8±0.30	5.9± 1.48	-22.0	-21.2	1.2	4.8	9.6	4.8	23
Sheep	-21.5±0.51	5.59±1.44	-22.5	-20.7	1.8	2.6	8.0	5.4	17
Pig	-21.1±0.45	7.1 ± 1.23	-21.9	-20.1	1.8	4.8	11	6.2	11

The Gloucestershire faunal $\partial^{13}C$ values range between -22.5‰ to -20.1‰ and the $\partial^{15}N$ values range between 2.6 and 11‰. Overall, the Gloucestershire faunal data are similar to the period general faunal averages. Cattle seem to be depleted in ^{13}C compared to the other species, but statistical analyses reveal that it is only significant between the pig and cattle data (p= 0.001), like it was at the 'national' level. One of the pigs is enriched in both ^{13}C and ^{15}N, suggesting that this particular animal might have been a younger animal. There is also an individual sheep depleted in both ^{13}C and ^{15}N (Table 6.23; Figure 6.21).

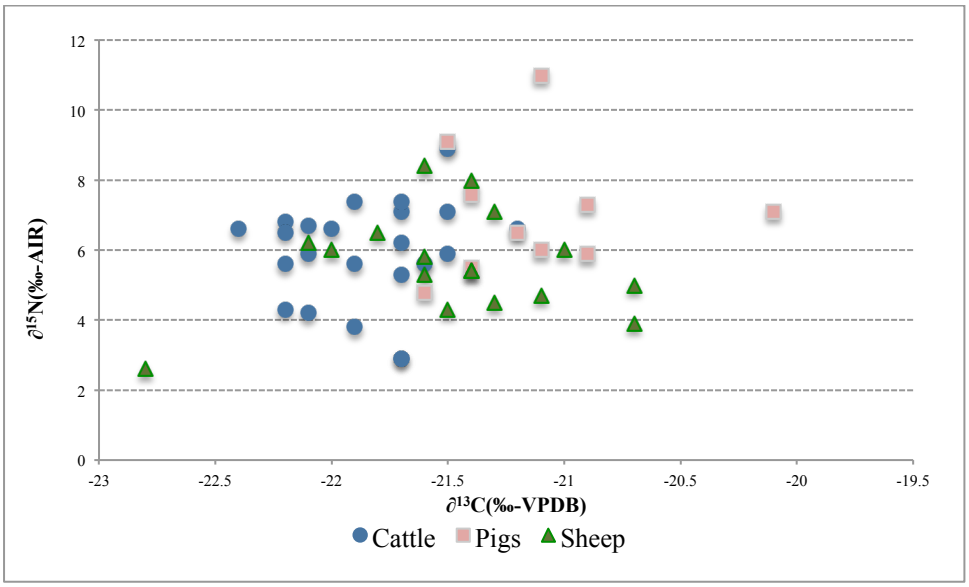


Figure 6.21. Results of the Gloucestershire faunal data in Roman Britain (Cattle n= 23, Sheep n = 17, Pig n = 11)

6.2.3.2 Oxfordshire

Table 6.24. Summary of the Oxfordshire data (data from Alchester n =13, Asthall n =17, Yarnton n = 35).

	Average $\partial^{13}C$(‰)	Average $\partial^{15}N$(‰)	min $\partial^{13}C$ ‰	max $\partial^{13}C$ ‰	range $\partial^{13}C$‰	min $\partial^{15}N$ ‰	max $\partial^{15}N$ ‰	range $\partial^{15}N$ ‰	n=
Cattle	-21.6±0.33	6.3± 1.81	-22.4	-21.0	1.4	2.4	10.4	8	29
Sheep	-21.4±0.45	7.33±1.60	-22.4	-19.9	2.5	2.5	10.5	5.6	23
Pig	-21.3±0.69	8.1 ± 1.51	-22.1	-20.3	1.8	5.2	10.0	4.8	13

The Oxfordshire faunal $\partial^{13}C$ values range between -22.4‰ to -20.3‰ with small ranges for each species observed. Cattle, sheep and pigs have similar $\partial^{13}C$ values (cattle: -21.6 ± 0.33‰; sheep: -21.4 ± 0.45‰; pigs -21.3 ± 0.69‰). The $\partial^{15}N$ values of all three species are higher than the overall species averages (Tables 6.16.and 6.24). The cattle data have the widest $\partial^{15}N$ range. The enrichment in ^{15}N is more marked in sheep and pigs but they have smaller ranges than the cattle (Figure 6.22). The presence of samples enriched in ^{15}N could be indicative of younger animals in the dataset.

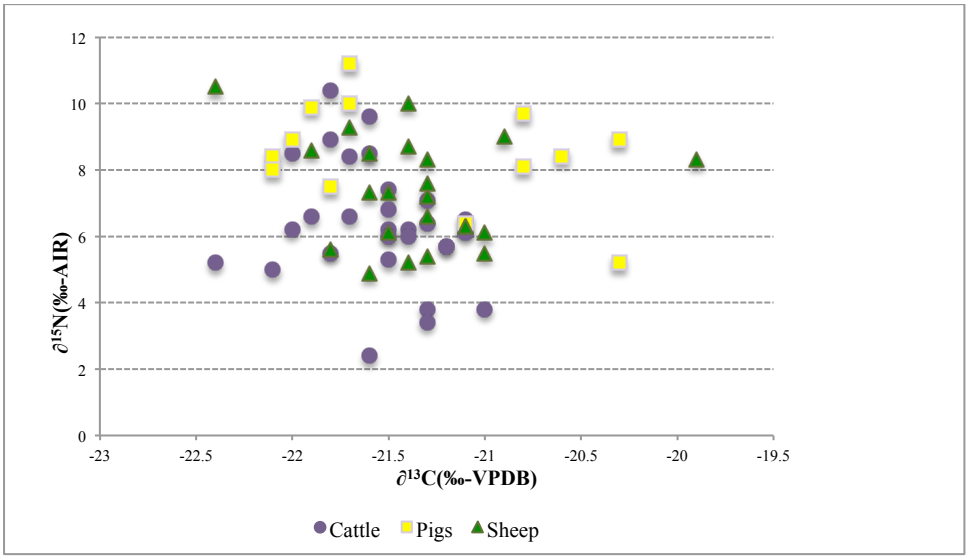


Figure 6.22. Results of the Oxfordshire faunal data in Roman Britain (Cattle n= 29, Sheep n = 23, Pig n = 13).

6.2.3.3 Yorkshire

Table 6.25. Summary of the faunal data from Yorkshire (data from 6 Driffield Terrace (York) n= 14, Blossom Street (York) n = 25, Catterick n= 21, York n = 24).

	Average $\partial^{13}C$(‰)	Average $\partial^{15}N$(‰)	min $\partial^{13}C$ ‰	max $\partial^{13}C$ ‰	range $\partial^{13}C$ ‰	min $\partial^{15}N$ ‰	max $\partial^{15}N$ ‰	range $\partial^{15}N$ ‰	n=
Cattle	-21.6± 0.34	5.9± 1.25	-22.1	-20.6	1.5	3.9	9.7	5.8	31
Sheep	-21.6± 0.34	5.9± 1.03	-22.3	-20.9	1.4	4.0	8.0	4	35
Pig	-21.8± 0.65	7.2± 1.59	-22.8	-20.6	2.2	4.6	10.4	5.6	18

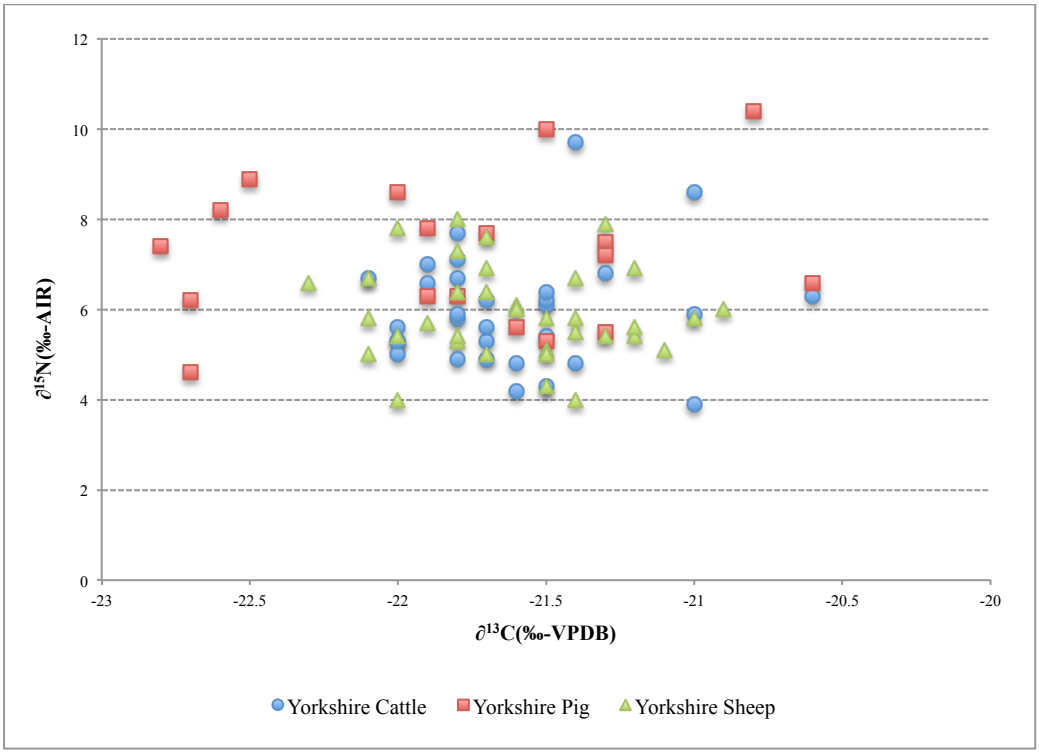


Figure 6.23. Results of the Yorkshire faunal data in Roman Britain (Cattle n= 31, Sheep n = 35, Pig n = 18)

All three species have similar $\partial^{13}C$ values (-21.6 ± 0.34‰ for cattle; -21.6 ± 0.34‰ for sheep and -21.8 ± 0.65‰ for pigs), as was expected. Once again, it is the $\partial^{15}N$ values that are the most varied. Cattle and sheep have the lowest $\partial^{15}N$ values (respectively 5.9 ±1.25‰ and 5.9 ±1.03‰). Pigs have the highest average (7.2 ± 1.59‰). The isotopic averages for all the species

are close to the overall faunal averages for the Roman period (Table 6.25; Figure 6.23). What is interesting in the Yorkshire data is the presence of pigs depleted in ^{13}C compared to the other species and the rest of the pigs. These pigs have a fairly wide $\partial^{15}N$ range (4.3‰) so the reason for this depletion in ^{13}C might be due to animals kept foraging in closed environment, but still given access to ^{15}N-enriched food, such as the waste from human population's' diet.

6.2.4 Regional comparisons

After this brief overview of the differences between species in each regions, it is interesting to investigate how each species differ from another other across regions.

6.2.4.1 Cattle

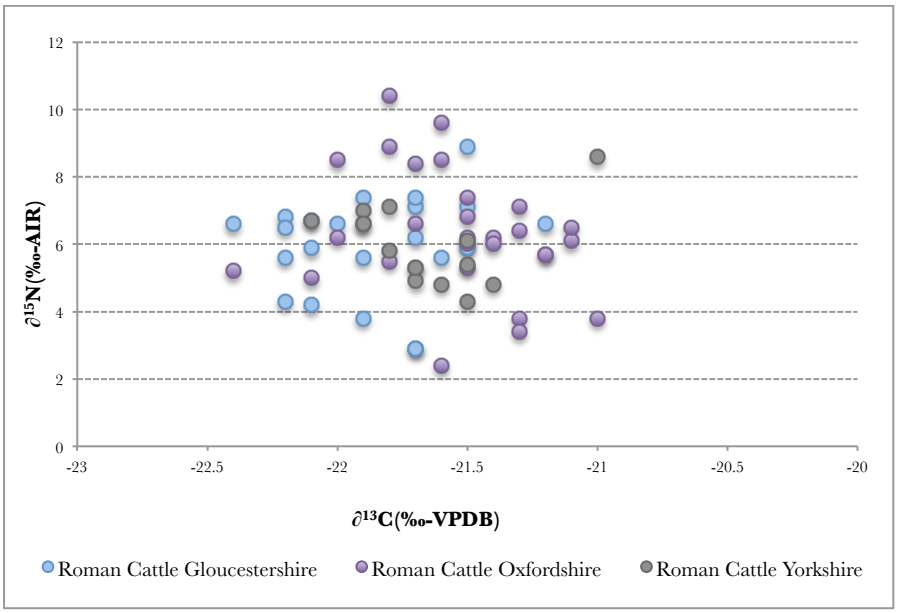


Figure 6.24. Comparison of the cattle data by regions in Roman Britain (Gloucester n =23, Oxfordshire n =29, Yorkshire n =31).

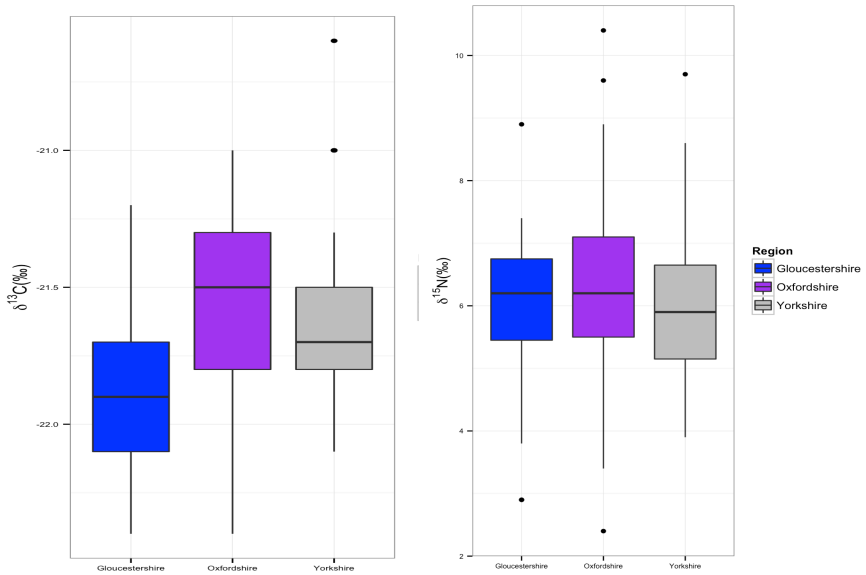


Figure 6.25. Boxplots comparison of the cattle data by regions in Roman Britain (Gloucester n =23, Oxfordshire n =29, Yorkshire n =31).

Despite Gloucestershire being visibly depleted in ^{13}C compared to the other regions, this difference is not statistically significant (Figure 6.24, 6.25; Table 6.26). Yorkshire also seems to be depleted in ^{15}N compared to Gloucestershire and Oxfordshire but again, this is not statistically significant. This lack of regional difference could be interpreted as a possible homogenisation of agriculture across the country, but it might also simply be that any regional difference in the cattle's diets cannot be detected through isotopic analyses.

Table 6.26. Statistical results for the cattle data when comparing regions in Roman Britain. Values in bold indicate statistical significance. The results remained similar between the same groups regardless of whether 'Sub-Period' was integrated as fixed or random effects.

Region	**Multi-Level Model With 'Sites' As Random Effect And 'Region' And 'Sub-Period' As Fixed Effects.**	
	p-value ($\partial^{13}C$)	*p-value* ($\partial^{15}N$)
Gloucestershire-Oxfordshire	0.127	0.996
Gloucestershire-Yorkshire -	0.215	1.000
Oxfordshire - Yorkshire	0.973	0.996

6.2.4.2 Sheep

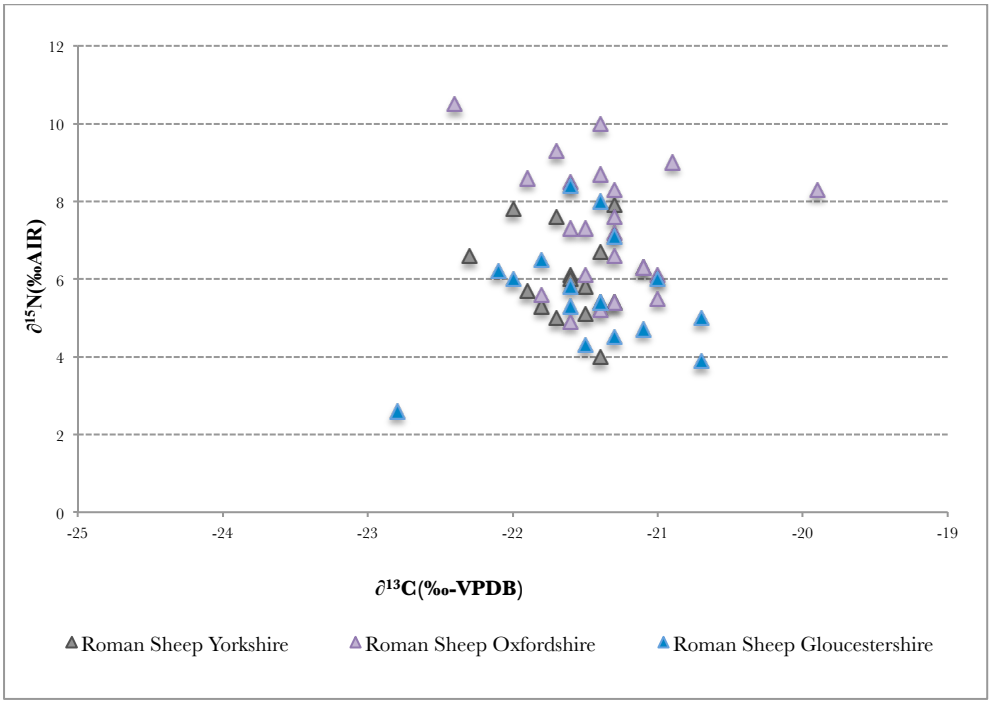


Figure 6.26. Comparison of the sheep data by regions in Roman Britain (Gloucester n =17, Oxfordshire n =23, Yorkshire n =35).

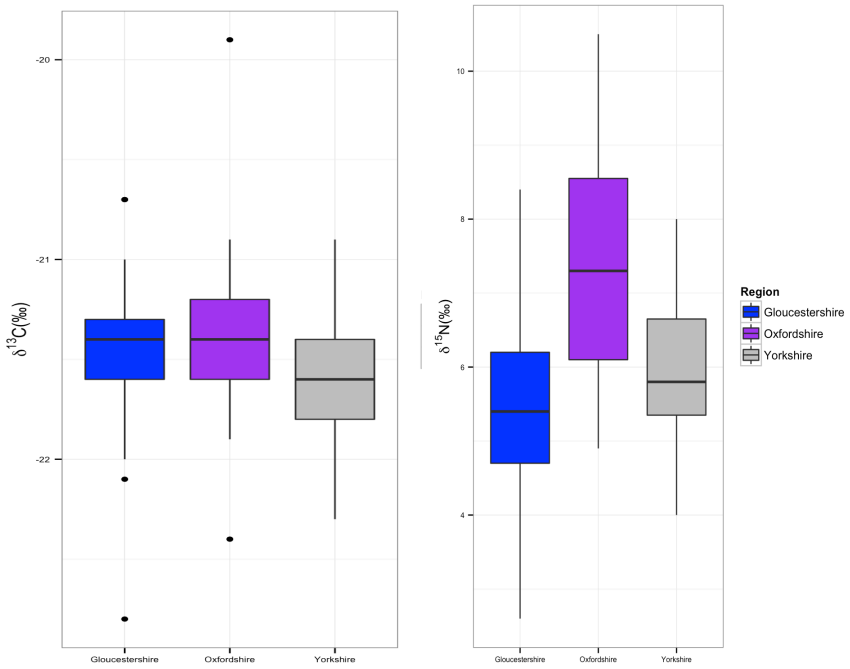


Figure 6.27. Boxplots comparison of the sheep data by regions in Roman Britain (Gloucester n =17, Oxfordshire n =23, Yorkshire n =35).

The data from Oxfordshire are visibly enriched in ^{15}N compared to the other regions, a difference that this suggestive (Figures 6.26, 6.27; Table 6.27), which would go against the suggestion of homogenisation of agriculture, unless sheep husbandry retained its regional characteristics while cattle did not. Again, however, this might be an over-interpretation of a small difference, but it remains interesting to note different regional patterns in the sheep and cattle data.

Table 6.27. Statistical results for the sheep data when comparing regions. Values in bold indicate statistical significance. The results remained significant between the same groups regardless of whether 'Sub-Period' was integrated as fixed or random effects.

Region	**Multi-Level Model With 'Sites' As Random Effect And 'Region' And 'Sub-Period' As Fixed Effects.**	
	p-value ($\partial^{13}C$)	*p-value* ($\partial^{15}N$)
Gloucestershire-Oxfordshire	0.921	0.062
Gloucestershire-Yorkshire -	0.913	0.922
Oxfordshire - Yorkshire	0.430	0.081

6.2.4.3 Pigs

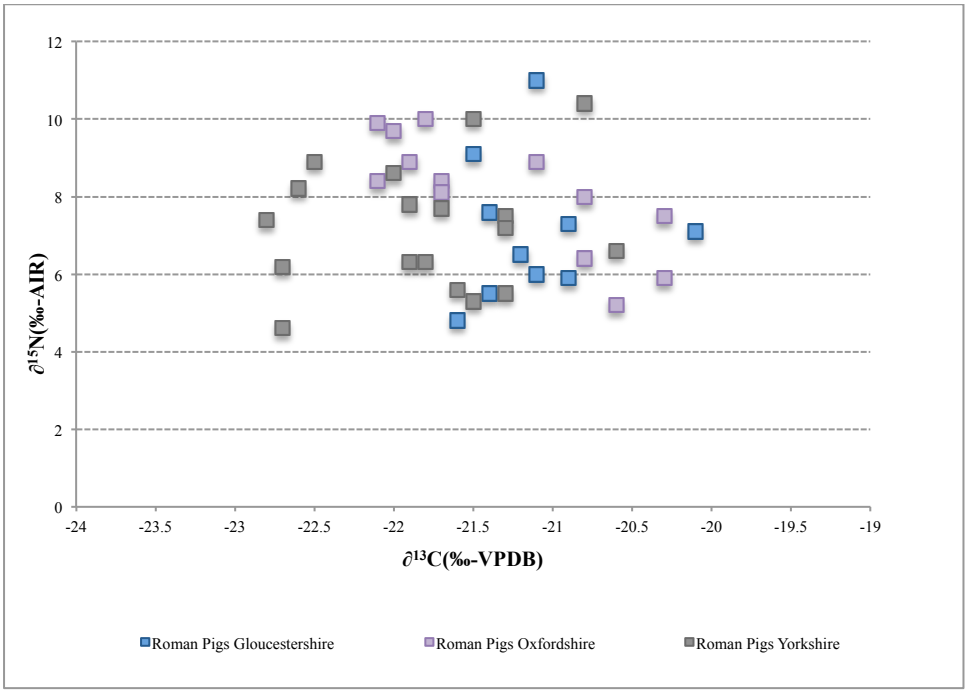


Figure 6.28. Comparison of the pig data by regions in Roman Britain (Gloucester n =11, Oxfordshire n =13, Yorkshire n =18).

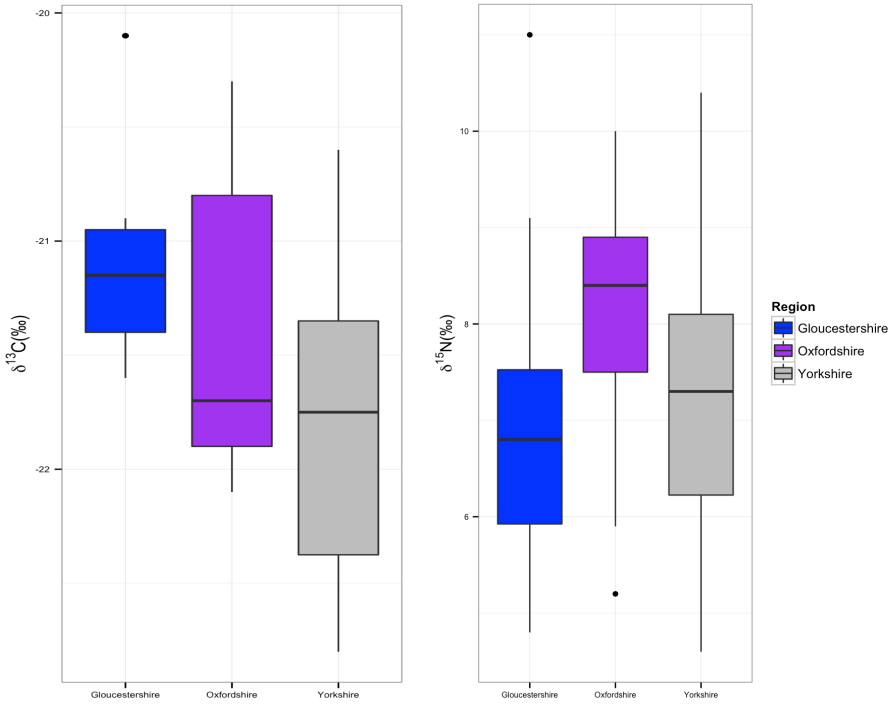


Figure 6.29. Boxplots comparison of the pig data by regions in Roman Britain (Gloucester n =11, Oxfordshire n =13, Yorkshire n =18).

Table 6.28. Statistical results for the pig data when comparing regions. Values in bold indicate statistical significance. The results remained significant between the same groups regardless of whether 'Sub-Period' was integrated as fixed or random effects.

Region	Multi-Level Model With 'Sites' As Random Effect And 'Region' And 'Sub-Period' As Fixed Effects.	
	p-value (∂^{13}C)	*p-value* (∂^{15}N)
Gloucestershire-Oxfordshire	0.979	0.986
Gloucestershire-Yorkshire -	0.948	0.993
Oxfordshire - Yorkshire	0.718	1.000

While some patterns might appear visible in the pig data, particularly between Gloucestershire and Yorkshire, with the pig data from Gloucestershire displaying high ∂^{15}N and low ∂^{13}C ratios, and the reverse pattern in Yorkshire, there are no statistical differences between them (Figures 6.28, 6.29; Table 6.28), as was the case in the Iron Age. Again, regional differences between the pigs' diet cannot be ruled out categorically, but is not visible in the data available here.

6.2.4.4 Urban and Rural Settlements

Another regional pattern worth investigating in the Roman period is the difference between urban centres and more rural settlements, the distribution of which is in Table 6.29.

Table 6.29. Distribution of the cattle data according to site location in the Roman period.

Site Type	N of sites	N of samples	Broad Archaeological Period	Region	Site
Rural	6	45	Roman	Gloucestershire, Oxfordshire, Somerset, Yorkshire	Alchester, Asthall, Bradley, Hill, Catterick, Hucclecote, Yarnton
Urban	6	54	Roman	Gloucestershire, Hampshire, Oxfordshire, Yorkshire	6 Driffield Terrace (York), Blossom Street (York), Cirencester, Gloucester, Winchester, York.

Figures 6.30 and 6.31 show the cattle data from rural and urban settlements from different regions around England (Gloucestershire, Yorkshire, Somerset and Oxfordshire). The cattle $\partial^{13}C$ and $\partial^{15}N$ values are on average a little bit higher in rural settlements but there is no statistical significance between them (Table 6.30).

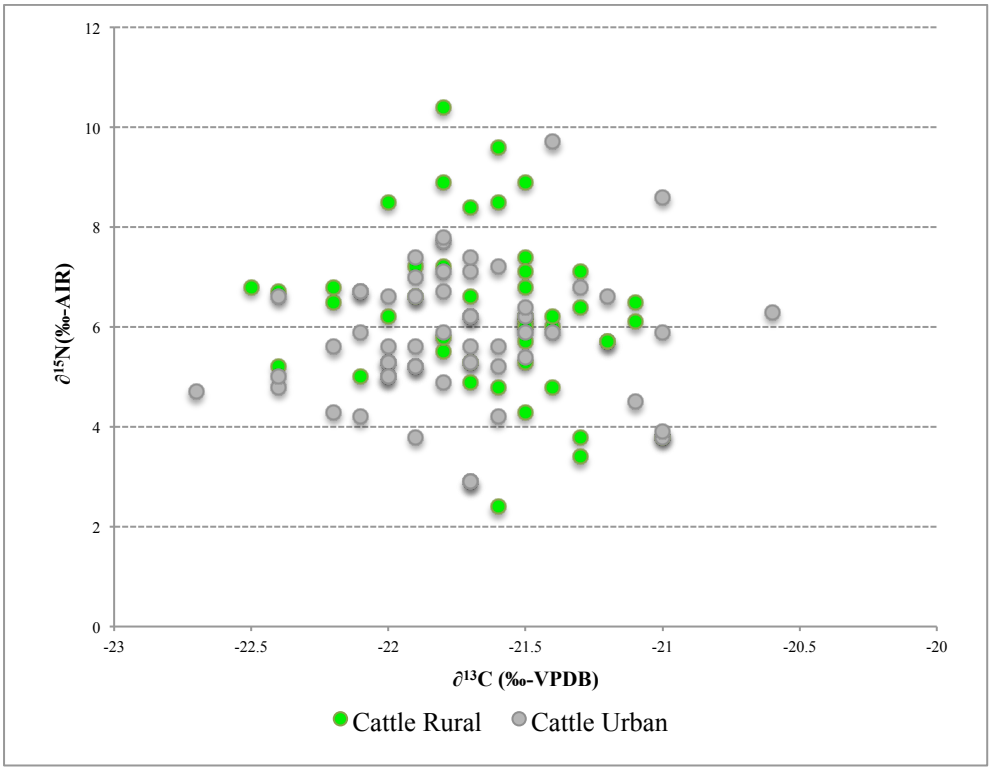


Figure 6.30. Comparison of the cattle data according to nature of site in the Roman period (Rural Cattle n=45, Urban Cattle 54).

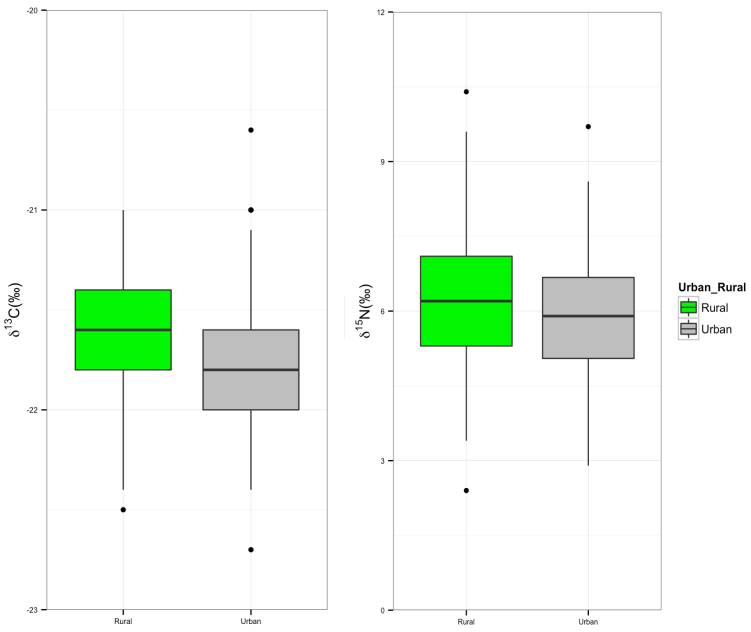


Figure 6.31. Boxplot comparison of the cattle data according to nature of site in the Roman period (Rural Cattle n=45, Urban Cattle 54).

Table 6.30. Statistics results for the cattle data when comparing urban/rural settlements. Since all the sites were in the same broad archaeological period ('Roman Britain'), models were tested with 'Sub-Periods' and 'Regions' as fixed/random variables. The results remained the between the same groups regardless of whether 'Sub-Period' and 'Regions' were integrated as fixed or random effects.

Urban-Rural	***Multi-level model with 'Sites', 'Region' and 'Sub-Period' as random effect, and 'Urban/Rural' as fixed variable.***	
	p-value (∂^{13}C)	*p-value* (∂^{15}N)
Urban-Rural	0.768	0.655

6.2.5 Preliminary discussion of the Roman faunal data

There are few patterns in the faunal data in the Roman periods, whether regionally or by sub-periods. The main pattern is the moderate different in the ∂^{15}N values of the sheep between Oxfordshire and both Gloucestershire and Yorkshire, with the sheep in Oxfordshire displaying higher ∂^{15}N values compared to the other regions. This might be due to the presence of younger

animals in the data, rather than environmental factors, which would have been expected in the other species too. The lack of variation in the rest of the data could be explained either by more homogenous agricultural practices across Britain or by the variation measured being within the error range. Overall, it is nonetheless important to note that the Roman faunal data are elevated compared to the Iron Age data, an observation already made by Hamilton (2016). This will be explored further and statistically tested in section 6.4 of this chapter.

6.3. Early Medieval

6.3.1 Faunal isotopic results

Table 6.31. Summary of the faunal data in the Early Medieval data.

	Average	Average	min	max	range	min	max	range	n=
	$\partial^{13}C$(‰)	$\partial^{15}N$(‰)	$\partial^{13}C$ ‰	$\partial^{13}C$ ‰	$\partial^{13}C$ ‰	$\partial^{15}N$ ‰	$\partial^{15}N$ ‰	$\partial^{15}N$ ‰	
Cat	-20.3 ± 0.49	9.5 ± 0.35	-20.7	-19.5	1.2	9.1	9.9	0.8	5
Cattle	-21.8 ± 0.68	5.1 ± 1.19	-23.3	-20.3	3	1.4	9.1	7.7	138
Chicken	-20.7 ± 0.54	10.8± 1.11	-21.4	-19.7	1.7	9.2	10.4	1.2	8
Freshwater Fish	-22.2 ± 3.66	11.8± 1.82	-25.7	-13.1	12.6	8.8	14.9	6.1	11
Marine Fish	-14.4 ± 1.11	12.8± 1.65	-15.8	-12.4	3.4	10.60	15.40	4.80	13
Pig	-21.4 ± 0.53	7.0 ± 1.76	-22.4	-19.6	2.8	2.5	12.1	9.6	90
Salmonid	-15.0 ± 0.59	11.2± 2.49	-15.6	-14	1.6	8.6	13.9	5.3	6
Sheep	-21.5 ± 0.65	5.4 ± 1.32	-24.5	-20.0	4.5	1.9	9.5	7.6	182

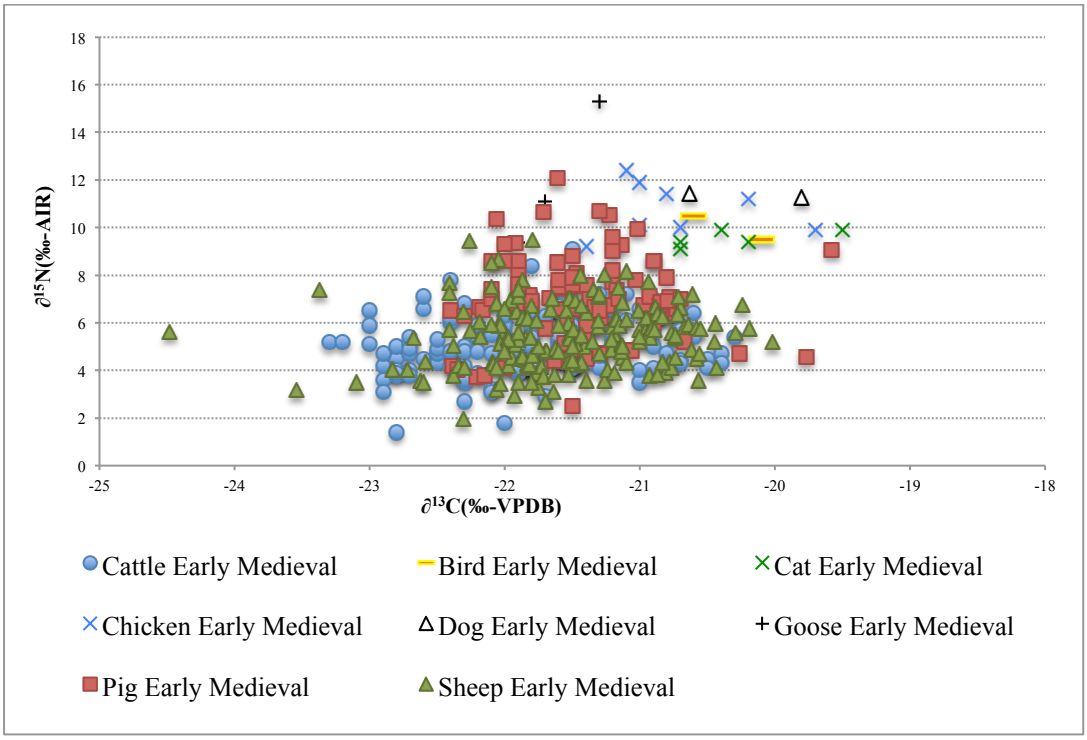


Figure 6.32. Isotopic distribution of the terrestrial faunal data species in Early Medieval Britain (Bird n=2, Cat n=5, Cattle n=138, Chicken n=8, Dog n=2, , Goose n=3, Pig n=90, Sheep n=182).

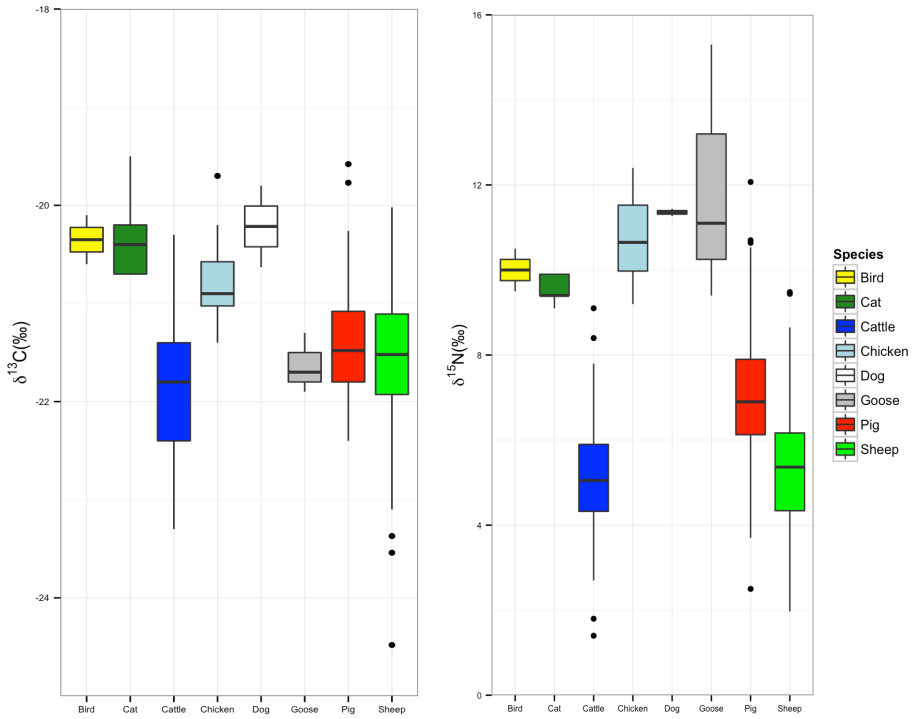


Figure 6.33. Boxplot comparisons of the isotopic distribution of the terrestrial faunal data species in Early Medieval Britain (Bird n=2, Cat n=5, Cattle n=138, Chicken n=8, Dog n=2, , Goose n=3, Pig n=90, Sheep n=182).

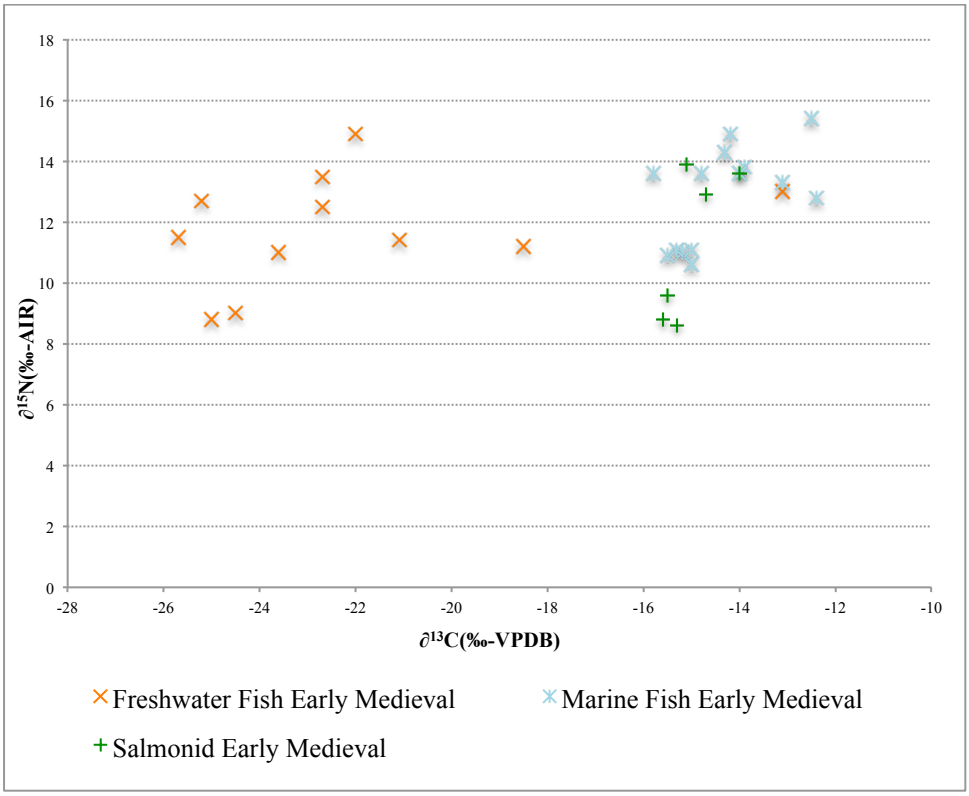


Figure 6.34. Isotopic distribution of the aquatic faunal data species in Early Medieval Britain (Freshwater fish n=11, Goose n=3, Marine Fish n=14, Pig n=90, Salmonid n=6).

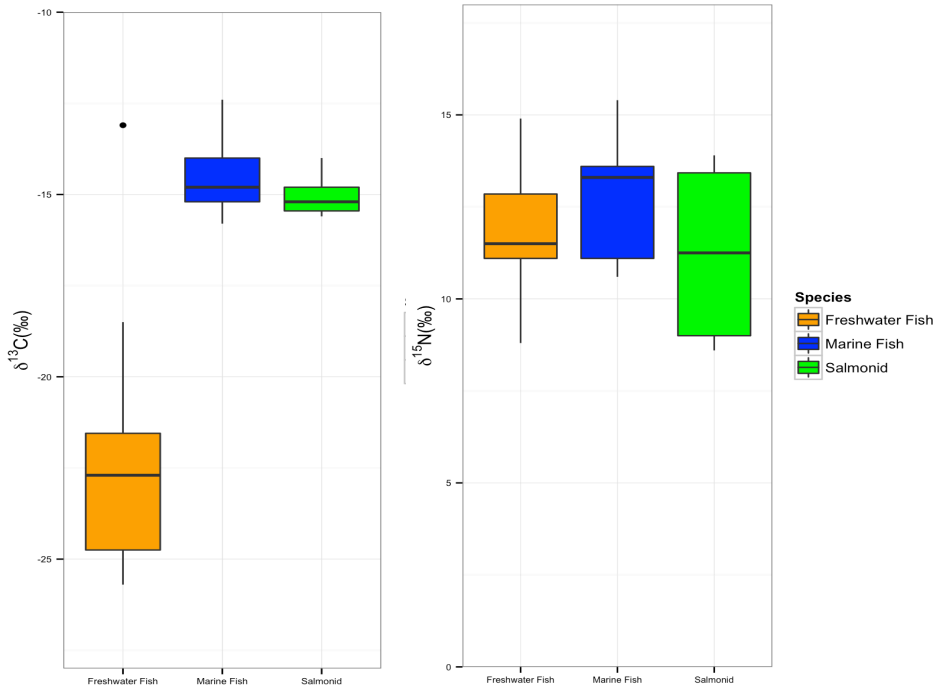


Figure 6.35. Boxplot comparison of the aquatic faunal data species in Early Medieval Britain (Freshwater fish n=11, Goose n=3, Marine Fish n=14, Pig n=90, Salmonid n=6).

Cattle and sheep have similar isotopic values (cattle $\partial^{13}C$: -21.8 ± 0.68‰, $\partial^{15}N$: 5.1 ± 1.19‰; sheep $\partial^{13}C$: -21.5 ± 0.65‰, $\partial^{15}N$: 5.4 ± 1.32‰). The sheep have a much wider $\partial^{13}C$ range (sheep $\partial^{13}C$ range: 4.46‰; cattle $\partial^{13}C$ range: 2.98‰) but this is due to the presence of three individual animals with very low $\partial^{13}C$ values in the sheep population. If these are removed, they have similar ranges (sheep $\partial^{13}C$ range: 2.72‰; cattle $\partial^{13}C$ range: 2.98‰). Again, while pigs have a similar $\partial^{13}C$ average to the other two species, their $\partial^{15}N$ average is higher ($\partial^{13}C$: -21.4 ± 0.53‰, $\partial^{15}N$: 7 ± 1.77‰). Chickens are the terrestrial animals with the highest $\partial^{15}N$ average but relatively low $\partial^{13}C$ average (Table 6.31; Figure 6.32 and 6.33). The chicken $\partial^{15}N$ values are even comparable to the aquatic freshwater fauna (eel $\partial^{15}N$: 10.86‰; salmon $\partial^{15}N$: 11.23‰; herring 10.94‰). Eels have the lowest $\partial^{13}C$ values of the faunal dataset ($\partial^{13}C$: -24.3‰), which is not surprising for fish that spend most of their life in fresh water. Salmon and herring have much higher $\partial^{13}C$ values, respectively -15.03‰ and -15.2‰ (Table 6.31; Figures 6.34 and 6.35). Once again, pigs have the most different $\partial^{15}N$ values compared to cattle and sheep, but also significantly differ in $\partial^{13}C$ compared to cattle (Table 6.32). It is also worth noting that the 'freshwater fish' sample with a $\partial^{13}C$ value of -13.1‰ is likely to have been misidentified, and that is particular sample is that of a marine fish.

Table 6.32 Statistics for the herbivores data in the Early Medieval period. Values in bold indicate statistical significance. The results remained significant between the same groups regardless of whether 'Region' and 'Sub-Period' were integrated as fixed or random effects.

SPECIES	*ANOVA + TUKEY HSD*		**Multi-Level Model With 'Sites' And 'Region' As Random Effects**	
	p-value (∂^{13}C)	*p-value* (∂^{15}N)	*p-value* (∂^{13}C)	*p-value* (∂^{15}N)
Cattle - Pig	**0.013**	**0.000**	**0.037**	**0.001**
Cattle - Sheep	0.080	1.000	0.206	0.364
Sheep -Pig	1.000	**0.000**	0.987	**0.001**

Overall, the carbon and nitrogen isotopic averages for all three domesticated fauna fall between the values of the Iron Age and Roman Britain. Contrary to either the Iron Age or the Roman period, the one example of correlation between both isotopes is in the cattle data, and this time there is a very small positive correlation (Table 6.33). Because Pearson's r is so low, and the *p-value* might be reflecting the sample size rather than true significance, it is considered not to be meaningful.

Table 6.33. Results of Pearson's correlation (r) between ∂^{13}C and ∂^{15}N for the faunal data in Early Medieval Britain.

Species	Pearson's *r*	*p-value*	*n*
Cattle	**0.18**	**0.026**	138
Sheep	0.10	0.172	182
Pig	0.029	0.782	90

6.3.2 Diachronic trends within the Early Medieval period

As was the case in the Iron Age and the Roman period, the cattle and sheep data were chosen to investigate diachronic variations within the broader period. Distribution of the data is in Tables 6.34 and 6.36

6.3.2.1 Cattle

Table 6.34. Distribution of the cattle data between the different sub-periods, by sites, number of samples and regions in Early Medieval Britain.

Sub-Period	n of sites	n of samples	Region	Site
Anglo-Saxon	4	57	North Lincolnshire, Northumberland, Suffolk Yorkshire	Black Cemetery (Newcastle), Masham, West Stow, Whitton
Early Anglo-Saxon	4	61	Gloucestershire, Hampshire, Oxfordshire	Abbot's Worthy, Berinsfield, Butler's Field Lechlade, Shavard's Farm
Middle Anglo-Saxon	2	10	Suffolk, Yorkshire	Bellevue (York), Bloodmoor Hill,
Late Saxon/ Norman	9	10	Yorkshire	Fishergate (York)

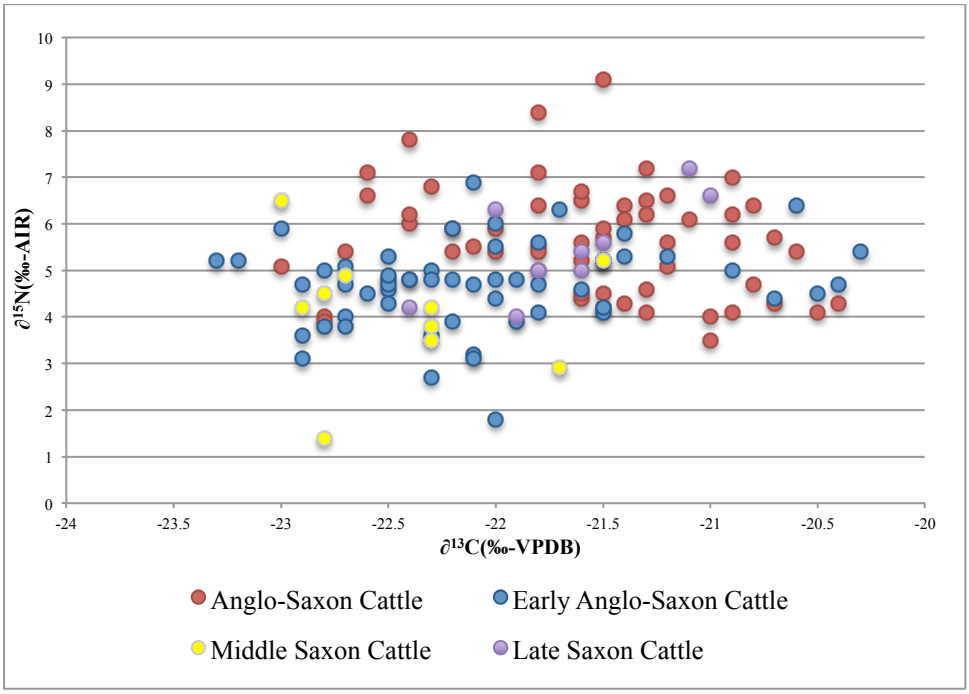


Figure 6.36. Chronological comparison of the cattle data within the broad Early Medieval period (Anglo-Saxon n =57, Early Anglo-Saxon n=61, Middle Anglo-Saxon n =10, Late Saxon/Norman n = 10)

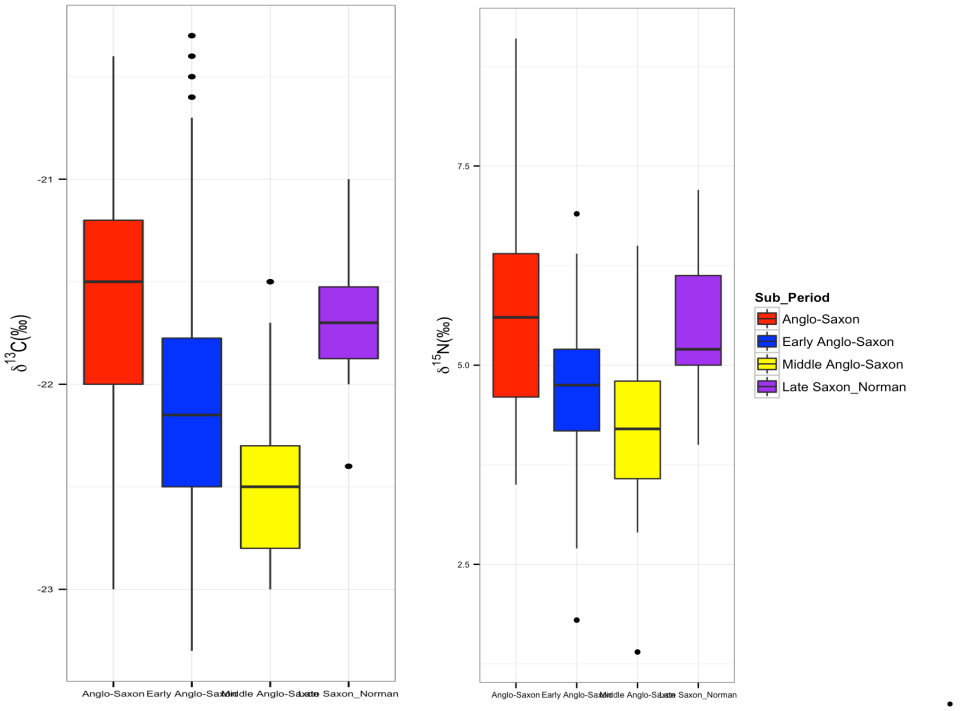


Figure 6.37. Boxplot comparisons of the $\partial^{13}C$ and $\partial^{15}N$ values for the cattle of the different sub-periods within Early Medieval Britain. (Anglo-Saxon n =57, Early Anglo-Saxon n=61, Middle Anglo-Saxon n =10, Late Saxon/Norman n = 10)

Figures 6.36 and 6.37 show that the Middle-Saxon cattle are depleted in both isotopes compared to the other sub-periods, but this difference is only significant when compared against the less well-dated samples ('Anglo-Saxon'; Table 6.35). Concerning the better-dated samples, a pattern of depletion and enrichment appears visible between the earlier and the later sub-periods, like was the case in the Roman periods (Figure 6.17, Table 6.20), but not in the Iron Age. This does not appear to be significant (Table 6.35) but will be reassessed in the broader context of the *longue durée* in section 6.4 of this chapter.

Table 6.35. Statistical results between the sub-periods in the Early Medieval cattle data. Different models were 'best-fit' for the different isotopes, but this did not affect significance, whether 'regions' was integrated as a random or a fixed effects in either model.

Sub_Period	Multi-Level Model With Sites As Random Effect	Multi-Level Model With Sites And Region As Random Effects
	p-value ($\partial^{13}C$)	*p-value* ($\partial^{15}N$)
Anglo-Saxon – Early Anglo- Saxon	0.957	0.502
Anglo-Saxon – Middle Anglo-Saxon	0.339	**0.026**
Anglo-Saxon – Late Anglo-Saxon/Norman	0.997	0.605
Early Anglo- Saxon – Middle Anglo-Saxon	0.947	0.619
Early Anglo- Saxon – Late Saxon/Norman	0.941	0.999
Middle Anglo-Saxon – Late Saxon/Norman	0.455	0.490

6.3.2.2 Sheep

Table 6.36. Distrubtion of the sheep data between the different sub-periods, by sites, number of samples and regions in Early Medieval Britain.

Sub-Period	n of sites	n of samples	Region	Site
Anglo-Saxon	4	81	North Lincolnshire, Northumberland, Suffolk Yorkshire	Black Cemetery (Newcastle), Masham, West Stow, Whitton
Early Anglo-Saxon	4	84	Gloucestershire, Hampshire, Oxfordshire	Abbot's Worthy, Berinsfield, Butler's Field Lechlade, Shavard's Farm
Middle Anglo-Saxon	2	8	Suffolk, Yorkshire	Bellevue (York), Bloodmoor Hill,
Late Saxon/Norman	9	9	Yorkshire	Fishergate (York)

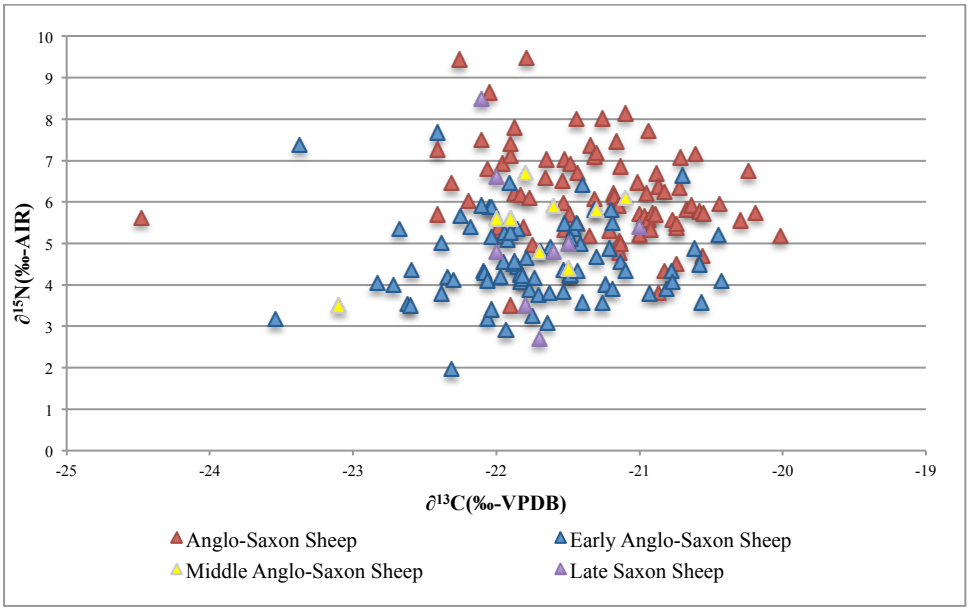


Figure 6.38. Chronological distribution of the sheep data within the broad Early Medieval period (Anglo-Saxon n =81, Early Anglo-Saxon n=84, Middle Anglo-Saxon n =8, Late Saxon/Norman n = 9)

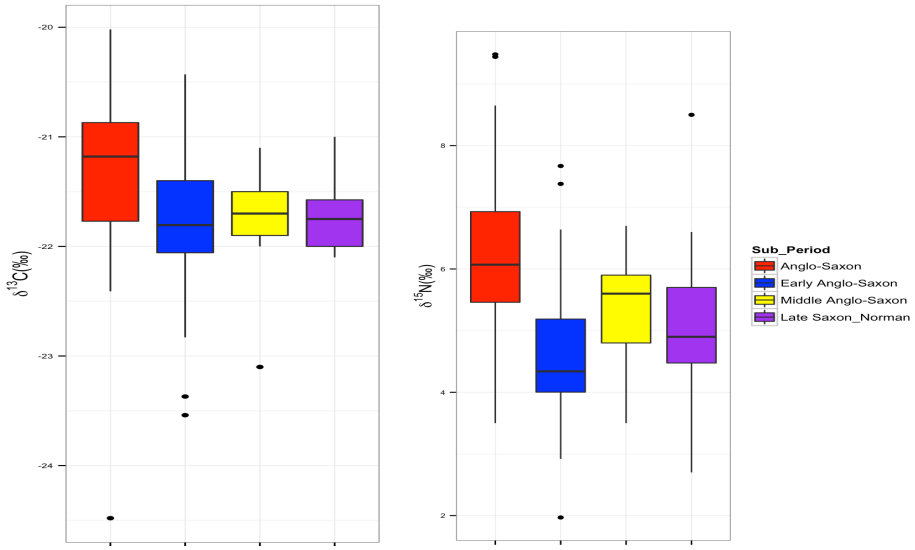


Figure 6.39. Boxplot distribution of the $\partial^{13}C$ and $\partial^{15}N$ values of the different sub-periods within Early Medieval Britain. (Anglo-Saxon n =81, Early Anglo-Saxon n=84, Middle Anglo-Saxon n =8, Late Saxon/Norman n = 9)

The sheep data appeared to be spilt in two groups, between the less well-dated data ('Anglo-Saxon') and the earlier samples ('Early Anglo-Saxon'), with the former enriched in both isotopes compared to the latter (Figures 6.38, 6.39). However, this is not statistically significant when taking into

account the site and regional distribution of the data (Table 6.37). While there is no significant difference between all the sub-periods, it is still worth noting that the sheep data do not display the same pattern as the cattle data for the sub-periods results (section 6.3.2.1). Indeed, in the sheep data, all three sub-periods have fairly similar $\partial^{13}C$ ratios, and the Middle-Anglo-Saxon data are enriched in ^{15}N compared to the others sub-periods (except for the 'Anglo-Saxon' data), while the Middle-Anglo-Saxon cattle data was depleted in ^{15}N compared to the other sub-periods. This might suggest differences in how the cattle and sheep were kept in the Early Medieval period.

Table 6.37. Statistical differences between the sub-periods in the Early Medieval sheep data. The results were not affected, whether 'Region' was integrated as a random or a fixed effect.

Sub_Period	Multi-Level Model With 'Sites' As Random Effect	Multi-Level Model With 'Sites' And 'Region' As Random Effects
	p-value ($\partial^{13}C$)	*p-value* ($\partial^{15}N$)
Anglo-Saxon – Early Anglo-Saxon	0.999	0.157
Anglo-Saxon – Middle Anglo-Saxon	0.984	0.393
Anglo-Saxon – Late Anglo-Saxon	0.997	0.997
Early Anglo-Saxon – Middle Anglo-Saxon	0.991	0.991
Early Anglo-Saxon – Late Anglo-Saxon	0.999	0.999
Middle Anglo-Saxon – Late Anglo-Saxon	0.999	0.999

6.3.3. Regional trends in the Early Medieval period

Three regions are analysed here, following the criteria established in Chapter 4, section 4.2.3

6.3.3.1 Hampshire

Table 6.38. Summary of the Hampshire (data from Abbot's Worthy n= 83, Shavard's Farm n = 63)

	Average $\partial^{13}C$(‰)	Average $\partial^{15}N$(‰)	min $\partial^{13}C$ ‰	max $\partial^{13}C$ ‰	range $\partial^{13}C$ ‰	min $\partial^{15}N$ ‰	max $\partial^{15}N$ ‰	range $\partial^{15}N$ ‰	n=
Cattle	-22.1 ± 0.71	4.6 ± 0.90	-23.3	-20.3	2	1.8	6.9	5.1	52
Sheep	-21.7 ± 0.62	4.5 ± 0.96	-23.5	-20.4	3.1	1.9	7.7	5.8	80
Pig	-21.6 ± 0.77	5.3 ± 1.40	-22.4	-19.8	2.6	3.7	8.5	4.8	14

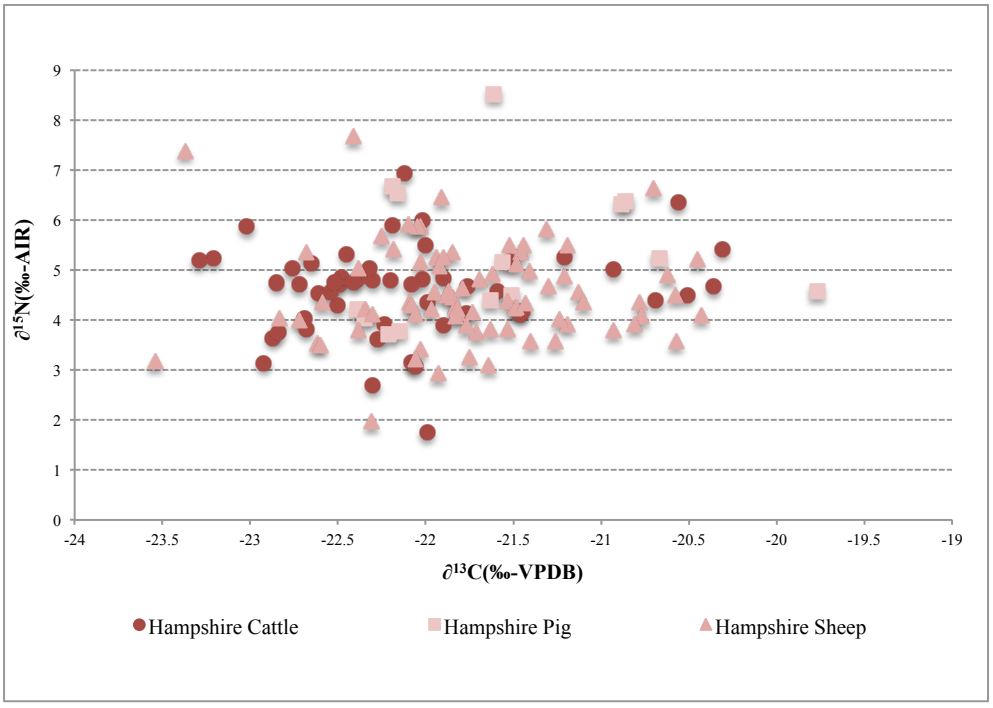


Figure 6.40. Results of the Hampshire faunal data in Early Medieval Britain (Cattle n= 52, Sheep n = 80, Pig n = 14)

The carbon isotopic data for the Hampshire fauna range between -23.5‰ to -19.8‰ with a relatively wide range for each species with > 3‰ difference between the lowest ∂-value and the highest one. On average though, cattle and sheep have lower $\partial^{13}C$ values (-21.7 ± 0.62‰ for sheep and -22.1 ±

0.71‰ for cattle), while pigs have slightly higher ones (-21.6 ± 0.77‰). While these values are close to the period average for all three species, their ∂^{15}N average values are much lower than the Early Medieval ∂^{15}N average (Tables 6.31; 6.38; Figure 6.40). This is particularly interesting as this was also the case in the Iron Age that the Hampshire faunal data were lower than the national average too, maybe pointing to perennial regional differences in Hampshire compared to other regions. This will be explored further in section 6.5.

6.3.3.2 Suffolk

Table 6.39. Summary of the Suffolk (data from West Stow n= 150, Bloodmoor Hill n = 17)

	Average ∂^{13}C(‰)	Average ∂^{15}N(‰)	min ∂^{13}C(‰)	max ∂^{13}C(‰)	range ∂^{13}C(‰)	min ∂^{15}N(‰)	max ∂^{15}N(‰)	range ∂^{15}N(‰)	n=
Cattle	-21.6 ± 0.71	5.2 ± 1.23	-23	-20.4	2.6	1.4	7.8	6.4	53
Sheep	-21.3 ± 0.67	6.0 ± 0.92	-24.5	-20.0	4.5	3.5	8.1	4.6	76
Pig	-21.2 ± 0.45	6.7 ± 1.59	-22.0	-19.6	2.4	2.5	10.5	8.5	38

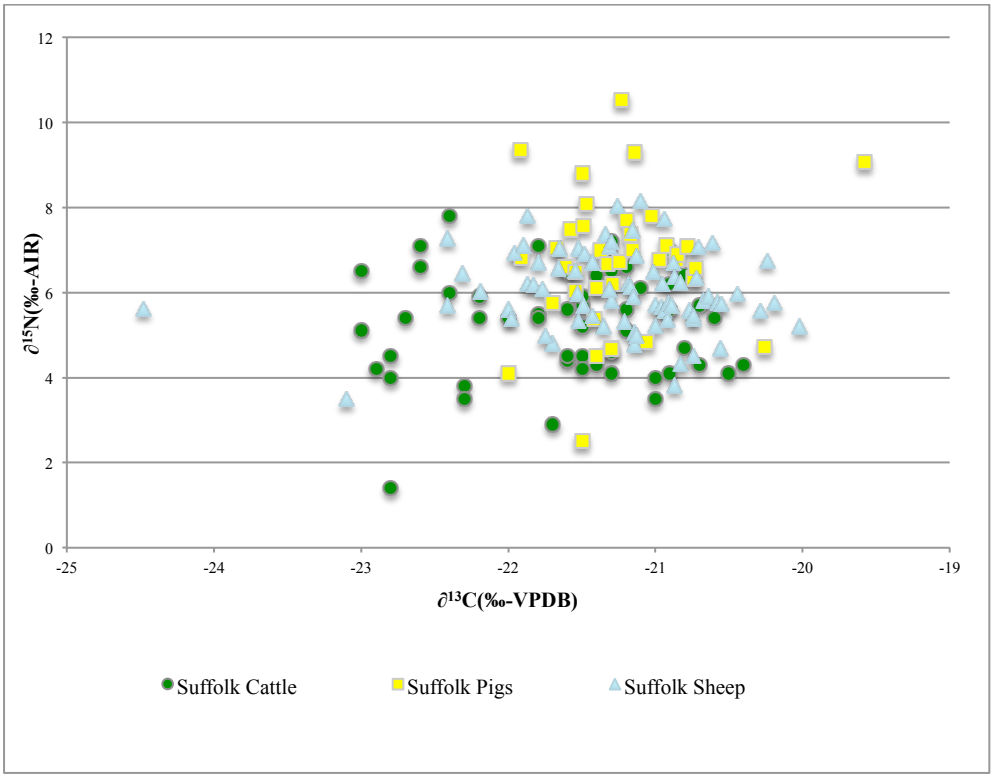


Figure 6.41. Results of the Hampshire faunal data in Early Medieval Britain (Cattle n= 53, Sheep n = 76, Pig n = 38)

The faunal data in Suffolk are slightly enriched in both isotopes compared to the period averages for these species (see Table 6.31, 6.39, Figure 6.41). It is worth noting that a group of cattle and sheep seems to have lower $\partial^{13}C$ values than the rest of the fauna (<22‰), and one sheep has an extremely depleted $\partial^{13}C$ ratio (-24.5‰), while some of the pigs display high $\partial^{15}N$ values (> 8.5‰). The data depleted in ^{13}C are from both West Stow and Bloodmoor Hill, but the data from Bloodmoor Hill systematically plot lower than the data from West Stow, suggesting possibly different ecological niches or animal husbandry strategies between the different sites in Suffolk (O'Connell and Lawler 2009).

6.3.3.3 Yorkshire

Table 6.40. Summary of the Yorkshire (data from Bellevue (York) n= 13, Fishergate (York) n = 37 , Masham n = 8).

	Average $\partial^{13}C$(‰)	Average $\partial^{15}N$(‰)	min $\partial^{13}C$(‰)	max $\partial^{13}C$(‰)	range $\partial^{13}C$(‰)	min $\partial^{15}N$(‰)	max $\partial^{15}N$(‰)	range $\partial^{15}N$(‰)	n=
Cattle	-21.8± 0.45	5.4 ± 0.94	-22.7	-21.0	1.7	4.0	7.2	3.2	15
Sheep	-21.7± 0.61	5.4 ± 1.61	-22.1	-21.0	1.1	2.7	8.5	5.8	15
Pig	-21.6± 0.44	7.7 ± 1.21	-22.4	-20.7	1.7	5.9	10.7	4.8	28

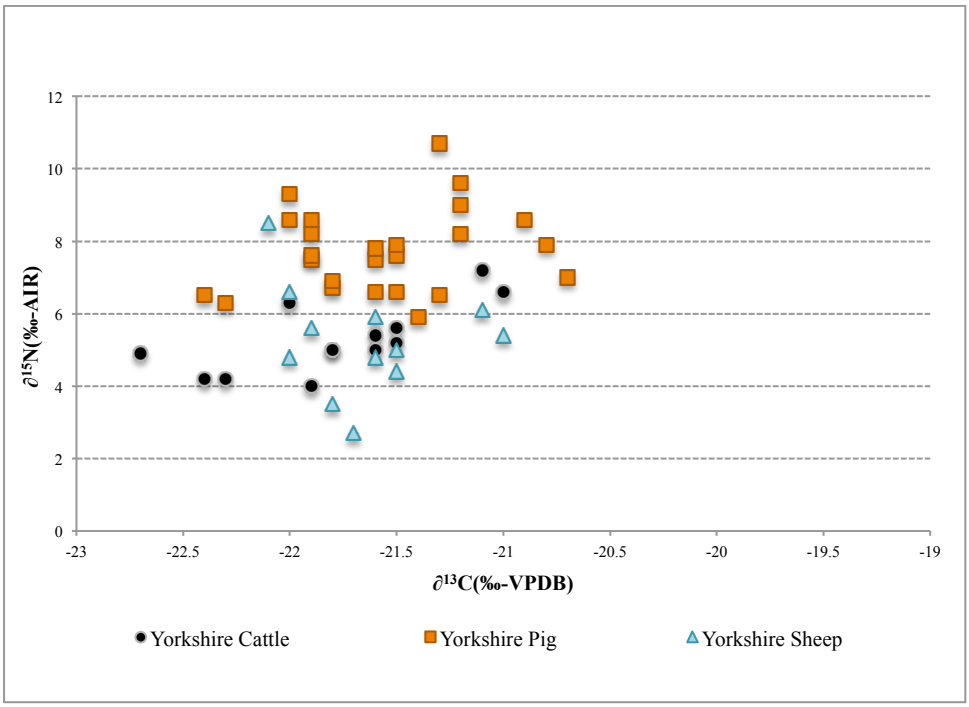


Figure 6.42. Results of the Yorkshire faunal data in Early Medieval Britain (Cattle n= 15, Sheep n = 15, Pig n = 28)

The Yorkshire faunal data for the Early Medieval period are unusal in that pigs dominate the record (n=28) over cattle (n=15) and sheep (n=15; Table 6.42). The Yorkshire faunal $\partial^{13}C$ data range between -22.7‰ to -20.7‰, which is similar to the averages seen so far. The cattle data have a $\partial^{13}C$ average of -21.8 ±0.45‰, sheep of -21.7 ± 0.61‰ and pig of -21.6± 0.44‰.

Cattle and sheep have exactly the same $\partial^{15}N$ averages (5.4‰) but the standard error is larger for sheep (±1.61‰) than it is for cattle (±0.94‰). Indeed, sheep $\partial^{13}C$ values have a wider range (3.2‰ for cattle and 5.8‰ for sheep). Pigs have higher $\partial^{15}N$ values (7.7 ± 1.21‰, which is higher than the period average (Table 6.31, Figure 6.42).

6.3.4 Regional comparisons

As was done in the other periods, each species has been compared across period.

6.3.4.1 Cattle

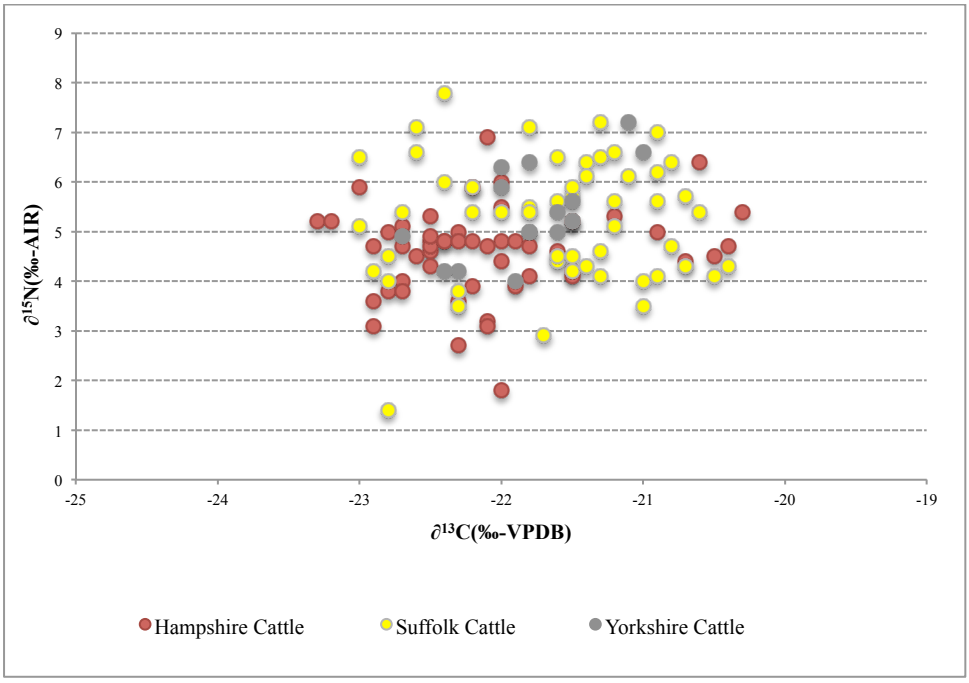


Figure 6.43. Comparison of the cattle data by regions in Early Medieval Britain (Hampshire n =52, Suffolk n =53, Yorkshire n =15).

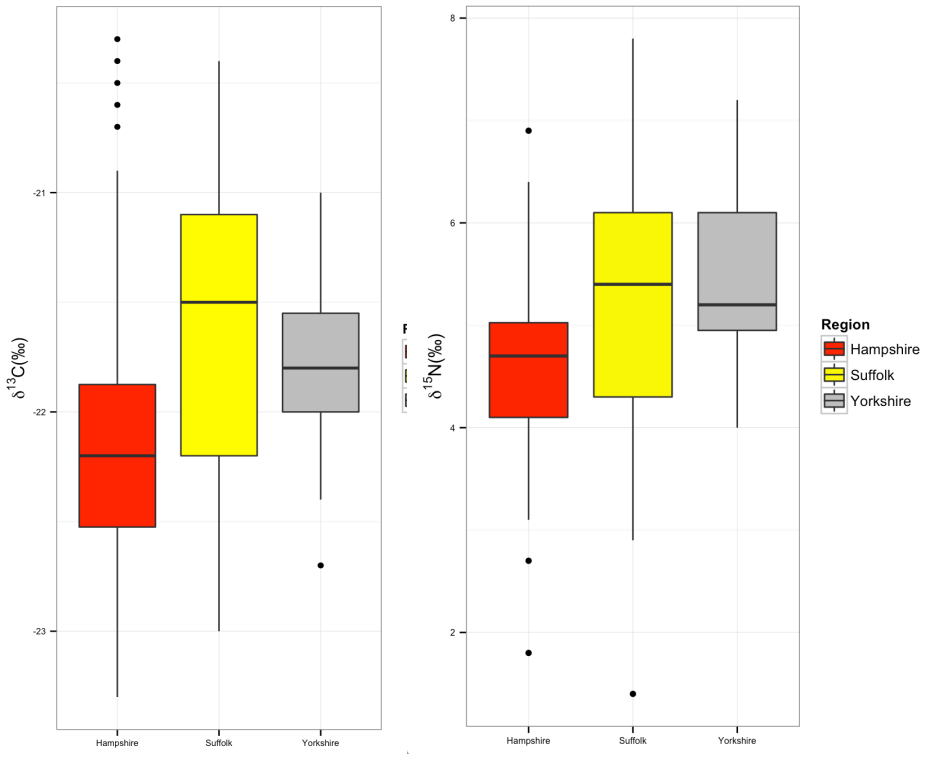


Figure 6.44. Boxplot comparison of the cattle data by regions in Early Medieval Britain (Hampshire n =52, Suffolk n =53, Yorkshire n =15).

There appears to be a distinction between the cattle from Hampshire and the cattle from Suffolk, with the latter displaying higher $\partial^{13}C$ values than the former (Figures 6.43, 6.44). However, these divisions are not significant when statistically analysed through a multivariate model taking into account the 'sub-period' variable (Table 6.41). Indeed, the data from Suffolk and Hampshire are also almost exclusively dated to the 'Anglo-Saxon' period (Suffolk) and 'Early Anglo-Saxon period' (Hampshire). In section 6.3.2.1, it was shown that there was a significant difference in the sub-periods (Figures 6.36, 6.37). The absence of significant difference here, whether sub-period is integrated into the statistical model as a fixed or random effect strongly suggest that the difference in the cattle data are due to changing diets and/or environments over time, rather than over space.

Table 6.41. Statistical differences between regions in the Early Medieval cattle data. The results did not change, whether 'sub-period' was integrated as a random or a fixed effect.

Region	*Multi-Level Model With 'Sites' As Random Effect And 'Region' And 'Sub-Periods' As Fixed Effects.*	
	p-value ($\partial^{13}C$)	*p-value* ($\partial^{15}N$)
Hampshire-Suffolk	1.000	1.000
Hampshire-Yorkshire -	0.999	0.874
Suffolk-Yorkshire	1.000	0.946

6.3.4.2 Sheep

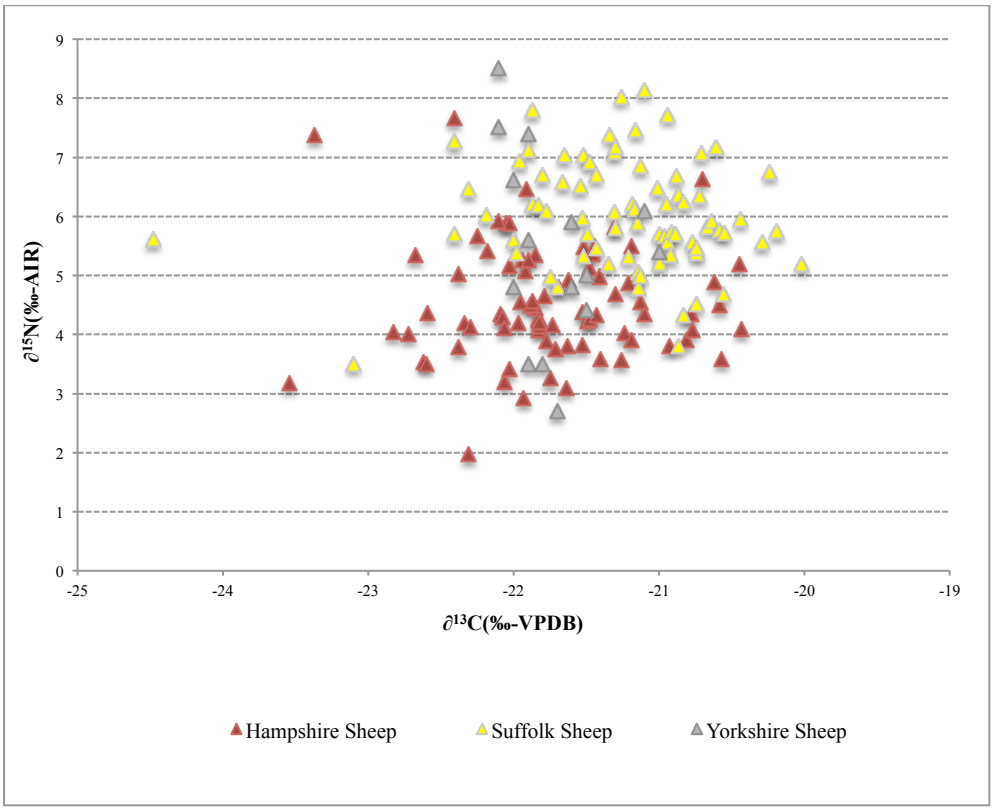


Figure 6.45. Comparison of the sheep data by regions in Early Medieval Britain (Hampshire n =80, Suffolk n =76, Yorkshire n =15).

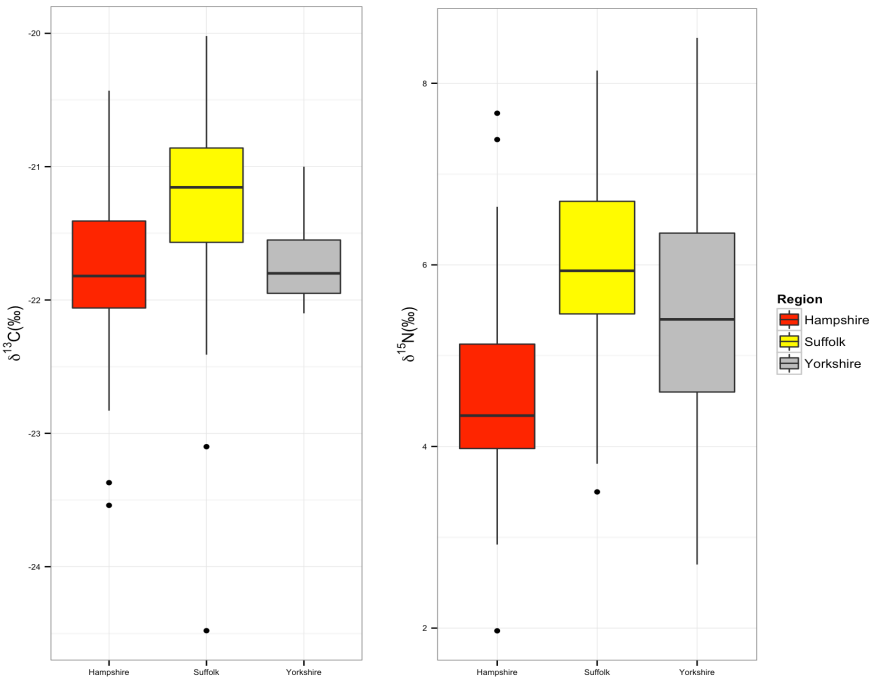


Figure 6.46. Boxplot comparison of the sheep data by regions in Early Medieval Britain (Hampshire n =80, Suffolk n =76, Yorkshire n =15).

The sheep data in the Early Medieval period show the same dichotomy between Hampshire and Suffolk as the cattle data, with the data from Hampshire depleted in both isotopes compared to the data from Suffolk (Figures 6.45, 6.46). However, contrary to the cattle, this time, there is a moderately significant difference between both regions (Table 6.42), while there was not one between sub-periods (Table 6.3.2.2). While this is interesting, one must wonder if these differences between the cattle/sheep data and these diachronic/regional patterns are a result of the data distribution, even when tested through multivariate statistical models. However, it is worth pointing out that the sheep data systematically revealed regional differences in all three periods. It is therefore possible that sheep husbandry varied regionally, while that of cattle did not, or did not in a way that is reflected in the isotopic record. It is worth comparing this with the conclusions from Hull (2007). He showed a significant difference between

Hampshire and Suffolk (East Anglia) when all species were pooled together. However, the results presented here offer a more nuanced understanding of that pattern, one that takes into account difference between sub-periods and species.

Table 6.42. Statistical differences between regions in the Early Medieval sheep data. The results did not change, whether 'sub-period' was integrated as a random or a fixed effects

Region	Multi-Level Model With 'Sites' As Random Effect And 'Region' And 'Sub-Period' As Fixed Effects.	
	p-value ($\partial^{13}C$)	*p-value* ($\partial^{15}N$)
Hampshire-Suffolk	0.939	**0.056**
Hampshire-Yorkshire -	0.999	0.466
Suffolk-Yorkshire	0.988	0.973

6.3.4.3 Pig

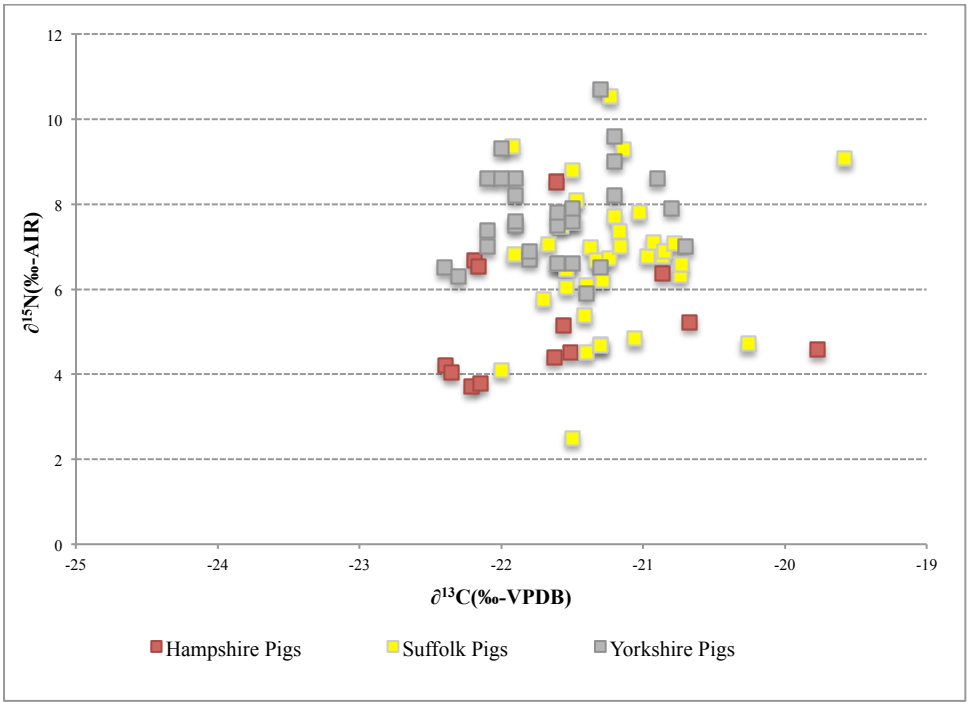


Figure 6.47. Comparison of the pig data by regions in Early Medieval Britain (Hampshire n =14, Suffolk n =38, Yorkshire n =28)

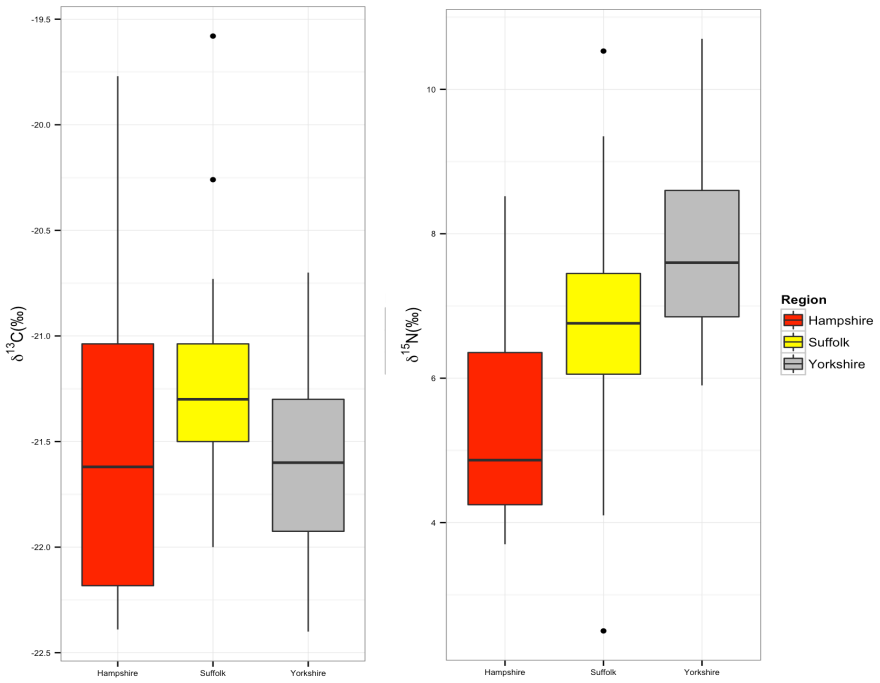


Figure 6.48. Boxplot comparison of the pig data by regions in Early Medieval Britain (Hampshire n =14, Suffolk n =38, Yorkshire n =28)

Interestingly, the division between Suffolk and Hampshire that was visible in the other species is not particularly striking in the pig's data. However, as for the two other species, the data in Hampshire display the lowest isotopic signatures of the regional fauna, as well as the smallest spacing compared with the cattle, suggesting that pigs were maybe kept on a more strictly vegetarian diet compared to the pigs in Yorkshire (Figures 6.47, 6.48) This will be explored further in section 6.5.2 of this chapter. There are however no statistical differences between the regions (Table 6.43).

Table 6.43. Statistical differences between region in the Early Medieval pig data. The results did not change, whether 'sub-period' was integrated as a random or a fixed effect.

Region	Multi-Level Model With 'Sites' As Random Effect And 'Region' And 'Sub-Period' As Fixed Effects.	
	p-value ($\partial^{13}C$)	*p-value* ($\partial^{15}N$)
- Hampshire-Suffolk	0.978	0.996
Hampshire-Yorkshire -	0.997	0.417
Suffolk-Yorkshire	0.798	0.633

6.3.5 Preliminary discussion of the Early Medieval faunal data

The Early Medieval data display the same trends seen in both the Iron Age and the Roman period: cattle have lower $\partial^{13}C$ average and similar $\partial^{15}N$ average as sheep, while pigs are enriched in both isotopes. Maybe the most interesting pattern here is that data Hampshire have values on average lower than the national average, as was the case the Iron Age. This will be explored further in the section 6.5 of this chapter. Another interesting trend is that the cattle appear to significantly vary between sub-periods while the sheep data vary between regions. This might suggest that more homogenous cattle management across the different regions, and localised sheep husbandry. However, it is also possible that these trends are due to the distribution of the data. In relation to the Iron Age and Roman Britain, these results are somewhat in between, with data closer to the Iron Age in the earlier Anglo-Saxon periods, but closer, and sometimes even enriched, compared to the Roman data in the later Anglo-Saxon periods. This will be investigated further in the next section.

6.4 Diachronic Trends Between Periods

In this section, all three main domesticated species will be compared in the *longue durée*, first by broad archaeological periods and then by sub-periods. While no particular patterns was revealed in the sub-period diachronic trends in each broad period at the exception of a difference in the Early Medieval cattle data (see section 6.3.2.1), considering all these sub-periods in the *longue durée* might allow to identify previously unseen trends.

6.4.1. Cattle

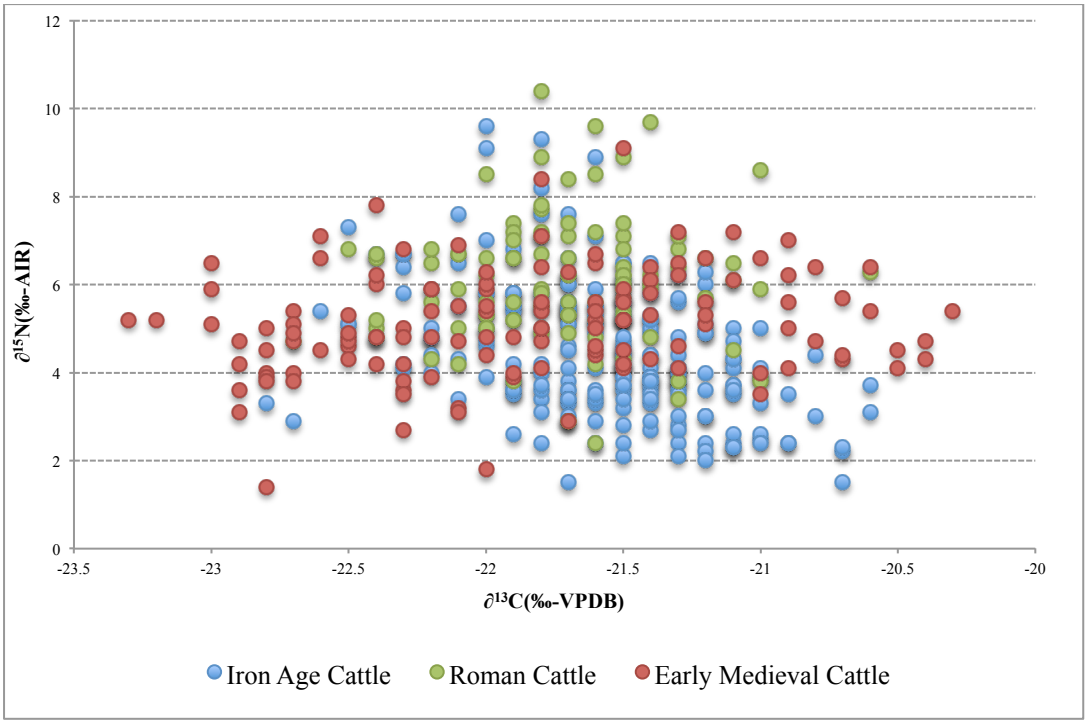


Figure 6.49. Comparison of the cattle data by broad period (Iron Age n = 206, Roman n = 99, Early Medieval n = 138)

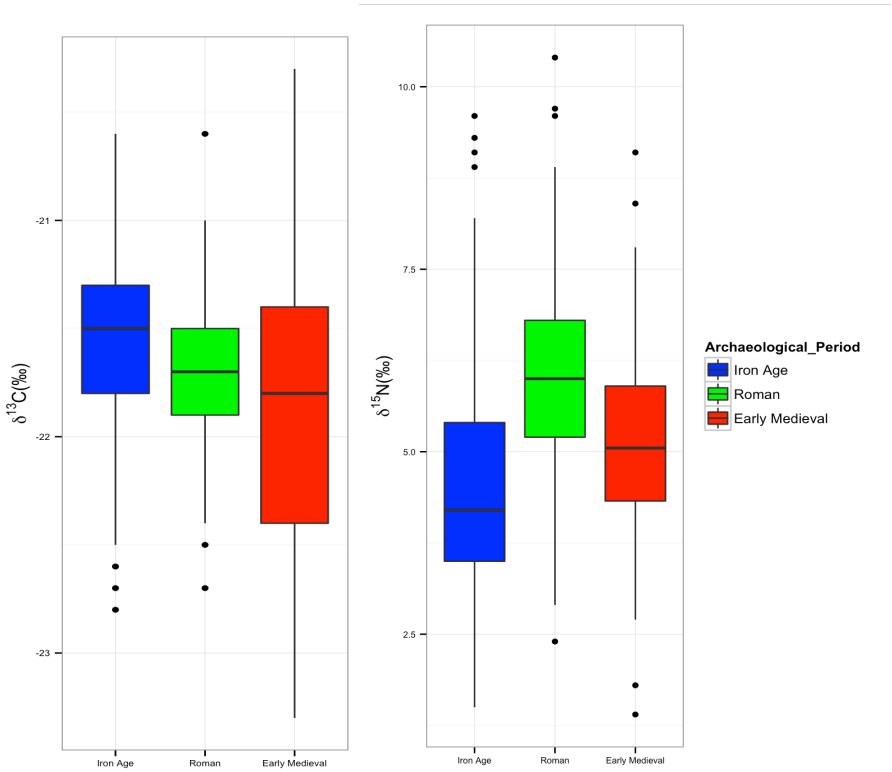


Figure 6.50. Boxplot comparison of the cattle data by broad period (Iron Age n = 206, Roman n = 99, Early Medieval n = 138)

Figures 6.49 and 6.50 show the cattle isotopic results according to the different broad periods. Visually, not one period stands out and the overall pattern between the three main periods is that a decline in $\partial^{13}C$ over time, and a ^{15}N peak in the Roman period. Statistically speaking, however, there is no difference between the broad periods, if the site and regional variables are integrated to the model (Table 6.44). It is worth noting that if the region variable is excluded from the model, then there is a significant difference between the Iron Age and the Roman period. However, the best-fit model does account for regional variation, suggesting that the interplay between regionality and temporality is one with a delicate balance, and that the statistical results presented here are highly dependent on the distribution of the data.

Table 6.44. Statistical results for the cattle data when comparing broad periods. Values in bold indicate statistical significance. *This p-value is significant (*p*= 0.007) when 'region' is not integrated to the model as a fixed effect, but the model presented in the table is the best fit one.

Archaeological Periods	Multi-Level Model With 'Sites' As Random Effect And 'Archaeological Period' And 'Region' As Fixed Effects.	
	p-value (∂^{13}C)	*p-value* (∂^{15}N)
Iron Age-Roman	0.997	0.288*
Iron Age-Early Medieval	0.136	0.933
Early Medieval Roman	0.162	0.569

While the medieval cattle have more varied ∂^{13}C ratios, both the Roman and Iron Age have more varied ∂^{15}N (Iron Age ∂^{15}N range: 9.6‰; Roman ∂^{15}N range: 8‰, Early Medieval ∂^{15}N range: 6.09‰), or rather, there is a group among the Roman and Iron Age cattle that have ^{15}N-enriched values compared to the rest (Figures 6.49 and 6.50). A first explanation for these relatively high cattle values (>8‰) is that these animals were younger individuals retaining a suckling signal. This is, however, difficult to assess on the basis of the information available here. It would also be surprising that the medieval faunal record did not contain any young animal remains. While there are no statistical differences between the broad periods, it is worth considering the data at a higher chronological resolution, which is done below.

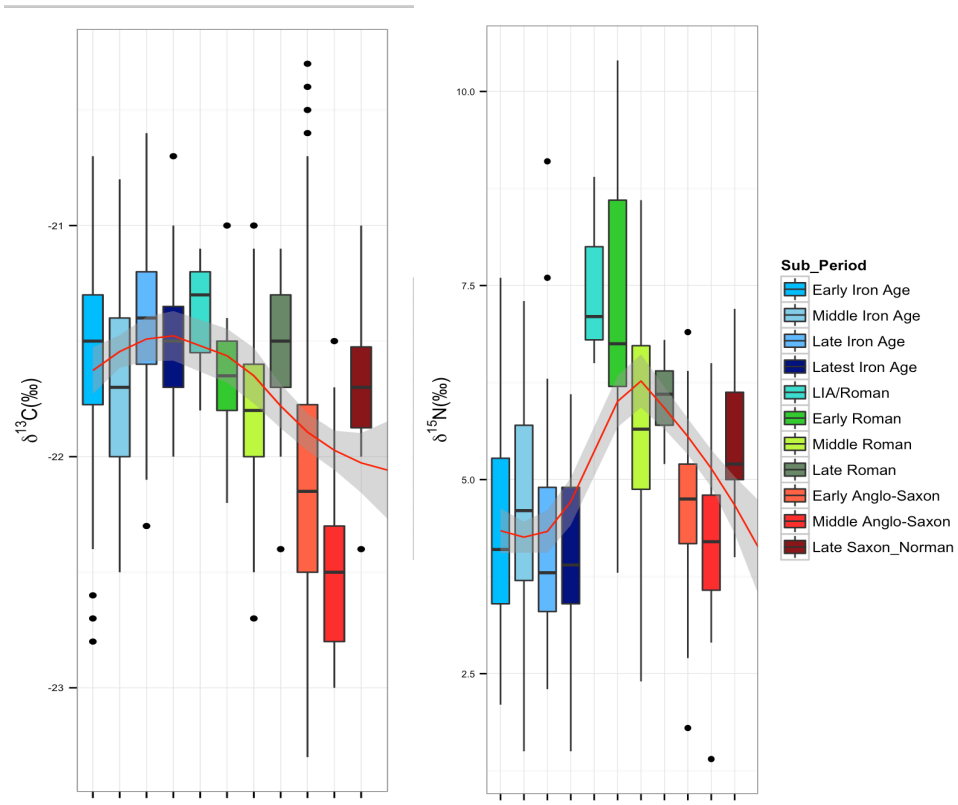


Figure 6.51. Boxplots distribution of cattle ∂^{13}C (left) and ∂^{15}N (right) values across all sub-periods (Early Iron Age n =74, Middle Iron Age n =53, Late Iron Age n=49, Latest Iron n=16, Late Iron Age/Early Roman n = 3, Early Roman n =12, Middle Roman n = 56, Late Roman n=13, Early Anglo-Saxon n=61, Middle Anglo-Saxon n = 10, Late Saxon/Norman n =10). The less well-dated samples have been excluded (Iron Age n = 14, Roman n =15, Anglo-Saxon n = 57). The red line is a LOESS regression, which is used to plot a smooth line through a series of data points by weighting quadratic least squares regression.

Figure 6.51 shows the boxplot distribution of the cattle data from the Early Iron Age to the Late-Saxon/Norman data. The red line is a LOESS line, that is a locally weighted scatterplot smoothing. i.e. it is used to plot a smooth line through a series of data points. The smooth values are calculated as the weighted quadratic least squares regression (Figure 6.51; Nitsch 2012, 259). This was done in the with the 'geom_smooth' function in the 'ggplot' R package, which automatically calculated the smoothed values. This confirms what was visible in the broader data, that is a decrease in ^{13}C over time and

a ^{15}N peak in the Roman period, although they allow to pin-point the decline in ^{13}C a bit more precisely to the Late Iron Age/Roman data (although since there are only three samples, for this particular sub-period, it is unlikely to be meaningful), and show that the ^{15}N peak has both a sharp increase and decrease before and after the Roman period. While there was no difference in the nitrogen isotopic data between the three broad periods, there is a significant difference between the $\partial^{15}N$ values of the Early Roman period and the Middle Iron Age, which is likely due to this sharp increase between periods. The reason for it could be dietary, with cattle grazing or foddering on manured cereals with elevated $\partial^{15}N$ values, or it could be environmental if confirmed in the other domesticated fauna. The Middle Saxon period is the most different from a number of other sub-periods, likely due to how depleted in ^{13}C the Middle Saxon period is compared to all the other periods. The Early Roman period is the most different for the nitrogen isotopic data (Table 6.45).

Table 6.45. Partial statistical results for the cattle data when comparing sub-periods. However, the results remained significant between the same groups regardless of whether 'Region' and 'Sub-Period' were integrated as fixed or random effects. Due to reasons of space, only significant and moderately significant results are shown here. The full results can be found in Appendixes II.2

Archaeological Periods	*Multi-level model with 'Sites' as random effect and 'Sup-Period' as fixed effect.*	*Multi-level model with 'Sites' as random effect and 'Sub-period' and 'Region' as fixed effect.*
	p-value ($\partial^{13}C$)	*p-value* ($\partial^{15}N$)
Early Iron Age-Middle-Saxon	**0.076**	1.000
Late Iron Age-Middle-Saxon	**0.048**	1.000
Latest Iron Age-Middle-Saxon	**0.092**	1.000
Early Roman-Middle IA	1.000	**0.023**
Early-Roman-Early Iron Age	1.000	**0.018**
Early-Roman-Late Iron Age	1.0000	**0.047**
Early-Roman-Middle Anglo-Saxon	0.146	**0.064**

6.4.2 Sheep

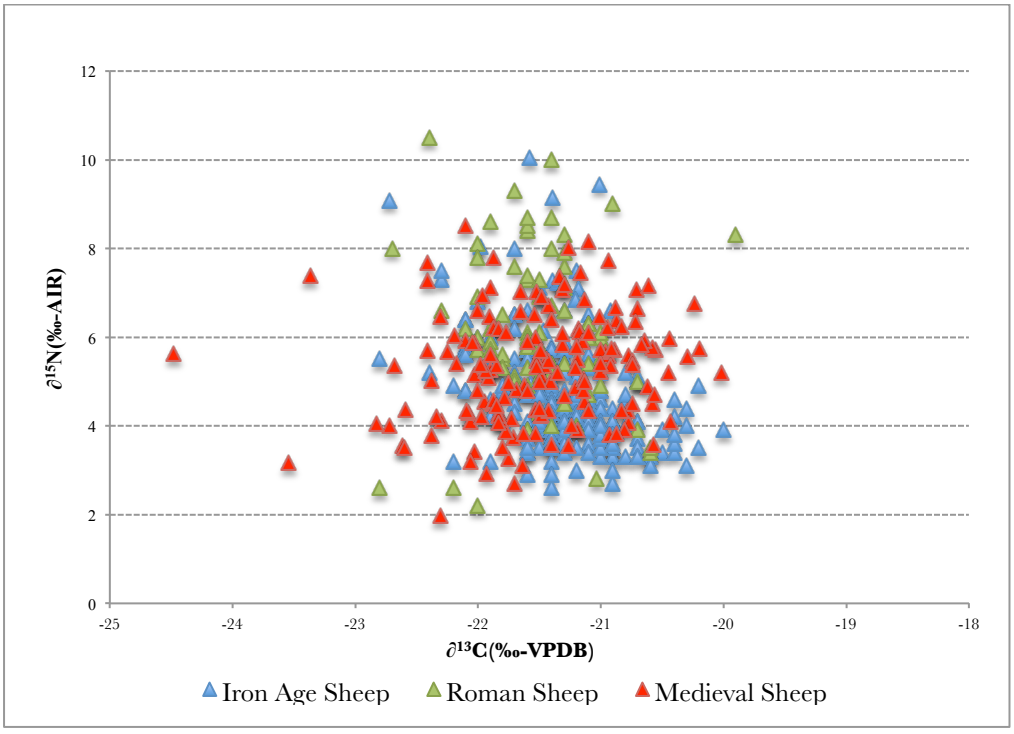


Figure 6.52. Comparison of the sheep data in the different broad time periods (Iron Age n = 230, Roman n = 96, Early Medieval n = 182)

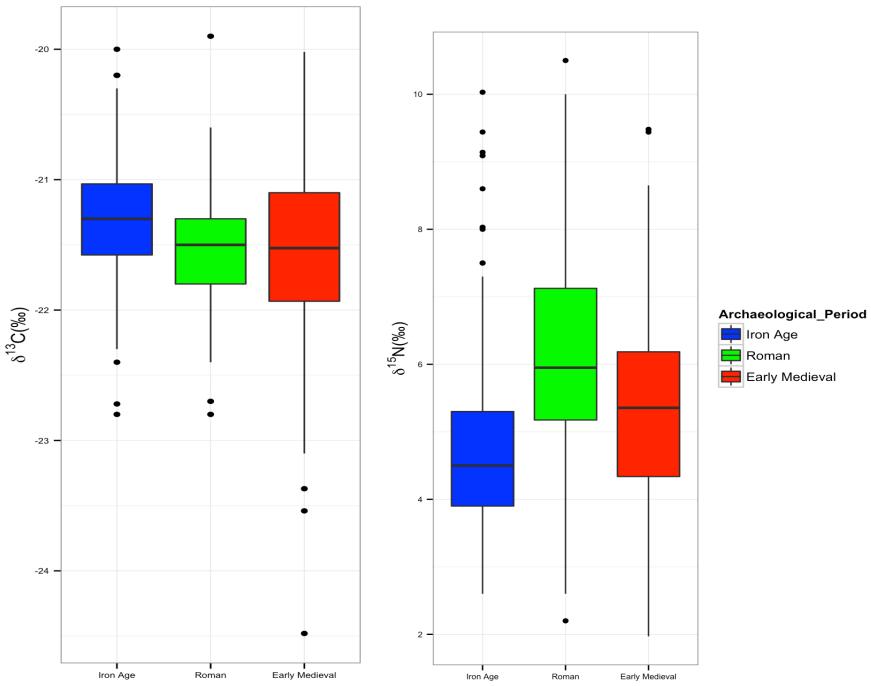


Figure 6.53 Boxplot comparison of the sheep data in the different broad time periods (Iron Age n = 230, Roman n = 96, Early Medieval n = 182)

The sheep distribution resembles that of the cattle, with sheep having the highest ∂^{13}C average in the Iron Age and the lowest ∂^{15}N average, while the Roman sheep have the highest ∂^{15}N average (Figures 6.52 and 6.53). Again, though, there is no statistical difference between these periods if regions are integrated into the model. As was the case with the cattle, there would however be a difference between the Iron Age and the Roman sheep data if region are not integrated in the model (p=0.037; Table 6.46).

Table 6.46. Statistics for the sheep data when comparing broad periods. Values in bold indicate statistical significance. *This difference was significant (*p*= 0.037) when region were not integrated into the model but the result presented here is the better fit.

Archaeological Periods	Multi-Level Model With 'Sites' As Random Effect And 'Archaeological Period' And 'Sub-Period' As Fixed Effects	Multi-Level Model With 'Sites' As Random Effect And 'Archaeological Period' And 'Region' As Fixed Effects
	p-value (∂^{13}C)	*p-value* (∂^{15}N)
Iron Age-Roman	0.591	0.997*
Iron Age-Early Medieval	0.080	0.779
Early Medieval Roman	0.391	0.664

Looking at the sub-periods reveals that these patterns are similar to those of the cattle, if somewhat less pronounced, and the only significant statistical difference is in the nitrogen isotopic data between the Early Roman and the Middle Iron Age (moderate difference, p=0.047, with sites and regions integrated as random effects and sub-period as a fixed effect), and Early Roman and Late Iron Age (p=0.013, with sites and regions integrated as random effects and sub-period as a fixed effect. For full results, see Appendixes II.2). The decrease in ^{13}C is also visible, as is the ^{15}N peak in the Roman period. The decrease in ^{13}C appear less pronounced in the sheep data than it did in the cattle data, likely because the Early Anglo-Saxon and Middle Anglo-Saxon sheep data are not as depleted in^{13}C as the cattle data were (Figure 6.51, 6.54). Another pattern not visible in the cattle data is the decrease in ^{15}N between the earlier and the later Iron Age, which will be discussed further in section 8.2.1.

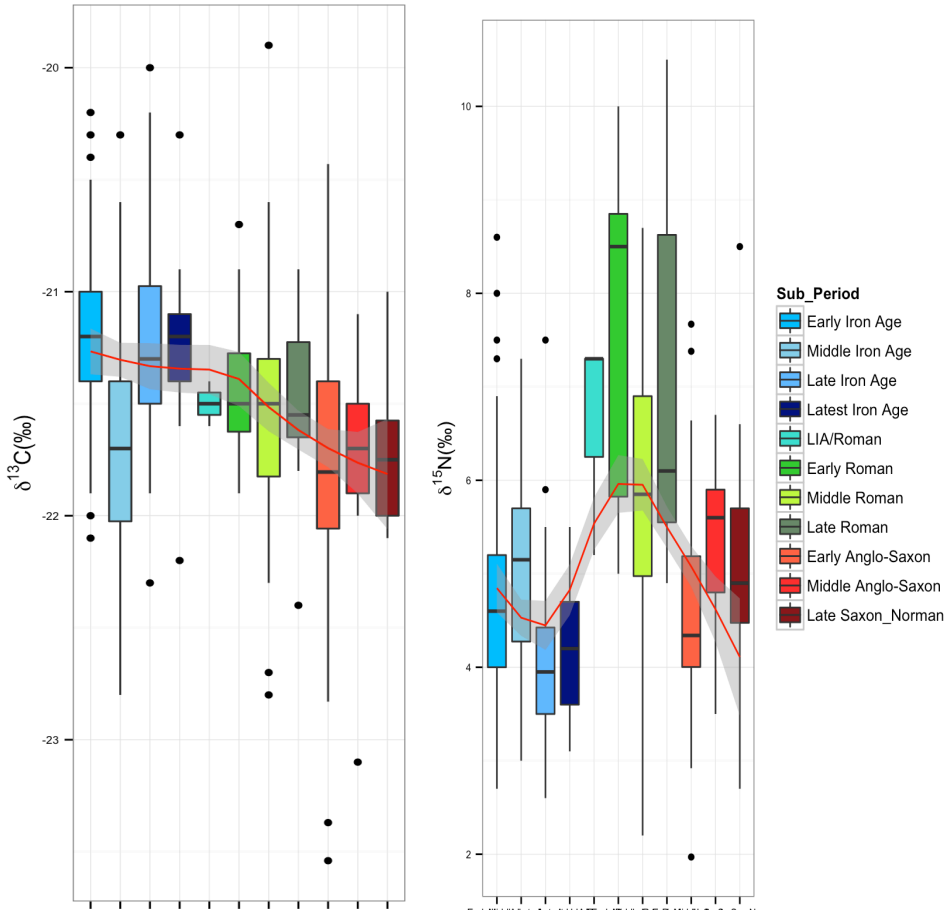


Figure 6.54. Boxplot comparisons of sheep $\partial^{13}C$ (left) and $\partial^{15}N$ (right) values across all sub-periods (Early Iron Age n =85, Middle Iron Age n =44, Late Iron Age n=48, Latest Iron n=17, Late Iron Age/Early Roman n = 3, Early Roman n =8, Middle Roman n = 56, Late Roman n=8, Early Anglo-Saxon n=84, Middle Anglo-Saxon n = 9, Late Saxon/Norman n =8). The less well-dated samples have been excluded (Iron Age n = 36, Roman n =21, Anglo-Saxon n = 81). The red line is a LOESS regression, which is used to plot a smooth line through a series of data points by weighting quadratic least squares regression.

6.4.3. Pigs

Pigs are difficult to analyse because their diet draws from much more varied sources than that of cattle or sheep. There are two models of pig management. The first is through the pannage system in which pigs are driven into woodland to feed upon mast, acorns, roots and fungi (Hamilton *et al.* 2009). The second model posits that pigs were kept close to settlements and were fed on the leftovers of human meals preparation and/or plants unfit for either human or the other domesticated species'

consumption (Hamilton *et al*. 2012). Of course, neither model is exclusive, and pigs might be kept on different regimes over their life cycles resulting in wide isotopic ranges, which may explain some of the variation seen here.

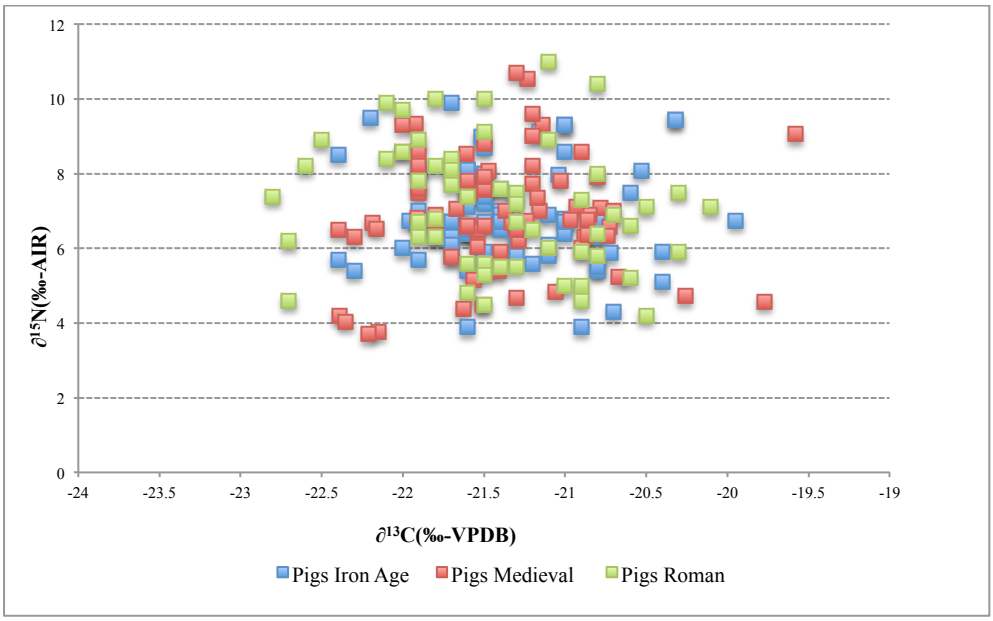


Figure 6.55. Comparison of the pig data in different broad periods (Iron Age n = 141, Roman n = 51, Early Medieval n = 90)

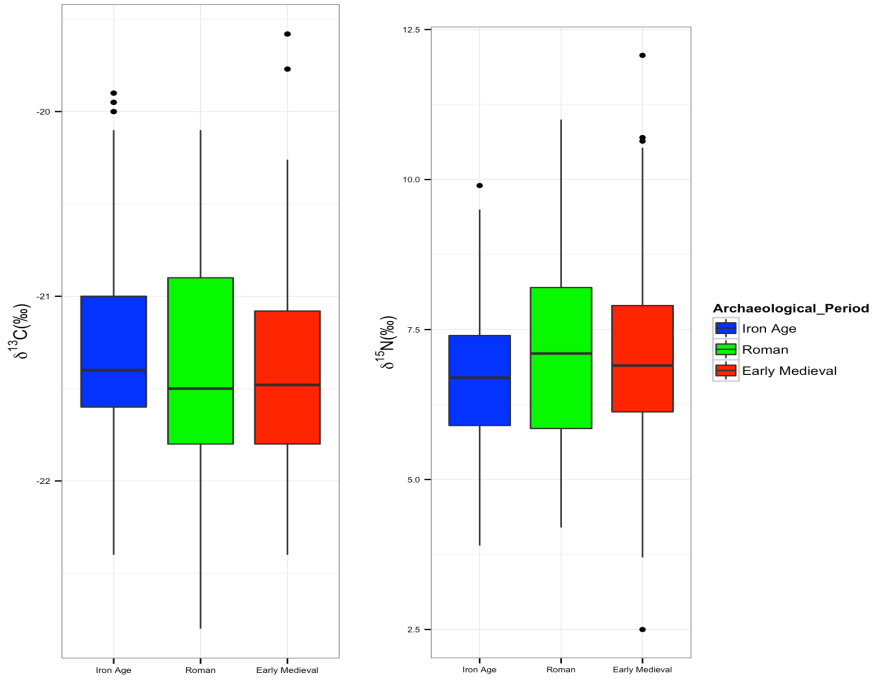


Figure 6.56. Boxplot comparison of the pig data in different broad periods (Iron Age n = 141, Roman n = 51, Early Medieval n = 90)

The pigs follow the same pattern of decrease in ^{13}C after the Iron Age and increase in ^{15}N in the Roman period but again, there are no statistical difference between the broad archaeological periods (Figures 6.55, 6.56. Table 6.47). Looking at the sub-periods show that the patterns seen in the sheep and cattle data are also visible in the pig data, with the decrease in ^{13}C less obvious than it was in the other species. Another difference is the ^{15}N increase in the Late Saxon/Norman period, to the same level as the ^{15}N Roman peak (Figure 6.57), which was absent in the other species. There are no statistical differences between the sub-periods (the full results are in Appendixes II.2).

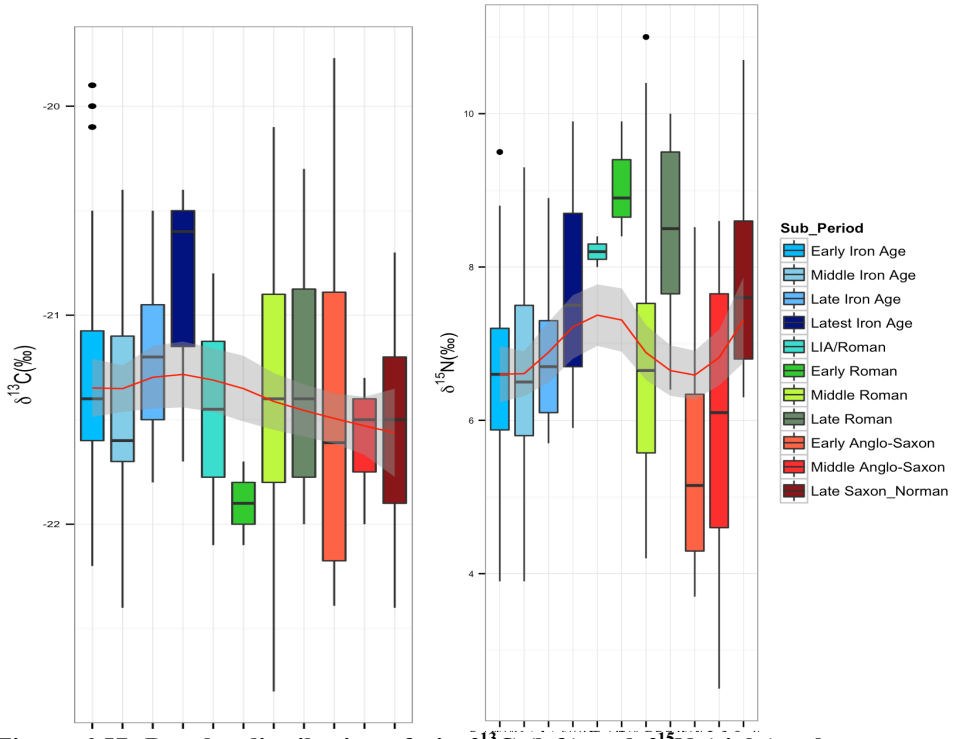


Figure 6.57. Boxplot distribution of pig $\partial^{13}C$ (left) and $\partial^{15}N$ (right) values across all sub-periods (Early Iron Age n =52, Middle Iron Age n =45, Late Iron Age n=27, Latest Iron n=3, Late Iron Age/Early Roman n = 3, Early Roman n =3, Middle Roman n = 44, Late Roman n=6, Early Anglo-Saxon n=16, Middle Anglo-Saxon n =11, Late Saxon/Norman n =19). The less well-dated samples have been excluded (Iron Age n = 14, Roman n =0, Anglo-Saxon n = 44). The red line is a LOESS regression, which is used to plot a smooth line through a series of data points by weighting quadratic least squares regression.

Table 6.47. Regional comparisons for the pig data when comparing broad periods. Values in bold indicate statistical significance. There was, however, no difference in the results whether region was integrated as a fixed or a random effect.

Archaeological Periods	***Multi-Level Model With 'Sites' As Random Effect***	
	p-value (∂^{13}C)	*p-value* (∂^{15}N)
- Iron Age-Roman	0.764	0.518
Iron Age-Early Medieval	0.530	0.823
Early Medieval Roman	0.277	0.958

6.5 Regional comparison across time.

6.5.1 The case of Hampshire

Unfortunately, not one region filling in the criteria for analyses was present in all three broad periods making it difficult to do a full comparison of the regional *longue durée* trends. However, a particular trend was noted between the Iron Age and the Early Medieval periods, that is Hampshire is below the national ∂^{15}N average in both periods for all three species. The Hampshire data in the Roman period came from only one site (Winchester), and therefore, its characteristics cannot be extended to the rest of the region, but it is worth noting that the Roman isotopic faunal data from Hampshire is also depleted in ^{15}N compared to the national average as shown in Figure 6.58.

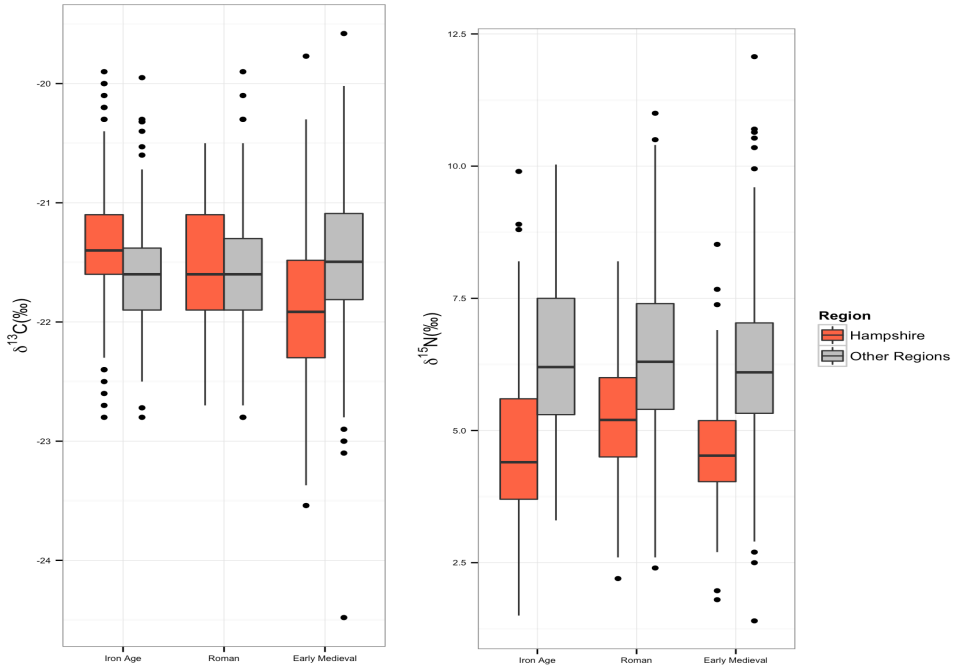


Figure 6.58. Comparison of the domesticated faunal data from Hampshire (n =601) against the domesticated fauna from the other regions in all three periods.

Comparing the Hampshire data with the data from all the other regions, even if not fulfilling the criteria for analyses, shows that the domesticated data from Hampshire is the lowest in all three periods, compared to all of the regions (Figure 6.59).

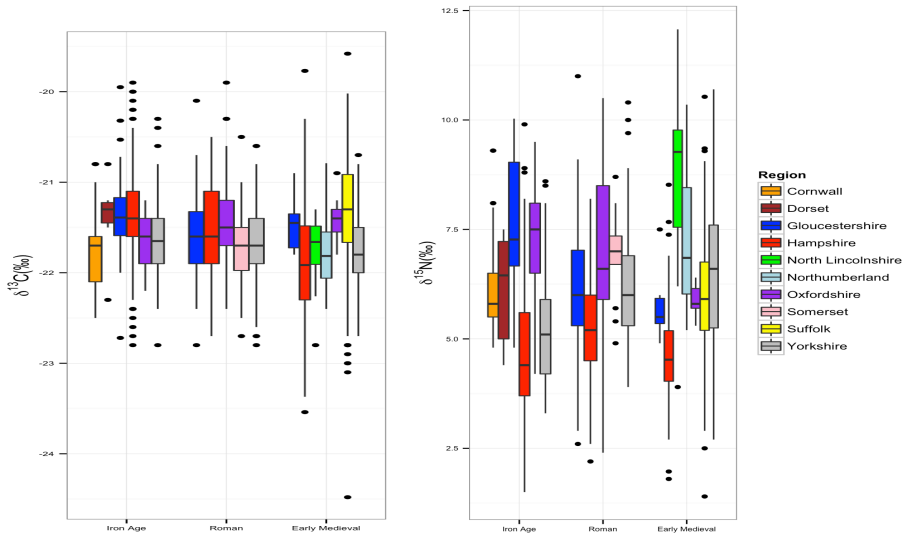


Figure 6.59. Boxplot comparison of the domesticated faunal data from Hampshire (n =601) against the domesticated fauna from the other regions in all three periods.

Because not all the regions fulfill the criteria for analyses, these results can only be seen as tentative, but it is nonetheless interesting to note the continuity in the Hampshire data over time. The reasons behind these patterns could be environmental, taking into account geology, such as the chalk soils, and climate (Schulting *et al.* 2019). It could also be down to vegetation grown in Hampshire, more specifically the presence of pulses, with low ∂^{15}N values, in the archaeobotanical record, which, if used as fodder, might have lowered the faunal overall ∂^{15}N ratios. This is consistent with known patterns of pulses distribution in the archaeobotanical record (see specifically Lodwick 2017). However, it does raise the question of how an environmental effect would be contained within modern Hampshire, and this pattern might need to be understood in a wider environmental context, such as 'the south', which will be explored further in section 6.6.5. The next chapter will investigate whether this pattern is also visible in the human data.

6.5.2 The case of the pigs

It was shown in previous sections that the pig data did not show any clear diachronic or regional patterns. One interesting aspect of pigs' diet to investigate, however, has not been discussed yet. Indeed, one of the pigs' particularity is that they can be kept in a number of ways, drawing from a large variety of foodstuff. Here, to assess whether the pigs had an omnivorous or vegetarian diet, the pig isotopic values were compared against a regional cattle baseline, i.e. the Iron Age pigs from Hampshire were compared to the Iron Age cattle average from Hampshire. It revealed two tentative patterns: while the pigs in Hampshire in the Iron Age were on

average depleted in ^{15}N compared to the pigs from Cornwall, the relative enrichment in ^{15}N relative to the baseline is similar in both regions and might suggest that the Hampshire pigs fed on a more omnivorous diet than the pigs from Cornwall (Figure 6.60). The opposite appears to be true in the Early Medieval pig data. While the pigs in Hampshire from the Early Medieval period were also depleted in ^{15}N compared to Suffolk and Yorkshire, comparison with the baseline suggest that these pigs were also kept on a more vegetarian diet than they were in the other region, at the exception of one individual with a $\Delta^{15}N_{pig\text{-}cattle}$ value of 3.9‰, although this might be a younger animal with a nursing signal (Figure 6.62). No particular pattern in relation to the baseline was noted in the Roman pig data (Figure 6.61). These results are only tentative, but they show the important of considering the pig data in relation to the other fauna rather than on its own.

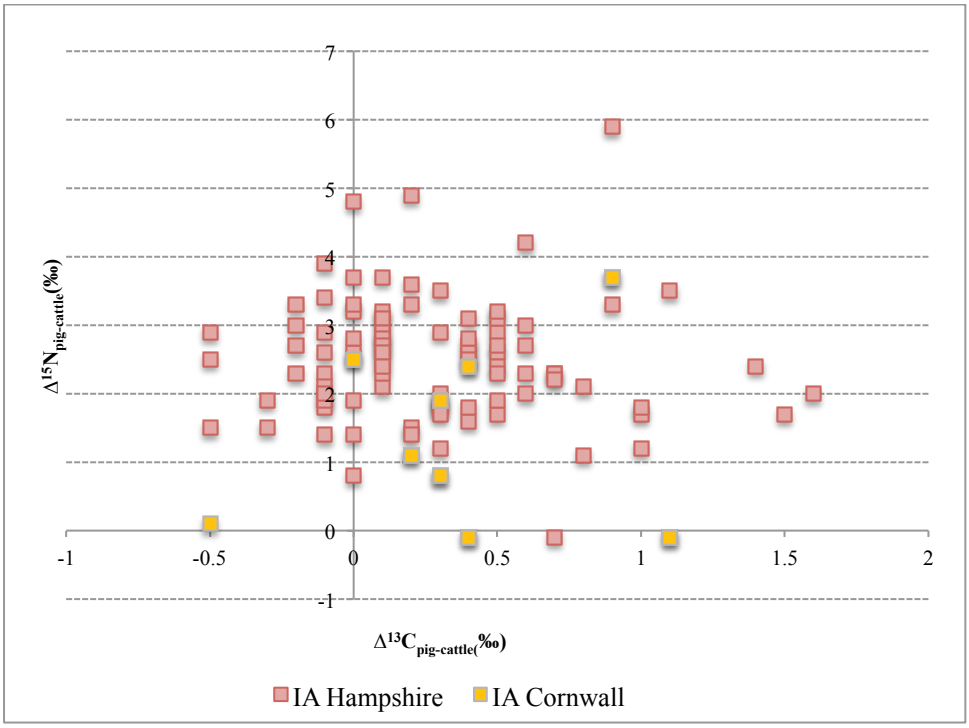


Figure 6.60. Comparison between the regional pig data in the Iron Age against a regional cattle baseline.

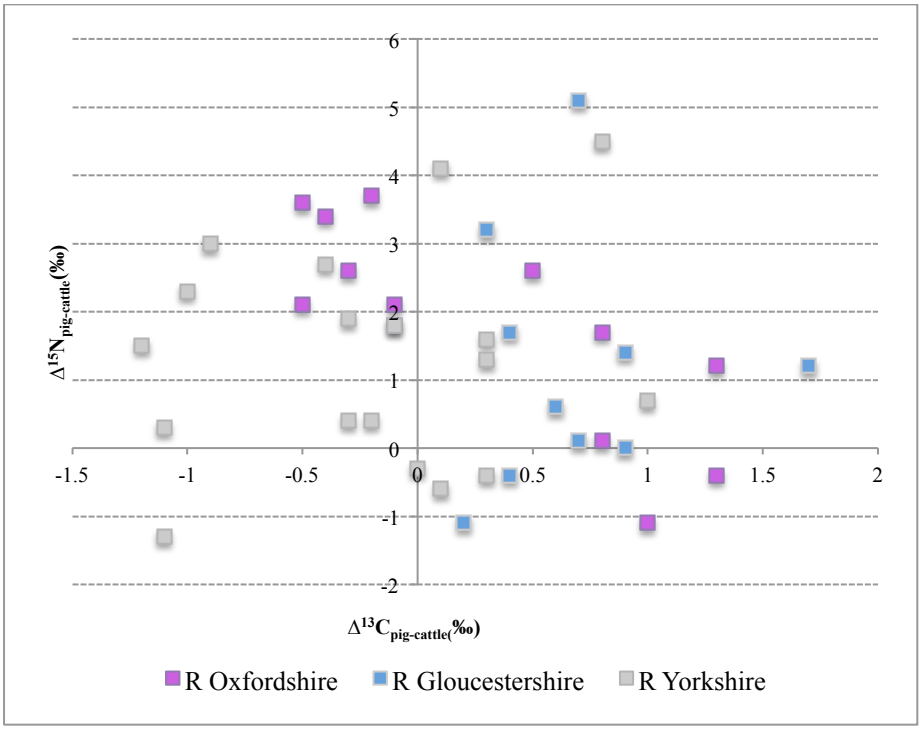


Figure 6.61. Comparison between the regional pig data in Roman Britain against a regional cattle baseline.

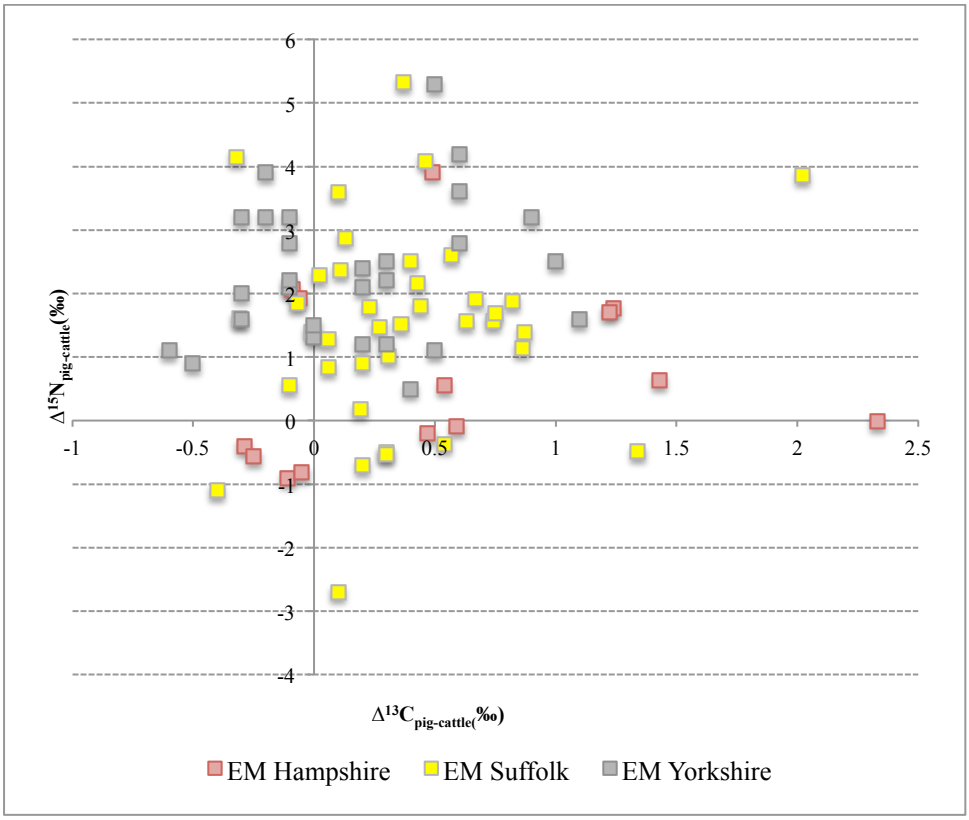


Figure 6.62. Comparison between the regional pig data in Early Medieval Britain against a regional cattle baseline

6.6. Physical Geography

The following sections will examine the relationship between the environment and the isotopic results of the fauna. This will be done to assess whether faunal isotopic patterns can be correlated with some climatic trends. Due to space constraints, only the cattle data are discussed here.

It is not necessarily simple to untangle whether the climate would have had an effect on the isotopic ratios of plants, thus affecting the entire food chain, or if colder and/or wetter periods would have affected food procurement strategies. If the cattle data from colder and/or wetter episodes display significantly different results with respect to cattle from warmer and/or dryer ones, then a climatic effect can be hypothesised but one caveat to make is that climate might have affected animal management strategies, and the variations seen could be the result of humans adapting the animal feeding strategies as a response to the climatic changes rather than a true reflection of the isotopic values at the environmental level. Data from wild animals would be preferable here to conduct the analyses but wild fauna present data are well distributed between the different units of analyses. Indeed the largest wild animal dataset is dated to the Roman period, and specifically distributed in the South (Madgwick *et al.* 2013).

Once the faunal data have been investigated, the offset between the humans and the cattle will then be examined to interpret whether human diets were affected by these climatic variations in Chapter 7, section 7.6. Four outcomes are possible: (1) faunal values show a significant difference according to cold/warm/dry/wet regions and/or periods; (2) faunal values do not show a significant difference according to cold/warm/dry/wet regions

and/or periods; (3) the offsets between the humans and the fauna show a significant difference according to cold/warm/dry/wet regions and/or period, (4) The offsets between the humans and the fauna do not show a significant difference according to cold/warm/dry/wet regions and/or periods.

The conclusion from the analyses will therefore be one of the following: (i) climate affects both the environment and diets, if outcomes 1 and 3; (ii.) climate affects the environment but does not affect diets, if outcomes 1 and 4; (iii.) climate affects neither environment nor diets, if outcomes 2 and 4; and (iv.) climate does not affect the environment but does affect diets, if outcomes 2 and 3.

Questions of scale have been prominent in this thesis. In a way, one of the fundamental questions raised by this work concerns the scale on which isotopic analyses and their interpretation can be carried out in an optimal way and how to represent different scales of analysis comprehensively (See Chapter 3). Climate reconstruction is another endeavour for which scale is crucial. Trying to correlate large climatic/environmental events with the isotopic record for Britain is difficult for a number of reasons. First, changes in temperature in the mid- to late Holocene are unlikely to have been dramatic (Macklin *et al*. 2005). The determinants of climate change are multiple and if the magnitude of change is small, then climatic proxies need to be extremely sensitive while the error range of climatic reconstruction must be kept at a minimum (Macklin *et al*. 2005). Not unlike palaeodietary reconstructions, the main issue of palaeoclimatic reconstruction is one of precision and accuracy, and how a true signal can be isolated from background noise (Macklin *et al.* 2005). Some coarse climatic

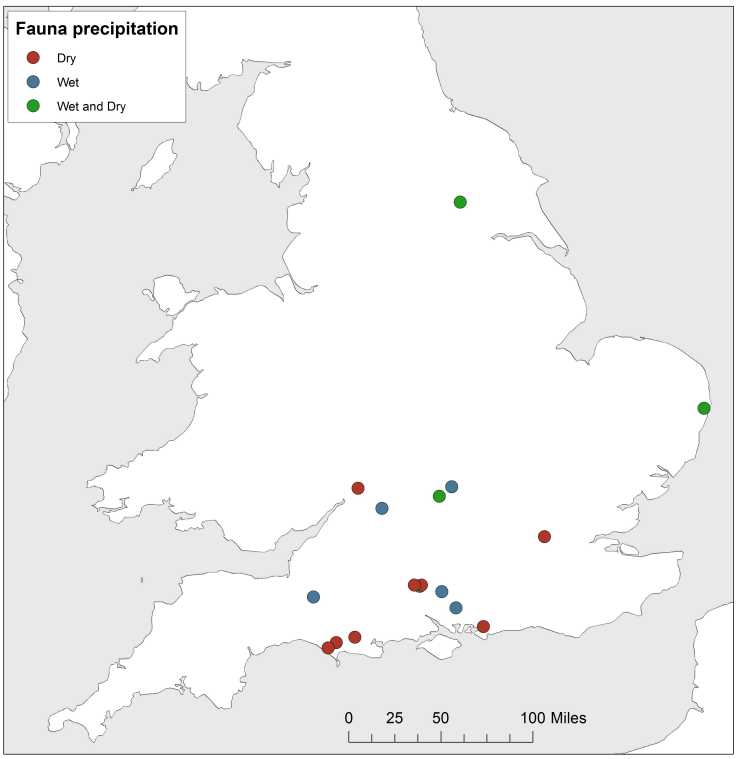
reconstructions exist for the periods this thesis investigates, against which the isotopic data can be analysed (see Chapter 4, section 4.2.5). In the following section, the effect of precipitation will be considered first, both on chronological and then regional levels. Then temperature fluctuations will be examined in relation to the isotopic data.

6.6.1 Rainfall through time: analyses of wet and dry periods

As was shown in Chapter 2, studies have both proven and disproven whether rainfall has an effect on the isotopic signal. It is worth repeating here that while some found no correlation between Mean Annual Precipitation (MAP) and $\delta^{13}C$ (Turner *et al.* 2008), others report a positive correlation between MAP and $\delta^{13}C$ (for example on the Tibetan plateau, Guo and Xie 2006). Kohn (2010) showed there is a distinct increase in $\delta^{13}C$ with decreasing MAP, i.e., the less it rains, the higher the plants' $\partial^{13}C$ values are likely to be. Using recent climatic reconstruction for North Western Europe and Britain (Büntgen *et al*. 2011; Charman *et al*. 2010), it is possible to identify broad dry and wet periods against which to compare the isotopic record, as was done in Chapter 4, section 4.2.5. Not all the data neatly fall into these wet/dry episodes, but the samples that did were plotted on an x/y scatterplot. The distribution of the data is shown in Table 6.48 and Map 6.1.

Table 6.48. Distribution of the cattle data according to precipitation between the Iron Age and the Early Medieval period.

Precipitation Event	N of sites	N of samples	Broad Archaeological Period	Regions	Sites
Dry	6	59	Iron Age, Roman	Gloucestershire, Hampshire, Oxfordshire, Yorkshire	Blossom Street (York), Danebury, Gloucester, Nettlebank Copse, Suddern Farm, Yarnton
Wet	8	84	Iron Age, Roman, Early Medieval	Gloucestershire, Hampshire, Oxfordshire, Somerset, Yorkshire	6 Driffield Terrace (York), Abbot's Worthy, Alchester, Bradley Hill, Cirencester, Danebury, Shavard's Farm



Map 6.1. Distribution of sites containing faunal data for the dry and wet events (Cattle from dry period n= 59, n cattle from wet period n =84).

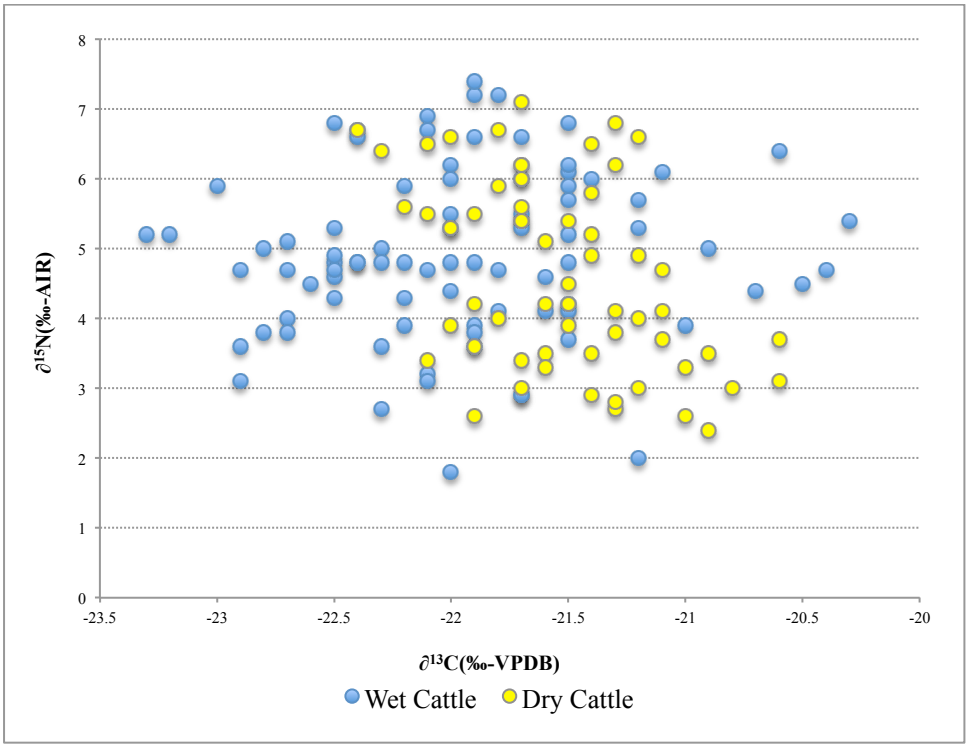


Figure. 6.63. Comparisons of the cattle according to wet and dry episodes between the Iron Age and the Early Medieval period. Climate modelled after Büntgen *et al.* 2011 and Charman 2010 (n cattle from dry period = 59, n cattle from wet period =84).

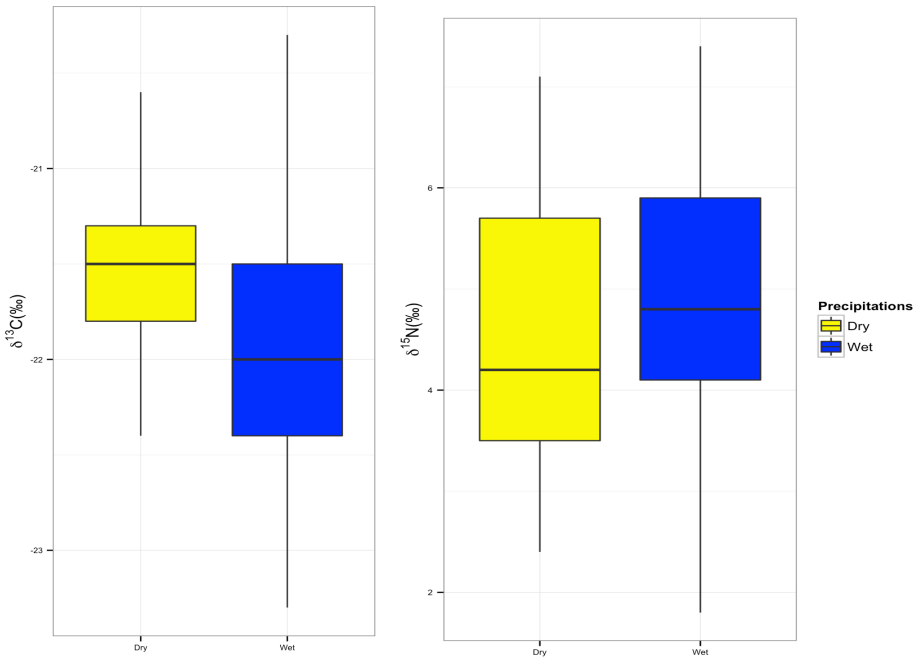


Figure 6.64. Boxplot comparison of the cattle according to wet and dry episodes between the Iron Age and the Early Medieval period. Climate modelled after Büntgen *et al.* 2011 and Charman 2010 (n cattle from dry period = 59, n cattle from wet period =84).

While previous studies did identify patterns in relation to rainfall (Budd 2015), this is not shown in the cattle data here (Figures 6.63, 6.64; Table 6.49). It could be that there are differences, which are too small to be picked up by the model, or that the magnitude of difference in precipitation was too limited to create visible patterns in the isotopic data.

Table 6.49. Statistical results for the cattle data when comparing wet/dry periods. The models were tested with as many variables as possible to contain variations not related to precipitation. The significance of the results did change if 'site', 'region' and 'sub-period were not integrated to the model, suggesting that climate variation is not significant independently from other factors.

Precipitation	**Multi-Level Model With 'Sites' As Random Effect And 'Precipitation' And 'Archaeological Period' As Fixed Effects**	**Multi-Level Model With 'Sites' As Random Effect And 'Precipitation', 'Archaeological Period', And 'Region' As Fixed Effects**
	p-value (∂^{13}C)	*p-value* (∂^{15}N)
Dry-Wet	0.544	0.317

6.6.2 Rainfall through space: patterns of regional precipitation in Britain.

As discussed in Chapter 4, section 4.2.5, variations in precipitation patterns are not limited to diachronic trends, but are also important to consider regionally as some regions receive more rain than others and this must be integrated into the model. Following Gregory *et al.* (1991)'s division of Britain into nine regions of coherent precipitation, regional precipitation patterns are investigated in all three broad periods in this section. The distribution of the data between all three broad periods is in Tables 6.50, 6.52, 6.54.

6.6.2.1 Iron Age

Table 6.50. Precipitation according to the region of coherent precipitation the Iron Age (NEE = North East of England, SEE = South East of England, SWE = South West of England).

Rain Regions	N of sites	N of samples	Sites
North East of England (NEE)	1	13	Wetwang Garton-Slack
South East of England (SEE)	7	166	Danebury, Houghton Down, Nettlebank Copse, New Buildings, Suddern Farm, Winnall Down, Yarnton
South West of England (SWE)	5	27	Fordington Bottom, Harlyn Bay, Lechlade, Trethellan Farm, Trevelgue Head

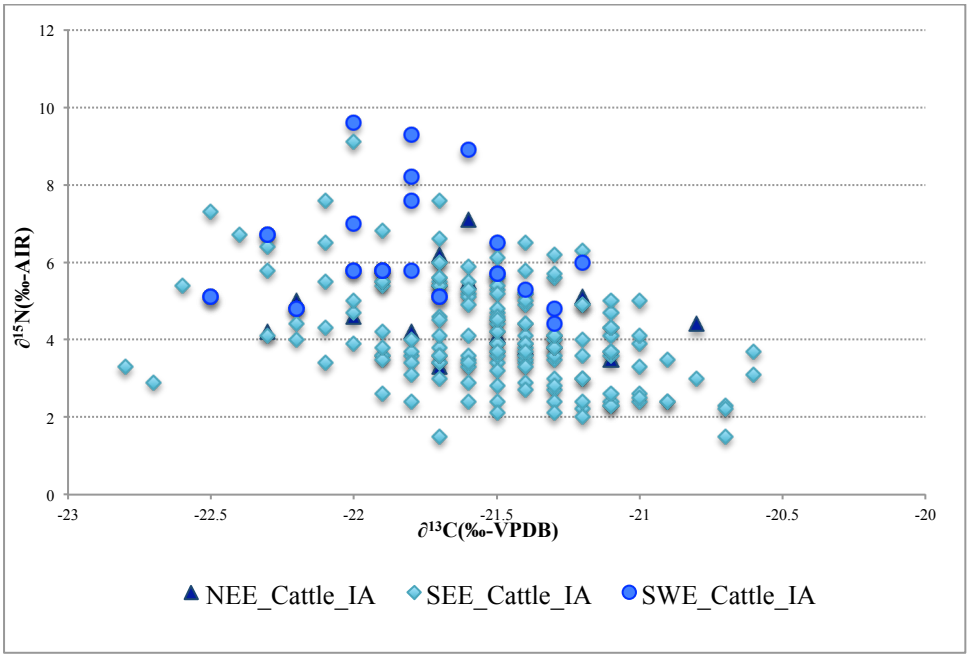


Figure 6.65. Comparison of the cattle data according to the different regions of coherent precipitation in the Iron Age (NEE (North East of England) n= 13, SEE (South East of England) n=166, SWE (South West of England) n=27).

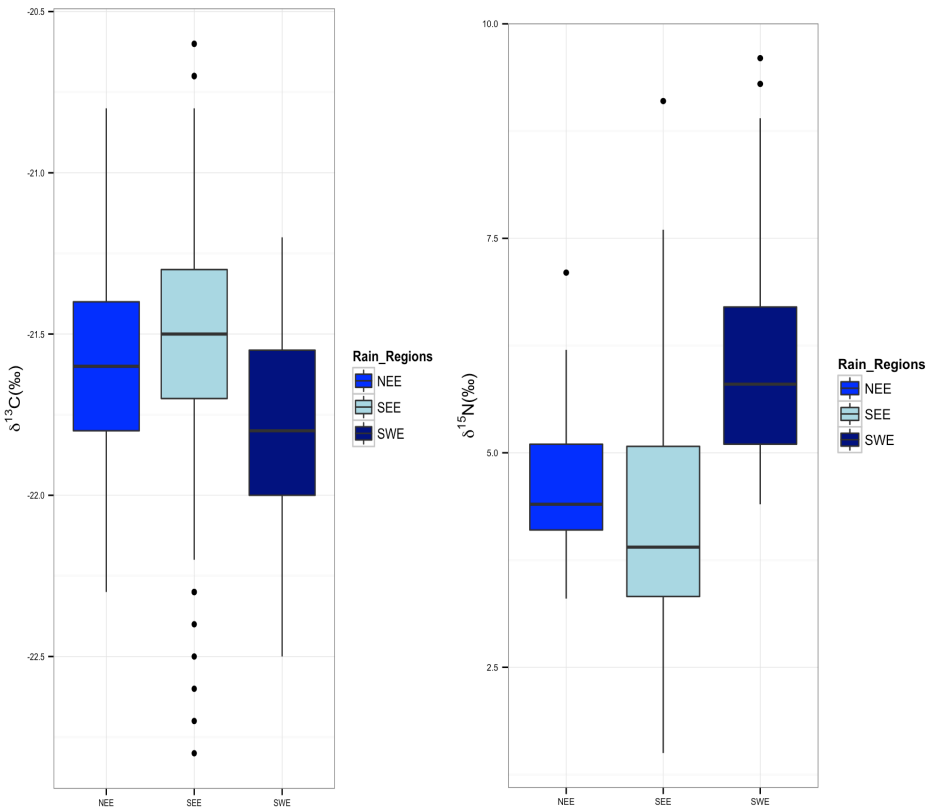


Figure 6.66. Boxplot comparison of the cattle data according to the different regions of coherent precipitation in the Iron Age (NEE (North East of England) n= 13, SEE (South East of England) n=166, SWE (South West of England) n=27).

Figures 6.65 and 6.66 show the distribution of the cattle data in the Iron Age according to coherent precipitation regions: the South West (SWE, Mean Annual Precipitation 1031.5ml), the South East (SEE; Mean Annual Precipitation 730ml) and the North East (NEE; Mean Annual Precipitation 777.1 ml).

Although there are not strong patterns in the cattle data, the South-western cattle seem to be slightly enriched in ^{15}N and depleted in ^{13}C relative to the other two regions. That the South-West cattle should display lower $\partial^{13}C$ values is consistent with a decrease in ^{13}C with increased rainfall since the South-West gets 290ml more rain in a year than the other two regions, but since most studies predict an effect for larger differences (around 1000ml, see Turner *et al.* 2008), one must be careful in assigning a rainfall effect

here. Statistical analyses taking into account the different factors that can be at play here (i.e. sub-period, site, location of sites, temperatures and diachronic trends of precipitation) reveal that there is no significant differences between the different regions of coherent precipitation in the Iron Age (Table 6.51).

Table 6.51. Statistical comparisons for the Iron Age cattle data when comparing regions of coherent precipitation. The models were tested with as many variables as possible to contain variations not related to precipitation. The best-fit models are presented below.

Rain-Region	**Multi-Level Model With 'Sites' As Random Effect, And 'Sub-Period', 'Precipitation' And 'Rain-Regions' As Fixed Effects.**	
	p-value (∂^{13}C)	*p-value* (∂^{15}N)
NEE-SEE	0.972	0.953
NEE-SWE	0.547	0.766
SEE-SWE	0.128	0.868

6.6.2.2 Roman Britain

Table 6.52. Precipitation according to the region of coherent precipitation in Roman Britain (NEE = North East of England, SEE = South East of England, SWE = South West of England).

Rain_Region	**N of sites**	**N of samples**	**Site**
North East of England (NEE)	4	31	6 Driffield Terrace (York), Blossom Street (York), Catterick, York.
South East of England (SEE)	4	40	Alchester, Asthall, Winchester, Yarnton
South West of England (SWE)	4	28	Bradley Hill, Cirencester, Gloucester, Hucclecote

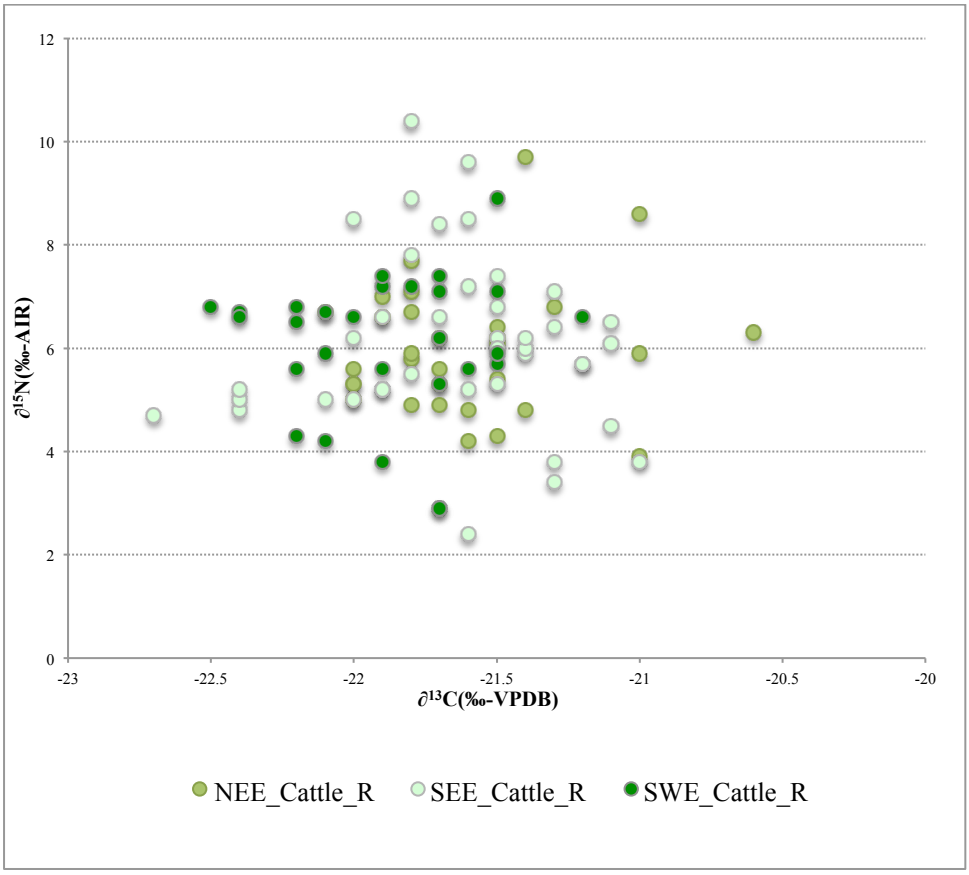


Figure 6.67. Comparison of the cattle data according to the different regions of coherent precipitation in Roman Britain (NEE (North East of England) n= 31, SEE (South East of England) n=40, SWE (South West of England) n=28).

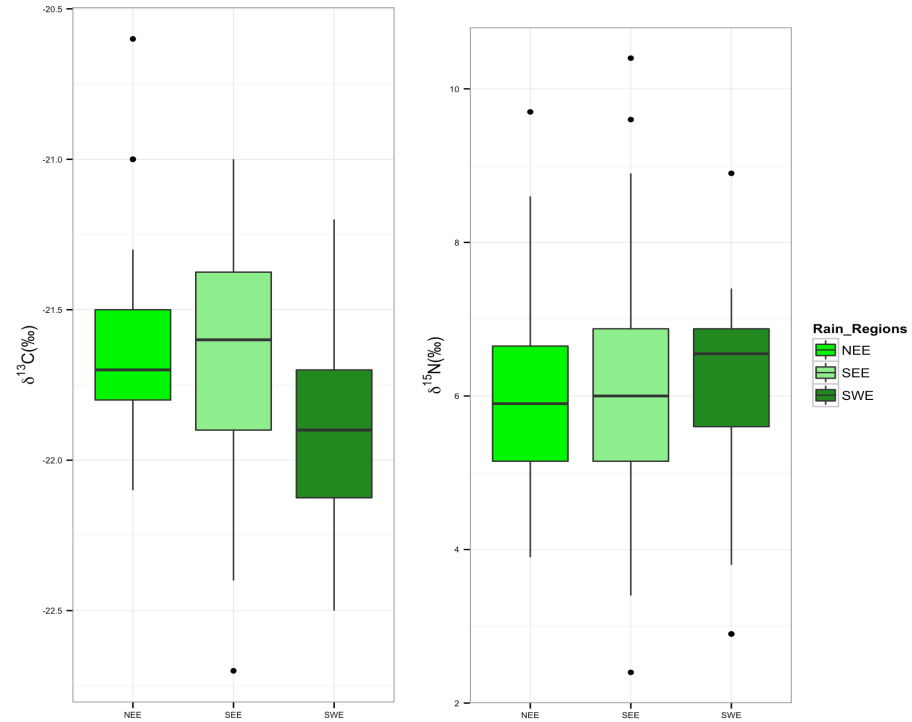


Figure 6.68. Boxplot comparison of the cattle data according to the different regions of coherent precipitation in the Roman Britain (NEE (North East of England) n= 31, SEE (South East of England) n=40, SWE (South West of England) n=28).

As was the case in the Iron Age, the Southwest data are depleted in ^{13}C compared to the other region of coherent precipitation, but somewhat enriched in ^{15}N (Figures 6.67, 6.68). However, statistical analyses integrating the different factors that can be at play here (i.e. archaeological period, sub-period, site, location of sites, temperatures and diachronic trends of precipitation) reveal no significant differences (Table 6.53).

Table 6.53. Statistical results for the cattle data in Roman Britain when comparing regions of coherent precipitation. The models were tested with as many variables as possible to contain variations not related to precipitation. The best-fit models are presented below.

Rain-Region	***Multi-level model with sites as random effect, and 'Sub-Period', 'Precipitation' and 'Rain-regions' as fixed effects.***	
	p-value ($\partial^{13}C$)	*p-value* ($\partial^{15}N$)
NEE-SEE	0.921	0.994
NEE-SWE	0.240	0.971
SEE-SWE	0.324	0.988

6.6.2.3 Early Medieval

Table 6.54. Precipitation according to the region of coherent precipitation in Early Medieval Britain (NEE = North East of England, SEE = South East of England, CEE = Central England).

Rain Region	**N of sites**	**N of samples**	**Sites**
CEE – EM	3	56	Bloodmoor Hill, West Stow, Whitton
NEE – EM	4	21	Bellevue (York), Black Gate Cemetery (York), Fishergate (York), Masham
SEE – EM	3	56	Abbot's Worthy, Berinsfield, Shavard's Farm

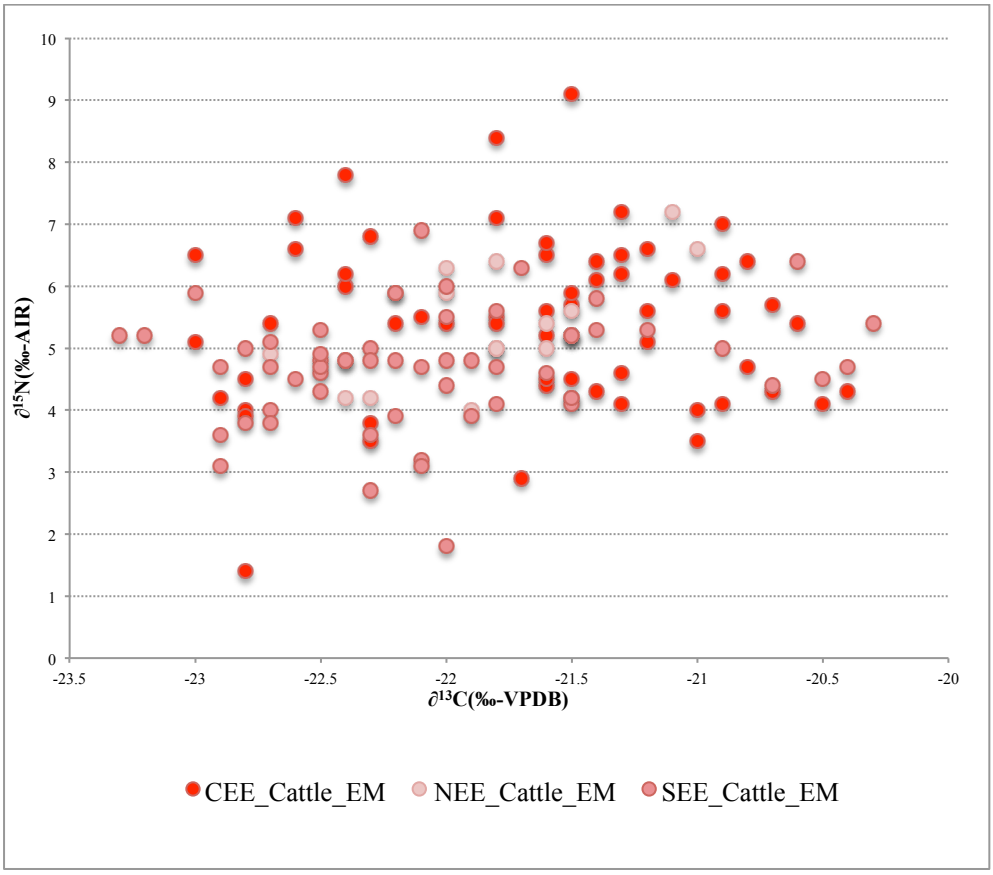


Figure 6.69. Comparisons of the cattle data according to the different regions of coherent precipitation in the Early Medieval Britain (NEE (North East of England) n= 21, SEE (South East of England) n=56, CEE (Central England) n=56).

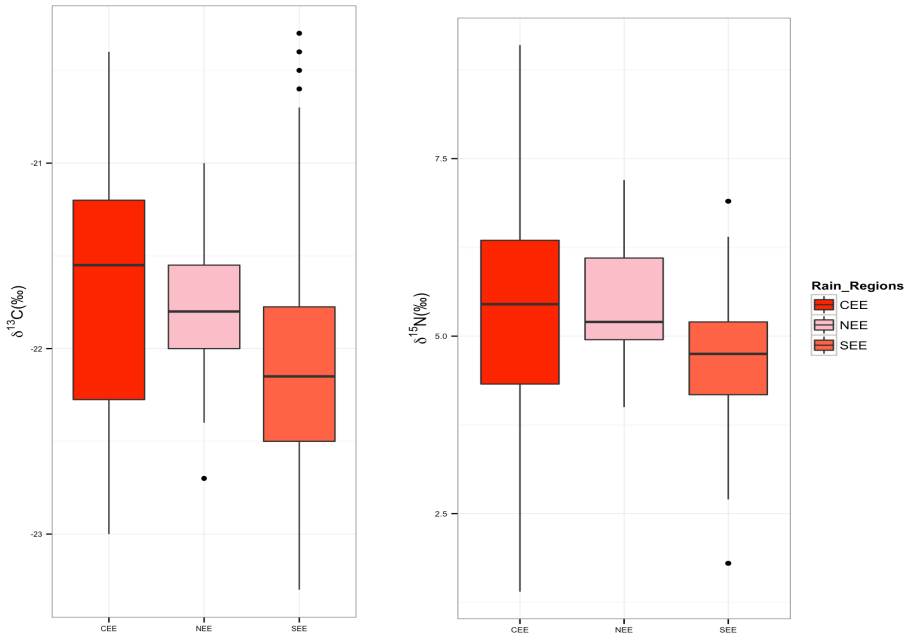


Figure 6.70. Boxplot comparison of the cattle data according to the different regions of coherent precipitation in the Early Medieval Britain (NEE (North East of England) n= 21, SEE (South East of England) n=56, CEE (Central England) n=56).

The Early Medieval coherent precipitation regions are slightly different to the Iron Age or the Roman ones because of the absence of data for the Southwest. Instead, there is sufficient data for the region identified by Gregory *et al*. as 'Central England' (CE; Cambridgeshire, Norfolk and Suffolk). The precipitation pattern for this region is much lower than that of the other eight regions (645 mml MAP), which should result in higher $\partial^{13}C$ values. While this appears to be the case (Figures 6.69, 6.70), as was the case in both preceding periods, there is no statistical difference between the different regions of coherent precipitation (Table 6.55).

Table 6.55. Statistical results for the Early Medieval cattle data when comparing regions of coherent precipitation. The models were tested with as many variables as possible to contain variations not related to precipitation. The best-fit models are presented below.

Rain-Region	***Multi-level model with sites as random effect, and 'Sub-Period', 'Precipitation' and 'Rain-regions' as fixed effects***	
	p-value ($\partial^{13}C$)	*p-value* ($\partial^{15}N$)
CEE-NEE	0.999	0.851
CEE-SEE	1.000	0.938
NEE-SEE	0.999	0.656

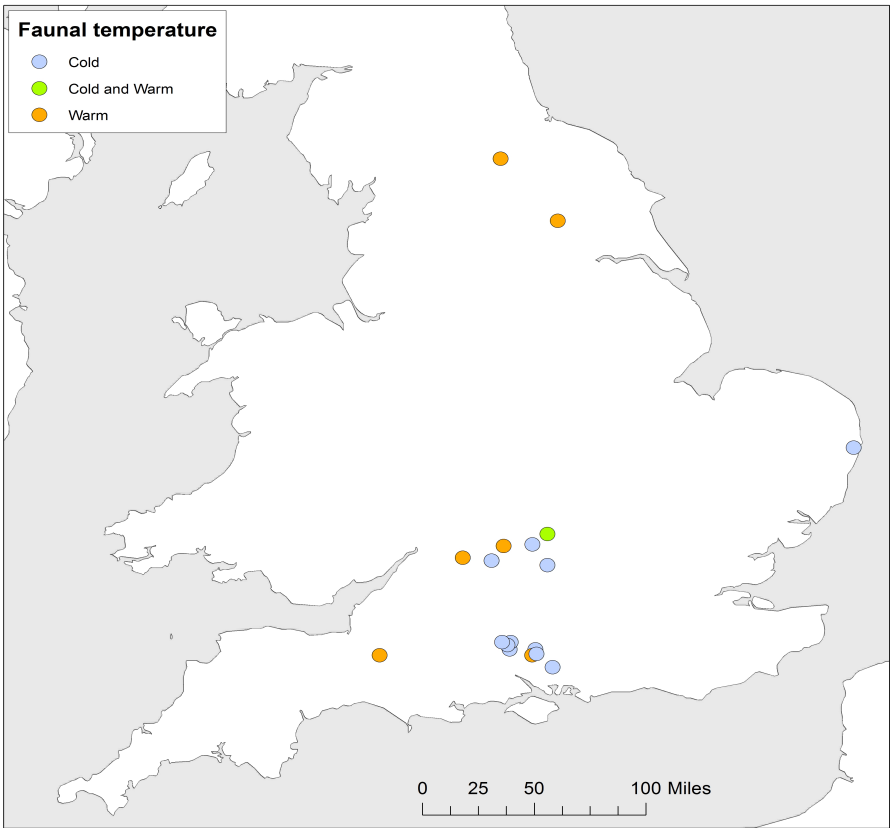
Between the results showing no significant difference in diachronic trends, or in regional ones, one must conclude that the effects of precipitation on the cattle data between the Iron Age and the Early Medieval periods are limited or too small to be picked up by isotopic analyses. However, it is possible that it is the patterns of precipitation themselves are not different enough to make a difference to the isotopic data of the plants consumed by the cattle.

6.6.3 Temperatures

Cold and warm climatic cycles are not correlated to wet/dry episodes, it is therefore important to model how temperature might have affected the data separately to rainfall (Macklin *et al*. 2005). As with precipitation, the resolution of temperature reconstruction is not necessarily precise enough, even when considering data on a relatively long time-scale. However, four phases can nonetheless be identified: a cold period in the Iron Age, a warm period during the Roman Empire, a cold one during the Migration period and another warm one for the last centuries of this dataset (see Chapter 4, section 4.2.5 for details). The distribution of the data is shown in Table 6.56 and Map 6.2.

Table 6.56. Distribution of the cattle data according to temperature between the Iron Age and the Early Medieval period.

Temp. Event	N of sites	N of samples	Broad Archaeological Period	Region	Sites
Warm	10	73	Roman, Early Medieval	Gloucestershire, Hampshire, Oxfordshire, Somerset, Yorkshire	6 Driffield Terrace (York), Alchester, Asthall, Blossom Street (York), Bradley Hill, Catterick, Cirencester, Fishergate (York), Winchester, York
Cold	10	136	Iron Age, Early Medieval	Gloucestershire, Hampshire, Oxfordshire	Abbot's Worthy, Berinsfield, Butler's Field, Danebury, Houghton Down, Nettlebank Copse, New Buildings, Shavard's Farm, Yarnton



Map 6.2. Distribution of sites containing cattle data for the warm and cold events.

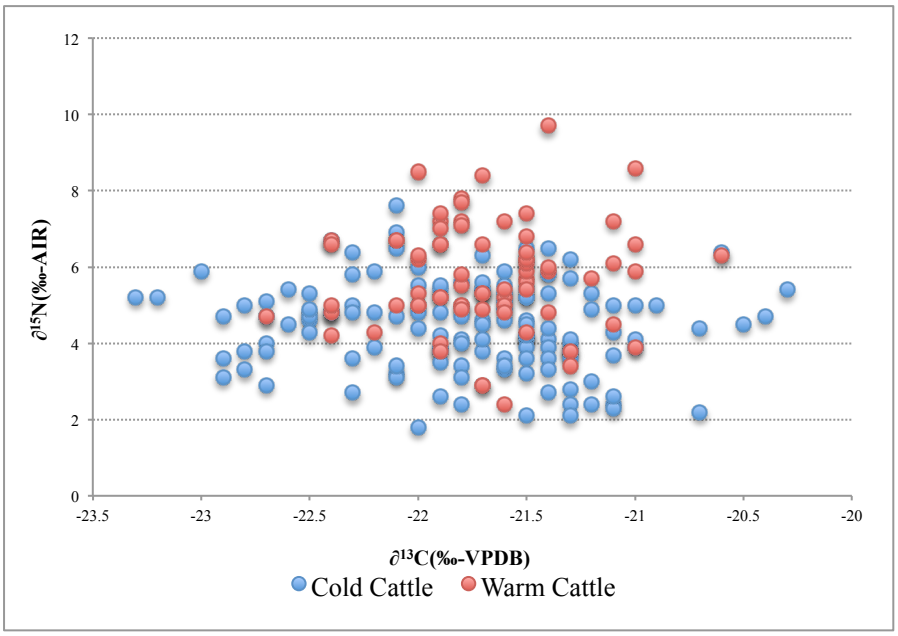


Figure 6.71. Comparison of the cattle data according to cold and warm episodes between the Iron Age and the Early Medieval period Climate modelled after Büntgen *et al.* 2011 and Charman 2010. (n cattle from warm period = 73, n cattle from cold period =136).

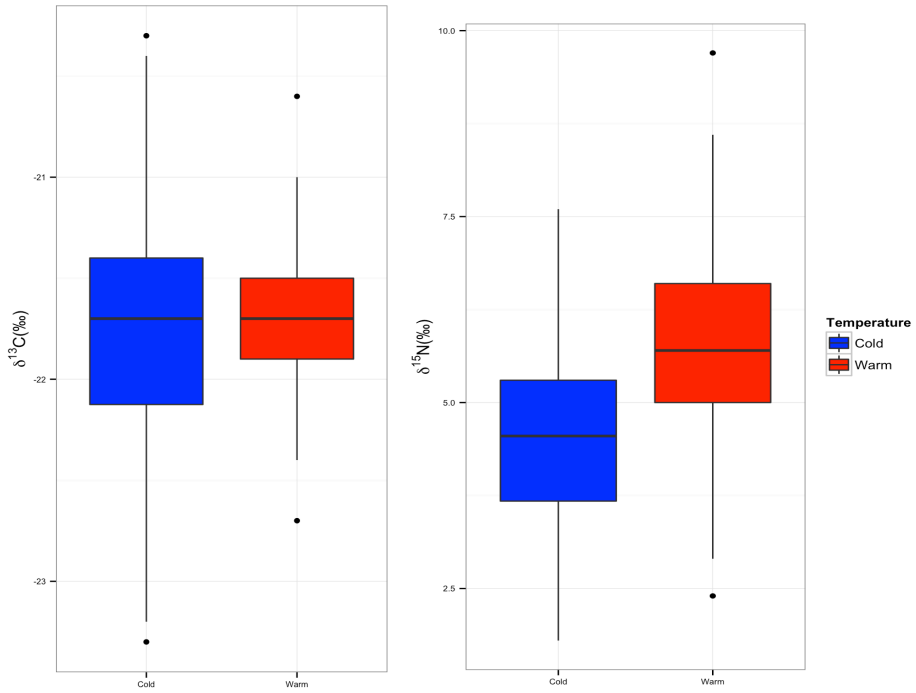


Figure 6.72. Boxplot comparison of the cattle according to wet and dry episodes between the Iron Age and the Early Medieval period. Climate modelled after Büntgen *et al.* 2011 and Charman 2010 (n cattle from warm period = 73, n cattle from cold period =136).

Figures 6.71 and 6.72 show the results of the cattle data according to cold and warm periods. A slight enrichment in ^{15}N in the warmer periods is visible, while $\partial^{13}C$ averages are similar between periods. To assess whether or not this a genuine pattern, different linear models were tested, each taking into account the distribution of the data in region/periods/periods of precipitation/region of coherent precipitation. These revealed a significant difference in the nitrogen isotopic data (Table 6.57). This is really interesting as it suggests that this result is significant, independent from factors at the site, regional, temporal and other environmental levels, and might therefore reveal a genuine pattern of higher $\partial^{15}N$ values for the fauna in warmer periods. It could be both an environmental effect, i.e. plants values were affected, and/or a change in animal husbandry in time of climatic amelioration. The relation between temperature and plant

enrichment in ^{15}N is not necessarily straightforward in temperate climate (O'Leary 1995). While it is expected that high levels of aridity would result in elevated nitrogen isotopic values, it is unlikely that this is what is seen here. However, heat might have had an effect on soil nitrates, hence raising the nitrogen isotopic profile of the plants consumed by the cattle. It is also possible that a change in how the cattle were fed happened due the better climatic conditions, although it is not necessarily obvious what this change would have been.

Table 6.57. Statistical results for cattle data when comparing warm and cold events. The models were tested with as many variables as possible to contain variations not related to temperatures. The best-fit models are presented below.

Rain-Region	**Multi-Level Model With 'Sites' As Random Effect And 'Precipitation' And 'Archaeological Period' As Fixed Effects**	**Multi-Level Model With 'Sites As Random Effect And 'Precipitation', 'Archaeological Period', And 'Region' As Fixed Effects**
	p-value ($\partial^{13}C$)	*p-value* ($\partial^{15}N$)
Cold-Warm	0.361	**0.028**

6.6.4 Inland and Coastal

Table 6.58. Distribution of the cattle data depending on proximity to the coast between the Iron Age and the Early Medieval period.

Site Type	N of sites	N of samples	Broad Archaeological Period	Region	Site
Coastal	4	23	Iron Age, Early Medieval	Cornwall, Suffolk	Bloodmoor Hill, Harlyn Bay, Trethellan Farm, Trevelgue Head
Inland	21	353	Iron Age, Roman, Early Medieval	Dorset, Gloucestershire, Hampshire, Oxfordshire, Somerset, Suffolk, Yorkshire	Abbot's Worthy, Alchester, Asthall, Berinsfield, Bradley Hill, Butler's Field, Cirencester, Danebury, Fordington Bottom, Houghton Down, Lechlade, Masham, Nettlebank Copse, New Buildings, Shavard's Farm, Suddern Farm, West Stow, Wetwang Garton-Slack, Winchester, Winnall Down, Yarnton
Riverine	9	67	Roman, Early Medieval	Gloucestershire, North Lincolnshire, Northumberland, Yorkshire	6 Driffield Terrace, Bellevue (York), Black Gate Cemetery, Blossom Street (York), Catterick, Fishergate (York), Gloucester, Hucclecote, Whitton, York.

Another environmental aspect that needs to be considered is the 'salinity effect', which predicts high $\partial^{13}C$ and $\partial^{15}N$ levels at the base level of the food chain due to the predominance of halophytes ('salt-loving') plants on the coast (Britton *et al.* 2008). There is strong archaeological evidence that salt marshes were used as grazing lands in the past, which would have raised the isotopic values of the whole food chain, all the way up to humans (Britton *et al*. 2008). Furthermore, the use of seaweed as supplementary animal feed and fertiliser is well attested in marginal coastal settlements (see Balasse *et al.* 2005 for a study of the isotopes of modern sheep on a seaweed diet; see Fleuriot 1986 for the use of seaweed as cattle feed in Brittany in the Early Medieval period). Coastal sites here are defined as sites located less than one kilometre from the coast (see Chapter 4, section 4.2.5). Table 6.58 shows the distribution of the data.

Figures 6.73 and 6.74 show the cattle isotopic data according to coastal/inland location. The cattle data from the coastal sites show a slight depletion in ^{13}C compared to the data from the inland sites.

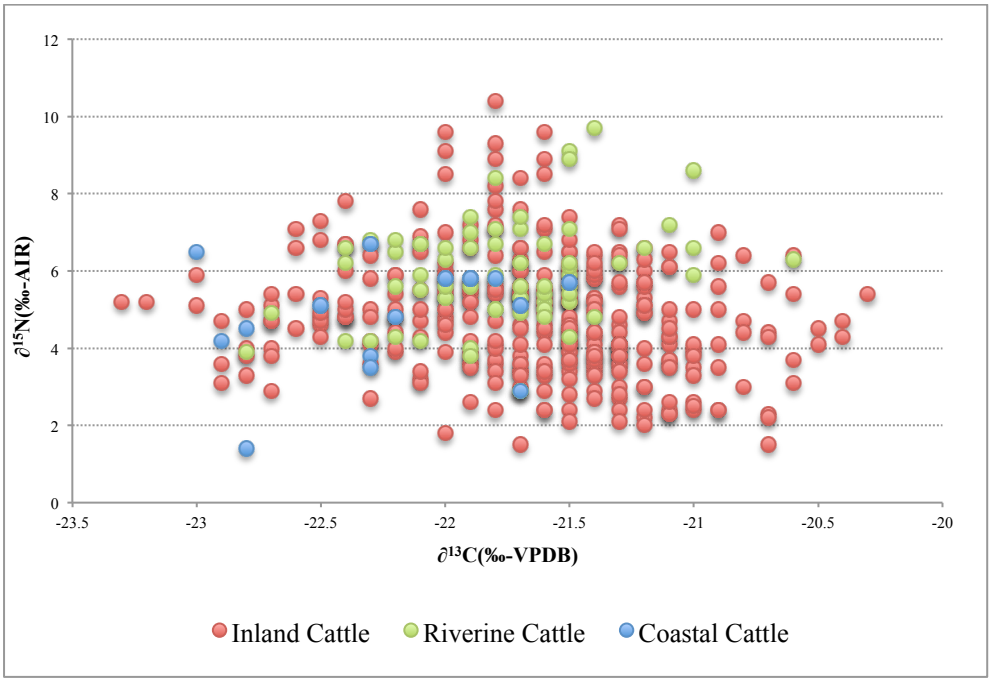


Figure 6.73. Cattle according to proximity to the coast between the Iron Age and the Early Medieval period depending on proximity to the coast (Coastal Cattle n = 23, Inland Cattle n =344, Riverine Cattle n = 78).

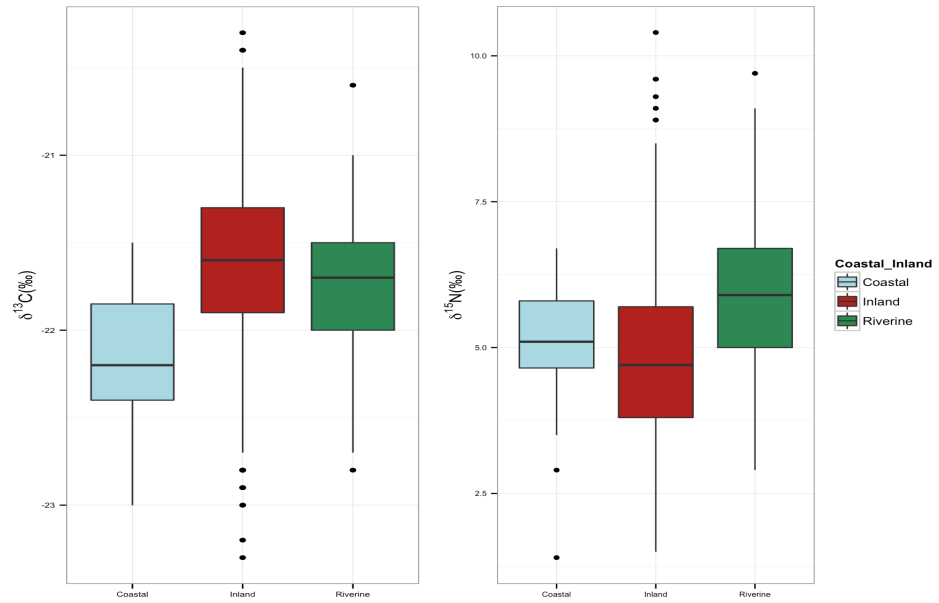


Figure 6.74. Cattle according to cold and warm episodes between the Iron Age and the Early Medieval period depending on proximity to the coast (Coastal Cattle n = 23, Inland Cattle n =344, Riverine Cattle n = 78).

Comparing these results with Britton *et al*. (2008)'s findings, which showed significant enrichment in ^{15}N for fauna in coastal sites compared to fauna from inland sites, these cattle also show some enrichment in ^{15}N compared to the inland data (Figures 6.73, 6.74). However, this is not statistically significant. Interestingly, however, the coastal data are significantly depleted in ^{13}C compared to the Inland and Riverine data, which, while it goes against what was expected from Britton *et al.* (2008)'s study, might nonetheless be caused by proximity to the coast since a decrease in ^{13}C due to salinity has been shown previously (Table 6.59; Van Groeningen and Kessel 2002).

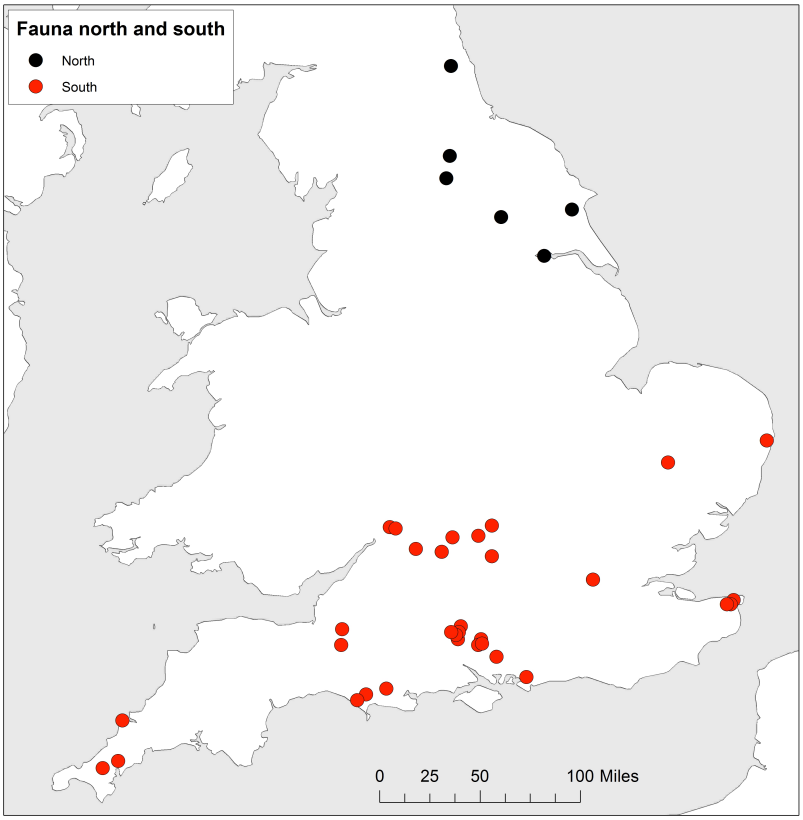
Table 6.59. Statistical results for the cattle data when comparing proximity to the coast. The best-fit models are presented below.

Proximity to the coast	***Multi-level model with 'Sites' as random effect and 'Archaeological Period' as fixed effects***	
	p-value ($\partial^{13}C$)	*p-value* ($\partial^{15}N$)
INLAND-COASTAL	**0.012**	0.436
INLAND-RIVERINE	0.597	0.479
COASTAL-RIVERINE	**0.072**	0.984

6.6.5 South and North

Table 6.60. Distribution of the cattle data according to latitude between the Iron Age and the Early Medieval period.

Latitude	N of sites	N of samples	Broad Archaeological Period	Region	Sites
North	10	68	Iron Age, Roman, Early Medieval	North Lincolnshire, Northumberland, Yorkshire	6 Driffield Terrace, Bellevue (York), Black Gate Cemetery, Blossom Street (York), Catterick, Fishergate (York), Masham, Wetwang Garton-Slack, , Whitton, York
South	14	375	Iron Age, Roman, Early Medieval	Cornwall, Dorset, Gloucestershire, Hampshire, Oxfordshire, Somerset, Suffolk	Abbot's Worthy, Alchester, Asthall, Berinsfield, Bloodmoor Hill, Bradley Hill, Butler's Field, Cirencester, Danebury, Fordington Bottom, Harlyn Bay, Houghton Down, Hucclecote Lechlade, Nettlebank Copse, New Buildings, Shavard's Farm, Suddern Farm, Trevelgue Head, Trethellan Farm, West Stow, Winchester, Winnall Down, Yarnton



Map 6.3. Distribution of sites containing faunal data for the North and South.

It was hypothesised in Chapters 1 and 4 that the North and the South of England would be have had different cultural traditions in all three periods considered. *Britannia Prima* (South) and *Britannia Secunda* (North) in the Roman period and then the Northern and Southern kingdoms of Anglo-Saxon England in the 7th and 8th centuries as well as the Southern Anglo-Saxon kingdoms and the Danelaw in the 9th century would display different isotopic results. Therefore, the data were analysed to investigate whether there are any differences between the southern samples (below the Humber) and the northern samples (above the Humber) regardless of time period (Table 6.60, Map 6.3).

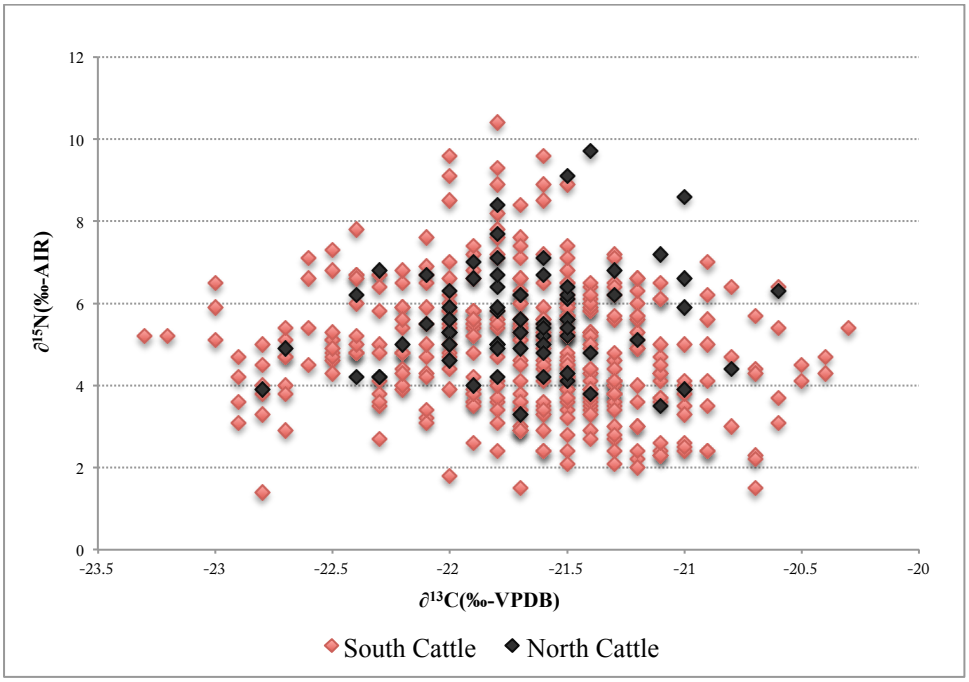


Figure 6.75, Comparison of the cattle in to the North (north of the Humber) and South (South of the Humber) between the Iron Age and the Early Medieval period. (North Cattle n = 68, Cold Cattle n =375).

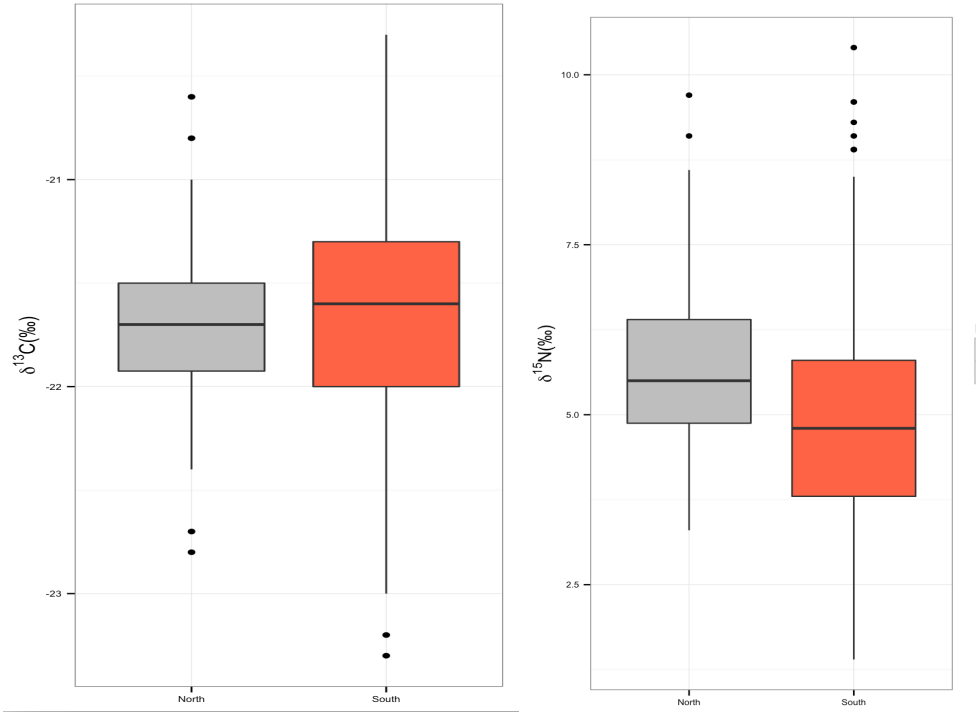


Figure 6.76. Boxplot comparison of the cattle in to the North (north of the Humber) and South (South of the Humber) between the Iron Age and the Early Medieval period. (North Cattle n = 68, Cold Cattle n =375).

While the southern data look depleted in ^{15}N compared to the North, this is very likely to be the aforementioned 'Hampshire' effect (Figures 6.75, 6.76). Indeed, while there is a significant difference between North and South when the regional distribution of the data is not integrated to the model, this difference disappears when considering it independently from both factors at the site and regional levels, strongly suggesting that the large dataset from Hampshire is biasing the results (Table 6.61).

Table 6.61. Statistical results for the cattle data when comparing latitude. The models were tested with as many variables as possible to contain variations not related to latitude. The best-fit model is presented below.

North-South	**Multi-Level Model With 'Sites' As Random Effect, And 'Sub-Period' And 'Region' As Fixed Effects.**	
	p-value ($\partial^{13}C$)	*p-value* ($\partial^{15}N$)
North-South	0.832	0.189

6.7. Summary and preliminary conclusions.

The most striking overall pattern in the faunal data is the decrease in $\partial^{13}C$ over time, and the $\partial^{15}N$ peak in the Roman period. The decrease over time is hard to explain, as it is not clear what would be causing higher $\partial^{13}C$ in the Iron Age, since it is usually associated with either decreasing rainfall or increased sunlight, when the Iron Age was allegedly colder and wetter than the other regions. High $\partial^{13}C$ vs. low $\partial^{13}C$ can also be interpreted in relation to forest canopies, but this does not match known patterns of woodland clearance and expansion in the periods investigated here, at least for the Iron Age and the Roman period. The Early Medieval period saw expansion of woodland, especially in the post Roman period, which could to some extent explain the lower $\partial^{13}C$ values in the period. The ^{15}N peak is easier to

explain, and is likely the result of agriculture development in the Roman period, with application of manure and the land worked more intensively.

There are other patterns worth noting:

i. The negative correlation in the domesticated faunal data in the Iron Age is unusual.

ii. The lack of clear diachronic patterns at the broad period level but some difference between sub-periods, suggesting more gradual changes.

iii. Regional patterns might be more accurately described as a "Hampshire" pattern, with the Hampshire faunal data depleted in both isotopes compared to the data from the other regions.

iv. Looking beyond temporal and regional divisions, temperature and the 'coastality' of sites appear to be the more important factors, and have been shown to be significant independently from site, regional or temporal level factors.

All of these will inform investigation of the human data in the next chapter, and will be discussed further in Chapter 8.

CHAPTER 7. HUMAN ANALYSES: RESULTS

In this chapter, the human isotopic data will be examined at different chronological and regional resolutions. As was done with the fauna, each broad period will be discussed first. Then, variations within the human population will be investigated further to assess whether there were differences in diets depending on gender or age groups. Then, as discussed in Chapter 4, each broad period has also been divided into sub-periods in order not only to examine the evolution of dietary practices within each period but also to look into the transition from one period to another with more precision. It is indeed probable that dietary practices were not static within one broad period and examining the data at a higher chronological resolution will shed light on the processes of dietary behaviours. Regionality within each broad period is examined to assess whether regional factors rather than chronological ones can explain the patterns in the data. Finally, factors beyond chronology and temporality are also investigated, to identify *longue durée* trends.

7.1. Iron Age

Table 7.1. Summary of the isotopic results of all the human Iron Age data.

	Average $\partial^{13}C$(‰)	Average $\partial^{15}N$(‰)	min $\partial^{13}C$ ‰	max $\partial^{13}C$ ‰	range $\partial^{13}C$ ‰	min $\partial^{15}N$ ‰	max $\partial^{15}N$ ‰	range $\partial^{15}N$‰	n=
Human	-20.2 ± 0.41	9.4 ± 1.15	-21.8	-18.9	1.9	5.3	13.1	7.8	311

Table 7.1 shows a summary of the human Iron Age data that will be discussed below. It contains 311 values, split between different demographic groups. It is the smallest dataset of the broad period investigated here.

7.1.1 Human isotopic results

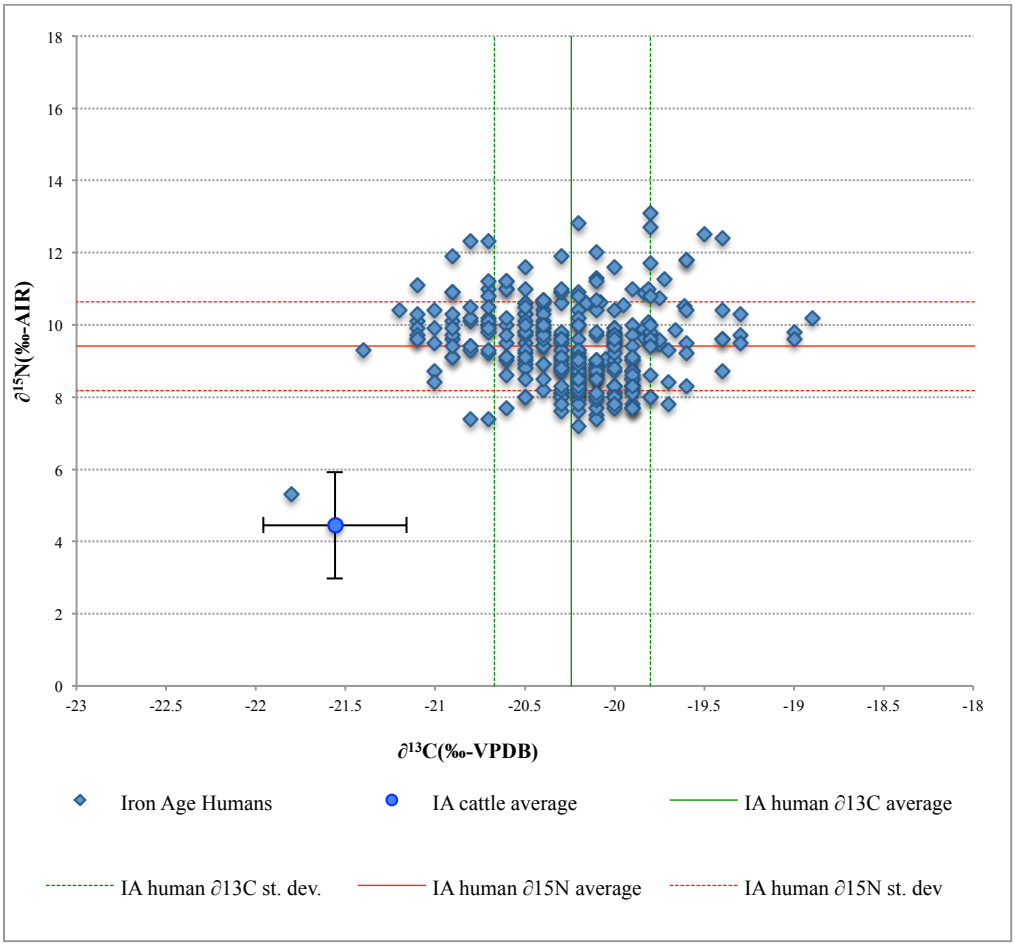


Figure 7.1. Human isotopic distribution of all the Iron Age data.

The human data for the Iron Age display $\partial^{13}C$ ranges between -21.8‰ and 18.9‰ and the nitrogen isotope values range between and 5.3‰ and 13.1‰. The $\partial^{13}C$ average is -20.2 ± 0.41‰ and the $\partial^{15}N$ average is 9.4 ± 1.15‰, which is consistent with a C_3-based terrestrial diet with no aquatic protein

contribution to the diet (Figure 7.1). There are some outliers in the data. The most obvious one is the one with low $\partial^{13}C$ and $\partial^{15}N$ values (-21.8 and 5.3‰), which plots near the cattle average, and might, in fact, be a cow. There is one outlier, with an enriched ^{15}N value (13.1‰), and a group of three individual outliers with values enriched in ^{13}C (>-19‰; See Table 5.2 for outliers values). Because the negative correlation seen in the fauna was unusual (See section 6.1.1, Table 6.2), the correlation between both isotopes was also tested in the human data but was found to be insignificant (r = 0.04, p=0.54). However, in section 7.1.2 below, it will be shown that the correlation between isotopes actually differs between genders.

7.1.2 Inter-Human variations

7.1.2.1 Sex

Table 7.2. Distribution of the data between the different sexes. Individuals who have not been attributed a sex (n=142) have not been included. R is the Pearson's coefficient.

Sex	N	Average $\partial^{13}C$	Average $\partial^{15}N$	min $\partial^{13}C$	max $\partial^{15}n$	min $\partial^{15}N$	max $\partial^{15}N$	*r*	*p-value*
Male	88	-20.14 ±0.33	9.20 ± 0.96	-21.1	-19	7.4	12.3	-0.31	0.002
Female	68	-20.28 ± 0.41	9.16 ± 0.86	-21.1	-19	7.7	12.7	-0.23	0.058

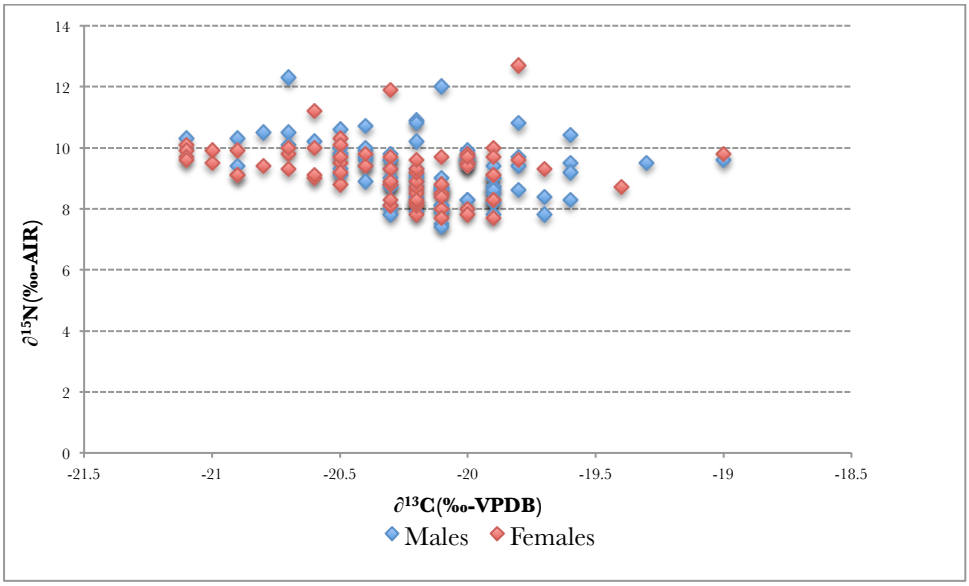


Figure 7.2.Comparison of males (n=88) and females (n=68) in the Iron Age.

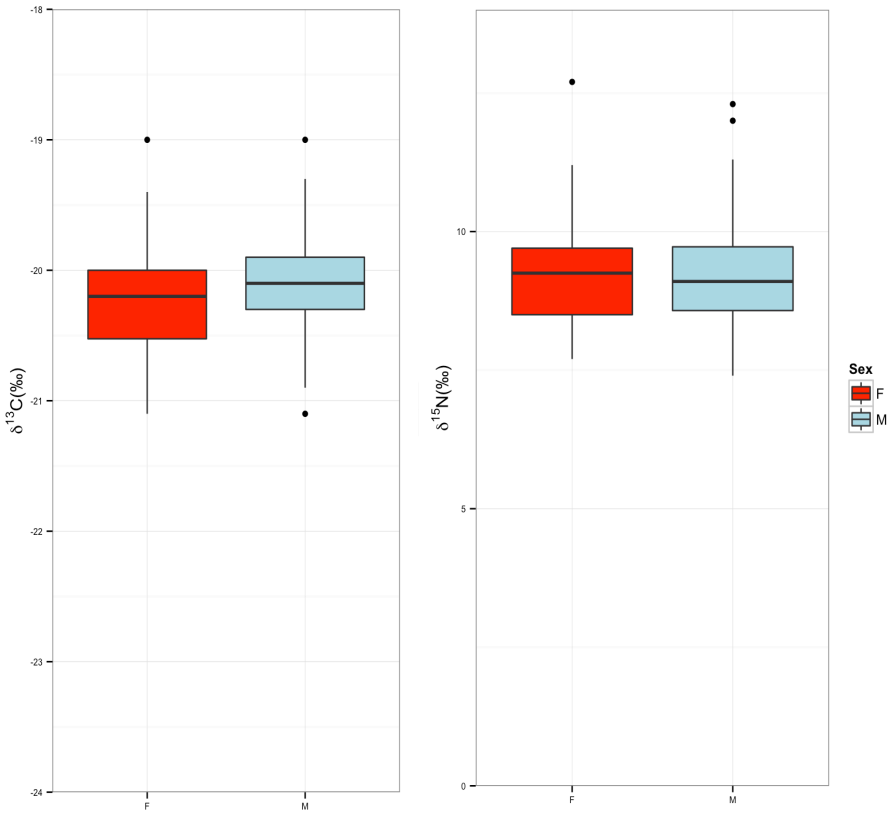


Figure 7.3. Boxplot comparisons of males (n=88) and females (n=68) in the Iron Age.

The sexed and aged samples were analysed to assess whether there are differences between the isotopic results of males and females or between different age groups in the Iron Age. Figures 7.2 and 7.3 show that there is very little difference between the sexes (See Table 7.2). They also have similar ranges with the carbon isotopic data falling into a range of 2.1‰ for both females and males, and the nitrogen isotopic data falling into a range of 2.1‰ for female and 4.9‰ for male. There is a significant difference between the male and the female $\partial^{13}C$ values (see Table 7.3). However, an effect size test (here 'cohen.d') reveals that this difference is only small (0.38).

Table 7.3. Statistical differences between males and females in the Iron Age. Integrating 'Region' or 'Sub-Period' as random effect and/or fixed effect does not affect the significance of the result.

Sex	**Multi-Level Model With 'Sites' As Random Effect And 'Sex', 'Region' And 'Sub-Period' As Fixed Effects.**	
	p-value ($\partial^{13}C$)	*p-value* ($\partial^{15}N$)
Females-Males	**0.014**	0.425

However, what might be more interesting than the difference between the male and female data here is the correlation between both isotopes (See Table 7.2). Indeed, males display a significant negative correlation between both isotopes (r=-0.31, *p*= 0.002). This correlation is also negative in the female data, but it is only moderately significant and less pronounced (r = -0.23, *p*= 0.058). Considering that the faunal data was also displaying this negative correlation, this difference between the sexes could be interpreted as males relying more on animal protein than females, thus displaying an

isotopic profile more similar to that of the animals. This will be discussed further in Chapter 8.

7.1.2.2 Age

Table 7.4. Distribution of the data between the different age groups. Individuals who have not been aged (n=73) have not been included. *R* is Pearson's correlation coefficient.

IA	N of samples	n of sites	Ave. $\partial^{13}C$	Ave. $\partial^{15}N$	r	p-value
Infant	17	3	-19.±0.42	10.1±0.92	0.21	0.396
Juvenile	10	6	-20.1±0.58	9.7± 1.37	-0.43	0.209
Young Adult	51	4	-20.4±0.35	9.3±1.02	-0.08	0.553
Adult	116	13	-20.8±0.41	9.1±1.12	0.06	0.515
Mature Adult	31	3	-20.5±0.23	9.7±1.10	-0.46	0.008

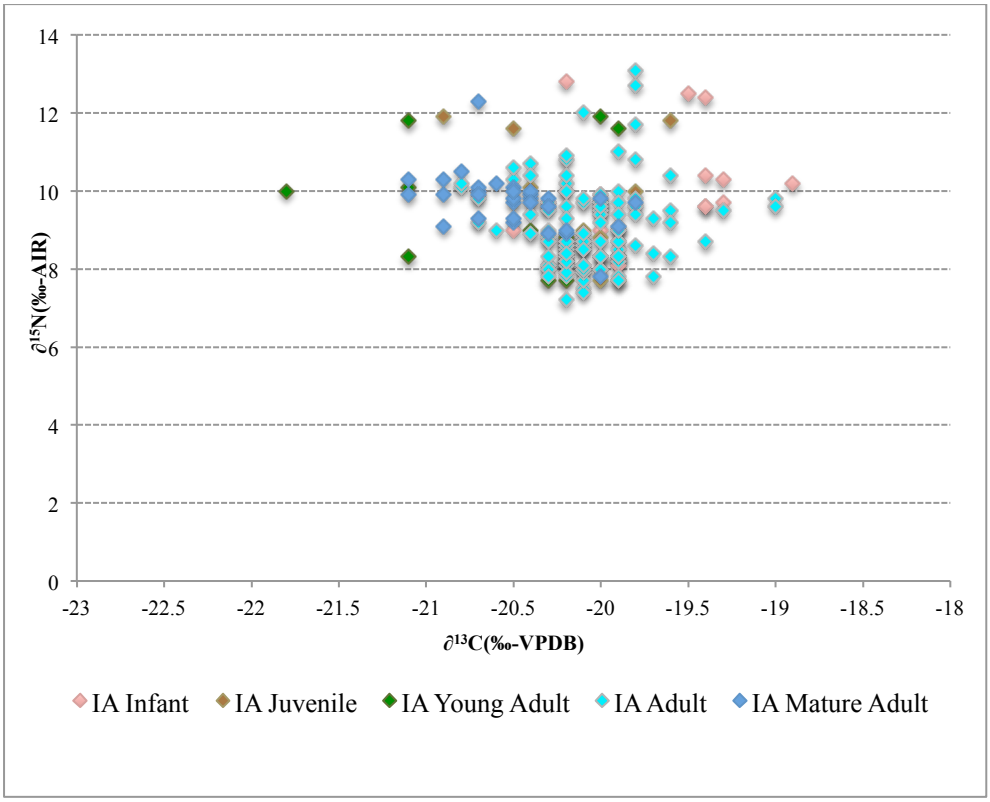


Figure 7.4. Comparison of the different age groups in the Iron Age (Infant n= 17, Juvenile n=10, Young Adult n=51, Adult n = 116, Mature Adult n = 31).

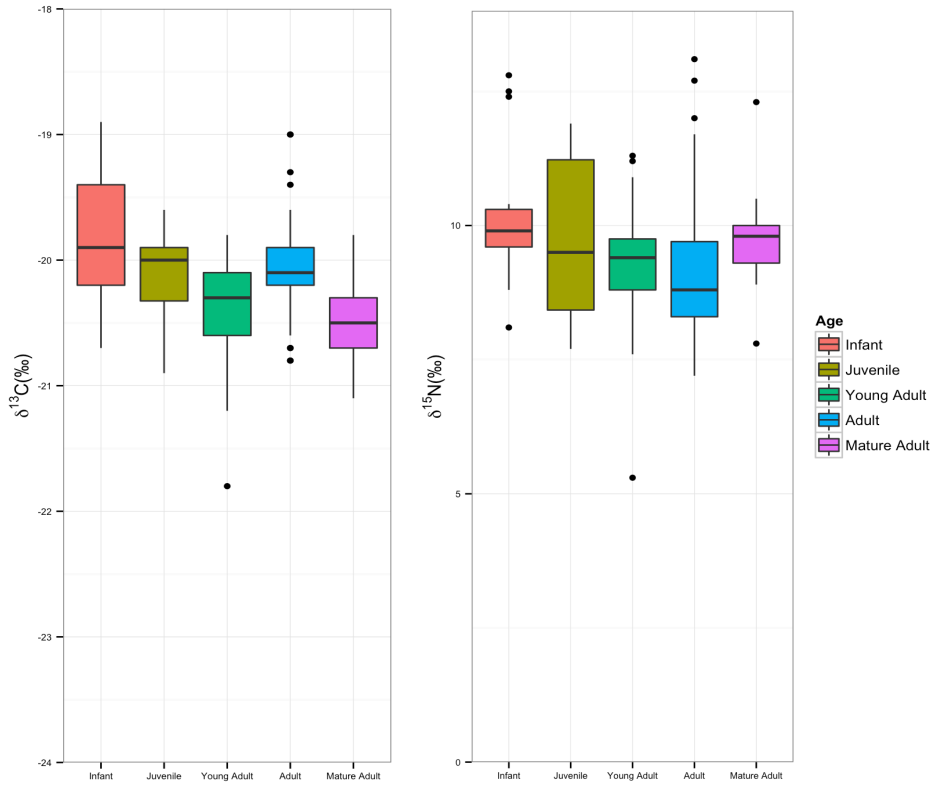


Figure 7.5. Boxplot comparison of the different age groups in the Iron Age (Infant n= 17, Juvenile n=10, Young Adult n=51, Adult n = 116, Mature Adult n = 31).

Unsurprisingly, considering the nursing effect, infants have the highest isotopic values relative to the other age groups in the Iron Age. While there seems to be a decline in both isotopes over time, the $\partial^{13}C$ values of the adults appear to rise before dropping again for the older groups. For the $\partial^{15}N$ values, the adult values are the lowest of all groups, but rise again in the older group (Figures 7.4, 7.5). However, this is not statistically significant when taking into account the regional and temporal (i.e. sub-period) distribution of the data (Table 7.5). The only significant difference between the age groups is between the infants and all the older groups, except for the juveniles, which is likely to be an indication of the nursing effect (Table 7.5). Again, an interesting pattern of correlation emerges, with the mature adults also showing a negative correlation between isotopes,

suggesting different access to resources between males and females, but also possibly between age groups, even if the statistical differences between are not significant (Tables 7.4 and 7.5). This will be explored further in Chapter 8.

Table 7.5. Statistical differences between the different age groups in the Iron Age. Integrating 'Region', 'Sub-Period' or 'Sex' as random effect and/or fixed effect does not affect the significance of the results.

Age	***Multi-Level Model With 'Sites' and 'Sub-Period' As Random Effect And 'Sex', 'Region' and 'Age' as fixed effects.***	***Multi-Level Model With 'Sites' and 'Sub-Period' As Random Effect And 'Age', 'Region' as fixed effects.***
	p-value (∂^{13}C)	*p-value* (∂^{15}N)
-Infant-Juvenile	0.269	0.031
Infant-Young Adult	**0.002**	**0.001**
Infant-Adult	**0.014**	**0.000**
Infant-Mature Adult	**0.009**	**0.016**
Juvenile-Young Adult	0.896	0.857
Juvenile-Adult	0.999	0.994
Juvenile-Mature Adult	0.900	0.999
Young Adult-Adult	0.808	0.833
Young Adult-Mature Adult	1.00	0.654
Adult-Mature Adult	0.858	0.999

Because 'Sex' was integrated in the model, the difference between the different age groups according to sex was also investigated and is shown in Figure 7.6 below. It shows that while females are depleted in ^{13}C compared to males when younger, this difference disappears with age. The difference in the ∂^{15}N ratio is reversed, with males and females having similar ∂^{15}N averages when younger, but males then displaying higher ∂^{15}N ratios than females when older. While this could indicate changes in diet over the

lifetime of an individual can also be affected by gender, these patterns are not significantly significant. (See Table A2.3.1. in Appendixes II.3)

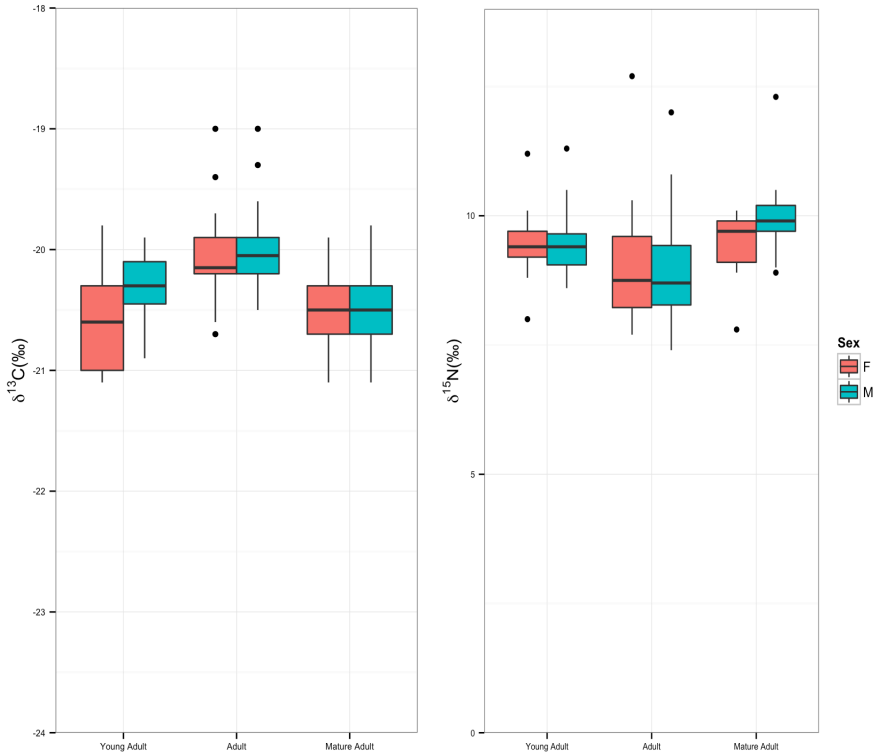


Figure 7.6. Comparison of the different age groups according to sex in the in the Iron Age (Females: Young Adult n=17, Adult n =38, Mature Adult n = 13; Males: Young Adult n=15, Adult n =56, Mature Adult n = 17). The differences between the different sexes according to age were not significant.

7.1.3 Intra-period variations.

Table 7.6. Distribution of the human data in different sub-periods in the Iron Age, according to number of sites, number of samples and regions.

Sub-Period	n of sites	n of samples	Region	Site
Early Iron Age	1	20	Hampshire	Danebury
Middle Iron Age	4	136	Cornwall, Hampshire, Kent, Yorkshire	Danebury, Gravesend, Harlyn Bay, Micheldewer Wood, Trethellan Farm, Wetwang Garton-Slack, Winnall Down
Late Iron Age	8	63	Dorset, Hampshire	Danebury, Flagstones, Fordington Bottom, Gussage All Saints, Manor Farm, Tolpuddle Ball, Whitcombe Farm

To look at variation within the Iron Age, both the human data and the offsets between human and cattle averages have been used. Figure 7.7 and 7.8 shows the human data according to the different sub-periods of the Iron Age, as well as the Iron Age cattle average, as defined in Chapter 4 (Section 4.2.3). The sites and sample numbers are shown in Table 7.6

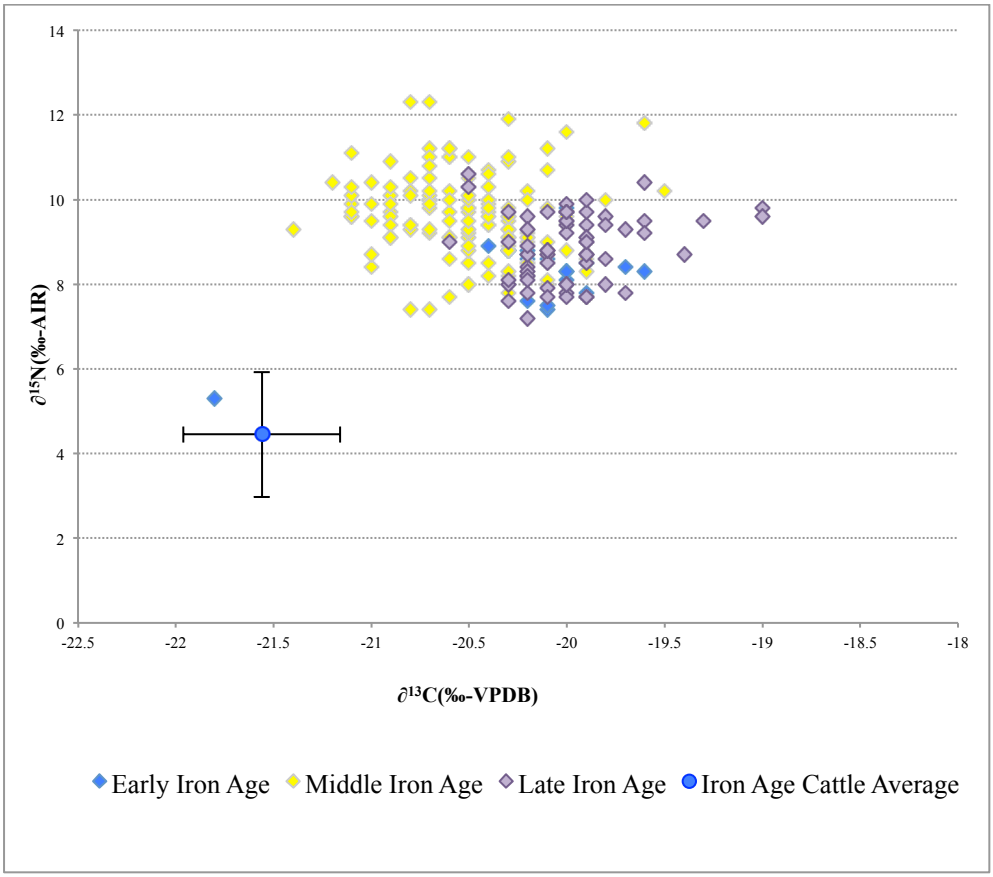


Figure 7.7. Comparison of the Iron Age human data in the different sub-periods in the Iron Age (Early Iron Age n=20, Middle Iron Age n=136, Late Iron Age n = 63). The samples only dated to the 'Iron Age' have been excluded from these analyses (n=79) as well as the only 'Latest Iron Age' sample (n=1).

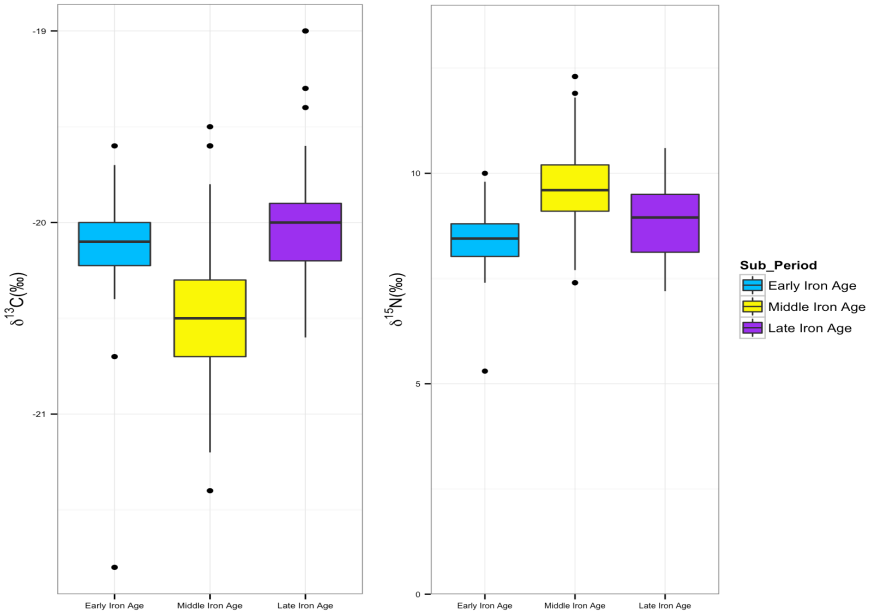


Figure 7.8. Boxplot comparison of the Iron Age human data in the different sub-periods in the Iron Age (Early Iron Age n=20, Middle Iron Age n=136, Late Iron Age n = 63). The samples only dated to the 'Iron Age' have been excluded from these analyses (n=79) as well as the only 'Latest Iron Age' sample (n=1).

Two groups emerge here with a difference between the Middle Iron Age and the Late Iron Age (Figures 7.7 and 7.8). When this difference is tested statistically, with 'site' and 'region' integrated as random effects, it is found to be significant, meaning it exists independently of sites and regional factors. It is however worth noting that when 'Region' is integrated as a fixed effect, which is the best-fit model, this significance disappears. This means that when both 'Region' and 'Sub-period' are integrated, the model finds no statistical difference between the different groups that are significant at **both** the sub-period and regional level (for example, between Early Iron Age Hampshire and Late Iron Age Cornwall; Table 7.7).

Table 7.7. Statistical significance between the different sub-periods for the humans in the Iron Age. *If 'Region' is integrated as a random effect rather than a fixed effect, the difference between the Middle Iron Age and the Late Iron Age is significant (*p*= 0.030), suggesting that there might be some significant difference between them, independent from factors at the regional level, when only sub-period is considered.

Sub_Period	***Multi-level model with 'site' as random effect and 'sub-period' and 'region' as fixed effects***	
	p-value ($\partial^{13}C$)	*p-value* ($\partial^{15}N$)
Early Iron Age –Middle Iron Age	0.947	0.807
Early Iron Age -Late Iron Age	0.538	0.558
Middle Iron Age-Late Iron Age	0.288	0.622*

Figures 7.9 and 7.10 show the evolution of the spacing between the human $\partial^{13}C$ values and the Iron Age cattle average, which shows that the $\Delta^{13}C_{human-cattle}$ values in the Middle Iron Age are on average lower than in the other periods but that most $\Delta^{15}N_{human-cattle}$ values in the Middle Iron Age are higher. With the exception of five samples, the Iron Age $\Delta^{15}N_{human-cattle}$ are all within one trophic level (3-5‰) and above compared to the baseline. However, it is worth remembering that the cattle baseline might be artificially low because of the Hampshire cattle data (see section 6.1.4 and

6.5). Having said that, even taking into account the 'Hampshire effect' some of these offsets remain high and above the range for one trophic level. These could be evidence of consumption of animals with elevated $\partial^{15}N$ values, such as omnivorous pigs, chicken, or possibly freshwater fish. The lack of ^{13}C enrichment rules out marine protein in either sub-periods. It is also possible that the ^{15}N-enrichment comes from the consumption of manured cereals. This suggestion cannot be supported by data, as there is only limited archaeobotanical isotopic data, but this possibility will be explored further in Chapter 8. Maybe more interesting is the difference in $\Delta^{13}C_{human\text{-}cattle}$ values between the Middle and the Late Iron Age, with most of the Late Iron Age displaying offsets over one trophic level (>1‰) but with lower $\Delta^{15}N_{human\text{-}cattle}$ ratios. This could be the result of a transition to more agrarian diets that were less reliant on animal products. However it does not entirely explain the sometimes large $\Delta^{13}C_{human\text{-}cattle}$ in the Late Iron Age. These might be the result of a small contribution of aquatic protein to the diet of some individuals, especially in the case when the $\partial^{15}N$ is also large (> 5‰).

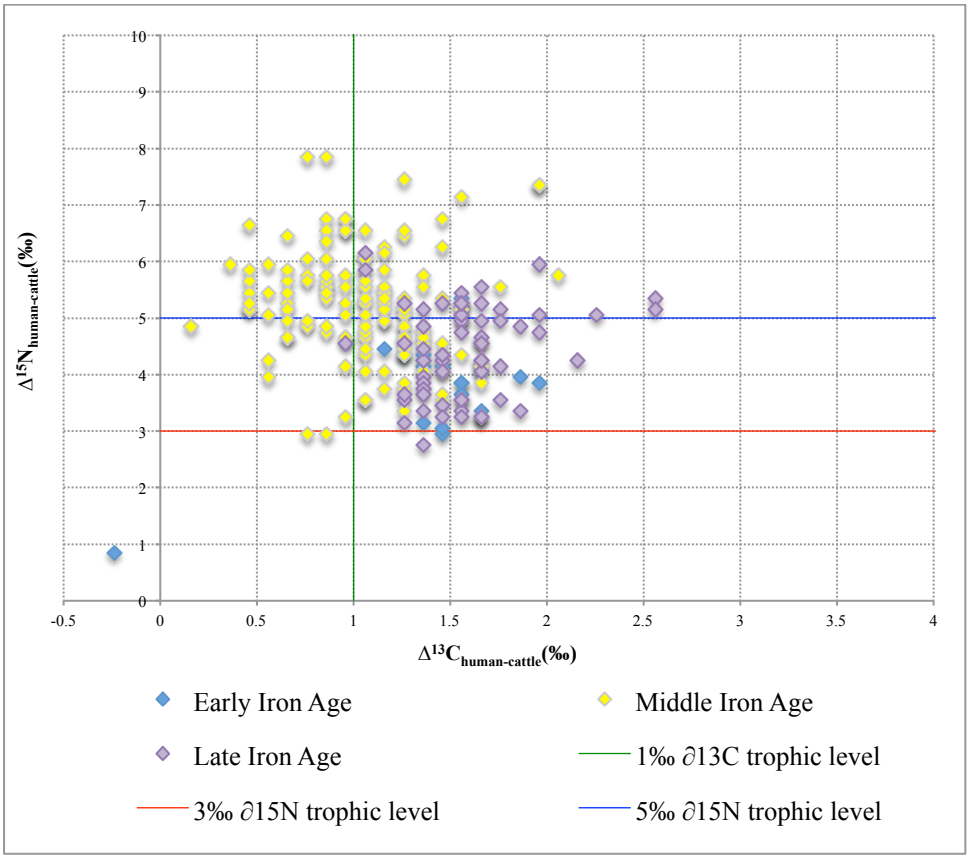


Figure 7.9. Comparison of the $\Delta_{human\text{-}cattle}$ spacing between the Early Iron Age and the Late Iron Age (Early Iron Age n=20, Middle Iron Age n=134, Late Iron Age n = 62). The samples only dated to the 'Iron Age' have been excluded from these analyses (n=79) as well as the only 'Latest Iron Age' sample (n=1). The cattle baseline used here has a $\partial^{13}C$ value of -21.40±0.40‰ and a $\partial^{15}N$ value of 4.5±1.49‰.

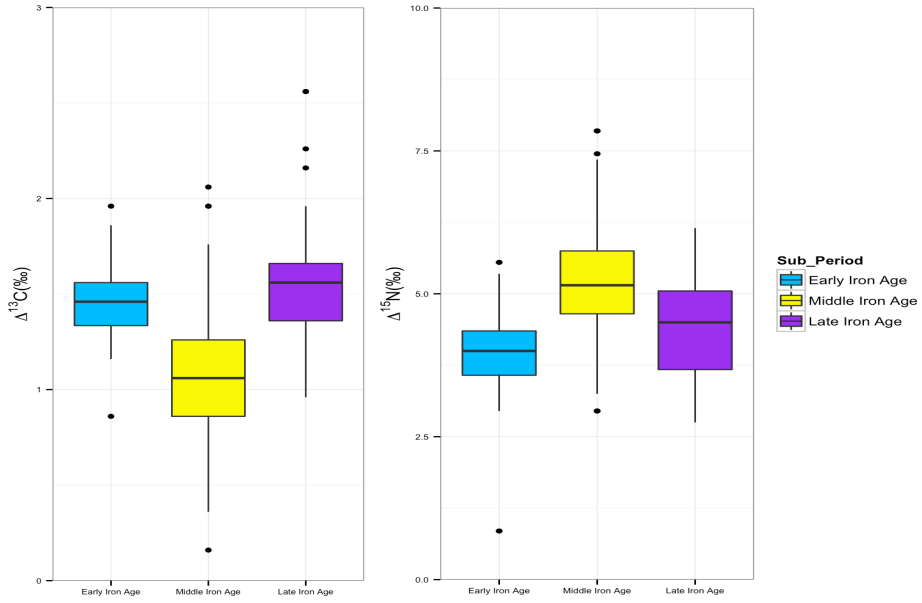


Figure 7.10. Boxplot comparison of the $\Delta_{human\text{-}cattle}$ spacing between the Early Iron Age and the Late Iron Age (Early Iron Age n=20, Middle Iron Age n=134, Late Iron Age n = 62). The samples only dated to the 'Iron Age' have been excluded from these analyses (n=79) as well as the only 'Latest Iron Age' sample (n=1). The cattle baseline used here has a $\partial^{13}C$ value of -21.40±0.40‰ and a $\partial^{15}N$value of 4.5±1.49‰.

7.1.4 Regional variation

Table 7.8. Summary of the regional human data (data from: Harlyn Bay n =20, Trethellan Farm n =4, (Cornwall), Alington Avenue n=5, Flagstones n=2, Fordington Bottom n=10, Gussage All Saints n= 5, Manor Farm n=4, Tolpuddle Ball n=2, Whitcombe Farm=7 (Dorset), Danebury n=56, Micheldewer Wood n=3, Suddern Farm n=37, Winnall Down n=26 (Hampshire).

	Mean Average $\partial^{13}C$(‰)	Mean Average $\partial^{15}N$(‰)	min $\partial^{13}C$ ‰	max $\partial^{13}C$ ‰	min $\partial^{15}N$ ‰	max $\partial^{15}N$ ‰	n=
Cornwall	-20.5± 0.37	10.7 ±0.53	-21.1	-19.6	9.5	11.8	24
Dorset	-19.9 ± 0.32	9.3 ± 0.45	-20.6	-19.0	8.3	10.3	31
Hampshire	-20.1 ± 0.35	8.6 ± 0.94	-21.8	-18.9	5.3	12.3	120

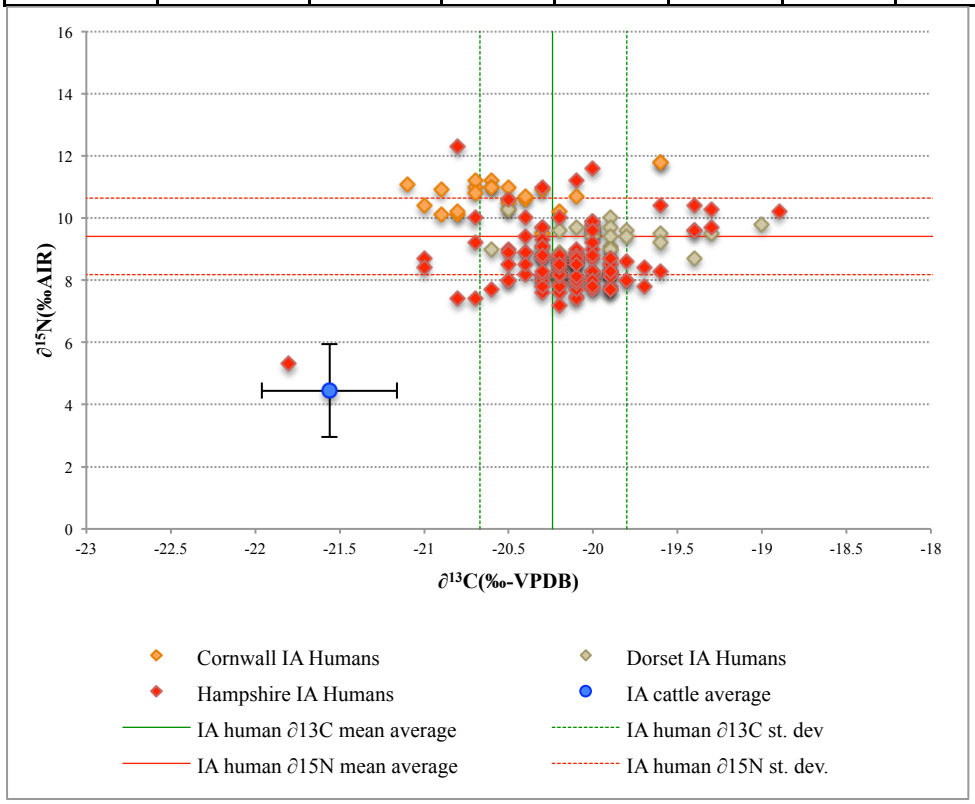


Figure 7.11. Comparison of the different regions present in the human in the Iron Age (Cornwall n=24, Dorset n=31, Hampshire n=120).

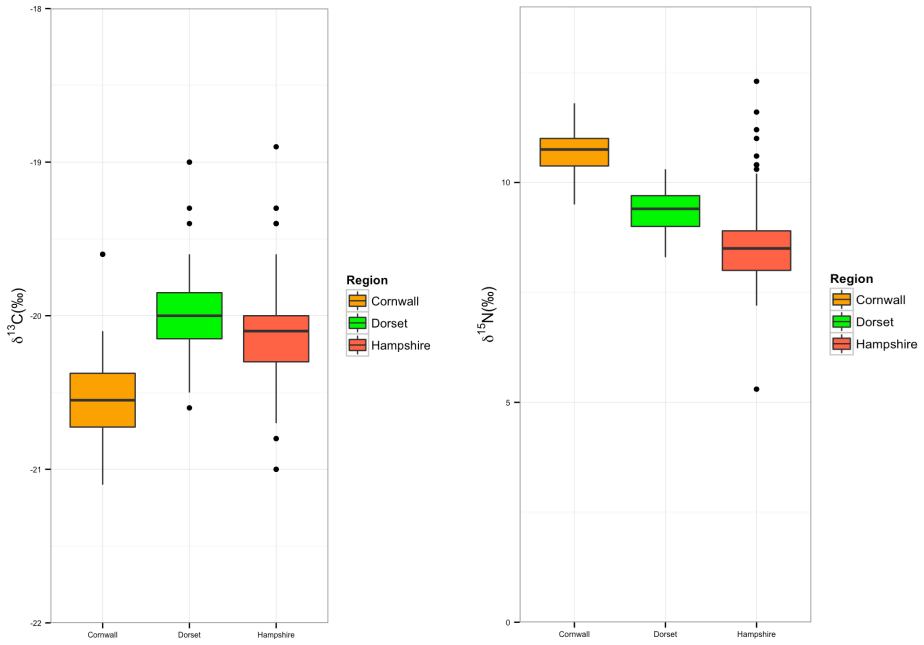


Figure 7.12. Boxplot comparison of the different regions present in the human in the Iron Age (Cornwall n=24, Dorset n=31, Hampshire n=120).

The Iron Age human data are distributed over six counties: Cornwall, Dorset, Gloucester, Hampshire, Oxfordshire and Yorkshire. However, because of the constraints on the analyses, Gloucester, Oxfordshire and Yorkshire have been excluded (Table 7.8). Figures 7.11 and 7.12 show the isotopic results for the human data in all of the Iron Age regions considered. Some patterns are immediately obvious: the data from Hampshire is ^{15}N-depleted compared to the other regions and compared to the 'national' Iron Age mean average, as was the case for the Iron Age faunal data. Both Cornwall and Oxfordshire are enriched compared to the overall Iron Age mean average. Cornwall, however, seems to have lower ∂^{13}C values compared to either Oxfordshire or Dorset, which is particularly visible in the boxplots shown in Figure 7.12. It must also be noted that these results are consistent with the findings from Jay and Richards (2007). Table 7.9 shows the statistical differences between each region of the Iron Age. The

best fit multi-level model integrated 'Sub-Period' as a fixed effect, and no significant difference was found between regions. However, it must be noted that if the 'Sub-Period' variable was removed, then a there was a significant difference between Cornwall and Hampshire, Dorset and Oxfordshire and Hampshire and Oxfordshire.

Table 7.9. Statistical results of the comparison between the different regions in the Iron Age. Integrating 'Sub-Period' was the best fit model, but did have an impact on the significance of some of the results (marked with *):

Region	Multi-Level Model With Sites As Random Effect and 'Region' and 'Sub-Period' as fixed effects.	
	p-value ($\partial^{13}C$)	*p-value* ($\partial^{15}N$)
Cornwall - Dorset	0.128	0.365
Cornwall - Hampshire	0.554	0.107*
Cornwall - Oxfordshire	0.214	0.999
Dorset - Hampshire	0.741	0.805
Dorset - Oxfordshire	1.000	0.555*
Hampshire-Oxfordshire	0.821	0.176*

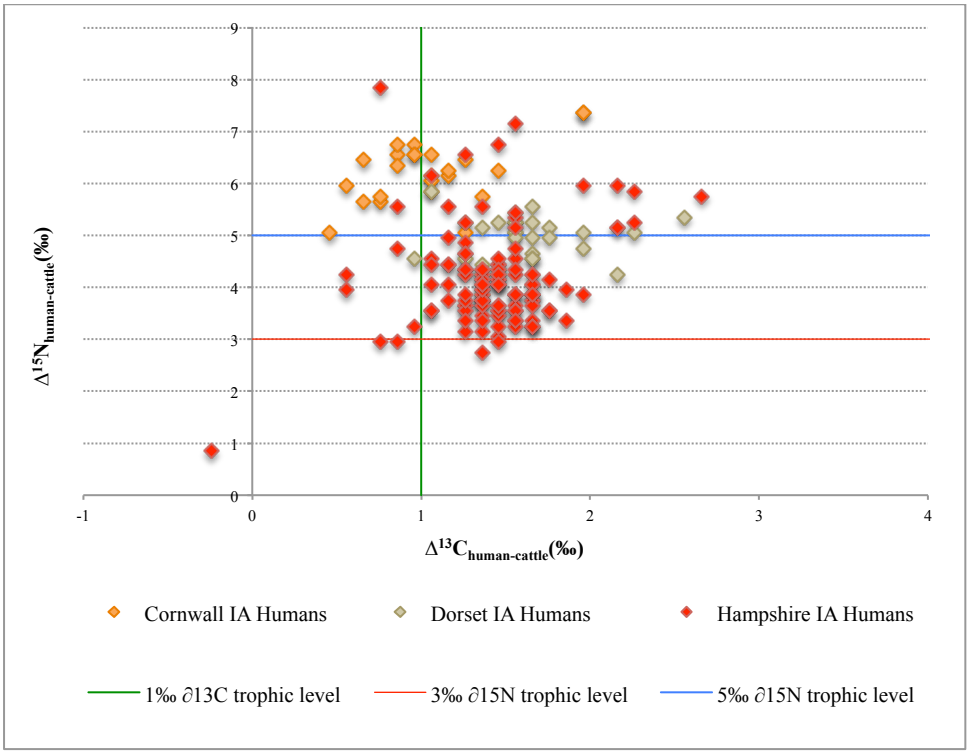


Figure 7.13. Comparison of $\Delta_{human\text{-}cattle}$ spacing between the different regions in the Iron Age. (Cornwall n=20, Dorset n=31, Hampshire n = 120).

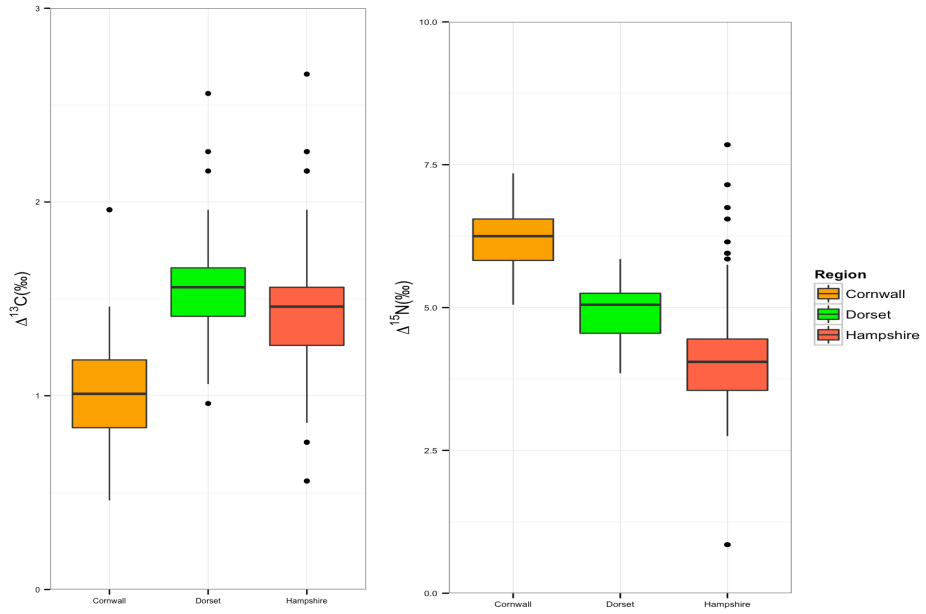


Figure 7.14. Boxplot comparisons of $\Delta_{human\text{-}cattle}$ spacing between the different regions in the Iron Age. (Cornwall n=20, Dorset n=31, Hampshire n = 120).

Comparing the regional data to the Iron Age cattle average reveals that Cornwall displays more enrichment in ^{15}N but is relatively depleted in ^{13}C, plotting below one ^{13}C trophic level (Figures 7.13 and 7.14). This is reminiscent of the cattle data, and possibly suggests a coastal effect. This will be explored in section 7.6.4 of this chapter. The data from Dorset plot slightly above both one ^{13}C and ^{15}N trophic levels, but this might be due to the cattle baseline being artificially low due to the presence of the Hampshire cattle data, which displayed significantly lower $\partial^{15}N$ relative to the other regional cattle. The human Hampshire data, despite being having lower $\partial^{15}N$ values than the other two regions, display enrichment in both ^{13}C and ^{15}N consistent with one trophic level relative to the baseline. Another trend worth noting is the positive correlation of the data in Hampshire (r =0.22, p=0.015) and Cornwall (r =0.38, p=0.066). It is particularly

interesting in Hampshire as the Hampshire faunal data displayed a strong negative correlation. The difference of patterns in the human and the faunal data raises question about the relationship between the fauna and the humans in Hampshire, which will be explored further in section 7.5, by investigating regional differences through a comparison of the human data with restricted regional baselines. This will allow for more nuance in these patterns.

7.1.5 Preliminary discussion of the Iron Age Results

As a preliminary conclusion, the strongest pattern in the human Iron Age data is the shift towards more ^{13}C-enrichment in the late Iron Age compared to the Middle Iron Age. There is no significant difference between the two groups, but it is hard to assess comprehensively when so many factors are at play. The patterns of correlation between both isotopes are interesting as they are unusual: males and females differ, with males maybe relying more on animal products than females. Finally, as had been noted before, there is a relatively high enrichment in both isotopes compared to the baseline, even taking into account the large faunal dataset from Hampshire which is depleted in ^{15}N compared to the rest of the regions and the possibility that this is somewhat biasing the results (Jay 2005). Three possible explanations could account for these patterns (1) the consumption of omnivorous animals; (2) the application of soil fertilisers; and (3) a small amount of aquatic protein, albeit at the individual level rather than the population level. These ideas will be more fully developed in the next chapter.

7.2. Roman Britain

Table 7.10. Summary of the human data from Roman Britain.

	Mean Average $\partial^{13}C$ ‰	Mean Average $\partial^{15}N$ ‰	min $\partial^{13}C$ ‰	max $\partial^{13}C$ ‰	min $\partial^{15}N$ ‰	max $\partial^{15}N$ ‰	n=
Human	-19.7±0.60	10.1 ± 1.81	-21.8	-15.2	6.7	14.8	829

Table 7.8 shows the summary of the Roman data that will be discussed below. It contains 829 humans. The Roman dataset is the second largest broad period dataset for the human groups.

7.2.1 Human Isotopic Results

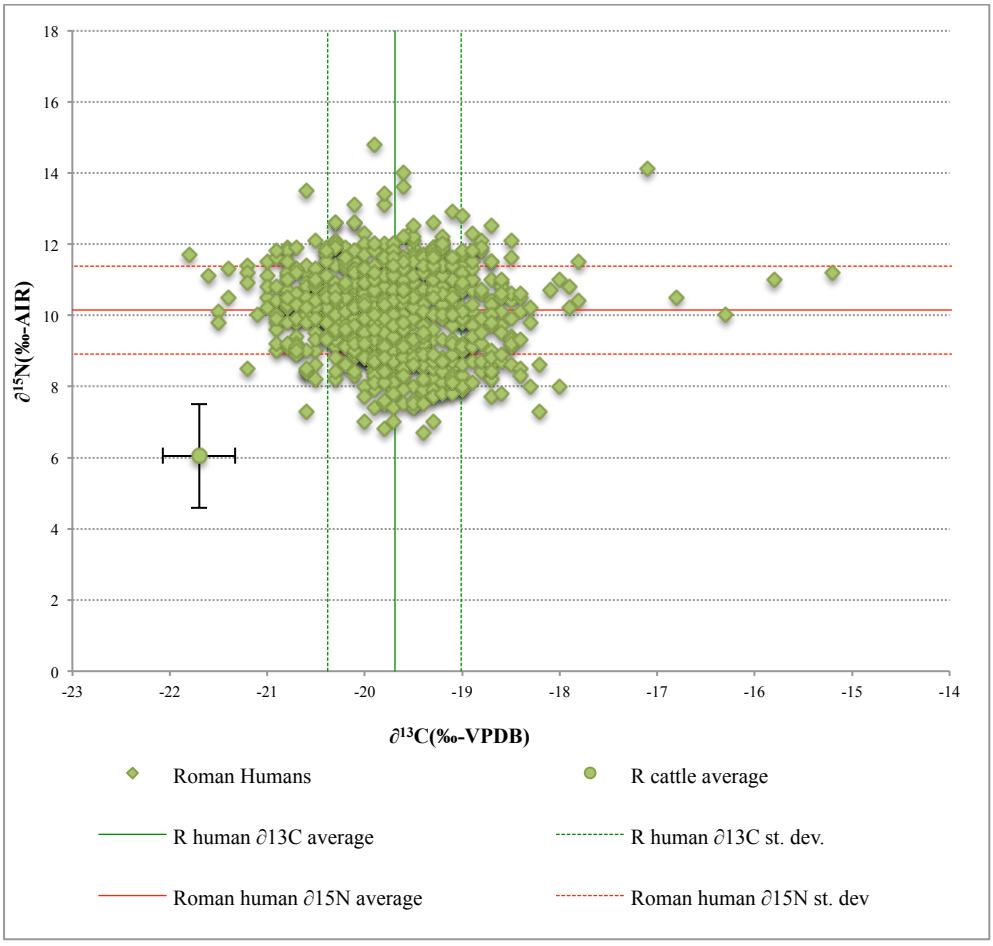


Figure 7.15. Isotopic results of the human isotopic data in Roman Britain.

The average $\partial^{13}C$ value for all of the human Roman data is -19.7 ± 0.60‰ and the average $\partial^{15}N$ value is 10.1 ± 1.81‰. The $\partial^{13}C$ values range between -21.8‰ and -15.2‰ and the $\partial^{15}N$ values from 6.7‰ to 14.8‰. The isotopic values for the Roman period are typical of a terrestrial, C_3-based diet, probably with a relatively large contribution from animal protein. There are a few outliers, which are all enriched compared to the mean, in both ^{13}C (> 17.9 ‰) and ^{15}N (>13.9‰), but only one sample who is an outlier in both isotopes ($\partial^{13}C$: -17.1‰; $\partial^{15}N$: 14.1‰, Figure 7.15).

7.2.2 Intra-population variations.

7.2.2.1 Sex

Table 7.11. Distribution of the data according to sex. Individuals who have not been sexed (n=528) have not been included. *R* is Pearson's correlation coefficient.

Sex	N	Average $\partial^{13}C$	Average $\partial^{15}N$	min $\partial^{13}C$	max $\partial^{13}C$	min $\partial^{15}N$	max $\partial^{15}N$	r	p-value
Male	206	-19.6±0.79	10.6± 1.14	-21.5	-15.2	7.4	14.8	0.24	0.000
Female	95	-19.9±0.64	10.0± 1.27	-21.8	-17.8	6.7	13.1	-0.19	0.059

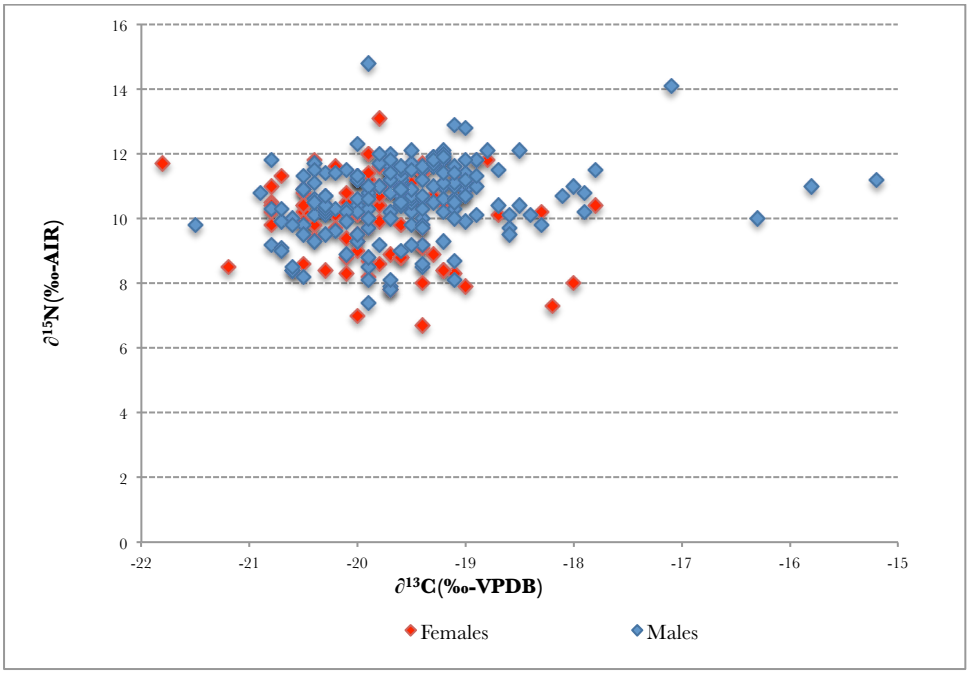


Figure 7.16. Comparisons of males (n=206) and females (n=95) in Roman Britain

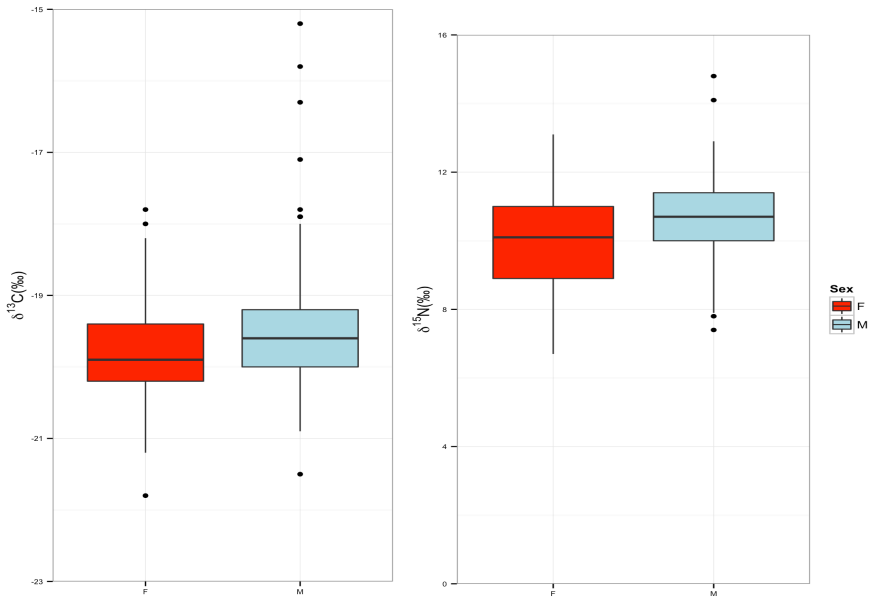


Figure 7.17. Comparisons of males (n=206) and females (n=95) in Roman Britain.

Looking at the 301 samples that have been attributed a sex, females have lower averages than males in both isotopes (Figures 7.16 and 7.17, Table 7.11). It is interesting to note the correlation between both isotopes and how it is different in the male and female data with males showing a significant

positive correlation between $\partial^{13}C$ and $\partial^{15}N$ values and females a moderately significant negative correlation between $\partial^{13}C$ and $\partial^{15}N$ values (Table 7.11). Written sources on Roman diet certainly suggest that there were dietary differences between the sexes, with females eating less meat than males, which could partially explain the patterns seen here (Garnsey 1999, 102-103). It could also suggest males having more access to marine protein than females. What is of particular interest here, in relation to questions of changes and continuity between broad archaeological periods is that females seemed to have a diet similar to that of the Iron Age humans. While this is only a tentative suggestion, it might a result of an 'army' effect, with the males in the dataset coming from abroad as part of the army while females are 'native'. There is not enough information about the data here to fully support this argument, but some of the Roman data do come from military cemeteries so it might something worth exploring in the future (Cummings 2008a, 43). Unfortunately, the distribution of the data between the different sub-periods and between sexes does not allow this hypothesis to be tested by measuring how correlation varied over time.

There is a significant difference between males and females when using a multi-regression model, integrating both 'Region' and 'Sub-period' as either fixed or random effect (Table 7.12). The multivariate model also reveals that there is significant difference in the $\partial^{13}C$ values of males and females within regions and between regions (males and females are significantly different from one another in Dorset, Kent and Gloucestershire). There is also a moderate significant difference between the males in Dorset and Yorkshire both with the females in Gloucestershire (Dorset/Gloucestershire

p=0.082; Yorkshire/Gloucestershire p=0.071). While there is no significant differences within region for the ∂^{15}N data, a moderately significant difference between the females in Dorset and Gloucestershire both with the males in Yorkshire (Dorset/Yorkshire p=0.072; Gloucestershire/Yorkshire p=0.071) has been observed. Sub-Periods differences were also investigated, with the males and females between the Early and Late Roman periods being the most divergent, between the genders as well as within each gender group (see full Tables A2.3.4, A2.3.5 in Appendixes II.3).

Table 7.12. Statistical differences between males and females in Roman Britain. Integrating 'Region' or 'Sub-Period' as random effect and/or fixed effects does not affect the significance of the result.

Sex	**Multi-Level Model With 'Sites' As Random Effect And 'Sex', 'Region' And 'Sub-Period' As Fixed Effects.**	
	p-value (∂^{13}C)	*p-value* (∂^{15}N)
Females-Males	**0.011**	**0.023**

7.2.2.2. Age

Table 7.13. Distribution of the data between the different age groups. Individuals who have not been aged (n=385) have not been included. *R* is Pearson's correlation coefficient.

R	**n of samples**	**n of sites**	**Mean average ∂^{13}C**	**Mean average ∂^{15}N**	**r**	**p-value (**
Infant	16	3	-19.9±0.41	11.6±1.52	0.08	0.745
Juvenile	2	2	-19.7±0.28	10.7±0.71	N/A	N/A
Young Adult	78	9	-19.8±0.92	10.5±0.76	0.11	0.303
Adult	303	14	-19.7±1.20	10.4±1.02	0.08	0.151
Mature Adult	13	2	-19.4±1.02	11.3±1.01	0.50	0.079
Older Adult	32	6	-19.8±0.54	10.7±1.22	0.29	0.095

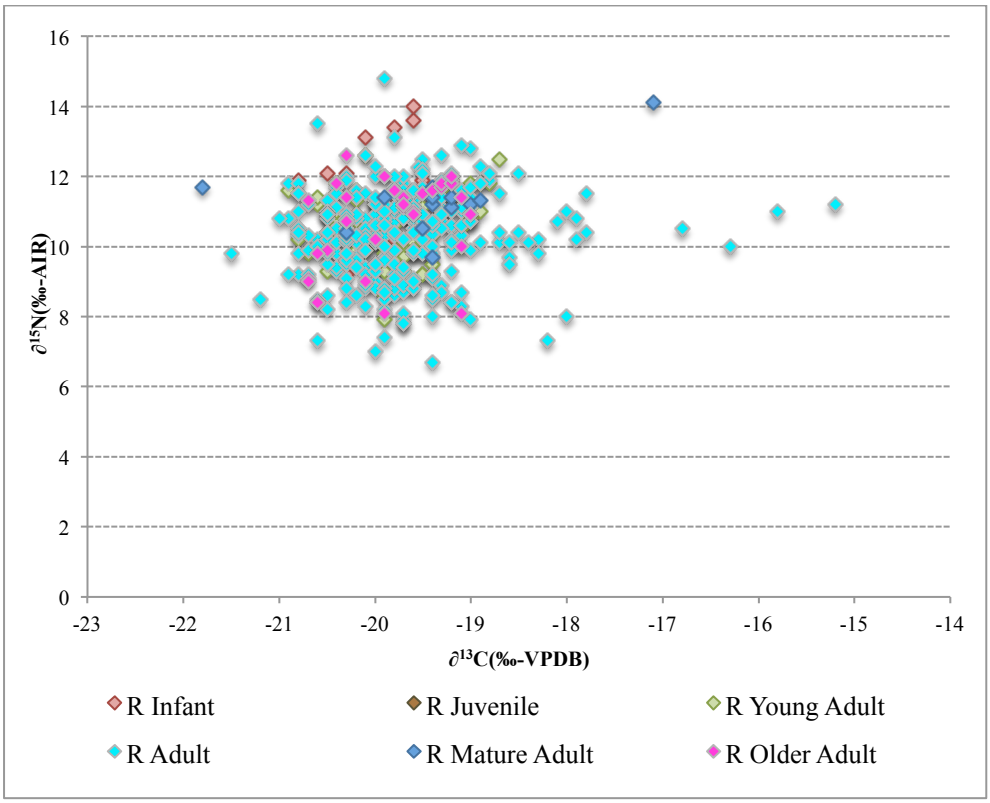


Figure 7.18. Comparison of the different age groups in Roman Britain (Infant n= 16, Juvenile n=2, Young Adult n=78, Adult n = 303, Mature Adult n = 13, Older Adult n=32).

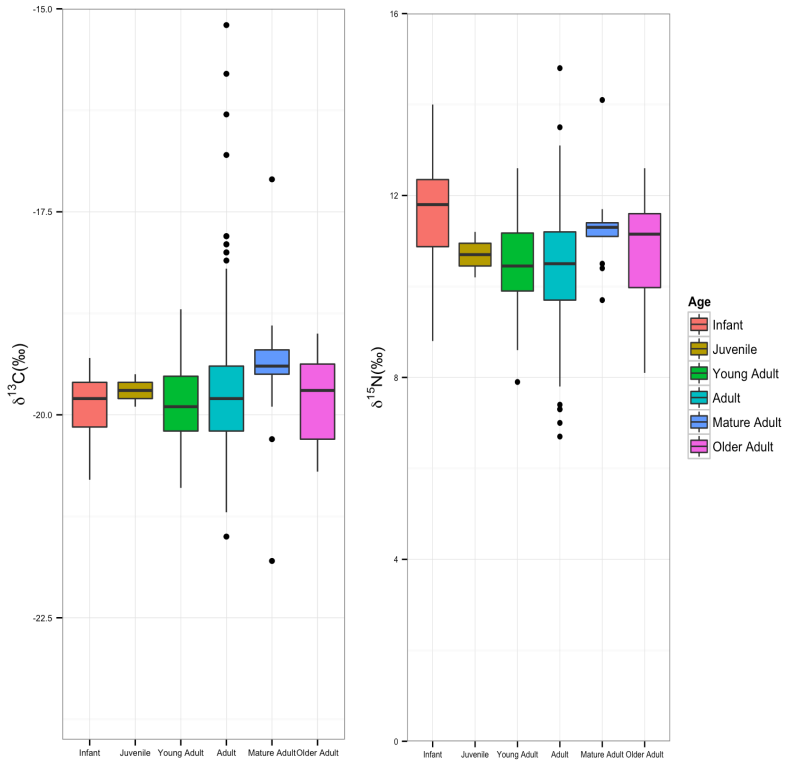


Figure 7.19. Boxplot comparison of the different age groups in Roman Britain (Infant n= 16, Juvenile n=2, Young Adult n=78, Adult n = 303, Mature Adult n = 13, Older Adult n=32).

Figures 7.18 and 7.19 show the data organised by age. Very few differences are visible between the groups, except once again in the infant data, which is significantly elevated compared to the other age groups. No other patterns emerge or are significant, except a moderately significant positive correlation in the older groups, as was the case in the Iron Age (Tables 7.13 and 7.14). As was done for the Iron Age, differences between the difference age groups were investigated by sex. Maybe the most suggestive trend is that males and females' $\partial^{13}C$ ratios seem to evolve in opposite ways, with the female $\partial^{13}C$ values decreasing as they age and while the male values increase (Figure 7.20). For the $\partial^{15}N$ values, females appear to have higher averages overall, except for the adult group. However, none of these differences are shown to be statistically different (Tables A2.3.2 in Appendixes II.3).

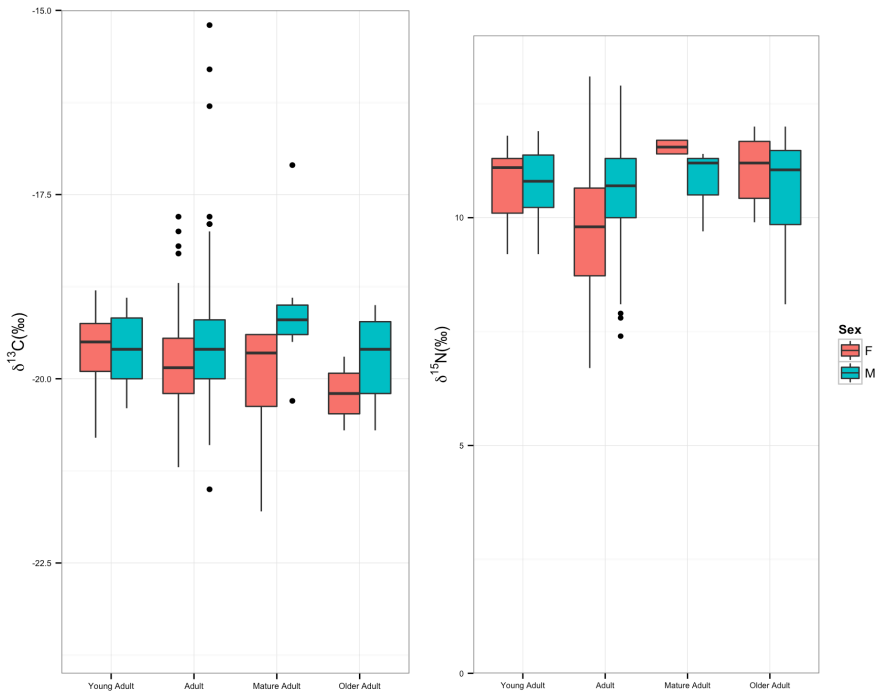


Figure 7.20. Comparison of the different age groups according to Sex in Roman Britain (Females: Young Adult n=7, Adult n =66, Mature Adult n = 4, Older Adult n=6; Males: Young Adult n=16, Adult n =145, Mature Adult n = 9, Older Adults n=22). The differences between the different sexes according to age were not significant.

Table 7.14. Statistical differences between the different age groups in Roman Britain. Integrating 'Region', 'Sub-Period' or 'Sex' as random effect and/or fixed effect does not affect the significance of the results.

Age	***Multi-Level Model With 'Sites' and 'Sub-Period' As Random Effect And 'Sex', 'Region' and 'Age' as fixed effects.***	***Multi-Level Model With 'Sites' and 'Sub-Period' As Random Effect And 'Age', 'Region' and as fixed effects.***
	p-value **(∂^{13}C)**	***p-value*** **(∂^{15}N)**
Infant-Juvenile	0.999	0.910
Infant-Young Adult	**0.002**	**0.001**
Infant-Adult	0.999	**0.001**
Infant-Mature Adult	1.000	**0.033**
Infant-Older Adult	0.949	**0.016**
Juvenile-Young Adult	0.896	0.999
Juvenile-Adult	1.000	0.999
Juvenile-Mature Adult	0.999	1.000
Juvenile-Older Adult	1.000	0.997
Young Adult-Adult	0.999	0.998
Young Adult-Mature Adult	0.999	0.999
Young Adult-Older Adult	0.836	0.998
Adult-Mature Adult	0.998	0.998
Adult-Older Adult	0.941	0.971
Mature Adult-Older Adult	0.844	0.992

7.2.3 Intra-period variations

Table 7.15. Distribution of the human data in different sub-periods in Roman Britain, according to number of sites, number of samples and regions.

Sub-Period	n of sites	n of samples	Region	Site
Early Roman	2	21	Dorset, Gloucestershire	Hucclecote, Poundbury
Middle Roman	14	610	Gloucestershire, Hampshire, Kent, Oxfordshire, Somerset, Yorkshire	3 Driffield Terrace, Asthall, Blossom Street (York), Bradley Hill, Catterick, Cirencester, Cotswolds Community, Gloucester, Gravesend, Horcott Quarry, Stanton Harcourt, Trentholme Drive (York), Winchester, York
Late Roman	2	49	Dorset, Oxfordshire	Alchester, Poundbury
Late Roman/Early Anglo-Saxon	1	87	Oxfordshire	Queenford

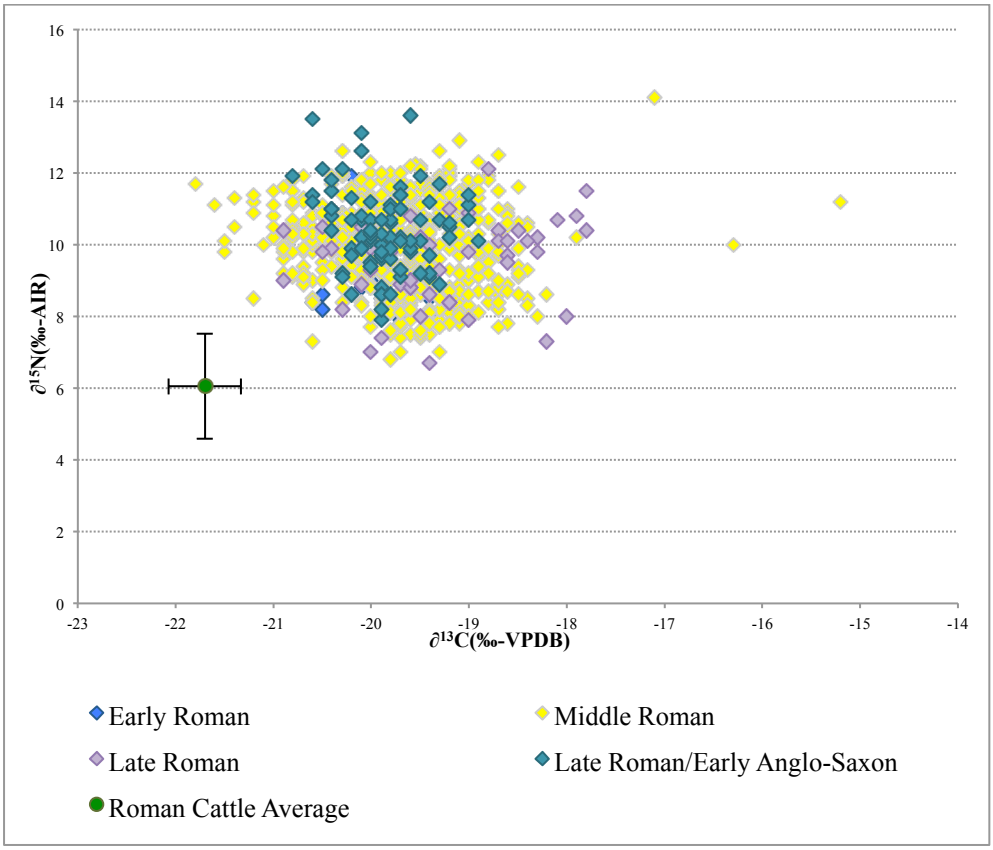


Figure 7.21. Comparison of the Roman human data in the different sub-periods in Roman Britain (Early Roman n=21, Middle Roman n=610, Late Roman n = 49, Late Roman/Early Anglo-Saxon n=87). The samples only dated as 'Roman' have been excluded from these analyses (n=61).

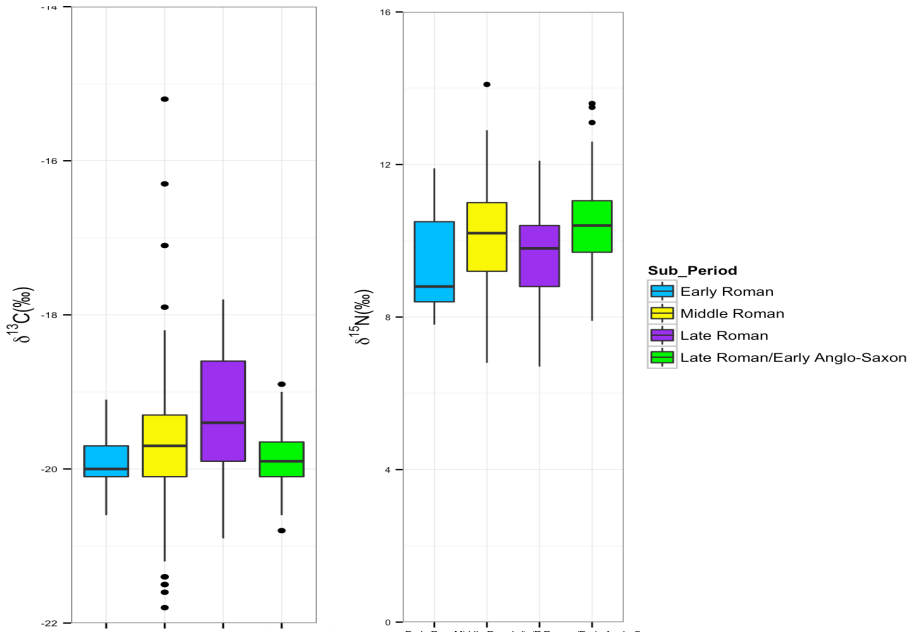


Figure 7.22. Boxplot comparison of the Roman human data in the different sub-periods in Roman Britain (Early Roman n=21, Middle Roman n=610, Late Roman n = 49, Late Roman/Early Anglo-Saxon n=87). The samples only dated as 'Roman' have been excluded from these analyses (n=61).

Interestingly there seems to be an increase in the $\partial^{13}C$ values of the Roman sub-periods, when the overall trend in the fauna was one of decrease over time (section 6.4). The $\partial^{15}N$ averages also seem to increase over time. However, the only significant pattern is the difference between the Early Roman data and the Late Roman data, although it is only moderately significant for the nitrogen isotopic data (Table 7.16). The pattern of Roman faunal $\partial^{13}C$ values was similar to the trends seen in the humans, which might indicate environmental factors affecting the entire ecosystem rather than a purely dietary effect. The Roman faunal pattern is however different for the $\partial^{15}N$ ratios, as the data for the Early Roman cattle were enriched compared to the data from the Late Roman period (Figures 6.17, 6.18, 7.21, 7.22; section 6.2.2.1), which suggest that this enrichment in the human data might have dietary causes, like an increase in the consumption of nitrogen-rich food, such as aquatic or omnivorous animal, or possible manured cereals. This will be explored further in Chapter 8.

Table 7.16. Statistical significance between the human data in the sub-periods of Roman Britain. The difference between the Early Roman and the Late Roman Data remain significant whether regions are integrated into the model as fixed or random effects.

	Multi-Level Model With 'Sites' As Random Effect And 'Sub-Period' And 'Region' As Fixed Effects.	
	p-value (∂^{13}C)	*p-value* (∂^{15}N)
Early Roman –Middle Roman	0.784	0.559
Early Roman –Late Roman	**0.000**	**0.059**
Early Roman – Late Roman/Early Anglo-Saxon	0.985	0.859
Middle Roman – Late Roman	0.830	0.999
Middle Roman - Late Roman/Early Anglo-Saxon	1.000	1.000
Late Roman - Late Roman/Early Anglo-Saxon	0.951	0.999

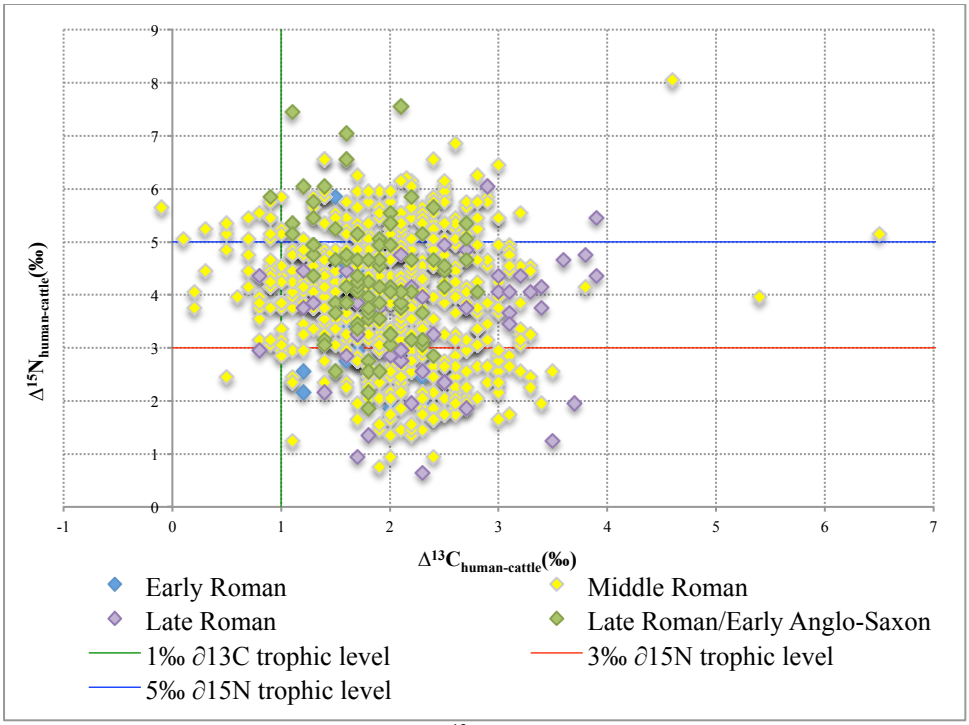


Figure 7.23 Boxplot comparison of $\Delta^{13}C_{human-cattle}$ spacing between Early and Late Roman Britain. (Early Roman n=21, Middle Roman n=610, Late Roman n = 49, Late Roman/Early Anglo-Saxon n=87). The samples only dated as 'Roman' have been excluded from these analyses (n=61). The cattle baseline used here has a ∂^{13}C value of -21.7 ± 0.37‰ and a ∂^{15}Nvalue of 6.1±1.46‰

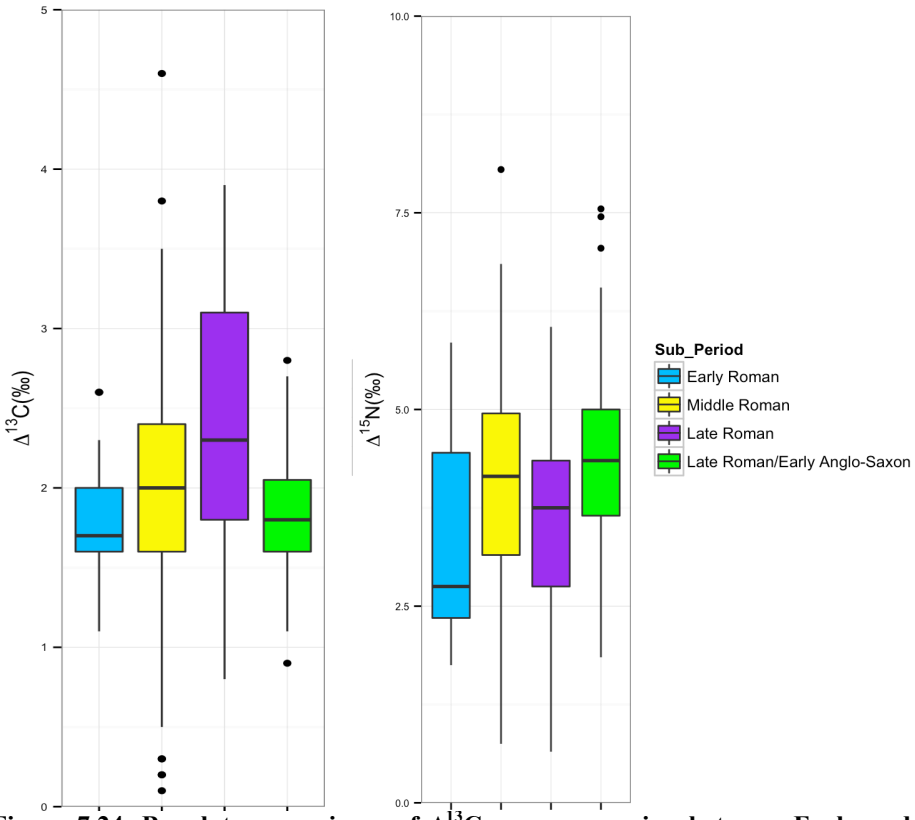


Figure 7.24. Boxplot comparisons of $\Delta^{13}C_{human\text{-}cattle}$ spacing between Early and Late Roman Britain. (Early Roman n=21, Middle Roman n=610, Late Roman n = 49, Late Roman/Early Anglo-Saxon n=87). The samples only dated as 'Roman' have been excluded from these analyses (n=61). The cattle baseline used here has a $\partial^{13}C$ value of -21.7 ± 0.37‰ and a $\partial^{15}N$value of 6.1±1.46‰

Comparing the Roman data with the Roman cattle baseline reveals that most of the data plots lower than the upper limit of one ^{15}N trophic level (<5‰), and that a significant proportion of the data also plot below the lower limit of one ^{15}N trophic level (<3‰, Figures 7.23 and 7.24). This is interesting as it shows that while the Roman data are on average enriched in both isotopes compared to the Iron Age data, they are actually displaying smaller offsets compared to the baseline. Maybe more interesting than the $\Delta^{15}N_{human\text{-}cattle}$ distribution however, is the $\Delta^{13}C_{human\text{-}cattle}$ distribution: most of the data clearly plot over one ^{13}C trophic level (>1‰), with a significant amount of data also above 2‰ enrichment compared to the baseline. This pattern of enrichment in ^{13}C for the Roman data has been noted elsewhere (Müldner

2013) and could be evidence of increased marine fish consumption, or a small contribution of C_4 plants, at least for some individuals (Müldner *et al.* 2011; Pollard *et al.* 2011). The average $\Delta^{13}C_{human\text{-}cattle}$ offsets seem to increase over time (Figure 7.24) before a sharp decrease in the Late Roman/Early Anglo-Saxon period. The $\Delta^{15}N_{human\text{-}cattle}$ increase between the Early Roman period and the Middle Roman period, before decreasing in the Late Roman period, and raising again in the Late Roman/Early Anglo-Saxon period, which might be consistent with patterns of a more agrarian based agriculture (and diets) in the earlier period and a return to pastoralism after the end of Roman administration in Britain.

7.2.4. Regional variation

Table 7.17. Summary of the Roman human data by region (data from: Cirencester n =145, Cotswolds Community n =24, Gloucester n =65, Horcott Quarry n =22, Hucclecote n=8, London Road (Gloucester) n=25 (Gloucestershire); Alchester n=13, Asthall n=9, Queenford n=87, Stanton Court n=27, Yarnton n=7 (Oxfordshire); 3/6 Driffield Terrace (York) n=79, Blossom Street (York) n=18, Catterick n=41, Trentholme Drive (York3 n=42, York n=7).

	Average $\partial^{13}C$(‰)	Average $\partial^{15}N$(‰)	min $\partial^{13}C$ (‰)	max $\partial^{13}C$ (‰)	min $\partial^{15}N$ (‰)	max $\partial^{15}N$ ‰	n=
Gloucestershire	-19.8 ± 0.55	10.1± 1.08	-21.5	-18.4	7	12.6	289
Oxfordshire	-21.3 ± 0.44	10.4 ± 1.99	-20.9	-18.5	7.9	14	143
Yorkshire	-19.7 ± 0.81	11.0 ± 0.75	-21.8	-15.8	9.2	14.8	188

The Roman dataset is biased towards the South, with the North only represented by Yorkshire (Map 5.2). Due to the constraints put on the analyses, only Gloucestershire, Oxfordshire and Yorkshire are analysed here (Table 7.17).

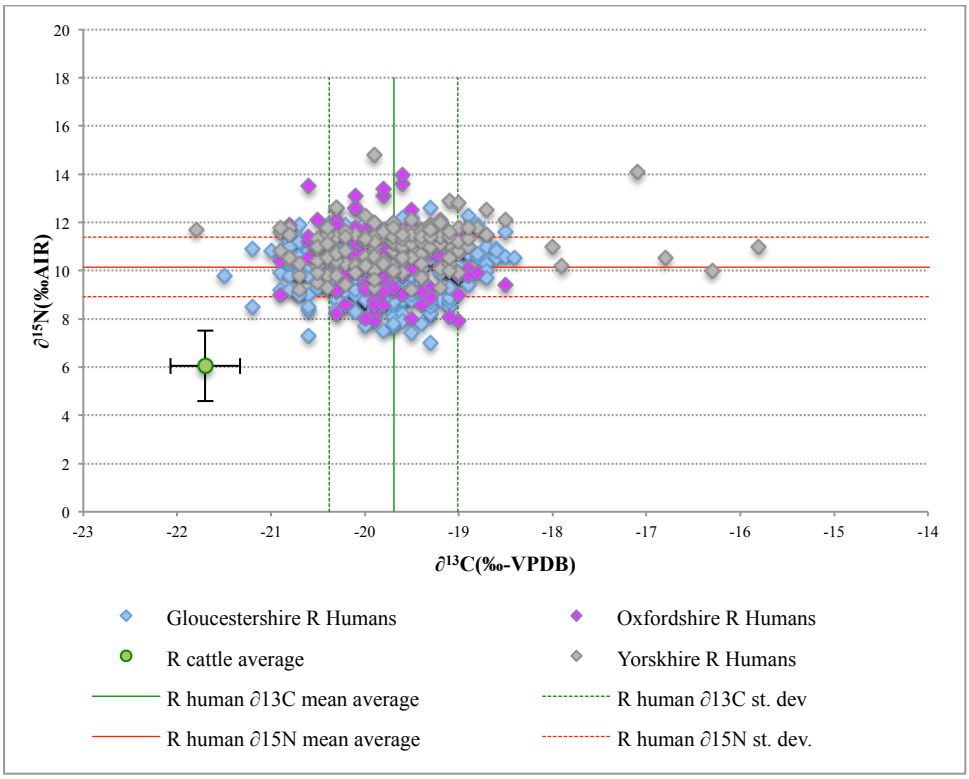


Figure 7.25. Comparison between regions of Roman Britain for the human data (Gloucestershire n=289, Oxfordshire n=143, Yorkshire n=188).

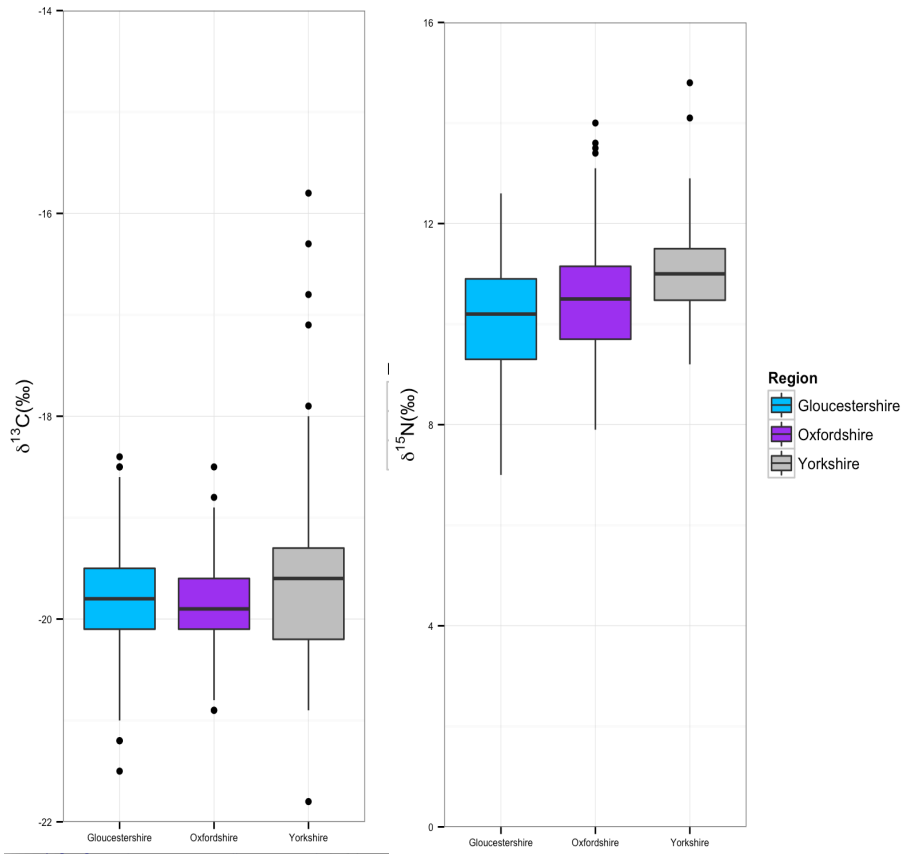


Figure 7.26. Boxplot comparisons between regions of Roman Britain for the Roman data (Gloucestershire n=289, Oxfordshire n=143, Yorkshire n=188).

There does not appear to be any regional difference in the Roman data, which is confirmed by statistical analyses (Figure 7.25, 7.26). Indeed, multi-level analyses, integrating sites and sub-periods to the model, do not pick a difference between the regions investigated here, as was the case in the Roman fauna (Table 7.18). Although, again, this does not necessarily mean than that agriculture and diets were homogenous across regions, but simply that the differences might be too small to be picked up on.

Table 7.18. Statistical significance between the regions of Roman Britain. The results remain the same whether sub-periods are integrated to the model.

Region	*Multi-level model with sites as random effect and 'Sub-Period' and 'Region' as fixed effects.*	
	p-value ($\partial^{13}C$)	*p-value* ($\partial^{15}N$)
Gloucestershire-Oxfordshire	0.997	0.997
Gloucestershire-Yorkshire	0.972	0.227
Oxfordshire-Yorkshire	1.000	0.576

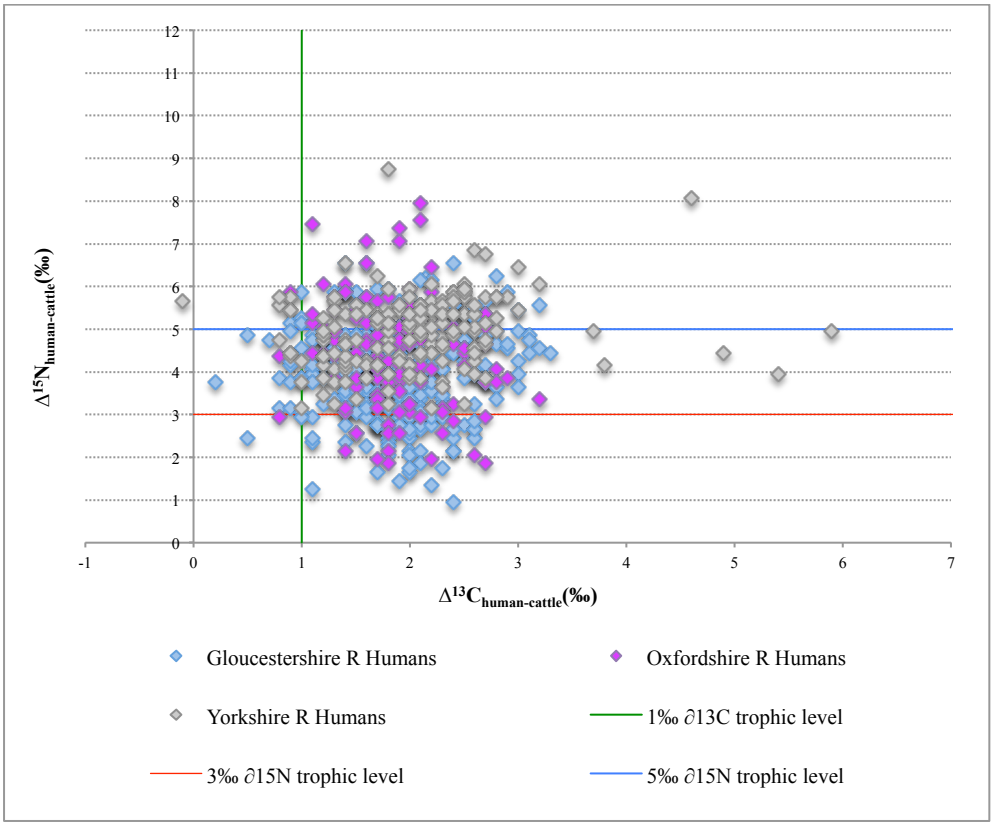


Figure 7.27. Comparison of $\Delta_{human-cattle}$ spacing between the different regions of Roman Britain (Gloucestershire n=289, Oxfordshire n=143, Oxfordshire n = 188).

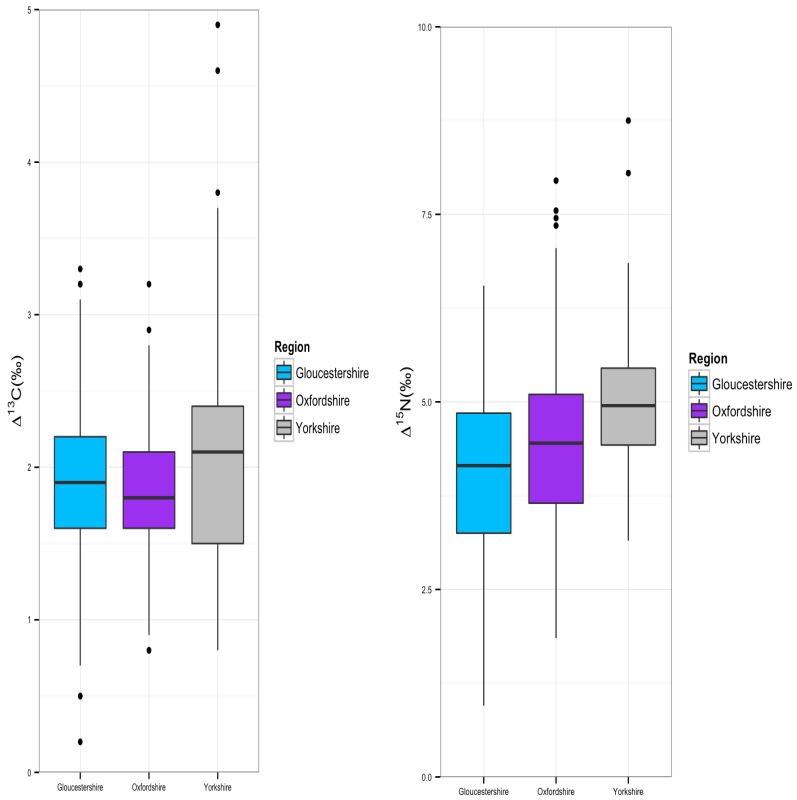


Figure 7.28. Boxplot comparison of $\Delta_{human\text{-}cattle}$ spacing between the different regions in Roman Britain (Gloucestershire n=289, Oxfordshire n=143, Oxfordshire n = 188).

The comparison between the Roman cattle baseline and the Roman human data does not reveal particular patterns, which was expected considering the lack of differences in the regional 'raw' data (Figures 7.27, 7.28). However, it is possible that an investigation of these differences by using restricted baselines will reveal more subtle trends (for restricted baselines, see section 7.5).

7.2.4.1 Rural and Urban Settlements

Table 7.19. Distribution of the human data according to site type in Roman Britain.

Site Type	N of samples	N of sites	Broad Archaeological Period	Region	Site
Rural	163	10	Roman	Gloucestershire, Kent, Oxfordshire, Somerset, Yorkshire	Alchester, Asthall, Bradley, Hill, Catterick, Hucclecote, Yarnton
Urban	655	15	Roman	Gloucestershire, Hampshire, Oxfordshire, Yorkshire	3 and 6 Driffield Terrace (York), Blossom Street (York), Cirencester, Gloucester, London_Road (Gloucester), Trentholme Drive (York), Winchester, York.

Another regional trend worth exploring in the Roman period is the differences between the population of urban and more rural settlements. Previous research has indeed shown a systematic difference between these different types of sites, but it is tested on a larger scale here (Cheung *et al.* 2011; Chenery *et al.* 2011). Interestingly, no difference was shown in the cattle data (see Section 6.2.4.4). In the human data, however, there is a clear pattern with the humans from urban settlements displaying a significant enrichment in ^{13}C (Figures 7.29, 7.30). This is consistent with what previous studies have demonstrated, and this difference is shown here to be

significant, regardless of sub-period and/or regions (Table 7.20). The reason for this pattern will be explored in Chapter 8.

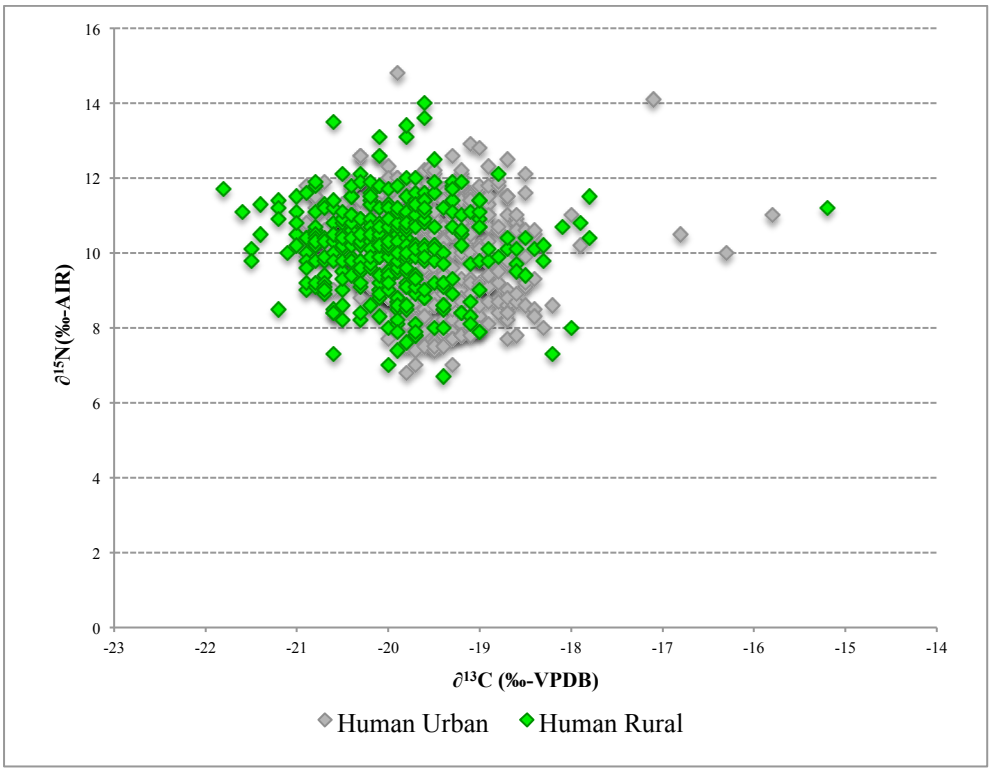


Figure 7.29. Comparison between the human population of rural and urban settlements (urban n=480, rural n=340).

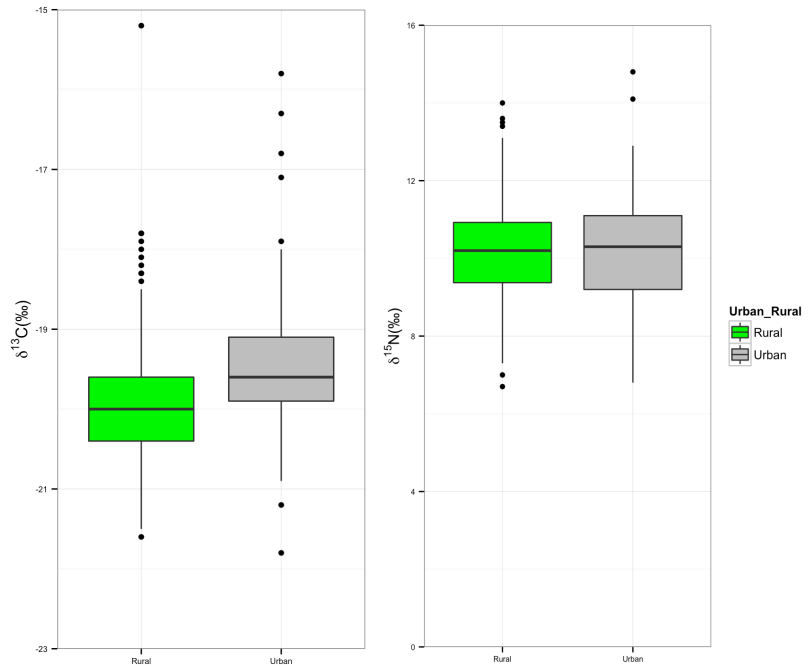


Figure 7.30. Boxplot comparison between the population of rural and urban settlements (urban n=480, rural n=340).

Table 7.20. Statistical significance between urban and rural sites in Roman Britain. The differences between the between the urban and rural data remain significant whether regions and sub-periods are integrated into the model as fixed or random effects.

	Multi-Level Model With 'Sites', 'Region' and 'Sub_Period' As Random Effect and 'North/South' as fixed effects.	***Multi-Level Model With 'Sites', 'Region' and 'Sub_Period' As Random Effect and 'North/South' as fixed effect***
	p-value (∂^{13}C)	*p-value* (∂^{15}N)
- Urban-Rural	**0.011**	0.905

However, one must nuance these results by pointing out that, while there appears to be an 'urban' pattern in the Roman data, this is does not mean that all the data from Roman cities are homogenous. Even in the same region, a comparison of Gloucester and Cirencester, chosen because both lie within Gloucestershire and belong to similar sub-periods, reveals that the data from the two cities significantly differ from one another (∂^{13}C p=0.213; ∂^{15}N p =0.000, Figure 7.31). Further analyses of all the cities reveal that Winchester is the most different, although that might be the 'Hampshire effect' (for details of site differences, see Appendixes II.1).

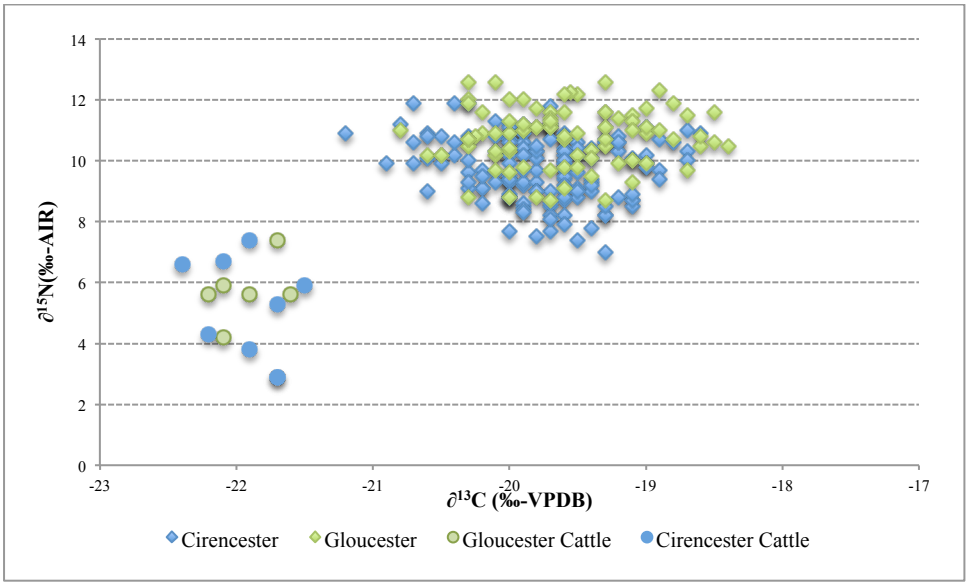


Figure 7.31. Comparison of the data from Gloucester and Cirencester.

The difference between the Gloucester and the Cirencester data is hypothesised here to be due to the presence of the Severn in Gloucester, making the consumption of freshwater fish more common that it might have been in Cirencester, something which will be addressed in section 7.6.4. However, the main point demonstrated here is that most broad patterns are unlikely to be clear-cut and straightforward.

7.2.5 Preliminary Discussion of the Roman data.

There are three patterns of note in the human data from Roman Britain: (1) the difference between males and females; (2) the difference between the Early Roman and Late Roman data; and (3) the difference between urban centres and rural settlements. Males and females differ significantly in more varied ways than they did in the Iron Age (i.e. between regions and sub-periods), but what is particularly noteworthy is that the females display a negative correlation between isotopes, while the males display a positive one, which maybe indicative of males having a 'foreign' diet and females having a 'native' one, which was more similar to the Iron Age. The difference in ^{13}C between the Early and Late Roman data was not present in the cattle data, which suggests that it is a dietary effect. The increase in ^{13}C is actually characteristic of the Roman human data and will be explored further in Chapter 8, as will be the urban/rural pattern.

7.3 Early Medieval

Table 7.21. Summary of the human Early Medieval data

	Average $\partial^{13}C$(‰)	Average $\partial^{15}N$(‰)	min $\partial^{13}C$(‰)	max $\partial^{13}C$(‰)	min $\partial^{15}N$(‰)	max $\partial^{15}N$(‰)	n=
Human	-20.1 ± 0.52	10.0 ± 1.37	-22.1	-17.0	6.6	14.9	1000

Table 7.21 is a summary of the data examined in the following section covering the Early Medieval period from 400 A.D to 1200 A.D. There are a total of 1000 values, making it the largest human dataset investigated here.

7.3.1 Human isotopic results

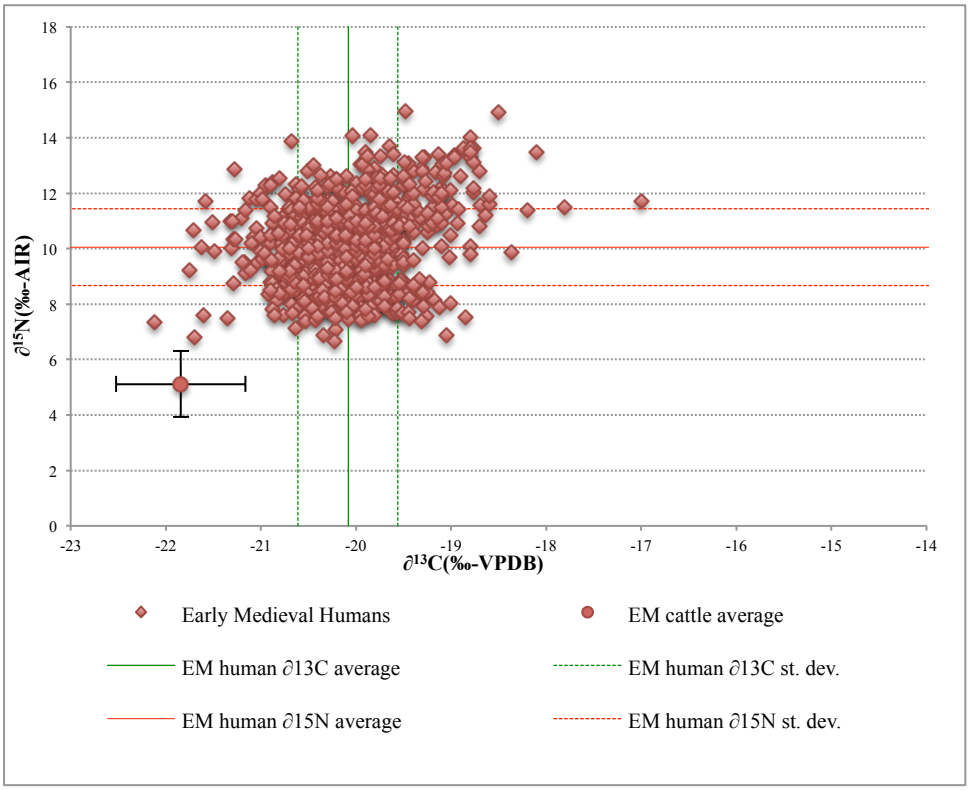


Figure 7.32. Results of the human isotopic data in Early Medieval Britain.

The average $\partial^{13}C$ value for all of the Early Medieval data is -20.1 ± 0.57‰ and the average $\partial^{15}N$ value is 10.0 ± 1.37‰. The $\partial^{13}C$ values range from -22.1‰ to -17.0‰ and the $\partial^{15}N$ values range 6.7‰ and 14.9‰. Like

in the other periods, the isotopic values for the Early Medieval period are typical of a terrestrial, C_3-based diet, with reliance on both terrestrial and aquatic protein (Figure 7.32). There are a few outliers in the data, either depleted or enriched in ^{13}C or enriched in ^{15}N compared to the mean. As with the Roman data, there is only one sample enriched in both isotopes ($\partial^{13}C$: -18.5‰; $\partial^{15}N$: 14.9‰).

7.3.2 Inter-Human Variation

7.3.2.1 Sex

Table 7.22. Distribution of the data between the sexes in Early Medieval Britain. Individuals who have not been sexed (n=342) have not been included. *R* is Pearson's correlation coefficient.

Sex	N	$\partial^{13}C$	$\partial^{15}N$	min $\partial^{13}C$	max $\partial^{15}N$	min $\partial^{15}N$	max $\partial^{15}N$	r	p-value
Male	336	-20.1±0.56	10.1 ±1.48	-21.7	-18.1	6.8	14.9	0.34	0.000
Female	332	-20.2±0.51	9.7 ± 1.25	-22.1	-17.8	6.9	14.1	0.14	0.009

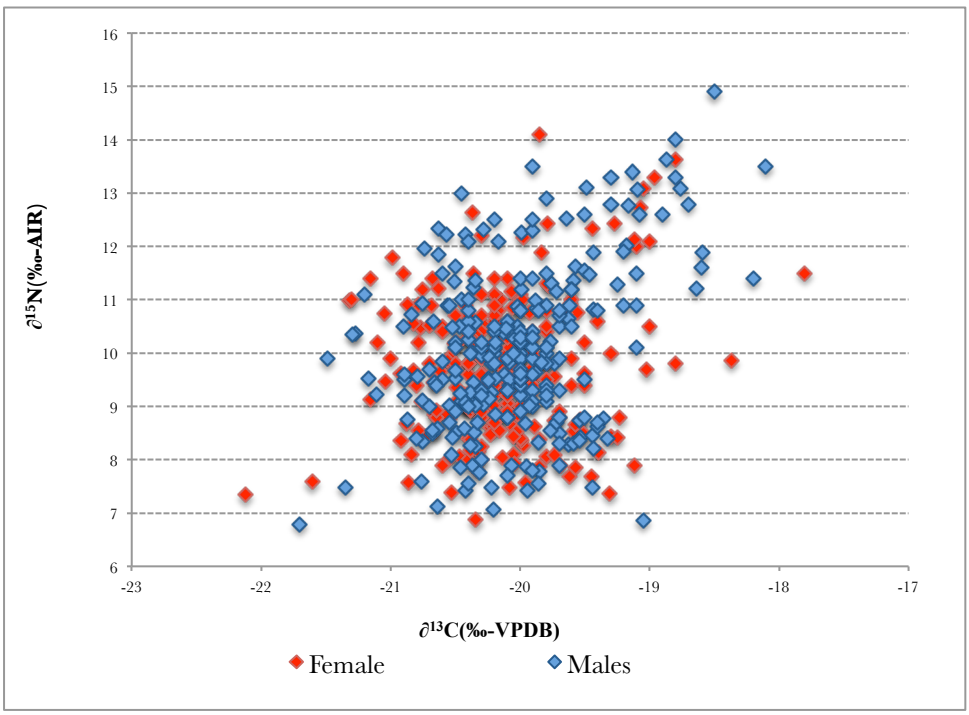


Figure 7.33. Comparison of males (n=336) and females (n=332) in Early Medieval Britain.

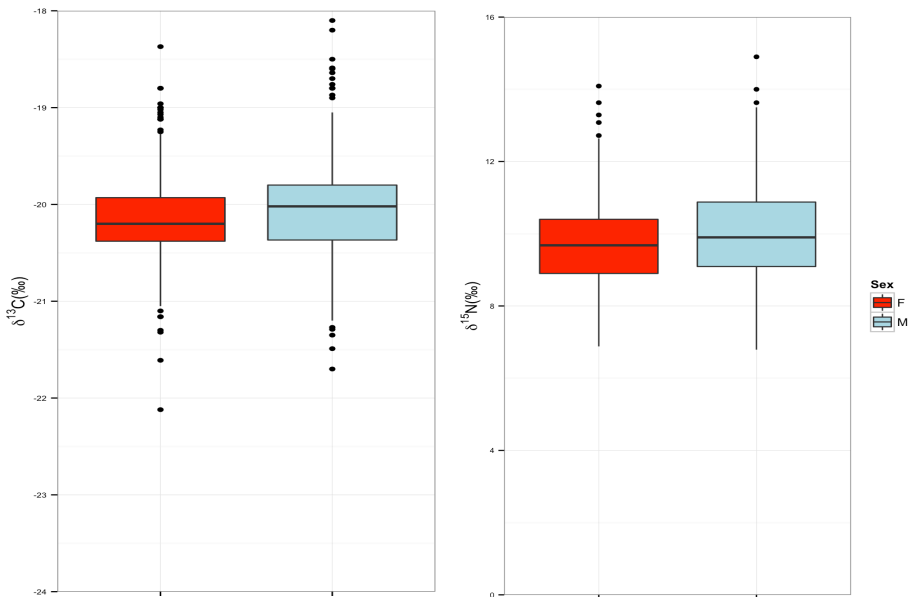


Figure 7.34. Comparison of males (n=336) and females (n=333) in Early Medieval Britain.

Looking at the 668 samples that have been attributed a sex, there does not appear to be a major difference between males and females, despite females' averages being a little lower for both isotopes (Figures 7.33 and 7.34, Table 7.22). Statistical differences have been shown to be significant in the carbon isotopic data between males and females, but not for the nitrogen isotopic data, with 'Region' and 'Sub-Period' as either fixed or random effects, and there is no further patterning between regions and/or sub-periods. Previous research had shown either a lack of differences (Hull 2007, 302; O'Connell and Lawler 2009; O'Connell and Wilson 2011) or a lack of systematic differences (Hull 2007, 302). Here, the data suggest an overall difference in ^{13}C between males and females but it is also important to note that an effect size test reveals that the difference between females and males is only small (Table 7.23; 'cohen.d' = 0.23).

Table 7.23. Statistical differences between males and females in Early Medieval Britain. Integrating 'Region' or 'Sub-Period' as random effect and/or fixed effects does not affect the significance of the result.

Sex	***Multi-Level Model With 'Sites' As Random Effect And 'Sex', and 'Sub-Period' as fixed effects.***	
	p-value (∂^{13}C)	*p-value* (∂^{15}N)
Females-Males	**0.011**	0.164

7.3.2.2 Age

Table 7.24. Distribution of the data between different age groups in Early Medieval. Individuals who have not been aged (n=86) have not been included. *R* is Pearson's correlation coefficient.

EM	**n of samples**	**n of sites**	**Mean Average ∂^{13}C**	**Mean Average ∂^{15}N**	**r**	**p-value)**
Infant	20	6	-20.1±0.63	11.5 ±1.62	0.31	0.182
Juvenile	22	5	-20.5±0.61	11.7±1.46	0.38	0.078
Young Adult	150	26	-20.1±0.46	9.9±1.34	0.12	0.889
Adult	574	37	-20.1±0.58	9.9±1.37	0.01	0.883
Mature Adult	116	16	-20.2±0.27	9.6±0.79	0.05	0.581
Older Adult	32	4	-20.0±0.30	9.8 ±0.94	-0.34	0.052

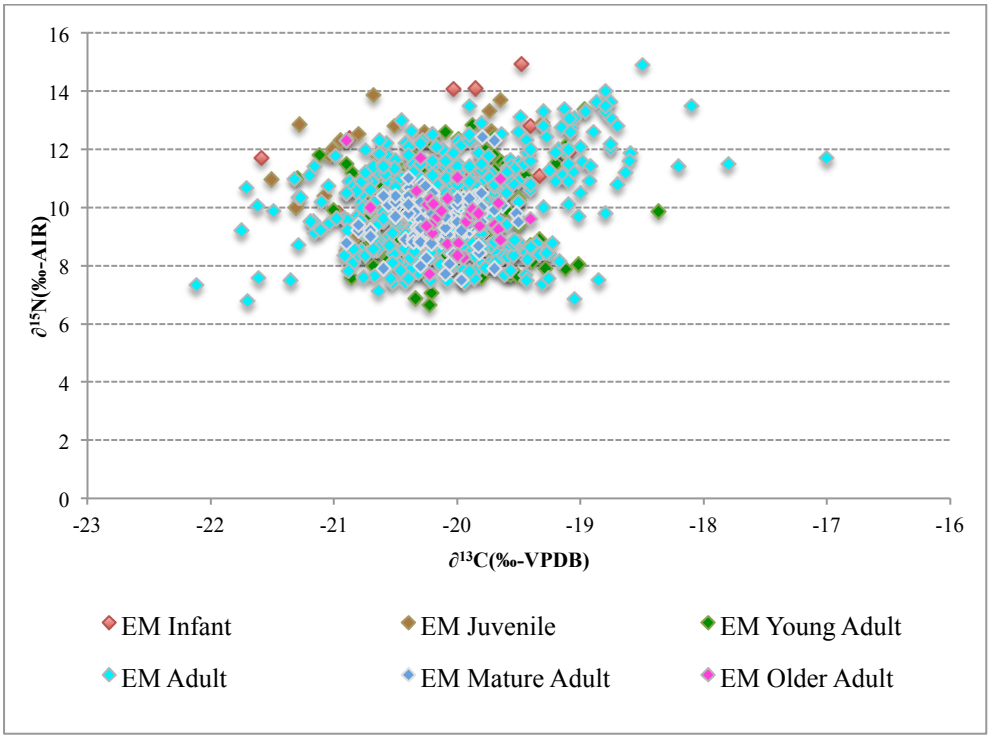


Figure 7.35. Comparison of the different age groups in Early Medieval Britain (Infant n= 20, Juvenile n=22, Young Adult n=150, Adult n = 574, Mature Adult n = 116, Older Adult n=32).

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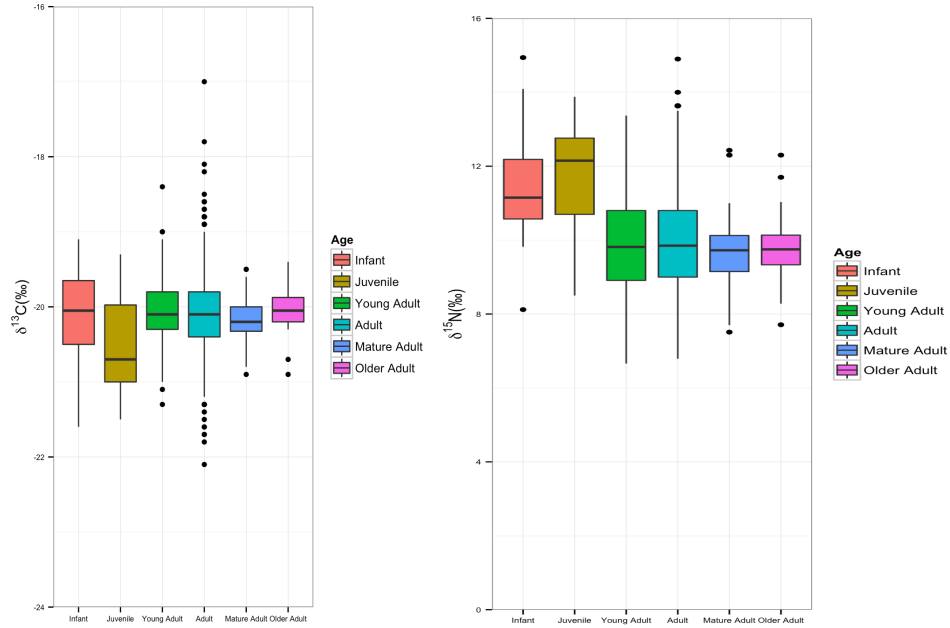


Figure 7.36. Boxplot comparison of the different age groups in Early Medieval Britain (Infant n= 20, Juvenile n=22, Young Adult n=150, Adult n = 574, Mature Adult n = 116, Older Adult n=32).

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Figures 7.35 and 7.36 reveal very little difference between the different age groups, except for the infants, as was the case in both the Iron Age and the

Roman period. There is no statistical difference between the different age groups, except for the infants with elevated $\partial^{15}N$ values, likely due to the nursing effect (Table 7.25).

Table 7.25. Statistical differences between the different age groups in Early Medieval Britain. Integrating 'Region', 'Sub-Period' or 'Sex' as random effect and/or fixed effect does not affect the significance of the results.

Age	Multi-Level Model With 'Sites', 'Region', And 'Sex' As Random Effect And 'Age' And 'Sub-Period' As Fixed Effects.	Multi-Level Model With 'Sites', As Random Effect And 'Age', 'Region', And 'Sub-Period' As Fixed Effects.
	p-value ($\partial^{13}C$)	*p-value* ($\partial^{15}N$)
-Infant-Juvenile	0.504	0.031
Infant-Young Adult	0.780	**0.001**
Infant-Adult	0.570	**0.001**
Infant-Mature Adult	0.431	**0.001**
Infant-Older Adult	0.959	**0.001**
Juvenile-Young Adult	1.000	0.556
Juvenile-Adult	0.994	0.634
Juvenile-Mature Adult	1.000	0.239
Juvenile-Older Adult	0.978	0.353
Young Adult-Adult	0.996	0.999
Young Adult-Mature Adult	0.864	0.862
Young Adult-Older Adult	0.978	0.945
Adult-Mature Adult	0.985	0.731
Adult-Older Adult	0.999	0.900
Mature Adult-Older Adult	0.910	1.000

Looking at the difference between males and females in the different age groups, it appears that the males are elevated compared to the females at all stages of life. However, none of these differences are significant (Table A2.3.3 in Appendixes II.3).

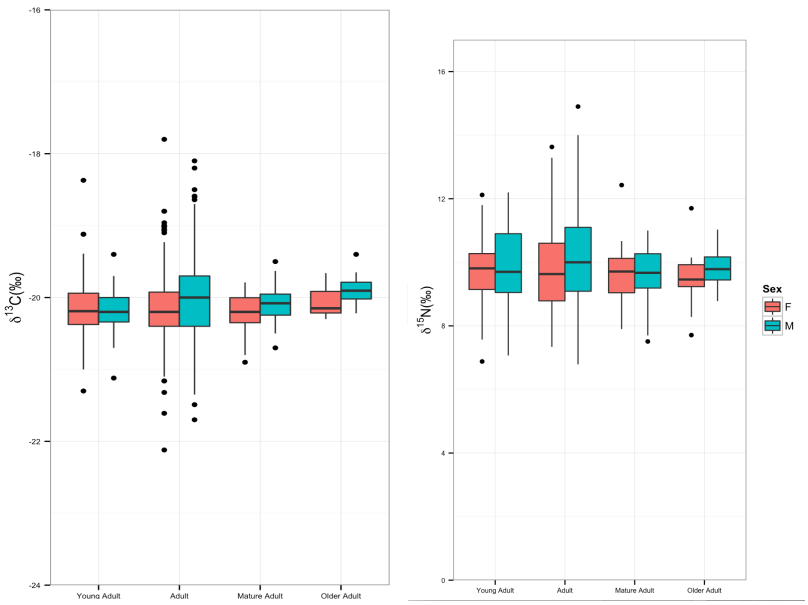


Figure 7.37. Comparisons of the different age groups according to sex in Early Medieval Britain (Females: Young Adult n=47, Adult n =212, Mature Adult n = 60, Older Adult n=15; Males: Young Adult n=25, Adult n =245, Mature Adult n = 40, Older Adults n=15). The differences between the different sexes according to age were not significant.

7.3.3. Intra-period variations

Table 7.26. Distribution of the human data in different sub-periods in Early Medieval Britain, according to number of sites, number of samples and regions. The less well dated samples (n=111) have been excluded.

Sub-Period	n of sites	n of samples	Region	Site
Early Anglo-Saxon	32	651	Bedfordshire, Buckinghamshire, Cambridgeshire, Gloucestershire, Hampshire, Kent, Lincolnshire, Norfolk, Oxfordshire, Suffolk, Surrey, Sussex, Warwickshire, Wiltshire, Yorkshire	Alchester, Alton, Appledown Compton, Aston Clinton, BerghApton, Berinsfield, Butler's Field Lechlade, Buttermarket, Casteldyke South, Coddenham, Dover Buckland, Droxford, Edix Hill, Ford Lavestock, Galley Hill, Lakenheath, Lechlade, Marina Drive, Melbourn Water Lane, Mill Hill, Morningthorpe, Portway, Shavard's Farm, Spong Hill, St Peter's Tip, Swaffham, Wasperton, West Heslerton, Westerfield Farm, Westgarth Gardens, Winnall Down, Worthy Park,
Early Anglo-Saxon/Mid-Saxon	1	12	Norfolk	South Acre
Middle Saxon	5	107	Norfolk, Suffolk, Yorkshire	Bellevue (York), Bloodmoor Hill, Burgh Castle, Caister-by-Yarmouth, Norwich
Late Saxon	3	68	Norfolk, Northamptonshire, Oxfordshire	Norwich, Raunds Furnell, St John's College (Oxford)
Late Saxon/Norman	1	51	Yorkshire	Fishergate (York)

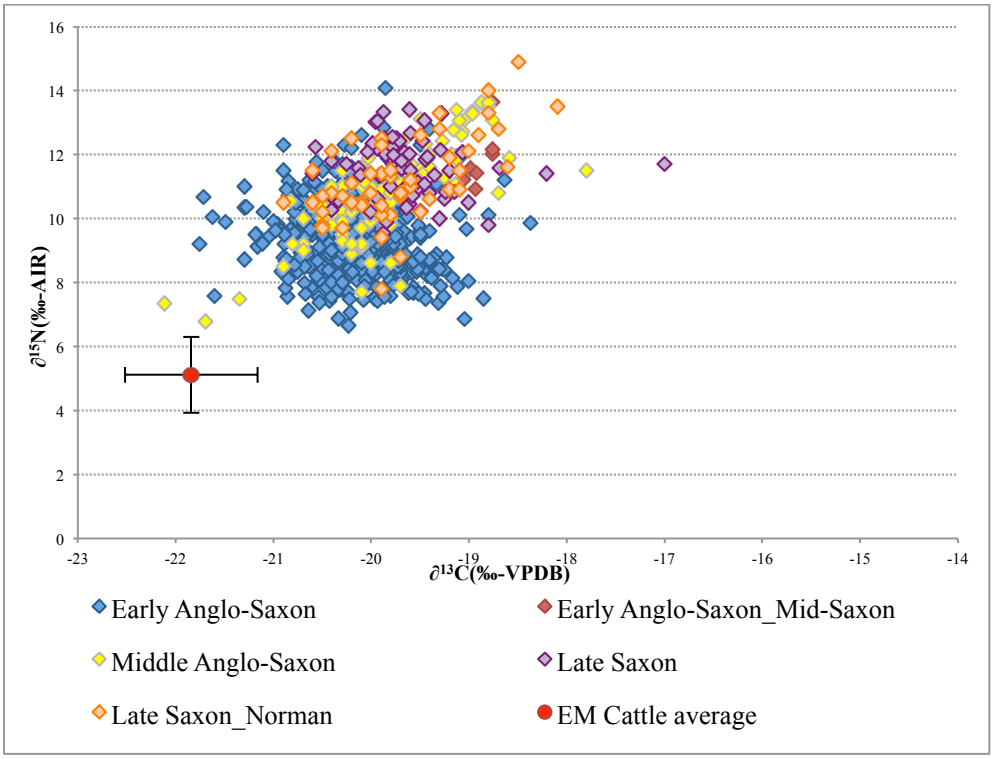


Figure 7.38. Comparison of the Early Medieval data in the different sub-periods (Early Anglo-Saxon n=651, Early Anglo-Saxon/Mid-Saxon n=12, Middle Saxon n=107, Late Saxon n = 68, Late Saxon/Norman n=51). The samples only dated as 'Anglo-Saxon' have been excluded from these analyses (n=111).

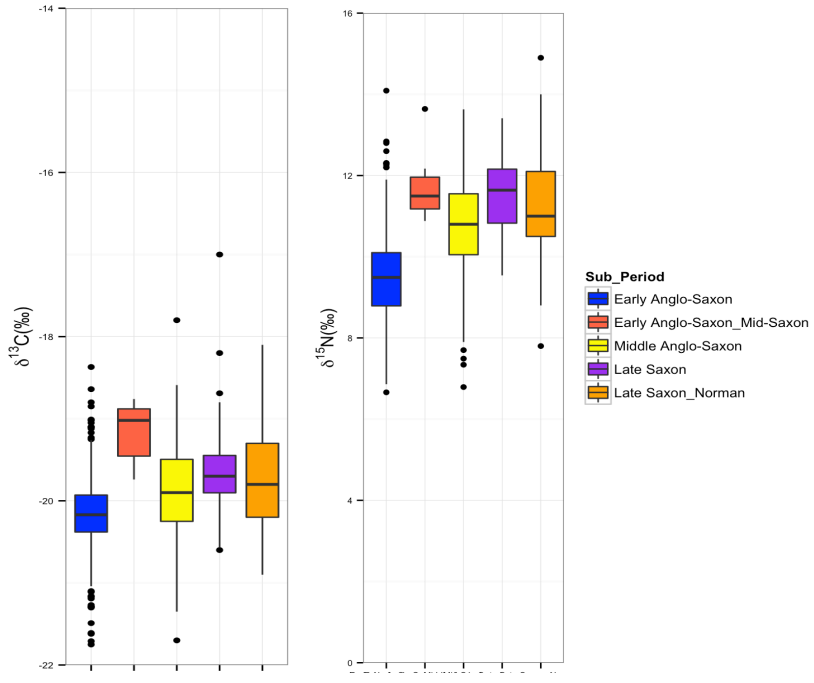


Figure 7.39. Boxplot comparison of the Early Medieval data in the different sub-periods (Early Anglo-Saxon n=651, Early Anglo-Saxon/Mid-Saxon n=12, Middle Saxon n=107, Late Saxon n = 68, Late Saxon/Norman n=51). The samples only dated as 'Anglo-Saxon' have been excluded from these analyses (n=111).

The Early Anglo-Saxon data are depleted in both isotopes compared to the other sub-periods, which is statistically significant (Figures 7.38, 7.39 and Table 7.28). It is also noticeable that the later data are showing a positive correlation between ^{13}C and ^{15}N, which is to likely due to an increase in fish consumption in the later periods, possibly because of Christianity (Müldner *et al.* 2009; Mayes and Beavan 2012; Table 7.27). The Early Anglo-Saxon/Mid-Saxon data also display a positive correlation between isotopes but since this is only for 12 samples, it is not likely to be significant (Table 7.26).

Table 7.27. Results of Pearson's correlation (r) between $\partial^{13}C$ and $\partial^{15}N$ for the human data according to the sub-periods of Early Medieval Britain.

Sub-Period	r	*p-value*	*n*
Early Anglo-Saxon	-0.089	**0.022**	651
Early Anglo-Saxon/Mid-Saxon	0.558	0.059	12
Middle Saxon	-0.062	0.611	107
Late Saxon	0.599	**0.000**	68
Late Saxon/Norman	0.753	**0.000**	51

Table 7.28. Statistical significance between the sub-periods of Early Medieval Britain. The results remain significant whether regions are integrated into the model as fixed or random effects.

Sub_Period	Multi-level model with 'Sites' as Random Effect and 'Sub-Period' and 'Region' as fixed effects.	
	p-value (∂^{13}C)	*p-value* (∂^{15}N)
Early Anglo-Saxon – Early Anglo-Saxon/Middle Saxon	0.028	0.120
Early Anglo-Saxon – Middle Anglo-Saxon	0.046	0.002
Early Anglo-Saxon – Late Saxon	0.156	0.028
Early Anglo-Saxon – Late Saxon_Norman	0.630	0.019
Early Anglo-Saxon/ Middle Saxon - Middle Saxon	0.492	0.992
Early Anglo-Saxon/ Middle Saxon – Late Saxon	0.465-	0.980
Early Anglo-Saxon/ Middle Saxon - Late Saxon/Norman	0.783	0.978
Middle Anglo-Saxon –Late Saxon	1.000	0.999
Middle Anglo-Saxon –Late Saxon _Norman	1.000	0.655
Late Saxon –Late Saxon _Norman	0.999	0.618

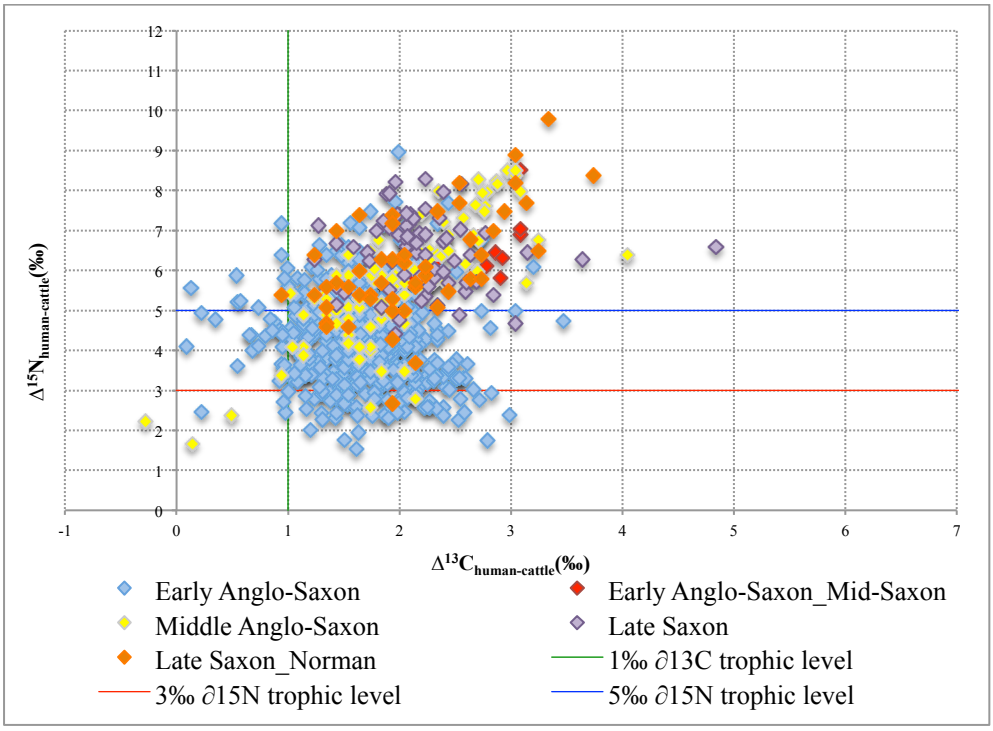


Figure 7.40. Comparison of the Early Medieval $\Delta_{human-cattle}$ values in the different sub-periods (Early Anglo-Saxon n=651, Early Anglo-Saxon/Mid-Saxon n=12, Middle Saxon n=107, Late Saxon n = 68, Late Saxon/Norman n=51). The samples only dated as 'Anglo-Saxon' have been excluded from these analyses (n=111). The cattle baseline used here has a ∂^{13}C value of -21.8 ± 0.68‰ and a ∂^{15}Nvalue of 5.1±1.19‰.

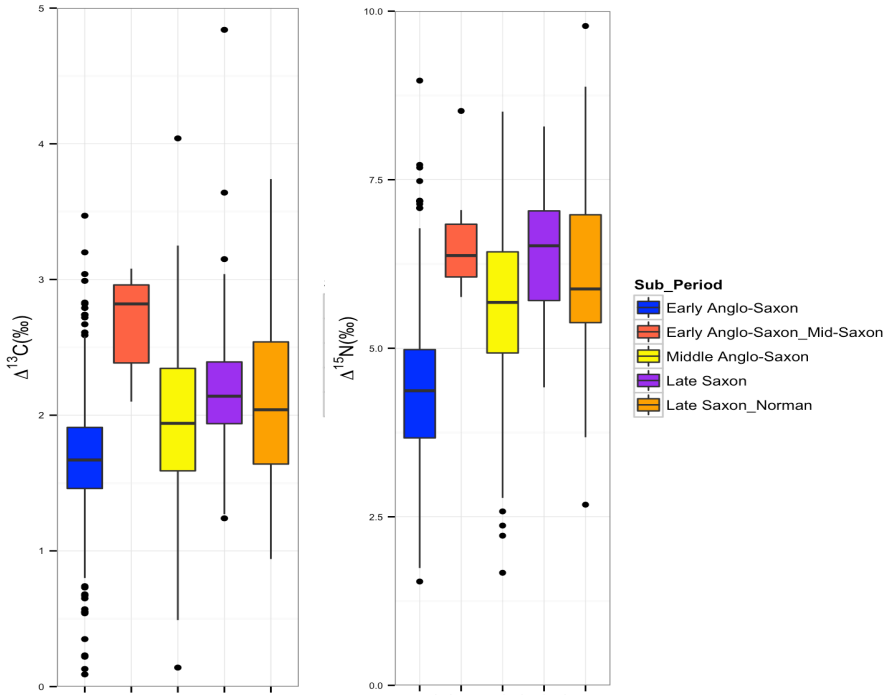


Figure 7.41. Boxplot comparison of the Early Medieval $\Delta_{human-cattle}$ values in the different sub-periods (Early Anglo-Saxon n=651, Early Anglo-Saxon/Mid-Saxon n=12, Middle Saxon n=107, Late Saxon n = 68, Late Saxon/Norman n=51). The samples only dated 'Anglo-Saxon' have been excluded from these analyses (n=111). The cattle baseline used here has a ∂^{13}C value of -21.8 ± 0.68‰ and a ∂^{15}Nvalue of 5.1±1.19‰.

When comparing the human data against the Early Medieval cattle data, it is revealed that the Early Anglo-Saxon data plot mainly within the range of one ^{15}N-trophic level (3-5‰) and it is the only period for which some of the data do not display at least one ^{13}C trophic level (1‰). The later periods, and in particular the Late Saxon period, display more enrichment in both isotopes, even up to two trophic levels (Figures 7.40, 7.41). As was mentioned above, this suggests a possible increase in the consumption of aquatic foodstuffs, which will be discussed in Chapter 8.

7.3.4. Regional variation

Table 7.29. Summary of the Early Medieval according to different regions (data from, Edix Hill n=8 Melbourn Water Lane n=9, Westerfield Farm n=11 (Cambridgeshire), Butler's Field n=119, Lechlade n=9 (Gloucestershire), Alton n=37, Droxford n=34, Portway n=69, Shavard's Farm n=13, Winnall Down n=37, Worthy Park n=35 (Hampshire); Dover Buckland n=6, Mill Hill n=8, St Peter's Tip n=12 (Kent); Bergh Apton n=13, Burgh Castle n=28, Caister n=21, Morningthorpe n=19, Norwich n=17, South Acre n=12, Spong Hill n=6, Swaffham n=10 (Norfolk), Alchester n=8, Berinsfield n=95, St John's College (Oxford) n=38, Yarnton n=8 (Oxfordshire); Bloodmoor Hill n=15, Buttermarket n=1, Coddenham n=1, Lakenheath n=1, Westgarth Gardens n=67 (Suffolk); Bellevue n=37, Coppergate n=3, Fishergate (York) n=51, Masham n=30, West Heslerton n=1)

	Average ∂^{13}C(‰)	Average ∂^{15}N(‰)	min ∂^{13}C(‰)	max ∂^{13}C(‰)	min ∂^{15}N(‰)	max ∂^{15}N(‰)	n=
Cambridgeshire	-20.1 ± 0.28	10.3 ± 1.10	-20.9	-19.4	8.8	12.6	28
Gloucestershire	-20.1 ± 0.23	9.5 ± 0.70	-20.9	-19.5	7.5	11.4	128
Hampshire	-20.1 ± 0.49	8.7 ± 0.90	-21.6	-18.8	6.7	12.3	225
Kent	-19.8 ± 0.26	9.6 ± 0.55	-20.0	-19.1	8.3	10.6	26
Norfolk	-19.9 ± 0.88	10.9 ± 1.28	-22.1	-17.0	6.8	13.6	126
Oxfordshire	-19.9 ± 0.35	10.5 ± 1.28	-20.7	-18.7	8.0	13.5	149
Suffolk	-20.2 ± 0.32	10.0 ± 0.87	-20.9	-19.6	8.4	14.1	85
Yorkshire	-20.0 ± 0.53	10.6 ± 1.18	-21.0	-18.1	7.7	14.9	122

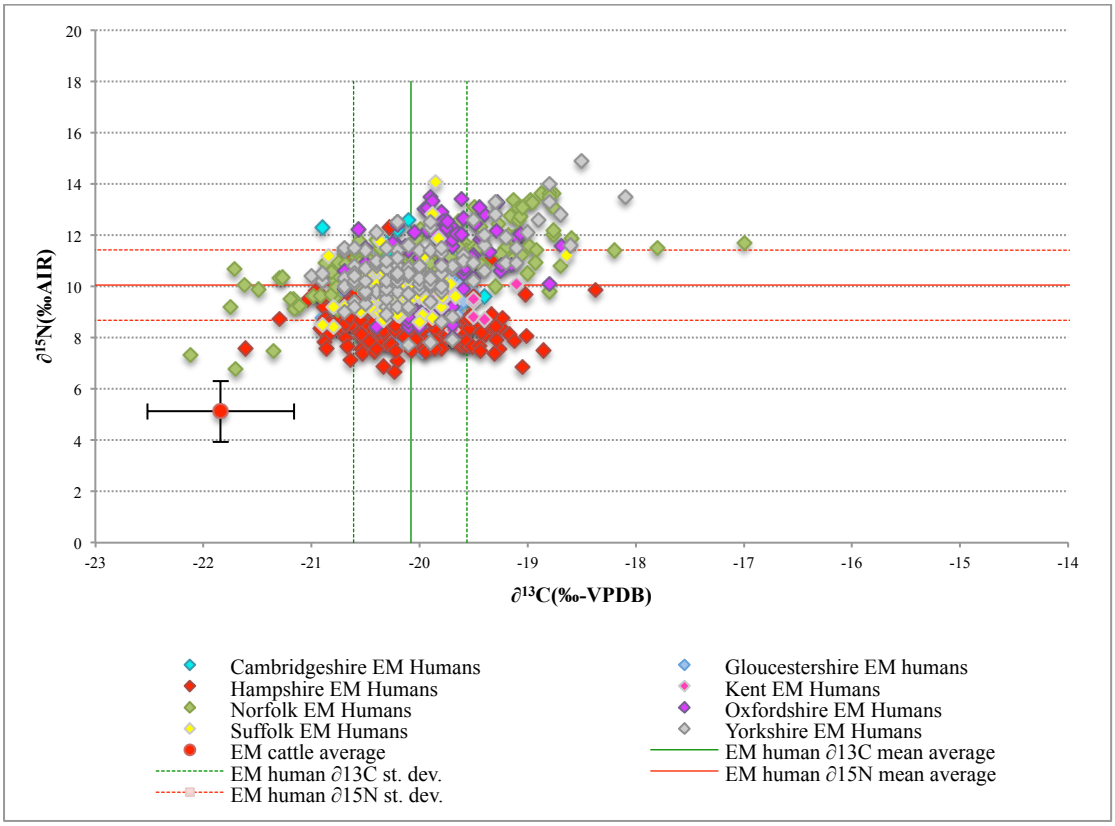


Figure 7.42. Comparison of the different regions in Early Medieval Britain (Cambridgeshire n=29, Gloucestershire n=119, Hampshire n=225, Kent n=26, Norfolk n=126, Oxfordshire n=149, Suffolk n=85, Yorkshire n=122).

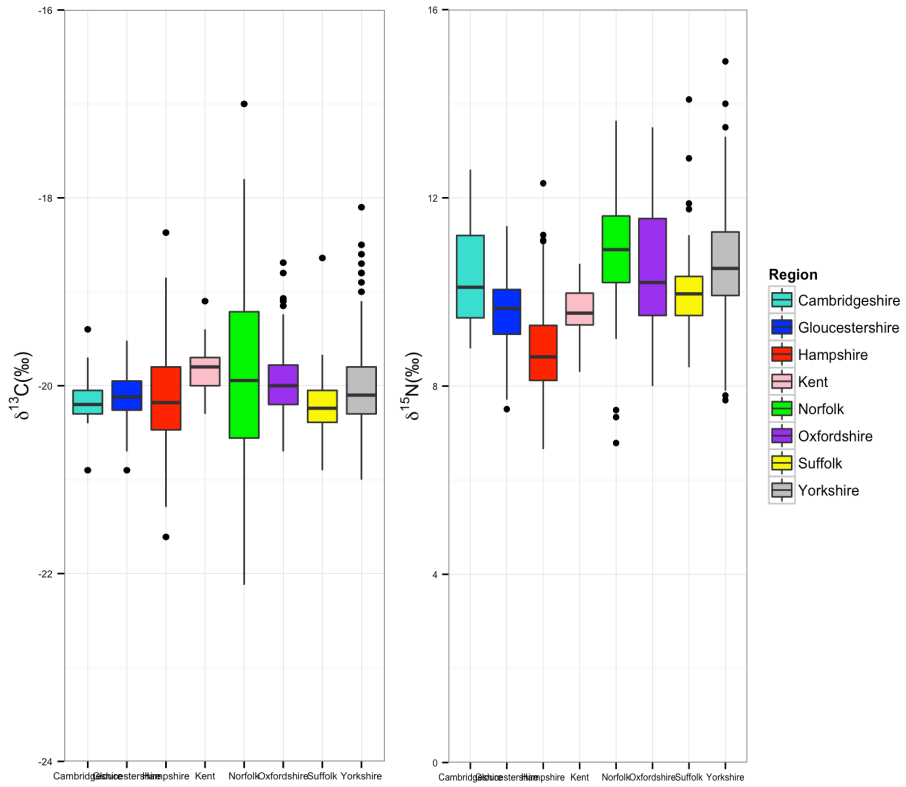


Figure 7.43. Boxplot comparisons of the different regions in Early Medieval Britain (Cambridgeshire n=29, Gloucestershire n=119, Hampshire n=225, Kent n=26, Norfolk n=126, Oxfordshire n=149, Suffolk n=85, Yorkshire n=122).

There are more regions analysed for the Early Medieval period that there were in the other broad periods (Table 7.29). The pattern that is immediately visible is that the Hampshire data are ^{15}N-depleted compared to the other regions, as was the case in the Iron Age, for both the fauna and the human data (Figures 7.42, 7.43). This is a pattern that was tentatively identified in the Roman faunal data as well. It possibly suggests an environmental effect, such as soil, or vegetation, that might be particular to Hampshire. However, this difference is only significant when compared against Norfolk and Oxfordshire, and not against all the other regions, so it is possible that a 'sub-period' effect is somewhat biasing the result. It is nonetheless interesting that Hampshire should display the same pattern relative to the other regions in all three broad periods. There is no other statistical difference in the data (Table 7.30).

Table 7.30. Statistical significance between the regions of Early Medieval Britain. The differences between different regions remain significant whether 'sub-period' are integrated into the model as fixed or random effects.

Region	Multi-Level Model With 'Sites', 'Sub-Period' As Random Effect And 'Region' As Fixed Effects	
	p-value (∂^{13}C)	*p-value* (∂^{15}N)
Cambridgeshire-Gloucestershire	1.000	0.986
Cambridgeshire-Hampshire	1.000	0.086
Cambridgeshire-Kent	0.999	0.993
Cambridgeshire-Norfolk	1.000	1.000
Cambridgeshire - Oxfordshire	0.999	1.000
Cambridgeshire - Suffolk	1.000	0.990
Cambridgeshire-Yorkshire	1.000	0.944
Gloucestershire - Hampshire	1.000	0.961
Gloucestershire -Kent	0.999	1.000
Gloucestershire-Norfolk	1.000	0.956
Gloucestershire-Oxfordshire	1.000	0.892
Gloucestershire-Suffolk	1.000	1.000
Gloucestershire - Yorkshire	1.000	1.000
Hampshire-Kent	0.999	0.851
Hampshire-Norfolk	1.000	**0.016**
Hampshire-Oxfordshire	0.999	**0.026**
Hampshire-Suffolk	1.000	0.882
Hampshire-Yorkshire	1.000	0.999
Kent-Norfolk	1.000	0.974
Kent-Oxfordshire	1.000	0.921
Kent - Suffolk	0.993	1.000
Kent - Yorkshire	0.999	1.000
Norfolk -Oxfordshire	1.000	1.000
Norfolk - Suffolk	1.000	0.919
Norfolk - Yorkshire	1.000	0.720
Oxfordshire - Suffolk	0.997	0.861
Oxfordshire-Yorkshire	0.999	0.516
Suffolk-Yorkshire	1.000	1.000

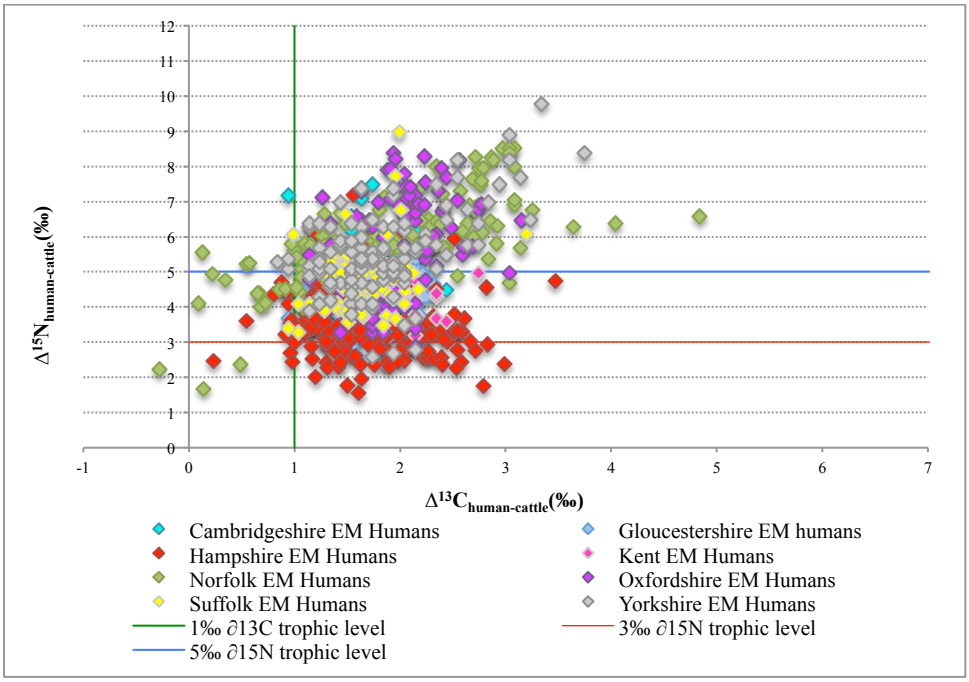


Figure 7.44. Comparison of the $\Delta_{human-cattle}$ in the different regions of Early Medieval Britain (Cambridgeshire n=29, Gloucestershire n=119, Hampshire n=225, Kent n=26, Norfolk n=126, Oxfordshire n=149, Suffolk n=85, Yorkshire n=122).

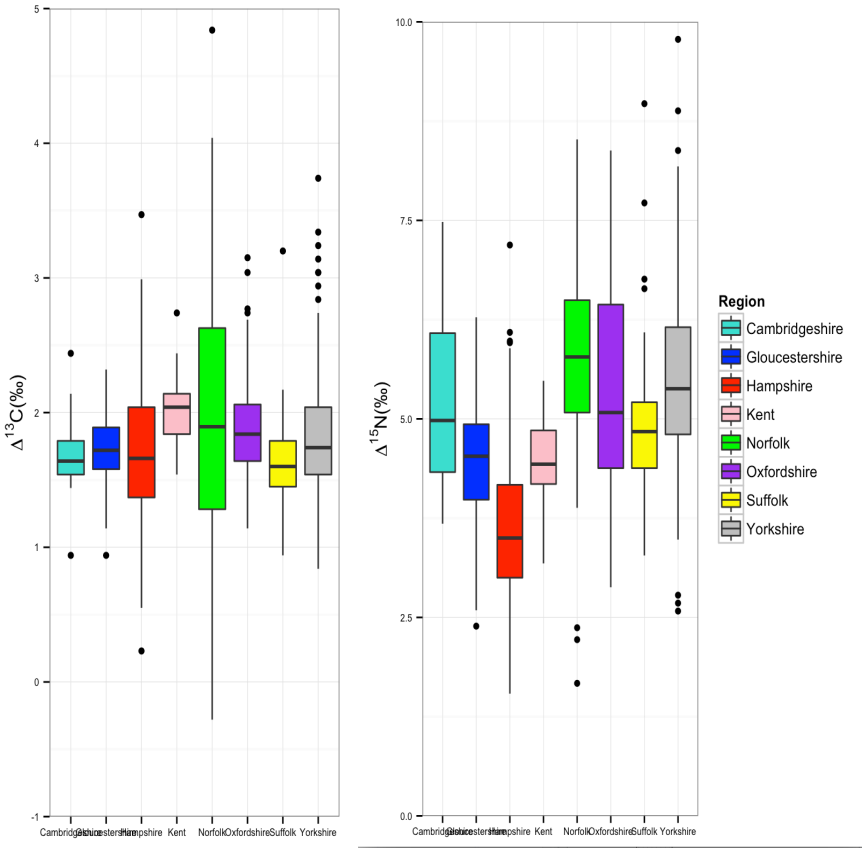


Figure 7.45. Boxplot comparison of the $\Delta_{human-cattle}$ in the different regions of Early Medieval Britain (Cambridgeshire n=29, Gloucestershire n=119, Hampshire n=225, Kent n=26, Norfolk n=126, Oxfordshire n=149, Suffolk n=85, Yorkshire n=122).

Figures 7.44 and 7.45 show the offsets between the cattle baseline and the Early Medieval humans data. The data from Norfolk display both the smallest and largest ^{13}C-enrichment compared to the baseline. Most of the data are enriched by one trophic level in both isotopes, except for the data from Norfolk that are more elevated. Since Norfolk display a strong correlation between both isotopes and that a number of Norfolk sites are on the coast, it is possible that this is due to aquatic foodstuff consumption. This will be discussed further in section 7.6.4 of this chapter. The $\Delta^{15}N_{human-cattle}$ values from Hampshire appear to be relatively low, but this will also be explored further in section 7.5 of this chapter, by using restricted baselines.

7.4. Diachronic Trends

This section investigates the data at both a coarse level (by broad periods) and at a more precise chronological resolution (by sub-period). The raw data are examined, and then compared with a cattle baseline to understand the relationship between the human data and the environment.

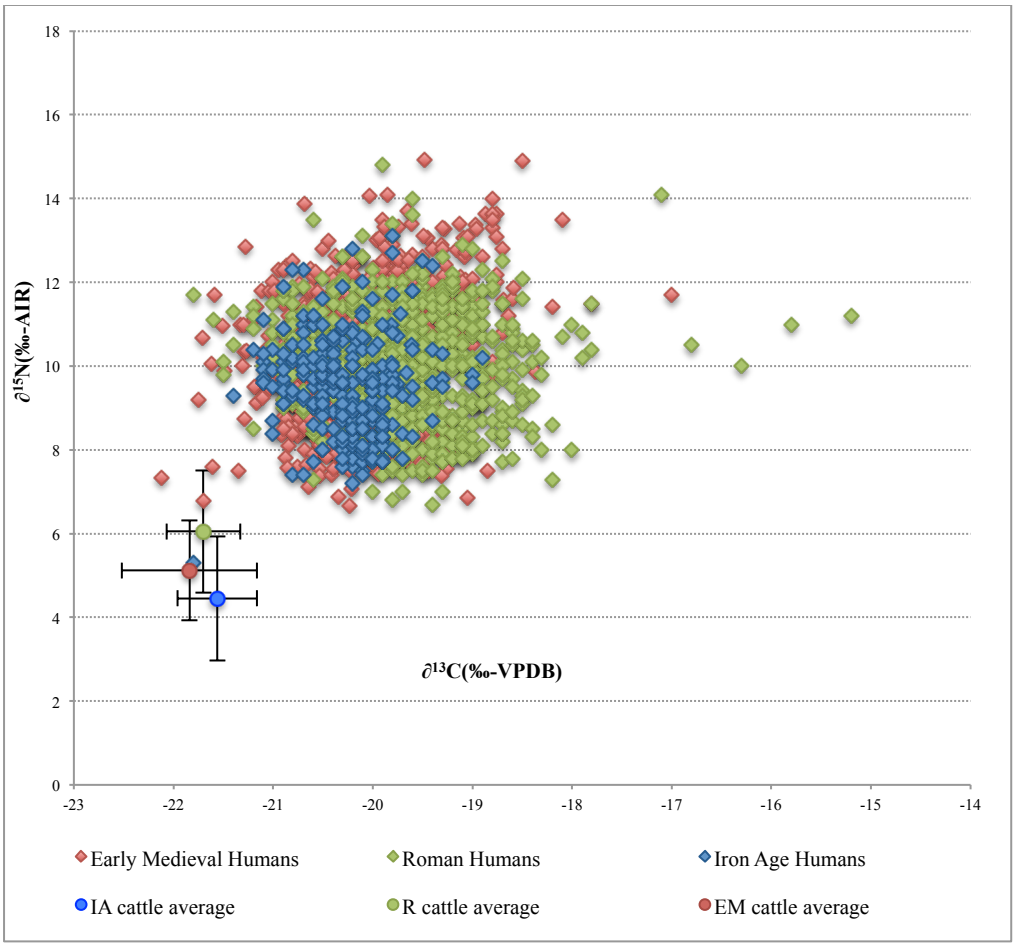


Figure 7.46. Comparison of the human results by broad archaeological periods (Iron Age n= 298, Roman n= 829, Early Medieval n= 1000).

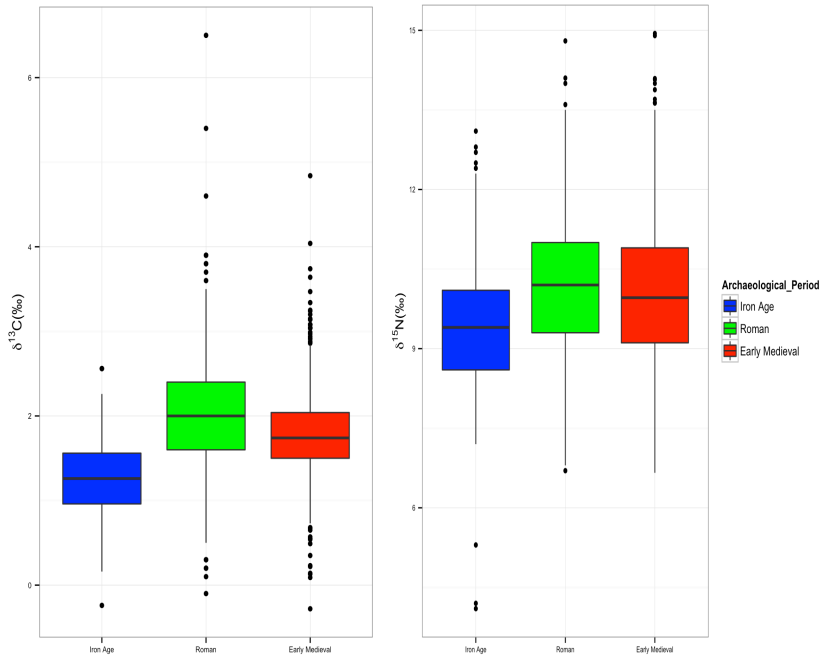


Figure 7.47. Boxplot comparison of human results by broad archaeological periods (Iron Age n= 298, Roman n= 829, Early Medieval n= 1000).

Figures 7.46 and 7.47 show the human data organised by broad periods. It is immediately noticeable that some of the Iron Age values seem to be depleted in ^{13}C, when the faunal data had the highest average (Figure 6.52 in section 6.4, Figure 7.46 and 7.47). The reasons for the enrichment in ^{13}C in the human data in the later periods may be many and varied. It may be evidence of marine fish consumption in the later period, especially in the later medieval periods, when the high $\partial^{13}C$ values are correlated to $\partial^{15}N$ values. It might also be evidence of individuals who have built a collagen signal in a place other than Britain and died before locally grown food could affect their collagen. It could also be evidence of the consumption of imported food, perhaps grown in regions where the isotopic signal would be different. Another explanation may be an increased consumption of food with higher $\partial^{13}C$, such as plants using the C_4 photosynthetic pathway (e.g. millet) or marine food. However, there are no native C_4 plants in

Britain and despite the presence of millet during the Roman period, it is not represented in high enough quantities to suggest it was a dietary staple and is therefore unlikely to be an important contributing factor to the enrichment of carbon (van der Veen 2008; Müldner 2013). Considering the differences in $\Delta^{15}N_{human\text{-}cattle}$ values (see below), it is immediately noticeable that most of the data display enrichment compared to the cattle data that is more than one or even two trophic levels (3-5‰). The relative enrichment of the British data compared to the animal baseline has long been noted by researchers (Müldner 2013), and needs to be explored more fully here.

However, as was the case with the faunal data, it is possible that the broad period analyses hide more subtle differences at the period level. To make visualisation simpler, the sub-period differences are show below in boxplots rather than scatter-plots (Figure 7.48). Figure 7.48 is particularly interesting when compared to the faunal sub-period data (Figure 6.52). Indeed, while the domesticated fauna displayed a decrease in ^{13}C-decrease from the Iron Age to the Early Medieval period and a peak in ^{15}N in the Roman period, the human data show something rather different. Instead of a decrease in ^{13}C, $\partial^{13}C$ mean averages increase to reach a peak in the Late Roman period, before decreasing immediately after the Roman period, and gradually increase in the later Early Medieval periods (Figure 7.48). The ^{15}N also differ, in that there is not really a peak in the Roman period, but a gradual increase, with periods of decrease, until a Middle Anglo-Saxon peak.

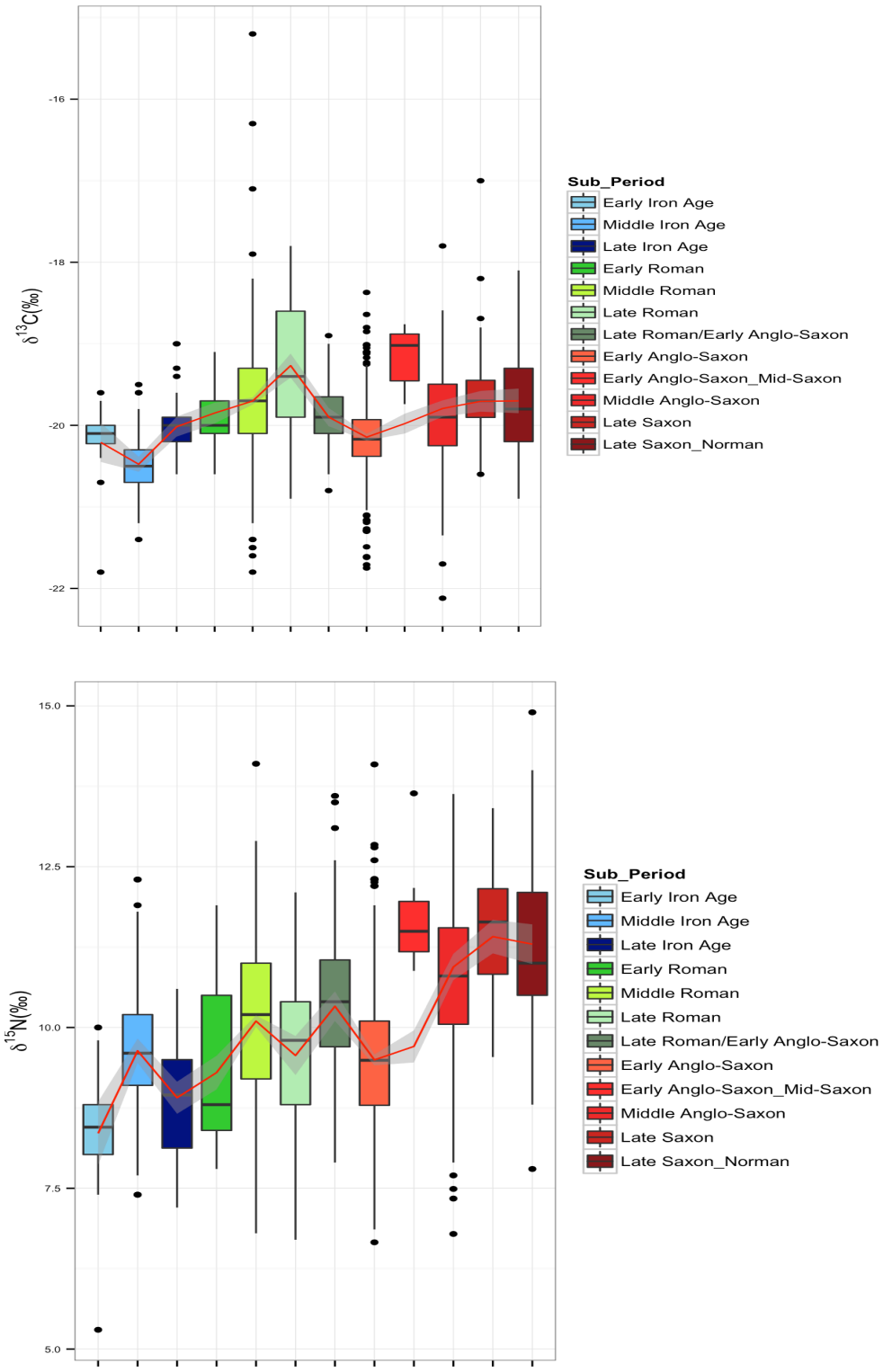


Figure 7.48. Diachronic evolution of the human data (Early Iron Age n=20, Middle Iron Age n=135, Late Iron Age n=62, Early Roman n=21, Middle Roman n=610, Late Roman n=49, Late Roman/Early Anglo-Saxon n=87, Early Anglo-Saxon n=651, Early Anglo-Saxon/Mid-Saxon n=12 Middle Anglo-Saxon n=107, Late Saxon n=68 , Late Saxon_Norman n=51. Samples dated less precisely, i.e. dated only to a broad period ('Iron Age' n=79, 'Roman' n=61, 'Anglo-Saxon' n=111, and the Latest Iron Age sample (n=1)) have been excluded. The red line is a LOESS regression, which is used to plot a smooth line through a series of data points by weighting quadratic least squares regression.

Statistically, the modelling done here is fairly complex as it must take into account broad periods, sites and region, as well as sex and age. Indeed, as significant statistical differences between the different sexes and age groups were shown above, one must be careful that this particular distribution of the data does not affect the results. The real difficulty, however, is in integrating 'Sub-Period' as a fixed effect in the model as it is a chronological sub-division and thus raises issues of auto-collinearity. For simplicity's sake here, sub-periods were not integrated to the model as fixed effects, but as random effects. The effect of sub-periods, however, is likely to be important. Therefore, another set of models was run, this time using sub-period as a fixed variable, and not integrating the broader periods. These results are shown in Table 7.31 and 7.32 below.

Table 7.31. Statistical analyses for the human in the broad period. *If sub-period was not integrated into the models, these results became significant.

Archaeological Periods	**Multi-Level Model With 'Sites' and 'Sub-Period' As Random Effects And 'Archaeological Period' + 'Region' + 'Sex' + 'Age' As Fixed Effect.**	
	p-value (∂^{13}C)	*p-value* (∂^{15}N)
Iron Age-Roman	0.154*	0.871
Iron Age-Early Medieval	0.084*	0.318
Early Medieval Roman	0.891*	0.509

Because the models found different significances in the carbon isotopic data, whether sub-periods were integrated as a random or fixed effect, the effect of sub-periods was investigated further and shown in the table below. Only the carbon isotopic data are given here for reasons of space: no significant difference was revealed in the nitrogen isotopic data at the more precise chronological resolution (the full results can be found in section A2.2.4 of Appendixes II.2). Table 7.32 shows that sub-periods can vary

across broad periods but interestingly, no transition periods seem to significantly differ from the sub-period immediately before or after, i.e. Late Iron and Early Roman, or Late Roman and Early Anglo-Saxon, suggesting that whatever changes are witnessed here, they are not necessarily immediately brought on by cultural change.

Table 7.32. Statistical analyses for the carbon isotopic data of the humans in the sub-period. The full results can be found in section A2.2.4 of Appendixes II.2.

Sub- Periods	**Multi-Level Model With 'Sites' and 'Sub-Period' As Random Effects And 'Archaeological Period' + 'Region' + 'Sex' + 'Age' As Fixed Effect.**
	p-value (∂^{13}C)
Early Anglo-Saxon/Early Anglo-Saxon_Mid Saxon	0.041
Early Anglo-Saxon –Middle Anglo-Saxon	0.059
Early Anglo-Saxon – Middle Roman	0.055
Early Anglo-Saxon_Mid Saxon – Early Iron Age	0.023
Early Anglo-Saxon_Mid Saxon – Early Roman	0.008
Early Anglo-Saxon_Mid Saxon – LIA	0.043
Early Anglo-Saxon_Mid Saxon –Middle Iron Age	0.012
Early Iron Age-Middle Anglo-Saxon	0.085
Early Iron Age-Middle Roman	0.076
Early Roman-Late Roman	0.003
Early Roman-Middle Roman	0.010
Middle Iron Age-Middle Roman	0.001

Having looked at the human values, it is now necessary, especially taking into account the different patterns in the fauna, to look at the offsets between each baseline (by broad period) and each human group.

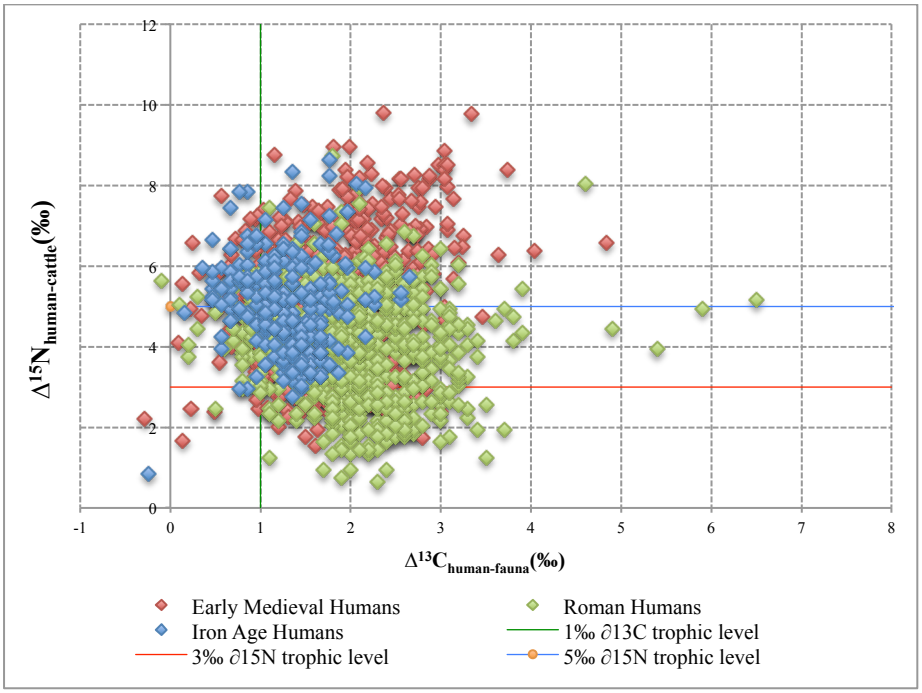


Figure 7.49. Comparison of the $\Delta_{Human\text{-}cattle}$ spacing results by broad archaeological periods (Iron Age n= 298, Roman n= 829, Early Medieval n= 1000). The Δ-values were calculated by averaging the cattle value of each broad period and comparing it with the human data.

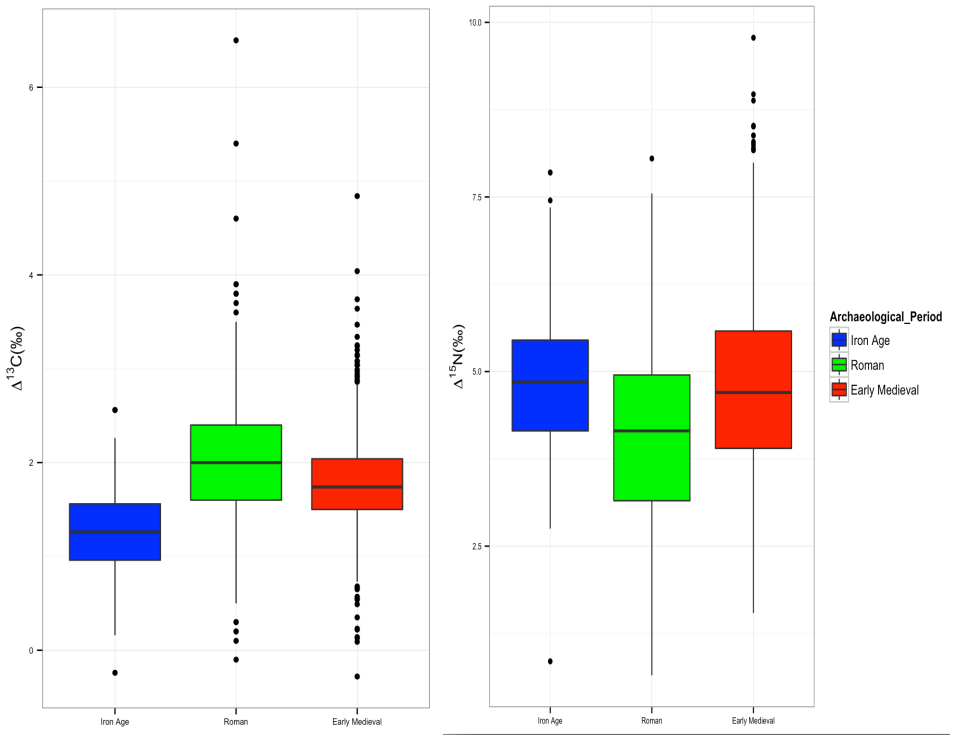


Figure 7.50. Boxplots comparisons of $\Delta_{\text{Human-cattle}}$ spacing results by broad archaeological periods (Iron Age n= 298, Roman n= 829, Early Medieval n= 1000). The Δ-values were calculated by averaging the cattle value of each broad period and compare it with the human data.

Figures 7.49 and 7.50 show how the broad period data behave in relation to their respective baselines. The Iron Age displays $\Delta^{13}C_{\text{human-cattle}}$ between 1 and 2‰, which is one trophic level. Again, this suggests no aquatic protein to the diet, except maybe in the case of the few individuals who plot above that 2‰ trophic level, but certainly not at the general population level. The Roman data are fairly enriched in ^{13}C compared to the baseline, with some samples displaying $\Delta^{13}C_{\text{human-cattle}}$ values above 5.5‰. These individuals displaying somewhat average $\Delta^{15}N_{\text{human-cattle}}$ values compared to the cattle baseline (between 3‰ and 5.15‰), so this is likely to be evidence of C_4 in their diets (Müldner *et al.* 2011; Pollard *et al.* 2011). Some of the data with enrichment in both isotopes could be evidence of an increase in marine protein consumption for these individuals. However, overall, the Roman

data seem to show the lowest $\Delta^{15}N_{human\text{-}cattle}$ enrichment compared to the other periods, showing that the ^{15}N-peak in the fauna is not matched, or at least not matched on the same scale, in the human data than it was in the faunal data. The Early Medieval data seem to show the most consistent enrichment in both isotopes compared to the baselines, which may be evidence of an increase of fish consumption.

Again, it is beneficial to look at the sub-periods, and how these trends can be refined chronologically, which is done in the figure below (Figure 7.51).

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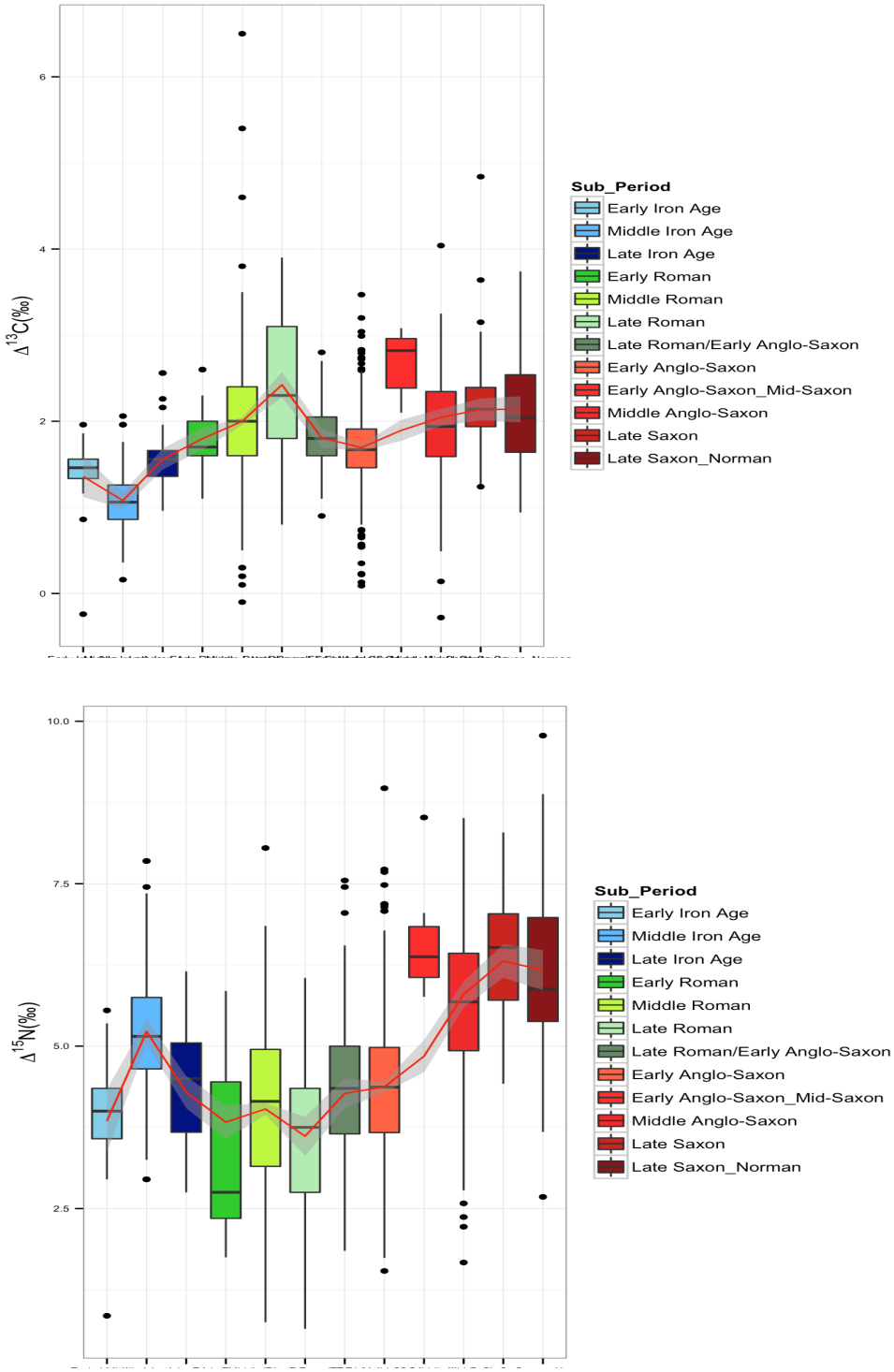


Figure 7.51. Diachronic evolution of the human data (Early Iron Age n=20, Middle Iron Age n=135, Late Iron Age n=62, Early Roman n=21, Middle Roman n=610, Late Roman n=49, Late Roman/Early Anglo-Saxon n=87, Early Anglo-Saxon n=651, Early Anglo-Saxon/Mid-Saxon n=12 Middle Anglo-Saxon n=107, Late Saxon n=68 , Late Saxon_Norman n=51. Samples dated less precisely, i.e. dated only to a broad period ('Iron Age' n=79, 'Roman' n=61, 'Anglo-Saxon' n=111, and the Latest Iron Age sample (n=1)) have been excluded. The red line is a LOESS regression, which is used to plot a smooth line through a series of data points.

Figure 7.51 shows that the offsets are similar to the $\partial^{13}C$ values, suggesting that the relation between the human data and its ^{13}C-baseline is somewhat straightforward. However, the dip in $\Delta^{15}N_{human\text{-}cattle}$ values from the Middle Iron Age onwards, when the human values were on the contrary increasingly enriched in ^{15}N (Figures 7.46, 7.47) suggest that while the cattle's $\partial^{15}N$ values increased, either for environmental or dietary reasons, the human data did not. This could be caused by introduction of ^{15}N-poor food, such as pulses, into the diets of the humans, while the cattle might have grazed on the remains of manured crops. This will be explored more fully in Chapter 8. It is also interesting to see a temporal effects in the Early Medieval data, with an enrichment relative to the baseline in both isotopes in the Early Anglo-Saxon/Mid-Saxon period, rather than in the Early Anglo-Saxon period, suggesting that changes in agricultures and/or diets did not occur immediately after the end of Roman Britain, but sometime later. By the Middle Saxon period, the enrichment in both isotopes in relation to both the baseline and the other groups suggest a change in diet or in agriculture on a large scale. This will be explored further in Chapter 8.

However, the diachronic analyses above are done on quite a coarse scale, since the sub-period human data are compared with their broad period cattle averages. It is likely that the relationship between the humans and the baseline might have varied on smaller chronological scales, and would not have been the same across species. Therefore, variation of all three main domesticates and the humans across the different sub-periods is shown in Figures 7.52 and 7.53.

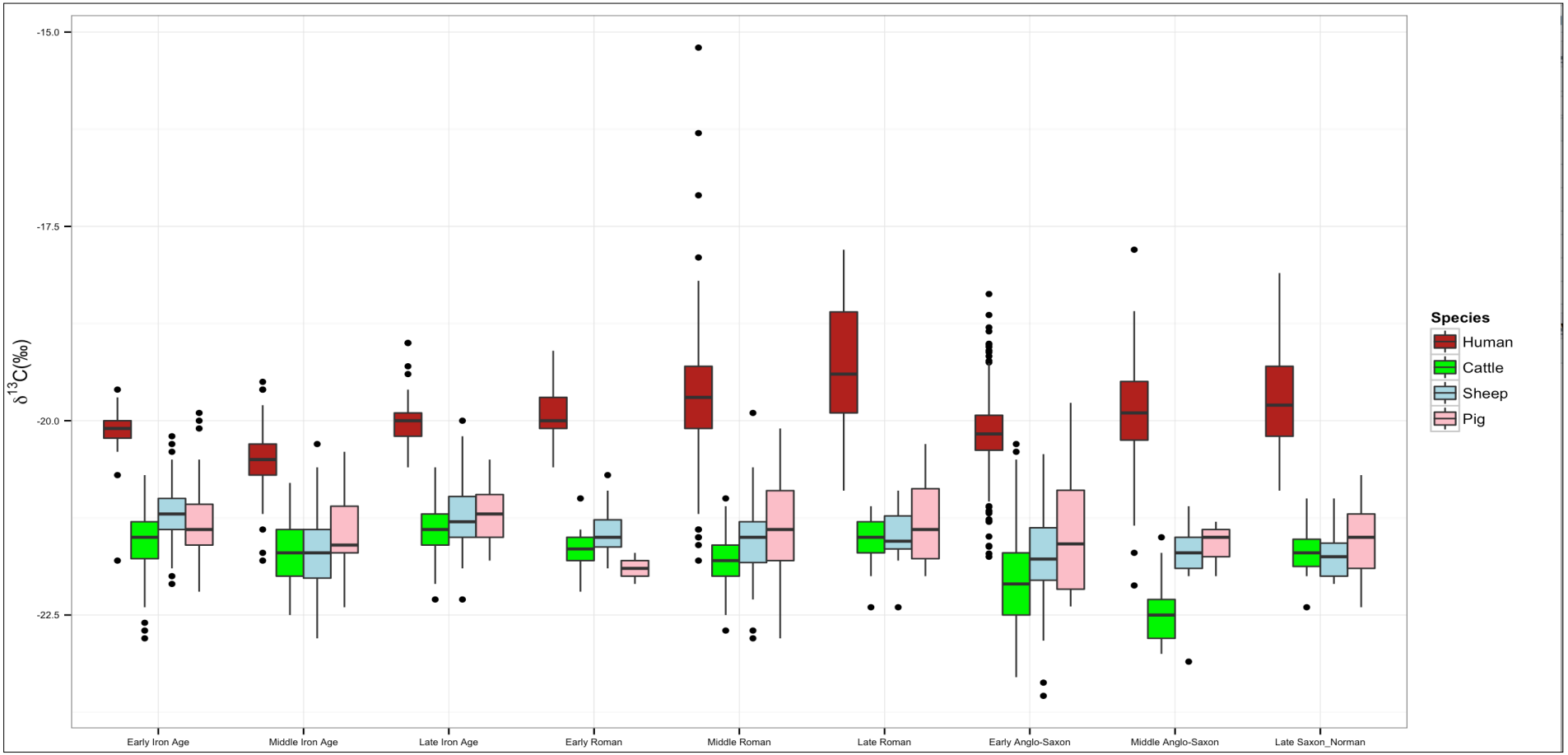


Figure 7.52. Boxplot distribution of the ∂^{13}C values of the four main species in all the sub-periods in which they are all present (LIA/Roman n=6, Late Roman/Early Anglo-Saxon n=87, Early Anglo-Saxon/Mid-Saxon n=12 and Late Saxon n=45 excluded).

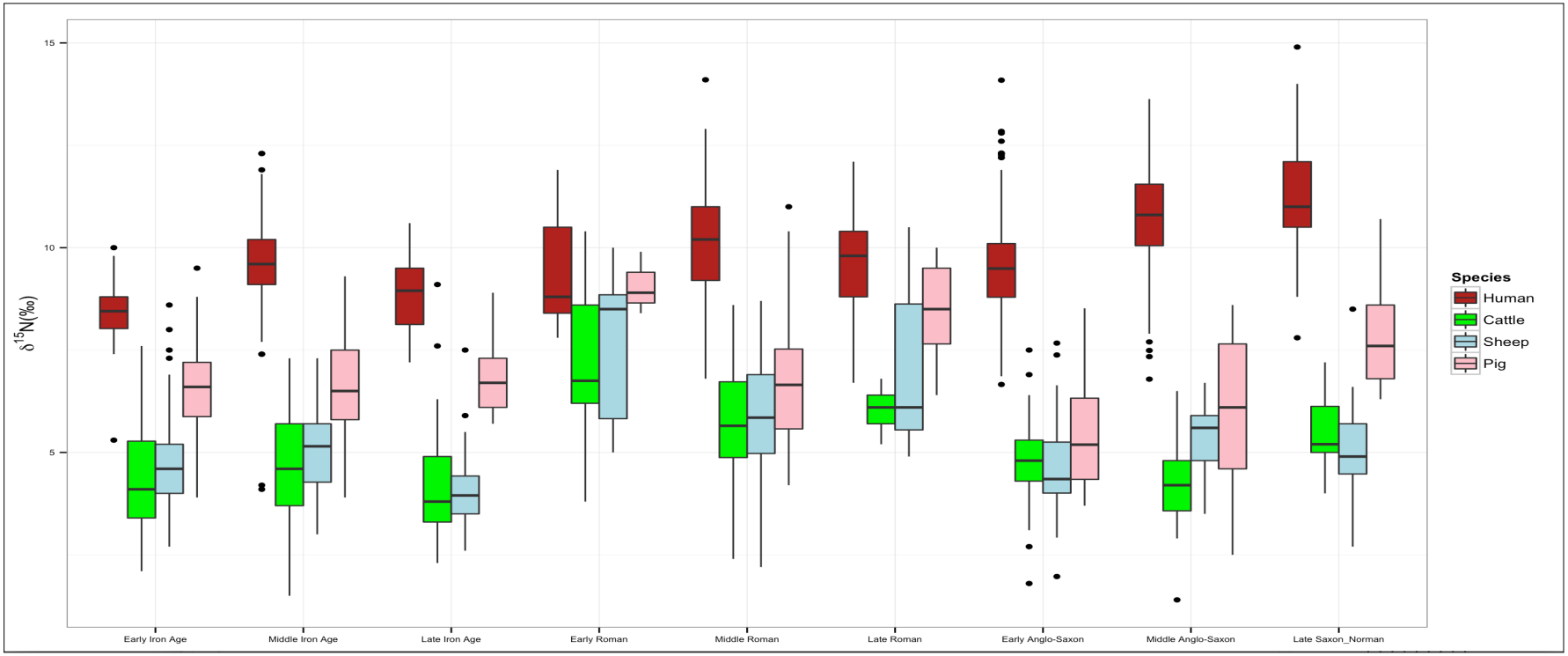


Figure 7.53. Boxplot distribution of the ∂^{15}N values the four main species in all the sub-periods in which they are all present (LIA/Roman n=6, Late Roman/Early Anglo-Saxon n=87, Early Anglo-Saxon/Mid-Saxon n=12 and Late Saxon n=45 excluded).

Figure 7.52 and 7.53 reveal two important nuancing factors to the trends discussed above. First, the small spacing in ^{15}N between the Roman humans and the Roman cattle is particularly visible in the Early Roman sub-period. The spacing in both the Middle Roman and the Late Roman sub-periods is wider, and more similar to the other sub-periods, maybe suggesting that the low $\Delta^{15}N_{human\text{-}cattle}$ values are specific to the Early Roman period. Second, it is important to note is that the large spacing between the human and cattle in the Middle Anglo-Saxon period is in part due to the cattle being depleted in ^{13}C compared to the other domesticates. It is important to take this into account, since a baseline integrating sheep would have resulted in a smaller spacing. Therefore, one must be cautious in over-interpreting this pattern (Figure 7.52 and 7.53).

7.5. Regional Trends

In the previous sections, variations within periods were identified. However, they could not be explained solely by the chronological differences between the different population groups. Therefore, it stands to reason that another factor might be at play here to explain these occasionally substantial variations. This section will therefore look at these results on a regional scale. While the previous section considered large-scale units of analyses, regional investigation is necessarily done on smaller subsets of the dataset. Here, as a way of testing regional variations, the human data are compared to a restricted regional baselines, rather than the national one to assess the regional variation between the cattle and the human data.

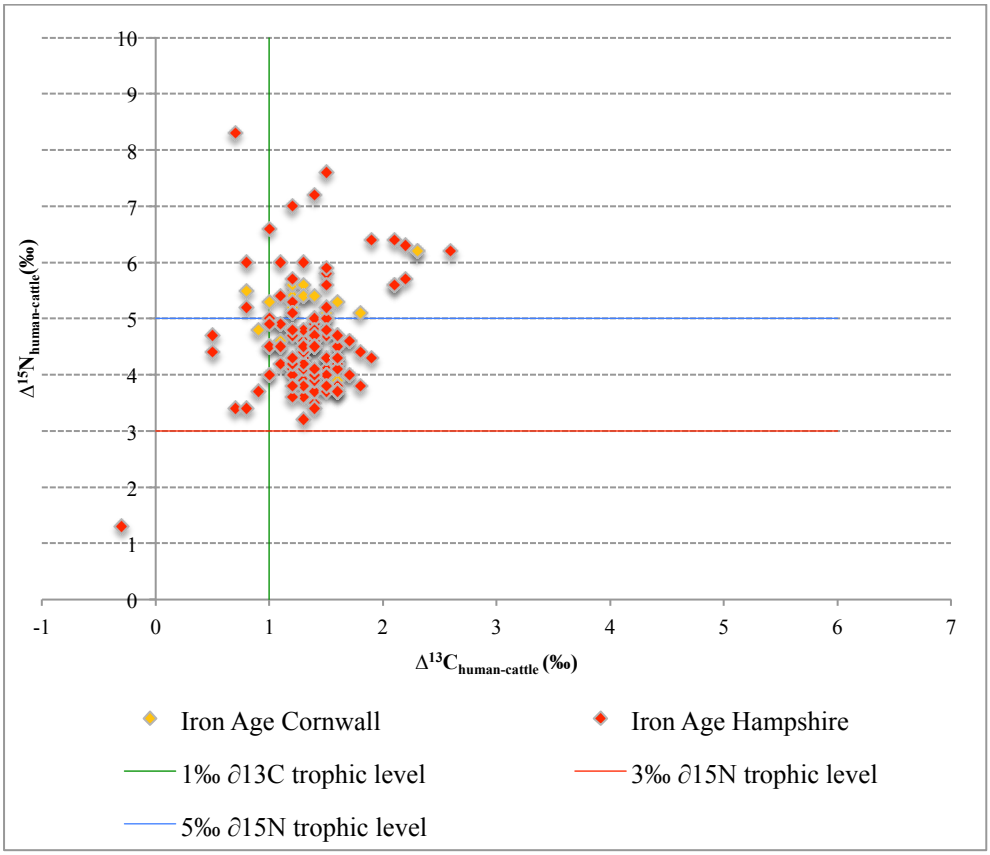


Figure 7.54. Regional comparison of the $\Delta_{human\text{-}cattle}$ values in Hampshire and Cornwall in the Iron Age, using restricted regional baselines.

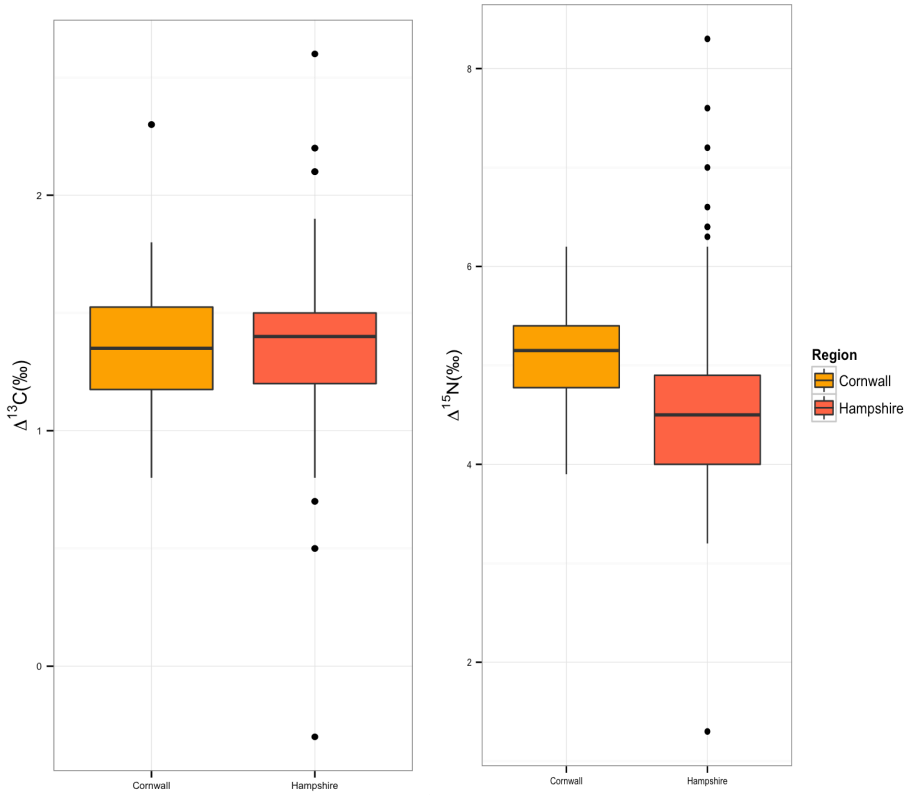


Table 7.54b. Boxplots of the regional comparisons of the $\Delta_{human\text{-}cattle}$ values in Hampshire and Cornwall in the Iron Age, using restricted regional baselines

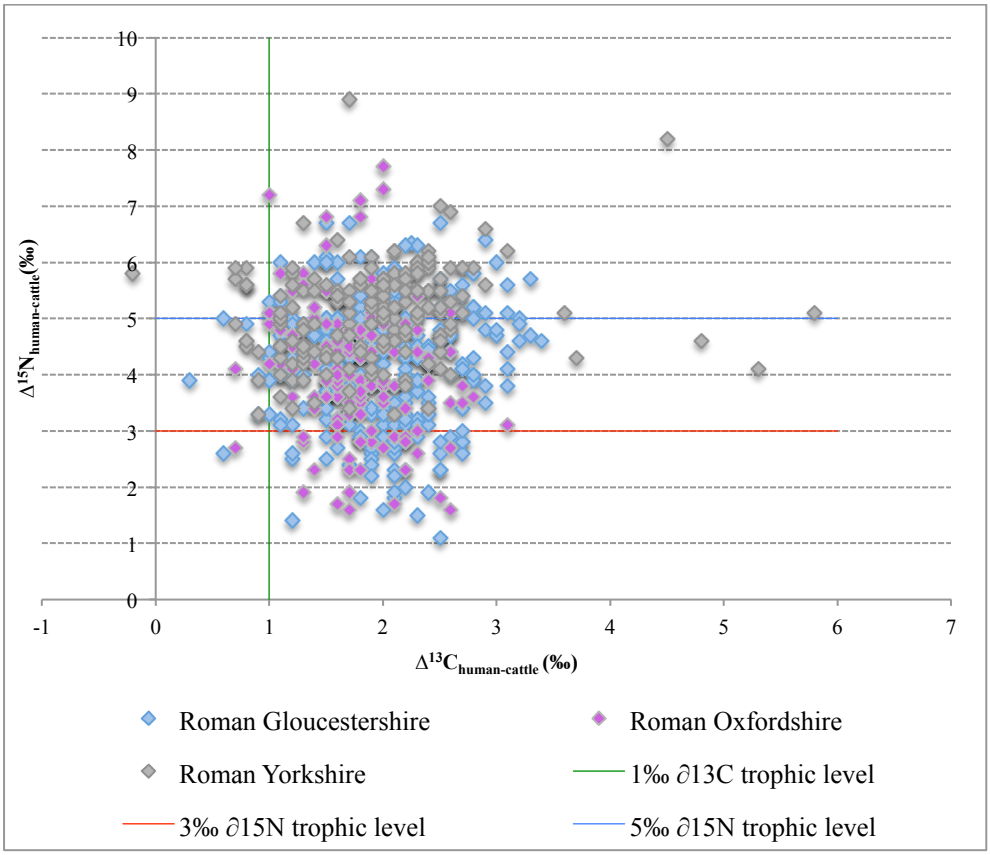


Figure 7.55. Regional comparison of the $\Delta_{human\text{-}cattle}$ values in Gloucestershire, Oxfordshire and Yorkshire in Roman Britain, using restricted regional baselines.

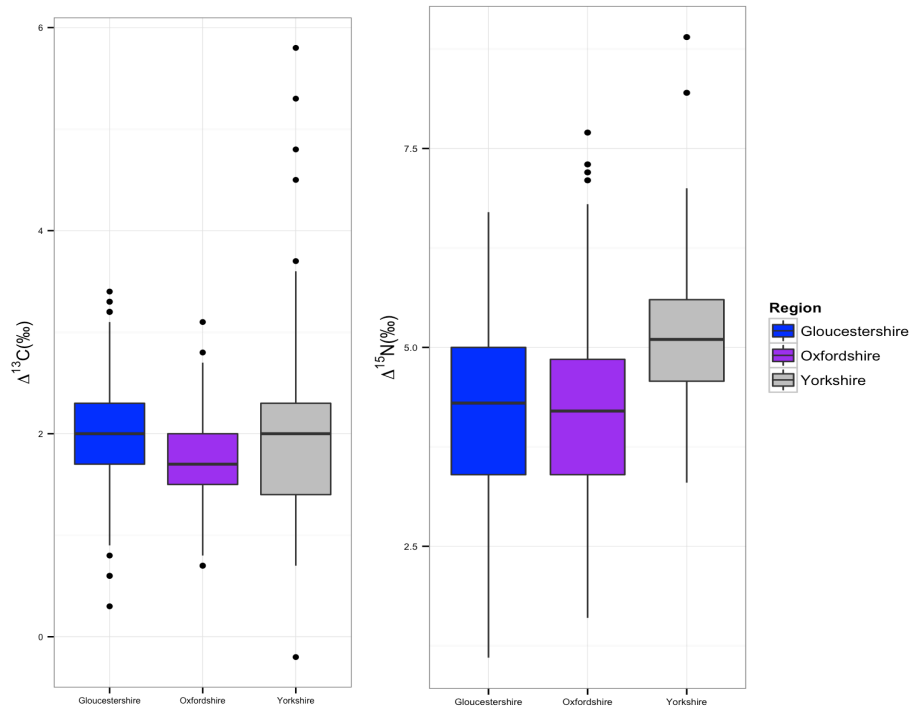


Table 7.55b. Boxplot of the regional comparison of the $\Delta_{human\text{-}cattle}$ values in Gloucestershire, Oxfordshire and Yorkshire in Roman Britain, using restricted regional baselines.

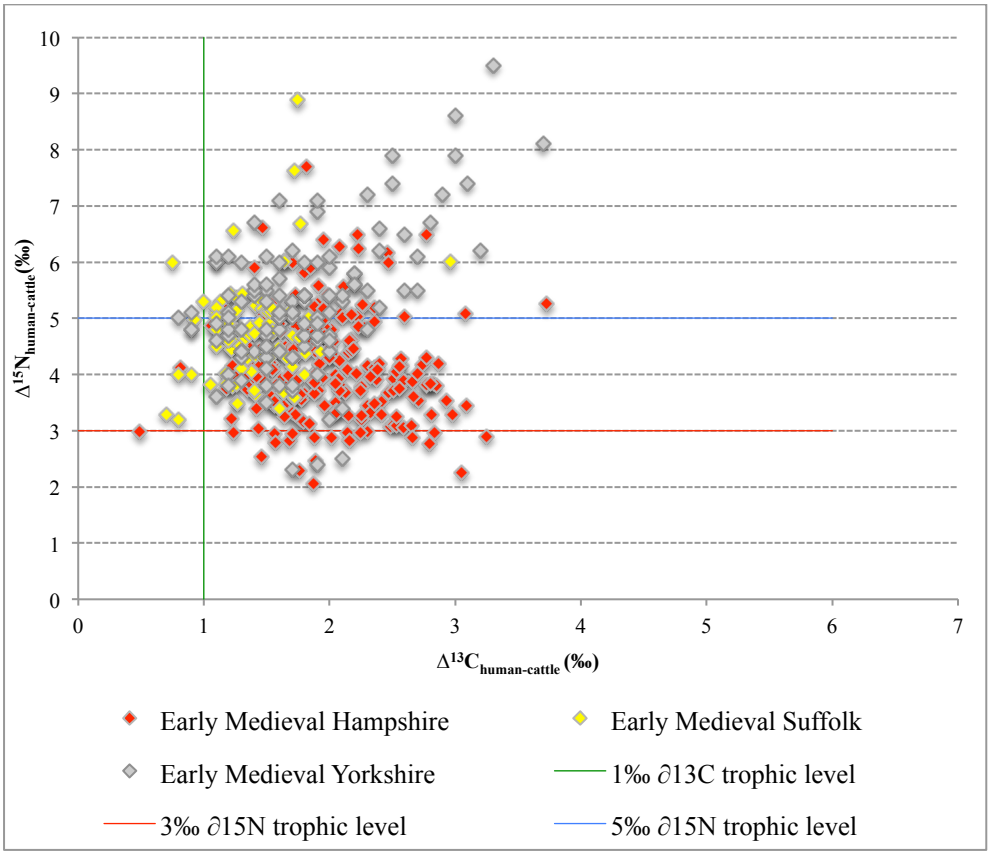


Figure 7.56. Regional comparison of the $\Delta_{human\text{-}cattle}$ values in Suffolk, Hampshire and Yorkshire in Early Medieval Britain, using restricted regional baselines.

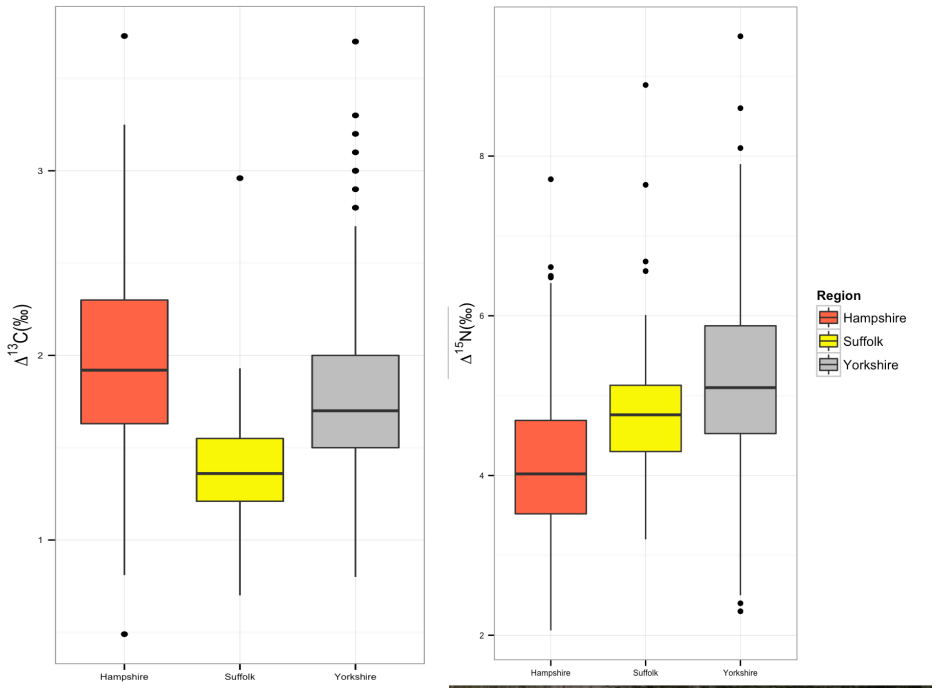


Table 7.56b. Boxplot of the Regional comparison of the $\Delta_{human\text{-}cattle}$ values in Suffolk, Hampshire and Yorkshire in Early Medieval Britain, using restricted regional baselines.

Three important observations can be made through these regional comparisons. First, the human data from Cornwall, which were depleted in ^{13}C compared to the 'national' baseline are now plotted above one trophic level, and are also enriched in ^{15}N above one trophic level (Figures 7.54 and 7.54b). The Hampshire data are also more enriched in ^{15}N against their regional baseline than the comparison with the national baseline would suggest. Most of the data plot well within the range of one ^{15}N trophic level (Figure 7.54). In both regions, some samples were enriched in both isotopes, but most these samples are from infants, showing a nursing signal. There are however two adult samples in this group, which might indicate possible marine fish consumption for them. Second, Roman human values depleted in ^{15}N compared to the baseline are characteristic of Gloucestershire and Oxfordshire, with none of the data from Yorkshire plotting the lower limit of the range of one ^{15}N trophic level (Figures 7.55 and 7.55b). Finally, the data from Hampshire in the early Medieval period, which was depleted in ^{15}N when compared about the broad period cattle average now clearly plot within the range of one ^{15}N trophic level (Figures 7.56 and 7.56b).

Most of the Hampshire data across both the Iron Age and the Early Medieval periods are enriched in ^{15}N compared to the baseline by about one trophic level. Some of the data plot higher and other lower, but the relationship between the human and the cattle is overall similar to what is seen in other regions. Therefore, the low $\partial^{15}N$ values of both the fauna and humans could be due to environmental factors, affecting the local vegetation, fauna and humans similarly but it seems odd that this environmental pattern should be confined to modern Hampshire. The

explanation suggested tentatively here is that it is possible that Hampshire, and maybe more generally the southern regions, cultivated and ate pulses, which would have lowered the overall $\partial^{15}N$ of the population. This could also explain the faunal data's low values, if they were fed fodder containing pulses. This will be explored further in Chapter 8. Further investigation of archaeobotanical data and wild fauna might allow for more in-depth exploration of this pattern. Combined with the pattern seen in the Roman data between Gloucester/Oxfordshire and Yorkshire, this might indicate a possible difference between Northern and Southern subsistence. The data from Cornwall might suggest a possible coastal effect in the both the human and cattle data, for which salinity cause depletion in ^{13}C.

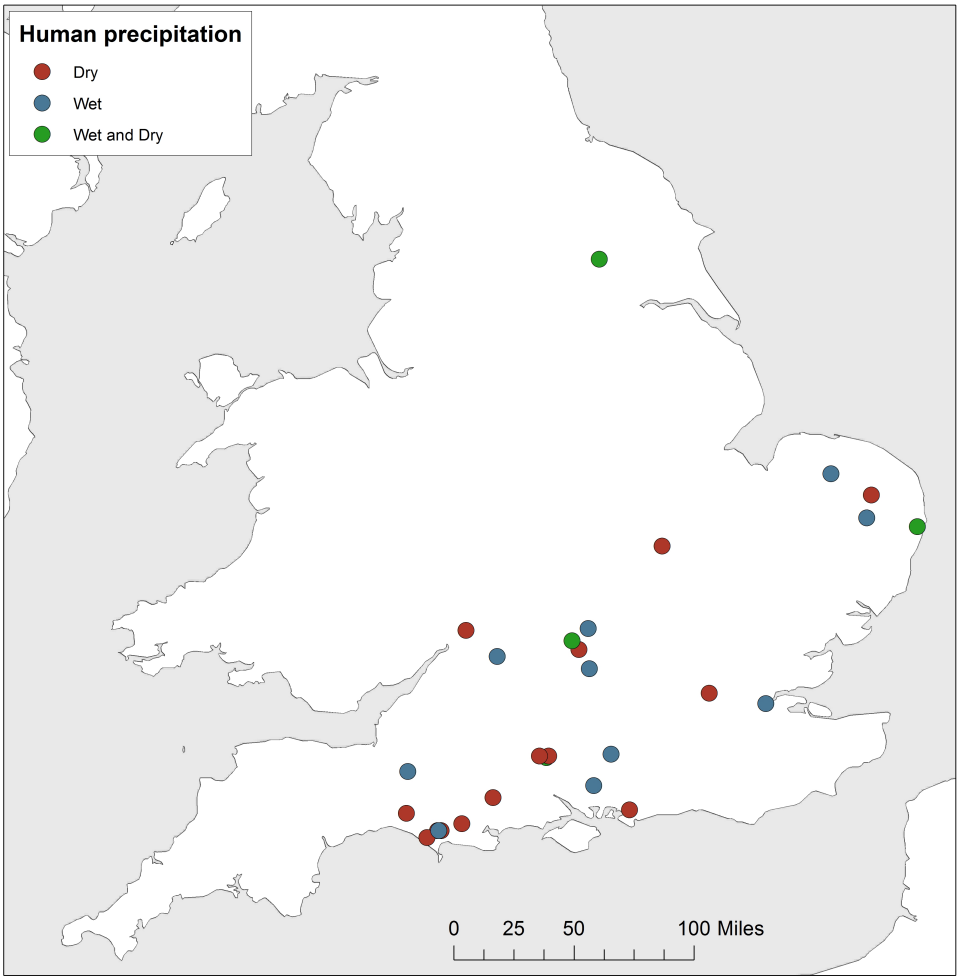
7.6. Physical And Social Geography

As was done for the faunal data, the human data will be investigated through units of analyses not necessarily available to researchers not investigating *longue durée* patterns. Rainfall will be investigated first, both temporally through dry and wet episodes pooled together from the different broad periods, and regionally, through regional of coherent precipitation (Gregory *et al.* 1991). Then temperatures, inland and coastal location, and North and South will also be investigated.

7.6.1 Rainfall through time: analyses of wet and dry period.

Table 7.33. Distribution of the human data according to precipitation between the Iron Age and the Early Medieval period.

Precipitation Event	N of sites	N of samples	Broad Archaeological Period	Region
Dry	14	164	Iron Age, Roman, Early Medieval	Dorset, Gloucestershire, Hampshire, Norfolk, Northamptonshire, Oxfordshire, Suffolk, Yorkshire.
Wet	11	406	Iron Age, Roman, Early Medieval	Dorset, Gloucestershire, Hampshire, Kent, Norfolk, Oxfordshire, Somerset, Suffolk.



Map 7.1. Distribution of the data according to wet and dry episodes between the Iron Age and the Early Medieval period (dry n =164, wet n= 406). Site distribution is in Table 7.33b below.

Table 7.33b. Distribution of the sites between wet and dry events.

Climatic event	Sites
Dry	Alington Avenue. Bloodmoor Hill, Coppergate, Danebury, Flagstones, Fordington Bottom, Gloucester, Gussage All Saints, Manor Farm, Norwich, Raunds Furnell, St Johns College, Tolpuddle Ball, Whitcombe Farm
Wet	Alchester, Alton, Bergh Apton, Bloodmoor Hill, Bradley Hill, Cirencester, Danebury, Gravesend, Morningthorpe, Poundbury, Queenford, SpongHill

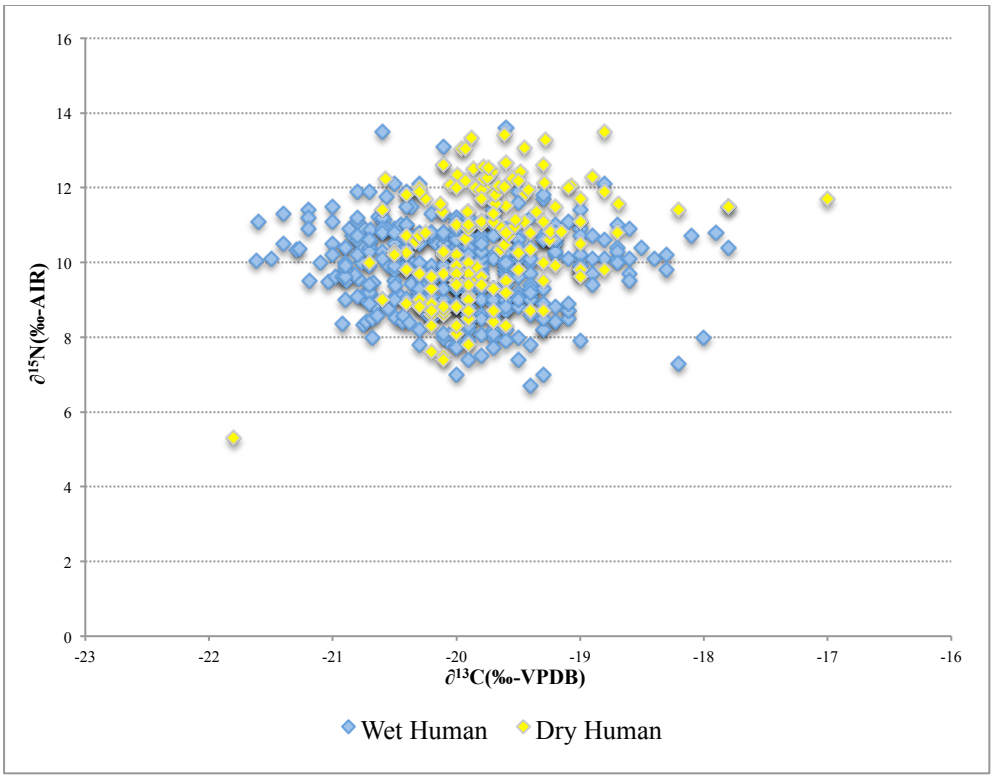


Figure 7.57. Comparison of the human data between wet and dry episodes between the Iron Age and the Early Medieval period (dry n =164, wet n= 406).

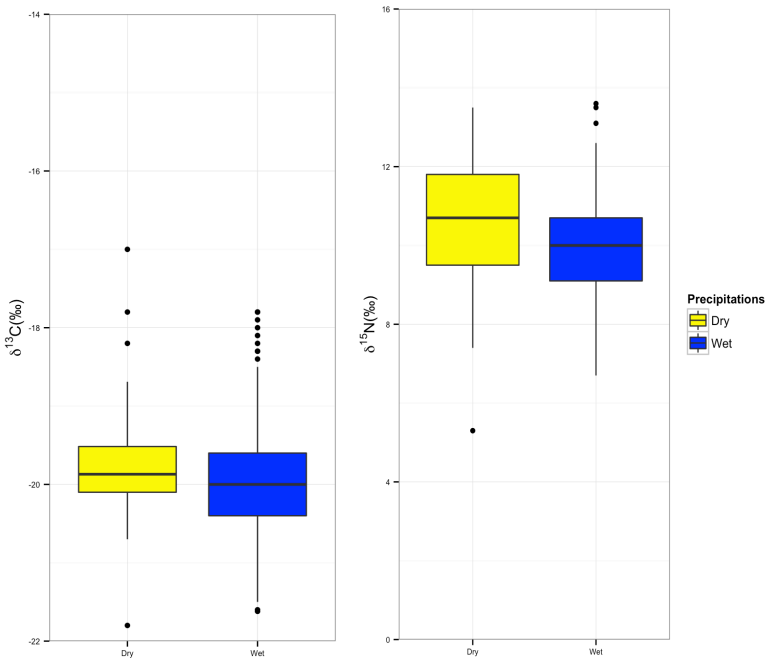


Figure 7.58. Boxplot comparison of the human data between wet and dry episodes between the Iron Age and the Early Medieval period (dry n =164, wet n= 406).

The data distribution is addressed in Tables 7.33 and 7.33b and Map 7.1. Two things are visible in the data as presented in Figure 7.57 and 7.58. The data from the drier periods are more enriched relative to the data from the wetter periods, which was not the case in the faunal data (see section 6.6.1 and 6.6.2).

Another visible trend is that there is a moderate positive correlation between ^{13}C and ^{15}N in the drier periods (r= 0.38, p = 0.000), which is not the case in the wetter periods. However, it is important here not to assign a climate effect to temporal or regional effects, because of the underlying structure of the data (See Chapter 5). Therefore, multivariate statistical models were tested, taking into account archaeological periods, sub-periods, regions, temperatures, region of coherent precipitation, and coastal/inland locations integrated both as random or fixed effect. In this case, however, the simpler model with only site as a random effect was the best-fit, for the carbon

isotopic data while a more complex model, integrating and site as random effects, and archaeological period, region and region of coherent precipitation was the best-fit for nitrogen isotopic data. This revealed a significant difference between the drier and wetter regions (Table 7.34). What is particularly interesting here is that this was not visible in the faunal data (Table 6.49), suggesting that the effects of rainfall on the isotopic data had an influence on diets, or rather resource procurement strategies, but not necessarily on the environment, at least in a way that is detectable in the cattle data. It is indeed possible that the effects of rainfall might be more noticeable in the wild animal data. Unfortunately, the deer data here only come from the drier episodes and this theory cannot be tested.

Table 7.34. Statistical differences between climatic episode. The model integrates regional variation as random effects, so the statistical difference seen here is independent from regional level factors.

Region	**Multi-Level Model With 'Sites' As Random Effect**	**Multi-Level Model With 'Sites', 'Sub-Period', 'Region', 'Rain-Regions', As Random effects and 'Precipitation' as fixed effect.**
	p-value ($\partial^{13}C$)	*p-value* ($\partial^{15}N$)
Dry-Wet	0.338	**0.052**

7.6.2 Rainfall through space: patterns of regional precipitation in Britain

This section addresses the regionality of precipitation by investigating the data according to region of coherent precipitation, as defined by Gregory *et al.* (1991), in all three broad periods. Again, interconnected factors are integrated in to the statistical models. The distribution of the data is in Table 7.35, 7.37 and 7.39.

7.6.2.1 Iron Age

Table 7.35. Distribution of the human data according to region of coherent precipitation in the Iron Age.

Region of coherent precipitation	N of sites	N of samples	Sites
NEE (MAP:777.1 ml)	1	74	Wetwang Garton-Slack
SEE (MAP:730ml)	6	150	Danebury, Gravesend,, Micheldewer Wood. Suddern Farm, Winnall Down, Yarnton
SWE (1031.5ml)	10	74	Alington Avenue, Flagstones, Fordington Bottom, Gussage All Saints, Harlyn Bay, Lechlade, Manor Farm, Tolpuddle Ball, Trethellan Farm, Whitcombe Farm

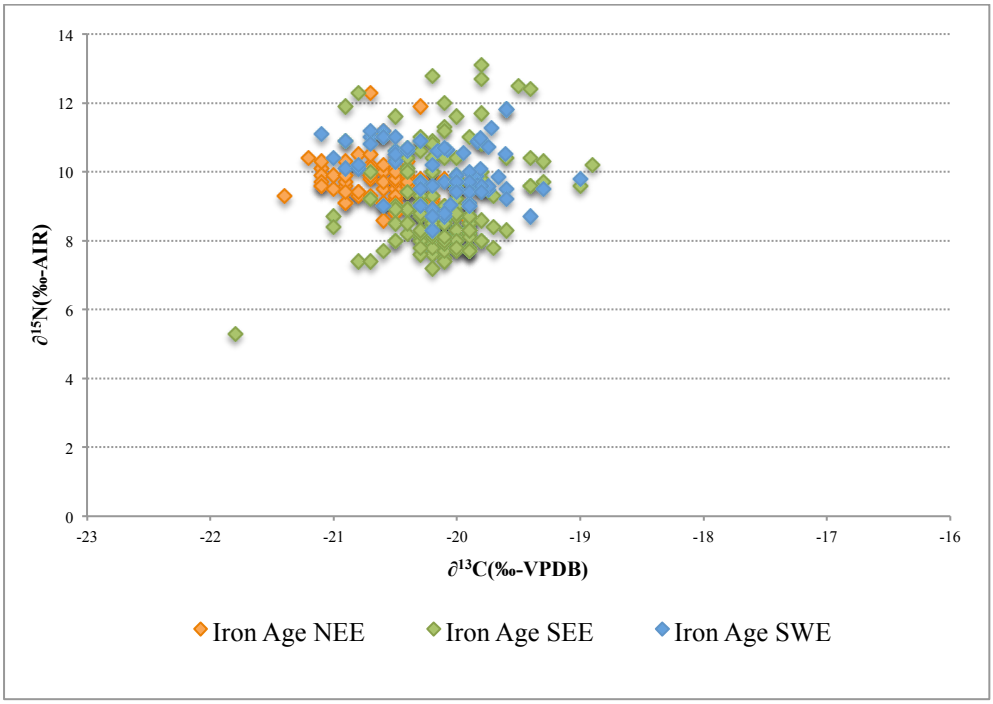


Figure 7.59. Comparison of the human data according to regions of coherent precipitation in the Iron Age.

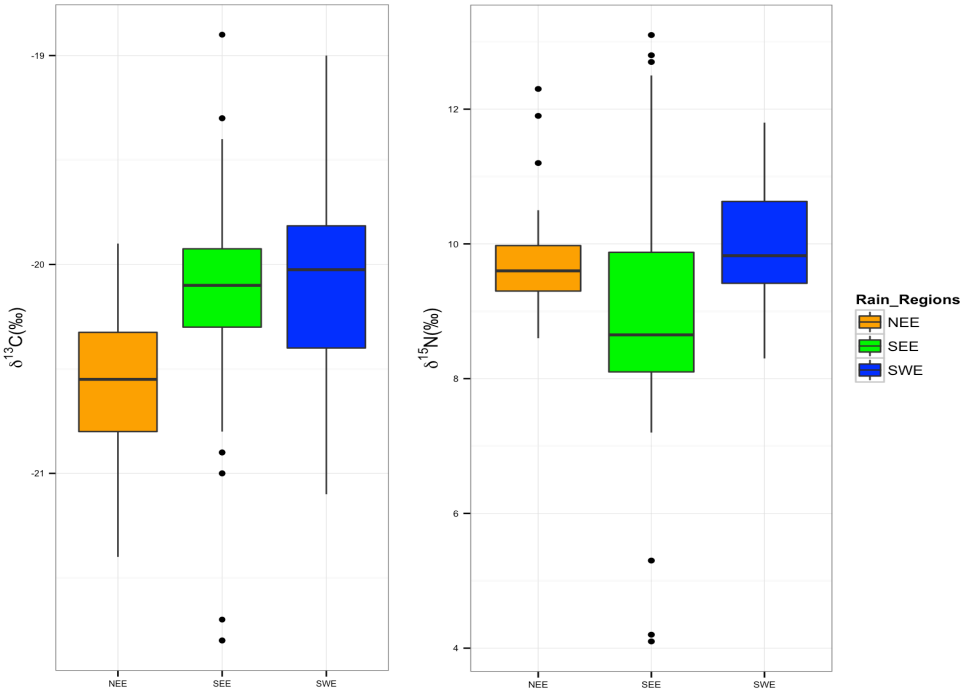


Figure 7.60. Boxplot comparison of the human data according to regions of coherent precipitation in the Iron Age.

While there seems to be a difference between the North-East of England (NEE) and the South-East of England (SEE), with the two groups plotting separately from one another, this is not statistically significant if other variables are integrated into the models (Figures 7.59, 7.60, Table 7.36). Therefore, this result is likely to be the result of the distribution of the data underlying the regions of coherent precipitation, such as the predominance of Hampshire in the SEE data.

Table 7.36. Statistical differences between regions of coherent precipitation in Iron Age Britain. The model integrates annual precipitation as random effect.

Rain-Region	***Multi-Level Model With Sites, Sub-Period, Region, Precipitation As Random effects and Rain-Region as fixed effect***	
	p-value ($\partial^{13}C$)	*p-value* ($\partial^{15}N$)
NEE-SEE	0.954	0.961
NEE-SWE	0.993	0.702
SEE-SWE	0.847	0.772

7.6.2.2 Roman Britain

Table 7.37. Distribution of the human data according to region of coherent precipitation in Roman Britain.

Region of coherent precipitation	**N of sites**	**N of samples**	**Sites**
NEE (MAP:777.1ml)	188	6	3DT_York, 6DT_York, Blossom Street_York, Catterick, Trentholme Drive_York, York
SEE (MAP:730ml)	261	7	Alchester, Asthall, Gravesend, Queenford, Stanton Court, Winchester, Yarnton
SWE (1031.5ml)	380	8	Bradley Hill, Cirencester, Cotswolds Community, Gloucester, Horcott Quarry Hucclecote, London Road_Gloucester Poundbury

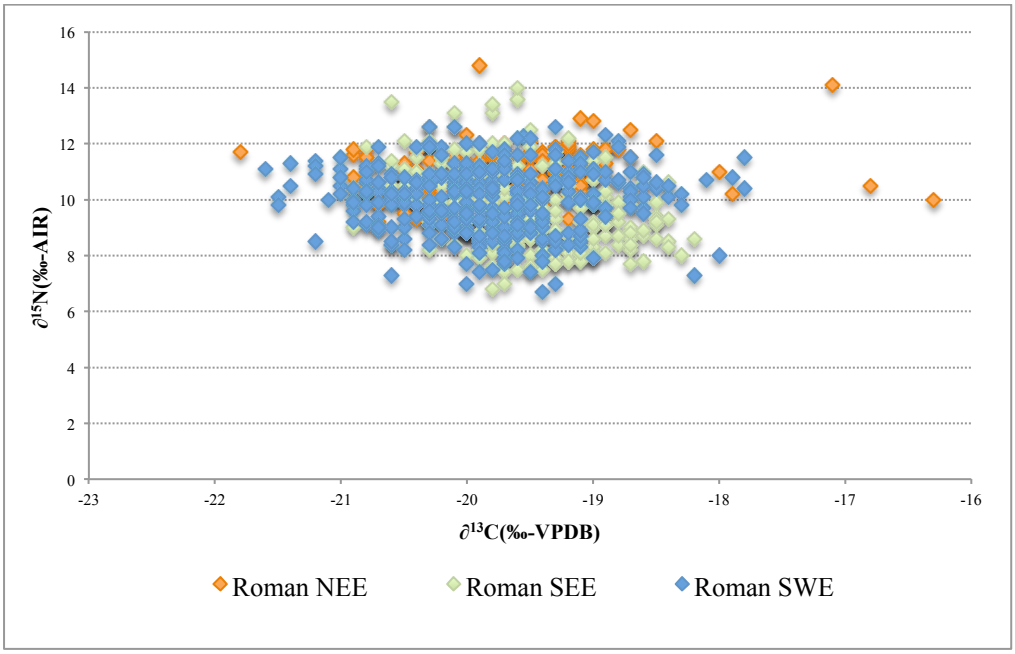


Figure 7.61. Comparison of the Roman human data according to coherent precipitation regions.

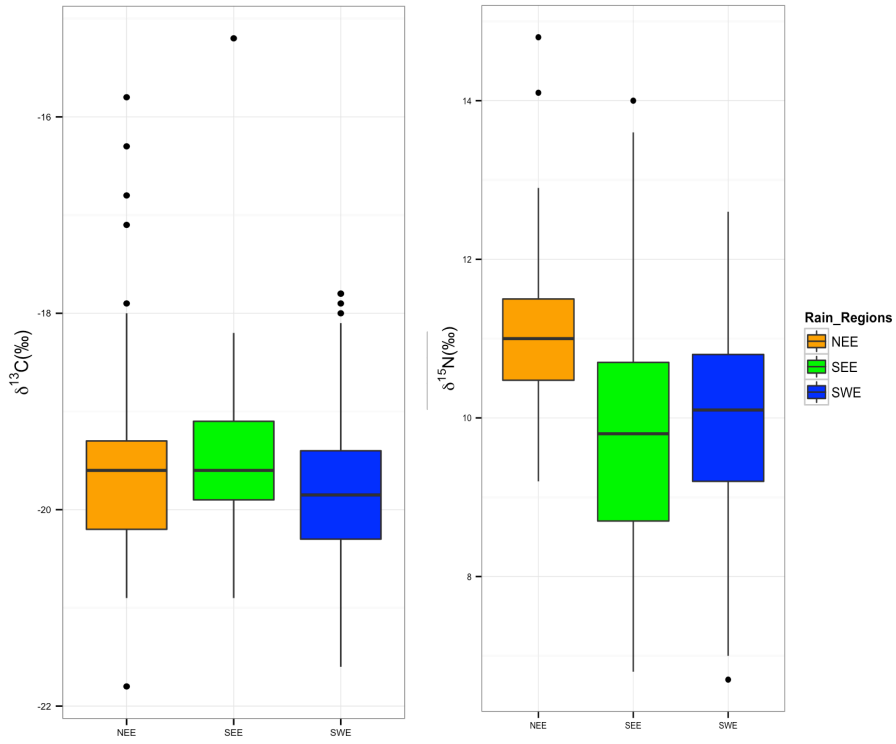


Figure 7.62. Boxplot comparison of the Roman human data according to coherent precipitation regions.

The NEE Roman data appear to be enriched in ^{15}N compared to the other regions. However, this difference is not statistically different when integrating other factors into the model (Figures 7.61, 7.62, Table 7.38).

Table 7.38. Statistical differences between regions of coherent precipitation in Roman Britain. The model integrates annual precipitation as random effect.

Rain-Region	***Multi-Level Model With Sites, Sub-Period, Region, Precipitation As Random effects and Rain-Region as fixed effect***	
	p-value ($\partial^{13}C$)	*p-value* ($\partial^{15}N$)
NEE-SEE	0.953	0.820
NEE-SWE	0.751	0.997
SEE-SWE	0.459	0.887

7.6.2.3. Early Medieval Period

Table 7.39. Distribution of the human data according to region of coherent precipitation in Early Medieval Britain.

Region of coherent Precipitation	N of sites	N of samples	Sites
CEE (MAP: 645ml)	22	273	BerghApton, Bloodmoor Hill, BurghCastle, Buttermarket, Caister-by-Yarmouth, Coddenham, Edix Hill, Fillingham, Kilton Hill Lakenheath, Marina Drive, Melbourn Water Lane, Morningthorpe, Norwich, Raunds Furnell,, SouthAcre, SpongHill, Swaffham, Wasperton, Westerfield Farm Ely, WestgarthGardens, Whitton
NEE (MAP: 777.1ml)	9	194	Aston Clinton, Barton upon Humber Bellevue_York, Black Gate Cemetary_Newcastle, Casteldyke South, Coppergate, Fishergate_York, Masham, West Heslerton
SEE (MAP: 730ml)	16	405	Alchester, Alton Appledown Compton, Berinsfield Dover Buckland, Droxford, Ford Lavestock, Galley Hill, Mill Hill, Portway, ShavardsFarm, St Johns College, St Peter's Tip, Winnall, Worthy_Park, Yarnton

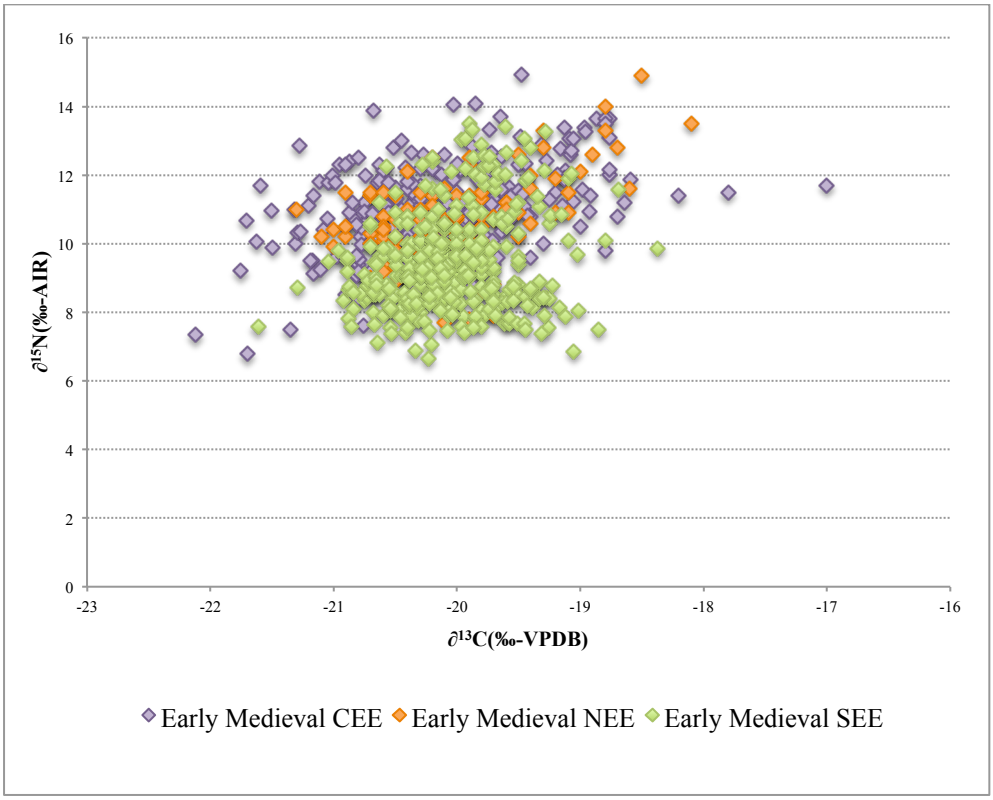


Figure 7.63. Early Medieval human and data according to coherent precipitation regions.

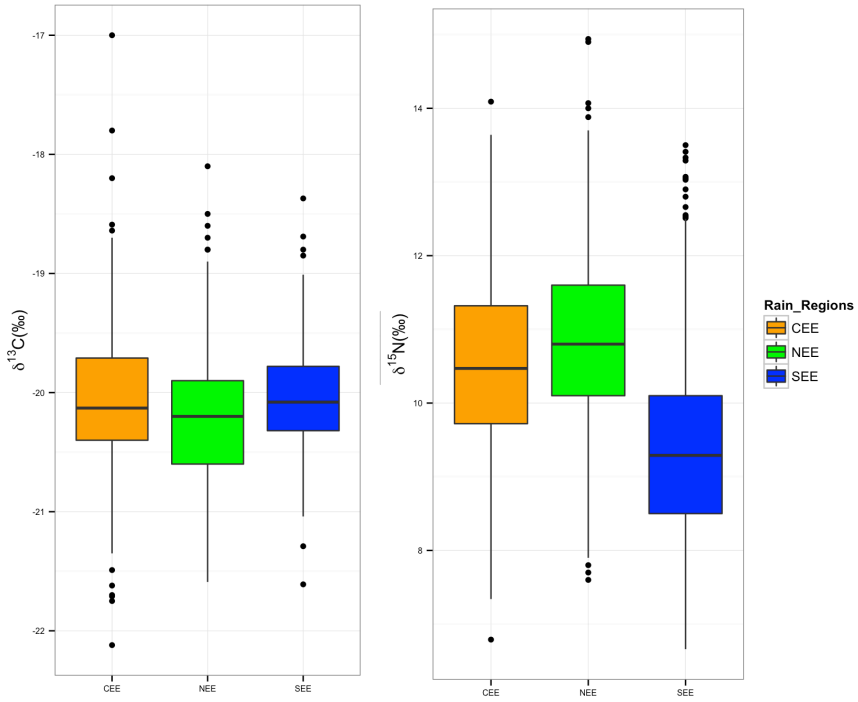


Figure 7.64. Early Medieval human and data according to coherent precipitation regions.

The SEE data from the Early Medieval period appear depleted in ^{13}C compared to the other regions, but this is not statistically significant and is likely due to the data from Hampshire (Figures 7.63, 7.64, Table 7.40).

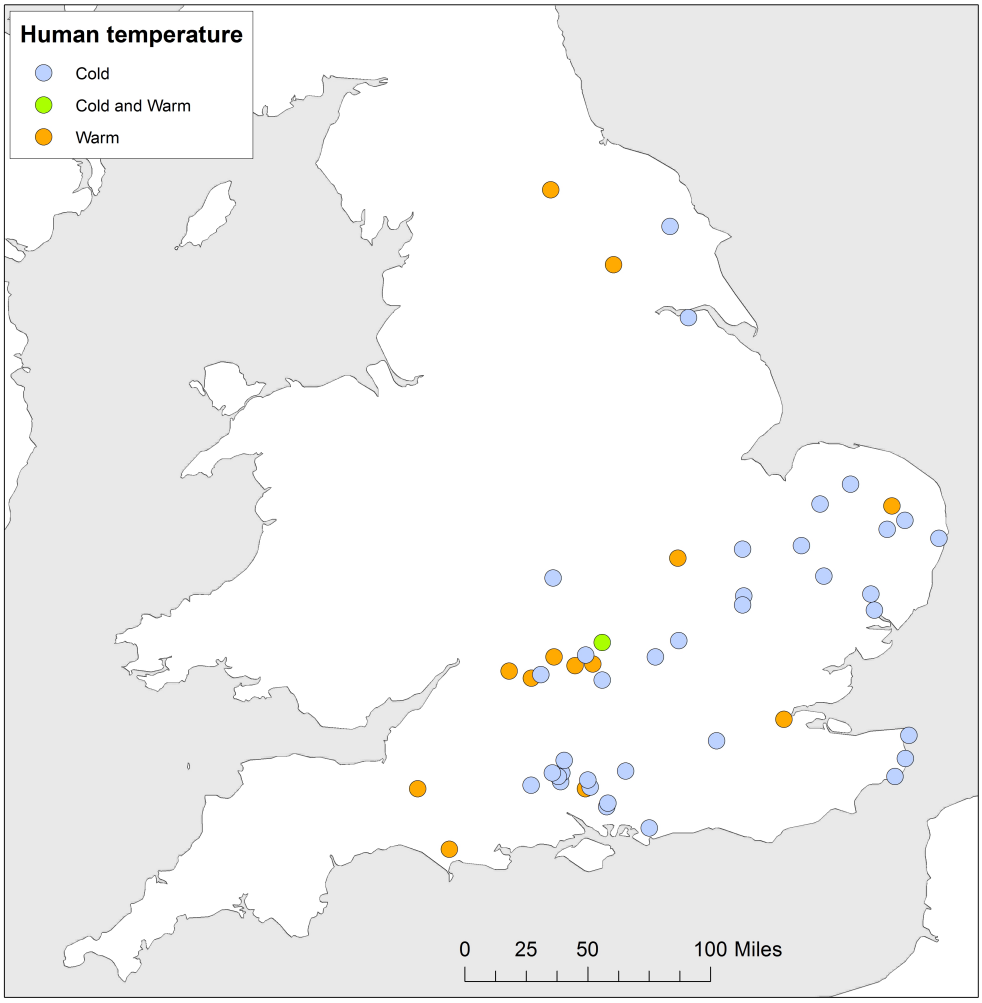
Table 7.40. Statistical differences between regions of coherent precipitation in Early Medieval Britain. The model integrates annual precipitation as random effect.

Rain-Region	***Multi-Level Model With Sites, Sub-Period, Region, Precipitation As Random effects and Rain-Region as fixed effect***	
	p-value ($\partial^{13}C$)	*p-value* ($\partial^{15}N$)
CEE-NEE	0.764	0.750
CEE-SEE	0.996	0.779
NEE-SEE	0.641	0.344

7.6.3 Temperatures

Table 7.41. Distribution of the human data according to temperature between the Iron Age and the Early Medieval period.

Temperature Event	**N of sites**	**N of samples**	**Broad Archaeological Period**	**Region**
Warm	34	684	Iron Age, Early Medieval	Gloucestershire, Hampshire, Kent, Norfolk, Northamptonshire, Oxfordshire, Somerset, Yorkshire
Cold	18	653	Roman, Early Medieval	Bedfordshire, Buckinghamshire, Cambridgeshire, Gloucestershire, Hampshire, Kent, Lincolnshire, Norfolk, Oxfordshire, Suffolk, Surrey, Sussex, Warwickshire, Wiltshire, Yorkshire, Suffolk



Map 7.2. Distribution of the human data according to warm and cold episodes between the Iron Age and the Early Medieval period (warm n =684, dry n= 653). Site distribution is in Table 7.38 below.

Table 7.41b. Site distribution within cold and warm periods.

Temperature	Sites
Cold	Alchester, Alton, Appledown Compton, Aston Clinton, BerghApton, Berinsfield, Bloodmoor Hill, Butler's Field Lechlade, Buttermarket, Casteldyke South, Coddenham, Danebury, Dover Buckland, Droxford, Edix Hill, Ford Lavestock, Galley Hill, Lakenheath, Lechlade, Marina Drive, Melbourn Water Lane, Mill Hill, Morningthorpe, Portway, ShavardsFarm, SpongHill, St Peter's Tip, Swaffham, Wasperton, West Heslerton, Westerfield Farm, WestgarthGardens, Winnall, Worthy_Park
Warm	3DT_York, Alchester, Asthall, Blossom Street_York, Bradley Hill, Catterick, Cirencester, Coppergate, Fishergate_York, Gravesend, Horcott Quarry, Norwich, Poundbury, Raunds Furnell, St Johns College, Stanton Court, Winchester, York

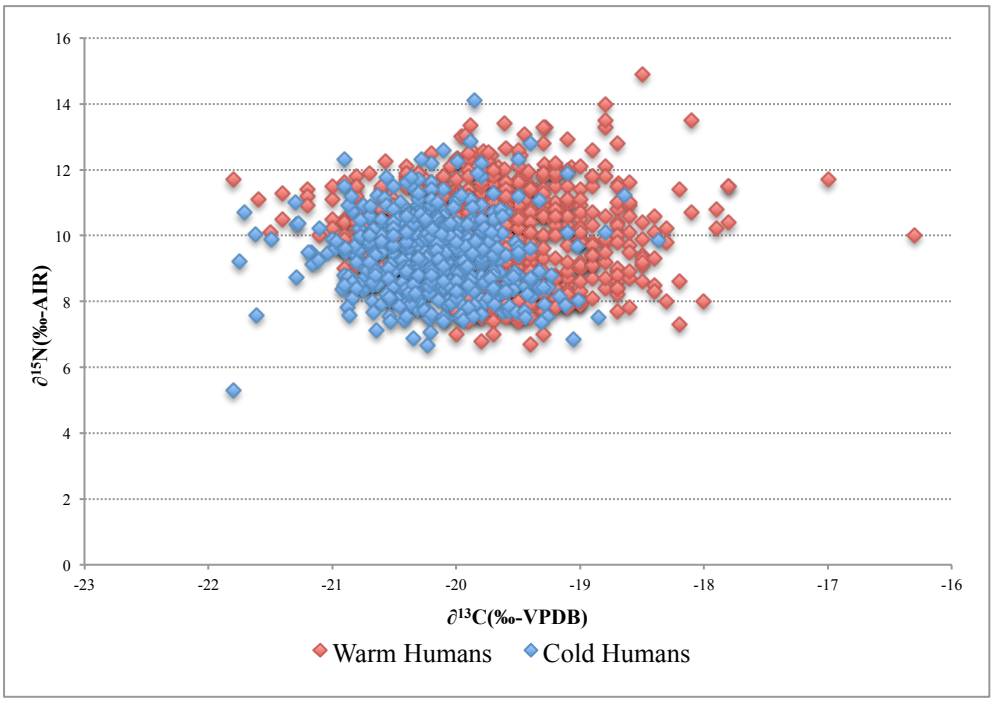


Figure 7.65. Comparison of the data between warm and cold episodes (warm n=684, cold n=653).

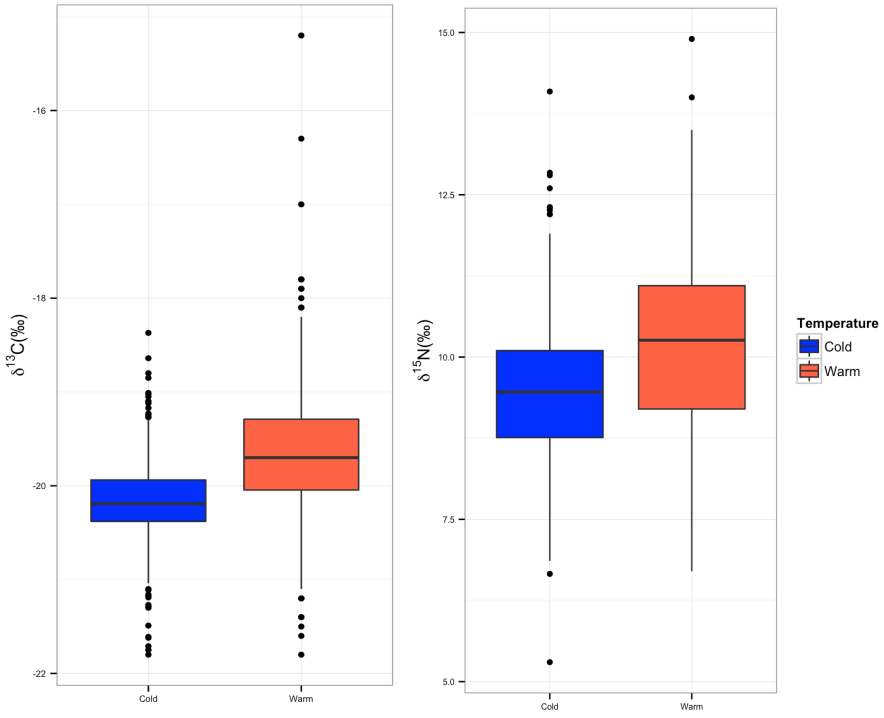


Figure 7.66. Boxplot comparison of the data between warm and cold episodes (warm n=684, cold n=653).

The data distribution is in Table 7.38 and 7.38b, and Map 7.2. Figures 7.65 and 7.66 show the results of the human data according to cold and warm periods, revealing a clear enrichment in ^{13}C in the warmer period, which is coherent with the trends noted in the literature of enrichment in ^{13}C with sunlight and reduced precipitation (Farquhar *et al*. 1989, however the effect of temperature remains somewhat debated, see Leavitt and Long (1992) and O'Leary (1995)). However, while this was also observed in the cattle data (section 6.6.3), it was not found to be significant, while the differences between the $\partial^{15}N$ values of cattle in drier and wetter periods were. In the human data, there is a significant difference in both isotopes (Table 7.39). As with the models for precipitation, other factors had to be integrated so the results would not just be a temporal or chronological difference hiding behind a climate label. Therefore, it can be stated with some certainty that both precipitation and temperatures have an impact on the human data, and some impact on the faunal data. This is interesting as it was expected here that such an effect would be more readily visible in the faunal data than in the human data, since the humans are several steps (and therefore several levels of isotopic averaging) from the plants, which would have been more directly affected by these climatic variations. However, this would suggest changes in food procurement strategies bore some sort of relation to climatic events. This will be explored further in the next chapter.

Table 7.42. Statistical differences warm and cold episodes. The model integrates regional variation as random effects, so the statistical difference seen here is independent from regional level factors.

Region	***Multi-Level Model With Sites As Random Effect and Temperatures and Rain-Region as fixed effects.***	***Multi-Level Model With Sites As Random Effect And Archaeological Period, Region, and Temperature As fixed Effect***
	p-value (∂^{13}C)	*p-value* (∂^{15}N)
Dry-Wet	**0.001**	**0.007**

7.6.4 Inland and Coastal

Table 7.43. Distribution of the human data according to site location between the Iron Age and the Early Medieval period.

Site Type	N of sites	N of samples	Broad Archaeological Period	Region
Coastal	7	106	Iron Age, Early Medieval	Cornwall, Kent, Norfolk, Suffolk
Inland	2	1328	Iron Age, Roman, Early Medieval	Bedfordshire, Buckinghamshire, Cambridgeshire, Dorset, Gloucestershire, Hampshire, Kent, Norfolk, Northamptonshire, Oxfordshire, Somerset, Suffolk, Surrey, Sussex, Wiltshire, Yorkshire
Riverine	53	679	Roman, Early Medieval	Gloucestershire, Hampshire, Lincolnshire, Norfolk, North Lincolnshire, Northumberland, Warwickshire, Yorkshire
Estuary	2	12	Iron Age, Roman	Kent

Table 7.43b. Site distribution in relation to proximity to the coast.

Proximity to coasts/rivers	Sites
Coastal	Bloodmoor Hill, BurghCastle, Caister-by-Yarmouth, Dover Buckland, Harlyn Bay, St Peter's Tip, Trethellan Farm
Estuary	Gravesend
Inland	Alchester, Alington Avenue, Alton, Appledown Compton, Asthall, Aston Clinton, BerghApton, Berinsfield, Bradley Hill, Butler's Field Lechlade, Buttermarket, Coddenham, Coppergate, Cotswolds Community, Danebury, Droxford, Edix Hill, Flagstones, Ford Lavestock, Fordington Bottom, Galley Hill, Gussage All Saints, Horcott Quarry, Lakenheath, Lechlade, Manor Farm, Marina Drive, Masham, Melbourn Water Lane, Micheldewer Wood, Mill Hill, Morningthorpe, Portway, Poundbury, Queenford, Raunds Furnell, ShavardsFarm, SouthAcre, SpongHill, St Johns College, Stanton Court, Suddern Farm, Swaffham, Tolpuddle Ball, West Heslerton, Westerfield Farm, WestgarthGardens, Wetwang Garton-Slack, Whitcombe Farm, Winchester, Winnall Down, Worthy_Park, Yarnton
Riverine	3DT_York, 6DT_York, Barton upon Humber, Bellevue_York, Black Gate Cemetary_Newcastle, Blossom Street_York, Casteldyke South, Catterick, Cirencester, Fillingham, Fishergate_York, Gloucester, Hucclecote, Kilton Hill, London Road_Gloucester, Norwich, Portway, Trentholme Drive_York, Wasperton, Whitton, York

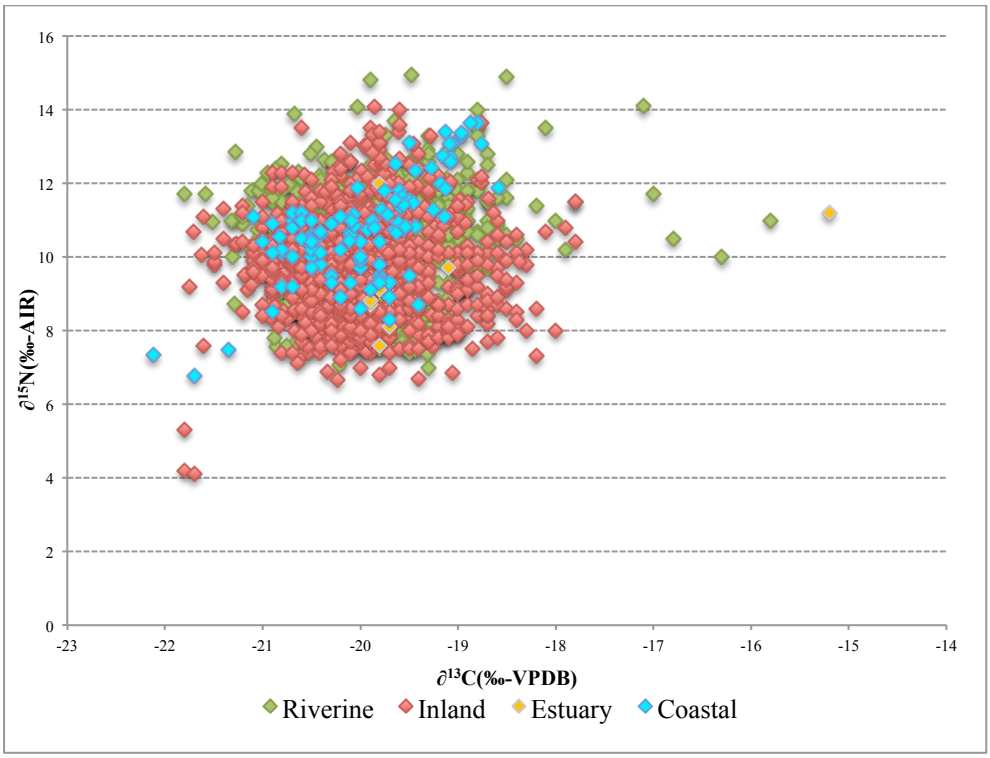


Figure 7.67. Comparisons between the human data depending on proximity to coasts or rivers (Coastal n=106 , Inland n= 1328, Estuary n= 12, Riverine n=679)

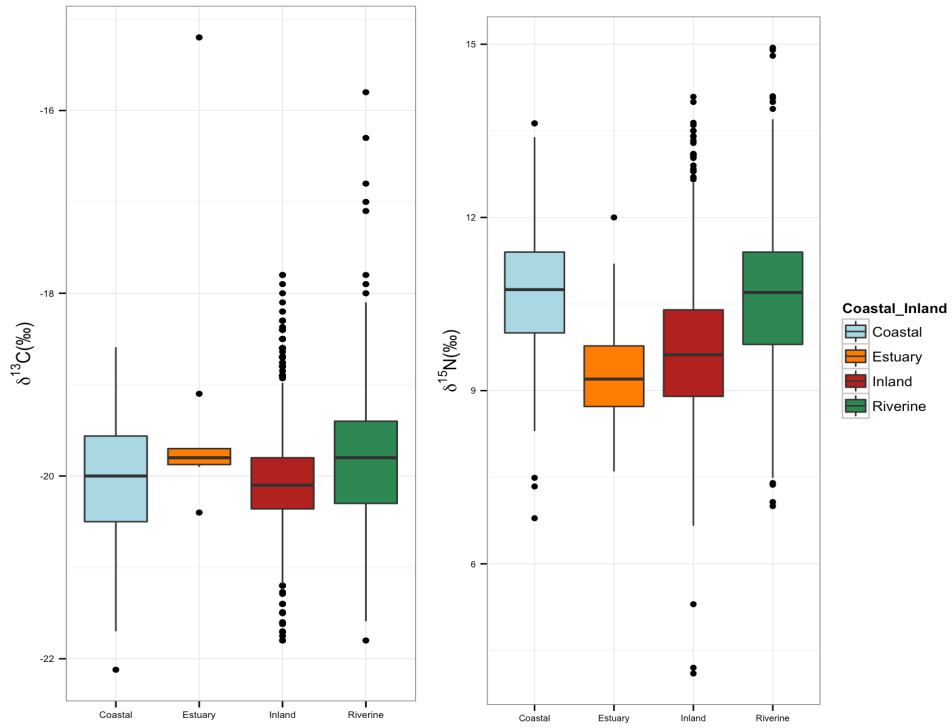


Figure 7.68. Boxplot Comparisons between the human data depending on proximity to coasts or rivers (Coastal n=106 , Inland n= 1328, Estuary n= 12, Riverine n=679)

Once again, the patterns of the human results when compared by proximity to the coast and/or rivers differ from that of the cattle (for distribution of the data, see Table 7.42, 7.42b). While the 'coastal' cattle displayed a significant enrichment in ^{13}C, like due to the effect of salinity, there is here no statistical difference between the humans on the coast and the other groups (Figures 7.67 and 7.68). However, there is a significant difference between the 'inland' and 'riverine' groups, with the data from riverine sites enriched in both isotopes compared to the data from 'inland' sites (Table 7.44). It is however possible here that this is a 'Roman city' effect considering that the riverine dataset contains the big urban settlements from Roman Britain. Unfortunately, this cannot be tested in the statistical model since only the Roman data has been attributed the 'Urban/Rural' variable,

and the importance of this variable cannot be measured for the other broad periods present in this analysis.

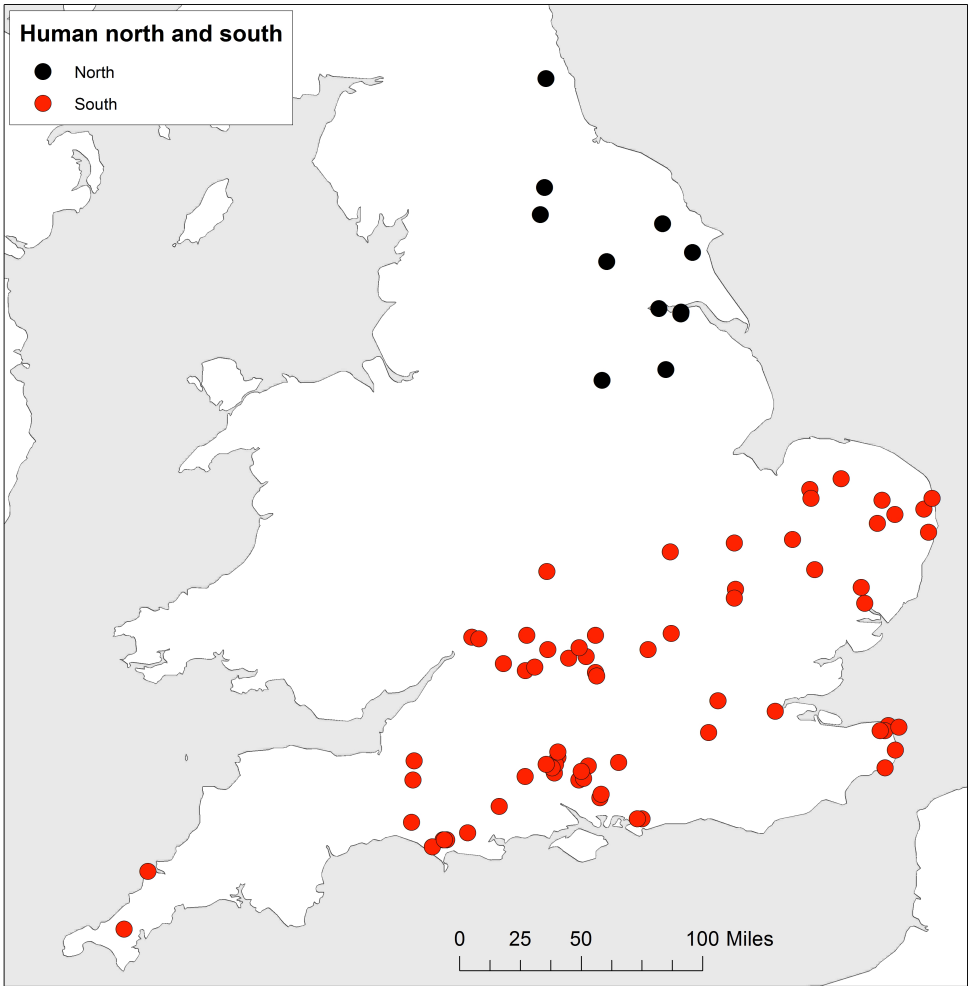
Table 7.44. Statistical differences depending on proximity to coasts/rivers. The model integrates archaeological period ($\partial^{13}C$) and region ($\partial^{15}N$) as random effect. The variable 'precipitation' and 'temperatures' did not affect the significance of the results.

Proximity to coasts/rivers	***Multi-Level Model With Sites and Archaeological Period As Random Effect and Coastal/Inland as fixed effects.***	***Multi-Level Model With Sites and Region As Random Effect and Coastal/Inland as fixed effect.***
	p-value ($\partial^{13}C$)	*p-value* ($\partial^{15}N$)
Coastal-Inland	0.999	0.614
Coastal –Estuary	0.905	0.956
Coastal-Riverine	0.576	0.975
Estuary - Inland	0.863	1.000
Estuary -Riverine	0.524	0.873
Inland -Riverine	**0.061**	**0.002**

7.6.5 North and South

Table 7.45. Distribution of the human data according to latitude between the Iron Age and the Early Medieval period.

Latitude	**N of sites**	**N of samples**	**Broad Archaeological Period**	**Region**
North	19	480	Iron Age, Roman, Early Medieval	Lincolnshire North Lincolnshire, Northumberland, Yorkshire
South	63	1645	Iron Age, Roman, Early Medieval	Bedfordshire, Buckinghamshire, Cambridgeshire, Cornwall, Dorset, Gloucestershire, Hampshire, Kent, Norfolk, Northamptonshire, Oxfordshire, Somerset, Suffolk, Surrey, Sussex, Warwickshire, Wiltshire.



Map 7.3. Distribution of the human data between North (n =480) and South (n=1645). Specific distribution is in Table 7.42 below.

Table 7.45b. Site distribution within the North and the South.

Latitude	Sites
North	3DT_York, 6DT_York, Barton upon Humber, Bellevue_York, Black Gate Cemetery, Blossom Street, Casteldyke South, Catterick, Coppergate, Fillingham,, Fishergate,, Kilton Hill, Masham, Trentholme Drive, West Heslerton, Wetwang Garton-Slack, Whitton, York
South	Alchester, Alington Avenue, Alton, Appledown Compton, Asthall, Aston Clinton, BerghApton , Berinsfield, Bloodmoor Hill, Bradley Hill, BurghCastle ,Butler's Field Lechlade, Buttermarket, Caister-by-Yarmouth, Cirencester, Coddenham, Cotswolds Community , Danebury Dover Buckland, Droxford, Edix Hill, Flagstones, Ford Lavestock, Fordington Bottom, Galley Hill, Gloucester, Gravesend, Gussage All Saints, Harlyn Bay, Horcott Quarry, Hucclecote, Lakenheath, Lechlade, London Road_Gloucester, Manor Farm, Marina Drive, Melbourn Water Lane, Micheldewer Wood, Mill Hill, Morningthorpe, Norwich, Portway, Poundbury, Queenford, Raunds Furnell, ShavardsFarm , South Acre , SpongHill, St Johns College, St Peter's Tip, Stanton Court, Suddern Farm, Swaffham, Tolpuddle Ball, Trethellan Farm, Wasperton, Westerfield Farm, Ely, WestgarthGardens, Whitcombe Farm, Winchester, Winnall Down, Worthy_Park, Yarnton

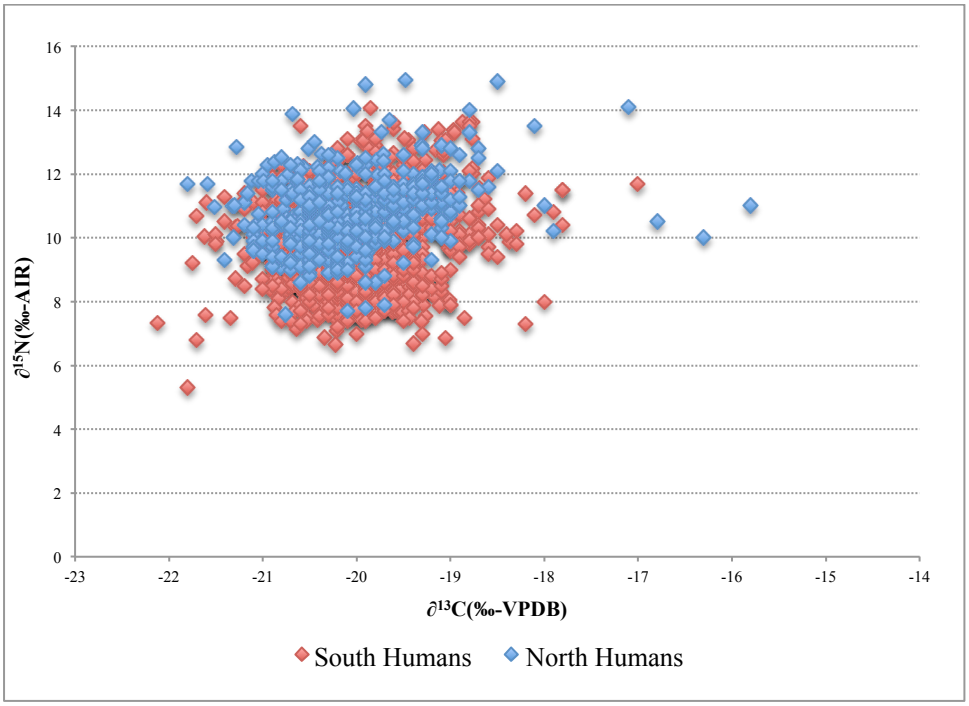


Figure 7.69. Comparison between the human data from the North (n=480) and the South (n=1645)

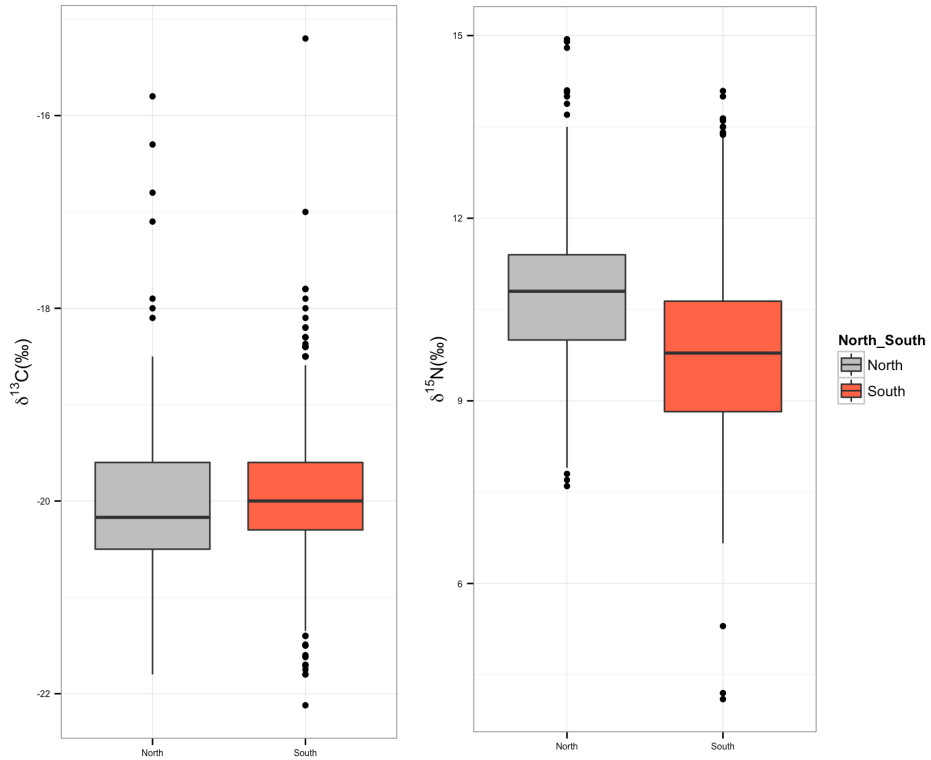


Figure 7.70. Boxplot comparison between the human data from the North (n=480) and the South (n=1645)

As was discussed in Chapter 4, possible differences between the North and the South were hypothesised and have already been tested in the faunal data, for which no significant difference was found. In the human data (see distribution Table 7.45, 7.45b, and Map 7.3), however, the data from South are significantly ^{15}N-depleted compared to the North (Figures 7.69, 7.70, Table 7.46). While one must be cautious since the Hampshire data might bias the data and lower the overall southern results, the statistical model did take into account the 'Region' variable as a random effect, suggesting that there is a genuine difference between the North and the South. This is particularly interesting since it would put the Hampshire data in the context of the South having overall lower ∂^{15}N values than the North. In section 7.5, it was suggested that pulses could be the reason for the lower ∂^{15}N values, which could be the case for the south in general. This will be discussed further in Chapter 8.

Table 7.46. Statistical differences depending on North/South location. The model integrates 'archaeological period' and 'region' as random effects. The variable 'precipitation' and 'temperatures' did not affect the significance of the results.

Latitude	**Multi-Level Model With 'Sites', 'Region' and 'Archaeological Period' As Random Effect and 'Latitude' as fixed effects.**	**Multi-Level Model With 'Sites', 'Region' and 'Archaeological Period' As Random Effect and 'Latitude' as fixed effects**
	p-value (∂^{13}C)	*p-value* (∂^{15}N)
- North –South!	0.175	**0.027**

7.7 Summary of the human results

There are three noteworthy diachronic trends in the human data: (1) the enrichment in ^{13}C in the Roman Period; (2) the overall enrichment in ^{15}N over time; and (3) the small spacing between the Roman nitrogen isotopic data and the cattle baseline. The relationship between the human data and the different baselines, however, is complex, showing variation both at the sub-period and regional levels, especially when the data are compared with a 'restricted' baseline. This is particularly true when comparing the data from different climatic events, or different geographical units, when significant differences between the groups analysed vary across the faunal and human categories. Considering inter-human variation, infants from all periods displayed a nursing signal but no other difference was found between the age groups. Difference between males and females were significant in all three periods, with different patterns (such as direction of difference, correlation, regional differences) also noted in all periods. All of this will be addressed in the next Chapter.

CHAPTER 8. DISCUSSION

Analysis of the isotopic data from England – the largest metadata data-set that has ever been examined for the country – reveals numerous patterns and trends of continuity and change in subsistence through time and space, which have been detailed in Chapters 6 and 7. From this investigation, five key points can be identified for the faunal data:

- The most striking overall pattern in the faunal data is the decrease in ^{13}C over time, and the ^{15}N peak in the Roman period.
- The negative correlation in the domesticated faunal data in the Iron Age is unusual and must be addressed
- There is a lack of clear diachronic patterns at the broad period level but variation between sub-periods are suggestive of more gradual changes.
- Regional patterns differ for species across sub-period, showing the complexity of the signal between temporal and regional variation.
- Looking beyond temporal and regional divisions, temperature and the 'coastality' of sites appear to be the more important factors.

Patterns in the human data are also complex with the interplay between regionality and temporality is not necessarily straightforward. The points that must be discussed here are:

- The overall isotopic trends between the Iron Age and the Early Medieval period, which do not match the faunal data, with enrichment in ^{13}C in the Roman period and a gradual increase in the $\partial^{15}N$ values of the human.

- Related to the point above, while there is a gradual increase in the $\partial^{15}N$ values of the human data, which is not consistent with the faunal patterns, and the $\Delta^{15}_{\text{human-cattle}}$ values actually show a drop in the Roman period.
- For regional patterns, Hampshire is the most different to the other regions in both the Iron Age and the Early Medieval period. While conclusions about Roman Hampshire can only be tentative since there is only one site investigated here, it is worth noting that it seems to be following the patterns of lower $\partial^{15}N$ values that are so characteristics in the other broad periods.
- However, to put the Hampshire data in context, it is also worth considering the North/South divide, which suggest that the Hampshire data might display characteristics that apply more widely to other southern regions.
- Climate and geography also seem to have had an impact on the human data, especially, dry/wet and cold/warm episodes and location of the sites in relation to the coast.
- Finally, there is a significant difference between large urban settlements and smaller ones, which has been noted by other researchers and is confirmed here on a larger scale, and can also be nuanced by taking into account variation between cities.
- On the individual level, males and females appear to have had diets that were significantly different. Differences in age group were limited to infants being significantly enriched compared to the others.

These trends will be discussed in more details in this chapter, with a special focus on the relationship between the faunal and the human. While there are but little archaeobotanical isotopic data for England, it is worth considering a model that could also hypothesise the contribution of plants to diets.

8.1. Dynamic isotopic modelling

The first point to make here is that isotopic modelling needs to account for the dynamism of diets and environmental factors determining the isotopic signatures of both human and non-human agents. Because of the lack of plant data, most dietary reconstructions assume a simple model in which plants represent the natural isotopic composition of the environment and in the absence of plant isotopic data, herbivores are then considered to be an acceptable proxy for those environmental values (Casey and Post 2011) However, such a model presupposes that both plants and animals are 'simple' organisms for which isotopic variation is minimal, without complex behaviours or physiology.

However, it is argued here that the processes determining isotopic signatures are a lot more dynamic. Instead of considering a linear relationship between plants, herbivores and humans, it may be more accurate to think of a complex nexus that can be both symbiotic (where all three elements are interconnected) and exclusive (where two of the elements are linked but not the third one, as shown in Figure 8.1). All of these relationships affect the isotopic values at each level of the process.

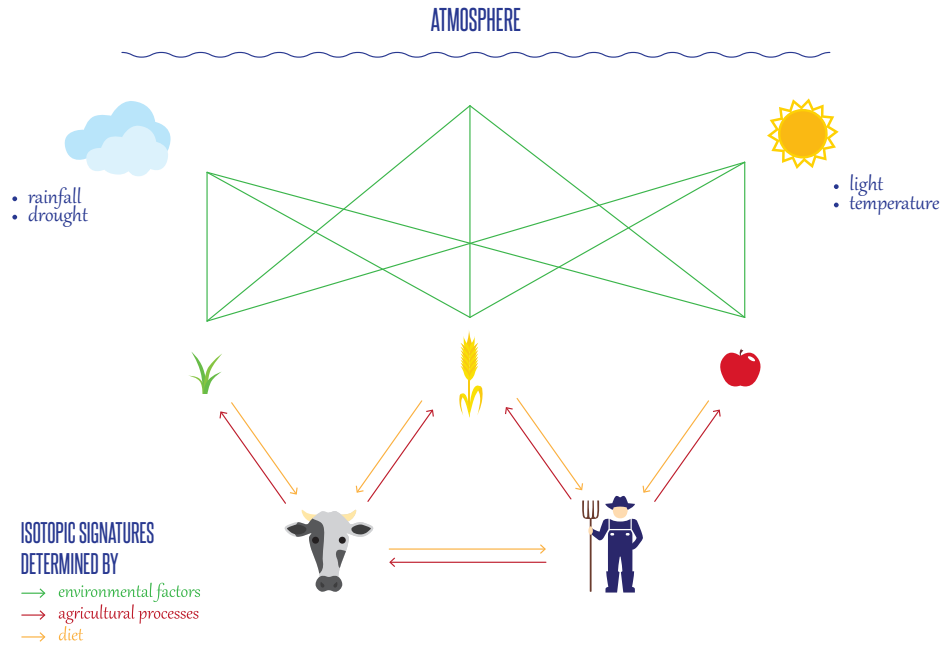


Figure 8.1. Proposed model of isotopic processes (illustration by Zoé Mallet).

8.2. Discussion of the faunal results

8.2.1 *Longue Durée* trends: ^{13}C decrease over time and ^{15}N-peak in the Roman period.

The same patterns are repeated in all three domesticate species: overall, the ∂^{13}C values of all three species are higher in the Iron Age and decrease over time while ∂^{15}N averages are the highest in the Roman period and the lowest in the Iron Age (see Section 6.4).

The ^{13}C pattern was unexpected: higher ∂^{13}C values are often associated with warmer and drier climates (see Chapter 2) and the Iron Age was allegedly cold and wet. Should that assessment of Iron Age climate be wrong, climate is still unlikely to be the answer, as such an isotopic pattern would also be seen in other periods of drier/warmer weather, for example during the Roman period. The difference between values depleted and enriched in ^{13}C is sometimes understood as evidence of animals

grazing/browsing in woodlands and open pastures. The canopy effect, well-attested in the literature, posits than plants under a forest canopy would have lower $\partial^{13}C$ values that plants growing in an open field (Vogel 1978). However, this goes against what is known of the patterns of woodland clearances in these periods. Indeed, it is well established that there was widespread forest clearing in the Roman period (Hamilton 2016). The canopy effect might nonetheless have played a role in the Early Medieval period, since woodland expansion is attested for the 5th and 6th centuries (Dark 1994; Banham and Faith 2014), but while this might explain the decrease in ^{13}C between the Roman and the Early Medieval periods, this still is not a satisfying explanation for the decrease in ^{13}C between the Iron Age and Roman Britain, unless it is suggested that the expansion of agriculture in the Roman period resulted in animals being pushed into the parts of the landscapes which had not been cleared yet. Possibly, Iron Age fauna were foddered on plants from open pastures, while Roman fauna were foddered on plants grown in forests, but this would suggested that the animals were strictly kept on fodder and did not graze/browse freely (or somewhat freely), which, again, is unlikely.

A link with plant water regimes may provide a more likely explanation. Water availability is an important factor for variation in ^{13}C in plants, with C_3 plants likely to be depleted in ^{13}C likely from systems with enough water, compared to C_3 plants enriched in ^{13}C, which are likely to be from under-watered systems. This would suggests that the Iron Age fauna fed on plants from under-watered system, while the later fauna had access to well-watered plants. This could be understood as the Roman and Early Medieval fauna

having greater access to crops grown for human consumptions, either as crop debris used as fodder, or by grazing on the remains of the harvest, while the Iron Age fauna and Iron Age crops were more strictly kept apart. The assumption here is that crops grown for human consumptions would receive more attention (i.e. proper watering) than either wild plants or crops grown for fodder. While this would account for the patterns seen here, and be consistent with a transition from a pastoral system (with more space for animals) to a more agrarian one (with less space for the domesticated species, and thus greater overlap between crops and animals), it remains only a partial explanation, as it does not take the climate into account, which if indeed it was wetter in the Iron Age, directly contradicts the idea that the plants in the Iron Age were 'under-watered'. Soil drainage is the final possible explanation that should be taken into account (Hamilton 2016, 130, 132). While soils have not been considered in this thesis, it might be worth mentioning that badly drained soils might result in plants being 'over-watered' and therefore enriched in ^{13}C. However, it is likely that there is not 'one' answer for the pattern seen here, it is more likely to be a combination of all the above factors.

The ^{15}N enrichment in the faunal data in the Roman period is more easily explained, and is consistent with more intensive agricultural practices, as the impact of farming is shown to raise the nitrate contents in the soils, leading to enriched plant values that are then passed on to the consumers (Fraser *et al*. 2011). The lower $\partial^{15}N$ values in the Early Medieval period are also consistent with the current understanding of an agricultural

depression after the end of Roman Britain and the land being worked less intensively (Banham and Faith 2014, 39).

8.2.2 Regional trends

Overall, the regional trends in the faunal data were fairly limited, except for Hampshire being the most different compared to the other regions. Overall, the Hampshire faunal data had lower ∂^{15}N values compared to the other regions, a difference which was statistically significant. Interestingly, contrary to the human data, there seems to be no difference between the northern and southern data, so the 'Hampshire effect' cannot be contextualised as a 'southern' pattern as it might tentatively be for the human data, at least not in light of the data available here. Having said that, the reasons why the ∂^{15}N values of Hampshire data are depleted must be examined. It is also interesting to note that the ∂^{13}C values of the data in Iron Age Hampshire are enriched compared to the other regions (Figure 6.58, section 6.5) This pattern of relatively high ∂^{13}C values and low ∂^{15}N is indicative of an open system (i.e. not under a forest canopy) and this could be evidence that deforestation in Hampshire had occurred as early as the Iron Age, which was not the case in other regions (Hamilton *et al.* 2009). In the Early Medieval period, however, the data from Hampshire is lower in both isotopes relative to the other regions. Because the Early Medieval data from Hampshire mostly comes from the Early Medieval period, it could be an indication of woodland expansion and animal feeding in a mixed closed/open system, although it does not explain why this model is not reproduced in other regions in the same period. It is also worth noting that the patterns seen in Hampshire could be caused by chalk geology, which has

been shown to result in lower ∂^{15}N values for plants (Stevens *et al.* 2010; Hamilton 2016; Schulting *et al.* 2019).

Briefly suggested in section 6.5 and 7.5 was the possibility that pulses were a contribution factors to the low ∂^{15}N ratios, which is worth consideration here. Consumption of pulses is an interesting solution since the distribution map of Celtic peas and beans shows them to be concentrated in the South, and they are absent from northern grain assemblages (Lodwick 2017). Again, it is unlikely that there is one model that explains the differences between Hampshire and the rest of the regions, but that a complex array of factors is at play. This difference between Hampshire and the other regions has been noted by Jay and Richards (2007) as well as by Hull (2007, 217, 305, 306), and it is interesting that it should still be visible through a larger scale comparison.

8.2.3 Environmental trends

While there is little difference in the data through chronological and regional divisions, patterns are more visible when physical geography is taken into account. It was shown in Chapter 6 that cattle in warmer periods had overall higher ∂^{15}N values, (section 6.6.3). While it is uncertain whether this is correlated with changes at the baseline levels or changes in animal management practices, both these trends are consistent with the macro-climate trends that predict higher ∂^{15}N values in both warmer and drier climates (Stevens *et al.* 2006). Therefore, it may suggest that these variations reflect a change at the plant level due to the improved climatic conditions and that variation within period and region may partly be due to climatic factors.

Another important pattern seen here is the significance in the data between Coastal and Inland or Riverine settlements (section 6.6.4). This could be due to both the ^{15}N enrichment of the plants due to sea-spray and marine sediments deposited by tides, as well as to the presence of salt-loving plants (Britton *et al.* 2008). While the $\partial^{15}N$ ratios seen are not high enough to suggest this is the case here, it is also possible that seaweed was used as a fertiliser, thus raising the $\partial^{15}N$ value of the plants that constituted the faunal diets. The significant depletion in ^{13}C in the coastal sites can also be explained due to the effect of salinity, likely on the local vegetation (van Groeningen and Kessel 2002)

8.2.4 Specifics of the faunal data

After this overview of the faunal data, it is important to point out that while larger trends might not have been revealed as the most significant, there are smaller trends and patterns worth investigating, such as the negative correlation between isotopes in the Iron Age fauna, sub-period/regional differences in the Early Medieval data and the overall large variation in the faunal data.

8.2.4.1 Negative correlation

Maybe the most striking pattern in all of the faunal data is the negative correlation between high $\partial^{15}N$ values and low $\partial^{13}C$ ones in the Iron Age. It is particularly marked in the earlier data for the sheep and the cattle, but seems to fade over time (sections 6.1.2.1 and 6.1.2.2). This pattern might be explained by the canopy effect, with animals grazing in wooded areas and/or browsing from forest floors, where the decomposition of organic materials would result in elevated $\partial^{15}N$ values (Hamilton *et al.* 2009).

As was mentioned above, water availability might also be worth considering, especially when linked with climate. Indeed, evidence points that the earlier Iron Age was wetter and colder than the later Iron Age (see section 4.2.5). However, while this potentially explains the lower $\partial^{13}C$ values, this does not explain the higher $\partial^{15}N$ ratios. On the contrary, $\partial^{15}N$ values are expected to rise with aridity, which directly contradicts the argument that $\partial^{13}C$ values were low because of the rain. High $\partial^{15}N$ values could possibly be explained by the application of manure on the fields from whence the animal feed came, but again, this would contradict the argument expressed in section 8.2.1 that the overall high $\partial^{13}C$ values might be due to less human intervention on the plants in the fauna's diets. However, it could be a combination of badly drained soils and manure. Indeed, the fact that the negative correlation between isotopes seems to be particularly marked in Hampshire, rather than other regions, could indicate that this trend is actually geographically limited, in which case local soil drainage might be a factor that needs to be taken into account.

Again, it is likely that his pattern is due to a number of factors, interlinked with one another, such as maybe the presence of younger animals, climate and human intervention.

8.2.4.2 Sub-period and regional differences in the Early Medieval period

An interesting pattern appeared in the Early Medieval period. There are two big datasets from Suffolk and Hampshire, with the first dated to the broad Early Medieval period and the second was dated to the Early Anglo-Saxon and Middle Anglo-Saxon period. Multivariate statistical models allowed

integration of these datasets and control for the Regional/Temporal ambivalence between them, i.e. whether the differences between them were driven by the regional or temporal factors. The statistics revealed that, while the sub-period variable was more significant for cattle, regions were more important for the sheep. It is entirely possible that this is due to the distribution differences between the species, but it cannot be ruled out that animal management strategies changed over time and space in ways that differed from species to species. Indeed, while the carbon isotopic values for the cattle dropped between the Early Medieval period and Middle-Saxon period, the sheep ∂^{15}N average for these sub-periods follow the opposite trend and is enriched in the later period compared to the earlier period. Similarly, the difference between Suffolk and Hampshire is more marked in the sheep data than it is in the cattle data. While this is not clear why, it strongly suggests a difference in how these species were kept. This must be contrasted with Hull's regional comparison between Hampshire and East Anglia (Hull 2007, 230). While he noted the statistical differences between these regions, he did not take into account differences between species or the fact that the samples were not dated to the same period. This is revealing of the complexity of patterns and how factors such as locality and temporality can affect species in different ways, as well as how this must be accounted for if one is to recreate past subsistence.

8.3 Discussion of human data

8.3.1 *Longue Durée* trends: ^{13}C enrichment in the Roman and later medieval periods.

A first observation that can be made of the human data is that trends do not match those seen in the faunal data. Indeed, while the ^{13}C general trend in the faunal data was one of decrease over time, the ^{13}C pattern in the human data is one of increase from the Iron Age to the Roman period, and then of decrease in the earlier Anglo-Saxon period, before increasing again towards the end of the investigated periods (see section 7.4). This ^{13}C increase is very clearly a dietary signal, since it would have been seen in the faunal data should its cause be environmental. Indeed, as discussed in Chapter 7, most of the Roman data display enrichment in ^{13}C above one, and in some cases two, trophic levels (see section 7.4). It must be acknowledge here that his might be an effect of using cattle as the baseline species, since sheep can be less ^{13}C depleted than cattle. However, in the data presented here, this difference is in the order of ±0.2/0.3‰ between the $\partial^{13}C$ mean averages of the sheep and cattle data in all three periods. Therefore, incorporating sheep into the baseline is unlikely to shift these results towards a significantly smaller $\Delta^{13}C_{human\text{-}fauna}$ value.

Three arguments can be made to explain this large ^{13}C enrichment in the Roman period and later medieval period: (1) the consumption of foodstuffs of marine origin; (2) the presence of C_4 plants in Britain, either through import or cultivation; and (3) the presence of migrants in the dataset, who built a ^{13}C signal outside Britain.

8.3.1.1 Marine Protein

High isotopic values can be explained by the consumption of aquatic resources, especially marine foodstuff, since freshwater fish tend to display low $\partial^{13}C$ values. As seen in Chapter 2, marine ecosystems, and those who feed in them, have a very different isotopic signature and are significantly enriched in ^{13}C and ^{15}N compared to terrestrial ones. Increased consumption of marine foodstuff in the Roman period compared to the Iron Age, and in the later Anglo-Saxon period, has been shown in previous studies (Richards *et al*. 1998; Mayes and Beavan 2012; Redfern *et al.* 2012; Müldner 2013). This is also confirmed by the archaeological record, with an increase in oyster shells and fishbone recovered in the Roman period (Richards *et al*. 1998; Cool 2006; Locker 2007; Cummings 2008a, 52) as well as zooarchaeological evidence pointing out to expansion of fisheries in the North Sea *c*. 1000 (Barrett *et al.* 2004; Barrett *et al.* 2011).

However, it must be pointed out that the Roman data display relatively low-level of ^{15}N enrichment compared to the cattle baseline for marine protein consumption. It is possible that the Roman baseline is artificially high due to the possible presence of younger animals in the data (see section 6.2). Removing these values (>8‰) reduces the baseline $\partial^{15}N$ value by 0.7‰ but while this raises the $\Delta^{15}N_{human\text{-}cattle}$ by the same amount, they remain relatively low compared to the baseline. It is of course possible that the human $\partial^{15}N$ values are lower due to the consumption of ^{15}N-depleted food. It must be noted here that the relative enrichment in both ^{13}C and ^{15}N, which is expected for marine fish consumption is actually visible in the human data if only considering the males (see section 7.2, Table 7.11), who display

a significant positive correlation between both isotopes. Therefore, it is possible that the consumption of marine foodstuff was not common to the entire Roman population, but specific to different groups, such as males. Richards *et al*. (1998) also showed a correlation between fish or oyster consumption with status. So while fish consumption cannot explain the enrichment in ^{13}C for all of the Roman dataset, it is likely to be a solid explanation for specific groups in Roman Britain.

Concerning the later Anglo-Saxon periods, increased consumption of fish may have resulted from the dietary restrictions imposed by Christianity, which forbade meat consumption for about half the year (Mays 2007). Indeed, the 'fish event horizon', coincides with the Benedictine reforms, when dietary restrictions on fasting days were reinforced, were imposed across Western Europe (Sykes 2007; Loog *et al.* 2017) While this has proven to be true in monastic populations (Mayes 1997; Müldner and Richards 2007a; Müldner *et al.* 2009), it should be questioned whether lay populations would have adhered so strictly to religious regulations. While the evidence is strong for an increase in fish consumption in the Late Anglo-Saxon period, reasons behind it may be more complex than the sole adoption of stricter Christian dietary obligations. Indeed, early Christian understandings of what constituted fish and meat may have been at odds with modern perceptions. Deeply influenced by the Galenic theory of humours, the opposition was not so much between "meat" and "fish" but rather between "hot" and "cold" flesh (Szabo 2008, 84). Therefore, some "cold" animals, such as water birds, aquatic mammals, or even beavers were deemed acceptable to eat on lean days (Szabo 2008, 84). Maybe the most

famous illustration of this can be found in Gerald of Wales, when he remarked upon people in Ireland eating barnacle geese for Lent, in 1187: 'Hence, in some parts of Ireland, bishops and males of religion make no scruple of eating these birds on fasting days, as not being flesh because they are not born out of flesh' (Gerald of Wales, *On the Topography of Ireland*, Chap. IX). This story stems from the common belief in Early Medieval Europe that barnacle geese were born out of barnacles attached to timber tossed at sea. They were therefore considered to be fish and could be eaten on fast days (Lankester 1915, 117). It was such a commonly held belief that the Pope Innocent III had to condemn the practice in 1215 during the Fourth Lateran Council (Lankester 1915, 117, 119). While Innocent recognised the mystery of how these birds were born, he nonetheless asserted that since they behaved like ducks they ought to be considered as such. This anecdote is outside of the chronological and geographical parameters of this work, but it illustrates rather well that understanding of the rules of fasting may have varied greatly and may well have depended on the local interpretation of what is, or is not, a fish. Therefore, while it seems likely that fish featured in the diets of the later Anglo-Saxons, some caution might need to be exercised in the cultural reasons behind that shift.

A final point must be made on the consumption of fish. While lack of fish consumption, or evidence thereof, between the Neolithic and Roman Britain has been noted before by various studies and archaeological reports, at the notable exception of a population in Orkney (Richards *et al.* 1998; Jay 2005, Richards and Schulting 2006; Richards *et al.* 2006; Jay 2008), it must be noted here that the trend of ^{13}C enrichment in the human data, and the

increase in the $\Delta^{13}C_{human\text{-}cattle}$ values, actually begins in the Late Iron Age (section 7.4, Figure 7.48). This might suggest that the shift towards an increase in fish consumption occurred earlier than the Roman period, contrary to what was previously thought. It is interesting as it raises the possibility that 'Romanisation', as defined by the introduction of new food-stuffs or fish consumption, were actually occurring slightly earlier than previously thought, suggesting that Britain might have been pulled into the network of a Romanised world before the military conquest in 43 A.D.

8.3.1.2 C_4 consumption

While there is evidence that supports C_4 consumption for at least two individuals, it is unlikely that C_4 plants were an important contribution to the diet of the population (Müldner 2013). Millet was known in Roman Britain but evidence for its cultivation remains minimal and is unlikely to have cause a widespread ^{13}C shift in the Roman population (van der Veen 2008). However, it is not impossible that a C_4 signal be present in the data through the movement of people and goods as investigated below.

8.3.1.3 Movements of people and goods

i. People

Indeed, while C_4 plants might not have made it to Britain, C_4-consumers might have. It is common to explain some of the more notable isotopic difference by the presence of migrants in the dataset. This is sometimes confirmed by other proxies such as ^{18}O analyses or dentine analyses (See Richards *et al*. 1998; Bayliss *et al*. 2004; Budd *et al.* 2004; Montgomery et *al.* 2005; Chenery *et al.* 2010; 2011). Here, however, concerning one of the individuals for whom consumption of C_4 plants is attested, migration could

not be conclusively shown (Pollard *et al* 2011), although this might be due to the limitations of Sr and O isotopic analyses (Eckardt *et al.* 2014). In the absence of hard evidence, one is left to speculate that some of the individuals buried in Britain might display an enriched $\partial^{13}C$ signal due to having lived and eaten in regions where the environment is different and/or the relationship to the environmental baseline would have been different to what is seen here. For example, the Roman human who is an outlier in both isotopes actually falls in within the range of Roman data from Leptimus in Tunisia (Keenleyside *et al.* 2009; Müldner 2013), suggesting that this particular individual could have came from afar.

ii. Goods

It is also important to consider the idea that if people could move, so could animal and grains. The question of locality for the fauna has been addressed elsewhere (Chapters 2 and 4) and does not need repeating here. Reading the literature, it is obvious that it is often assumed that only high-status goods were traded and that most of these are unlikely to be seen in the isotopic record (such as spices or condiments, Lodwick 2016). However, this distinction between 'exotic' diets for the elite opposed to a locally grown one for the lower status population may be too simplistic. There is indeed ample evidence for regular grain imports to Britain. One of the most convincing proxies for grain import is the presence of non-native grain pests (i.e. insects, see Smith and Kenward 2011) in Britain after the Roman conquest. For these insect populations to thrive, it is necessary to assume regular import of grains as they would not have been able to breed within storage pits due to high levels of carbon dioxide (Smith and Kenward 2011).

Imported grains from different provinces of the Empire would have a different isotopic signal to British grain, which would be then be visible in its human consumers.

As was seen in Chapter 7, and will be discussed below, there is a difference in the ^{13}C enrichment of major centres compared to more rural settlements, which also has been noted by other researchers (Cummings 2008a; Cheung *et al.* 2011; Chenery *et al.* 2011). While elsewhere this is used as evidence that major centres are more likely to attract migrants, here the argument is made that major centres were also likely to be a hub of trade while rural settlements were more likely to have relied on locally sourced food. Therefore, it stands to reason that city dwellers would display larger $\Delta^{13}C_{human\text{-}cattle}$ offsets if they had access to more 'exotic' food. One caveat is that to sustain this level of enrichment, one must assume that imported grains were preferably consumed over locally grown one for a long span of time and this may not be a realistic model. However, it is unlikely that there is only one explanation for these enriched values and, as the presence of migrants cannot solely explain these high carbon isotopic values, they also cannot solely be explained by trade and export. Rather, what is visible in these isotopic signatures is the reflection of a world where the movements of people and goods were not limited in space and whose biographies were dynamic stories of complex movements.

8.3.2 Longue Durée trends: ^{15}N-increase over time

Again, the Roman period displays the most striking pattern. As mentioned in section 7.4, the Roman ^{15}N-spacing compared to the faunal baseline is relatively small compared with the other two broad periods (Figures 7.50

and 7.51). The number of samples below one ^{15}N trophic level of enrichment is much higher in the Roman period than it is in other periods, while the number of samples above the higher end of the enrichment range is much lower (Figure 8.2).

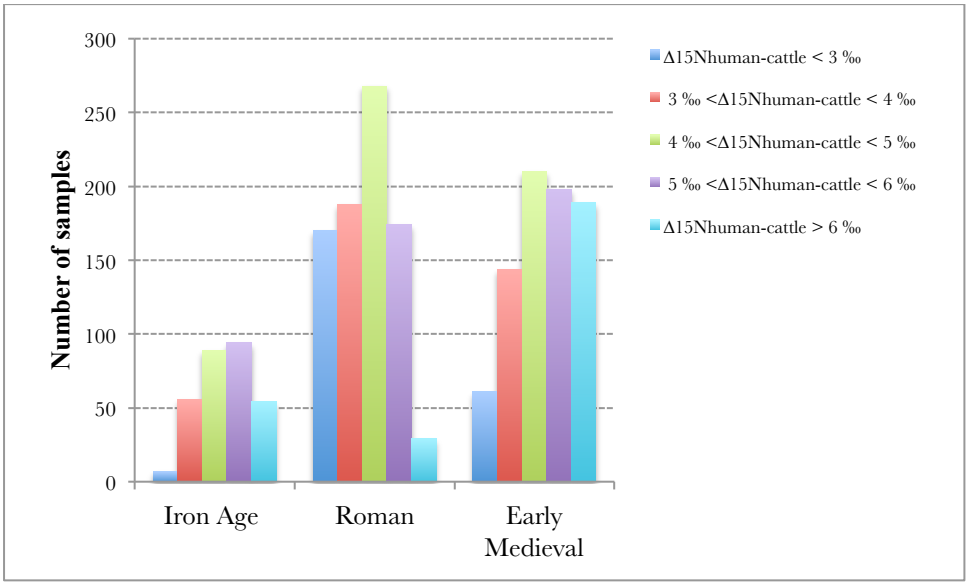


Figure 8.2. Distribution of the data according to the different level of enrichment.

This pattern between the main archaeological periods is consistent with the changes of agricultural regimes at the times, which posits a pastoral system in the Iron Age, and then a change towards a more agrarian economy, with land used to grow crops rather than raise animals to support the Roman economy, and a return to a pastoral system following the end of the Roman administration and the subsequent economic depression. The isotopic data broadly support the hypothesis that humans may have relied more on animal products in the Iron Age and the earliest medieval sub-period (Banham and Faith 2014, 39), while the Roman diet was primarily grain-based, with contribution of terrestrial and marine protein for certain populations. The data enriched in ^{15}N in the later medieval period, associated with enrichment in ^{13}C, discussed above in section 7.3.3, indicate yet another shift in which

fish become an important diet staple, caused by (or causing) the expansion of fisheries in the North Sea at the turn of the 11th century (Barrett *et al.* 2004; Barrett *et al.* 2010).

It is also worth noting that a fair amount of the data falls above one, or even two, ^{15}N trophic level enrichment (n of Iron Age samples with $\partial^{15}N$ values > 5‰ = 148 (50 % of total data); n of Roman samples with $\partial^{15}N$ values > 5‰ = 203 (24.5% of total data); n of Early Medieval samples with $\partial^{15}N$ values > 5‰ = 387 (38.7 % of total data). Considering the complexity of ^{15}N fractionation and the debate surrounding it, it is difficult to assign a value that can unequivocally be regarded as representing a 'large' ^{15}N spacing relative to the baseline, but it remains that the data generally display more than one ^{15}N trophic level enrichment compared to the baseline, which suggests that nitrogen enriched components of the diet need to be identified. This pattern of high $\partial^{15}N$ values with terrestrial carbon has already been noted by most researchers (See references in Chapter 3), who have suggested the possibilities outlined below. It is also argued here that instead of only considering possible meat sources for these high values, the possibility of manured cereals must be raised.

8.3.2.1. Marine and Freshwater foodstuff

High $\partial^{15}N$ values are often explained by the consumption of aquatic resources (freshwater or marine). As discussed in section 8.3.1.1, marine protein is a good explanation for the enrichment in ^{13}C of some of the data, specifically some Roman populations and the later period Anglo-Saxons, for whom a ^{15}N-enrichment is also attested. However, there is a significant portion of the data for which the enrichment in ^{15}N is not matched with

enrichment in ^{13}C, making it harder to see a clear 'marine' signal. It is however possible that these particular isotopic signatures can be explained by the consumption of freshwater resources, which have both high $\partial^{15}N$ and low $\partial^{13}C$ values. Indeed, the isotopic profile of freshwater fish present in this database may be a good match for the human isotopic signal as their $\partial^{13}C$ values tend to be very low (see Figures 6.35, 6.36). However, the substantial consumption of freshwater resources is not supported by the archaeological record (Hedges and Reynards 2007). It is true that much of the data analysed here comes from sites excavated in the 1970s or 1980s and some were excavated under less than ideal conditions, which is likely to result in fish bones being overlooked. However, in more recent excavations where systematic sieving is undertaken insufficient quantities of fish bones are found to account for the isotopic signal (Hedges and Reynard 2007). There is certainly an issue of preservation here that must be taken into account too, and while freshwater fish cannot be ruled out only on the basis of the archaeological record, it is unlikely that freshwater fish were consumed in quantities large enough to satisfactorily explain the high $\partial^{15}N$ values without looking for alternative sources of nitrogen-rich food.

8.3.2.2 Omnivorous animals

Omnivorous animals with elevated $\partial^{15}N$ values have also been suggested. The most important of these animals are pigs, although integrating them into the analyses is fraught with difficulties, mostly because while they *can* be omnivorous, they do not have to be. This adds a lot of uncertainties when attempting to reconstruct their feeding habits. In the dataset presented here, the variation in the isotopic results from pigs indicated that neither region

nor time periods was a good predictor of how pigs were kept (see Chapter 6, sections 6.4 and 6.5). The farming of pigs and consumption of pork is interesting on many levels and there is a debate whether pork meat would be seen as high status meat or not (Hamilton *et al.* 2012). Pigs are relatively easy to keep, and can feed on resources otherwise inedible to the rest of the domesticated animals, making them 'a highly productive source of food that was especially amenable to preservation' (Hamilton *et al*. 2012). On the other hand, compared to the rest of the domesticated species, pigs are not multi-purpose animals and are raised solely for their meat and fat, which could be seen as a luxury. Indeed, in the medieval period, pig remains are particularly abundant at high status sites (Hamilton *et al.* 2012). One explanation for this is that pigs were paid as 'food-rent', which would imply that they might have been kept as a commodity rather than a food source. Privat *et al*. (2002) identified some high ^{15}N trends in the poorer graves at Berinsfield and argued that this could be evidence of pork consumption and that pork was therefore a low status meat. However, they also noted the one pig value from Berinsfield was close to the herbivore, and that the pattern seen in the human data was more likely caused by consumption of freshwater resources (Lightfoot *et al.* 2002). In the data presented here, there is no particular pattern that could be interpreted as pig being more omnivorous in a specific period and/or region. However, looking at the spacing between cattle and pig from the same broad archaeological periods (done in the same way as was done for the human data), it shows that while pigs may have been kept in a numbers of different ways in the same period

and/or regions, a number of individuals pigs display enrichment in ^{15}N within the 3-5‰ trophic level range relative to the cattle (Figure 8.3).

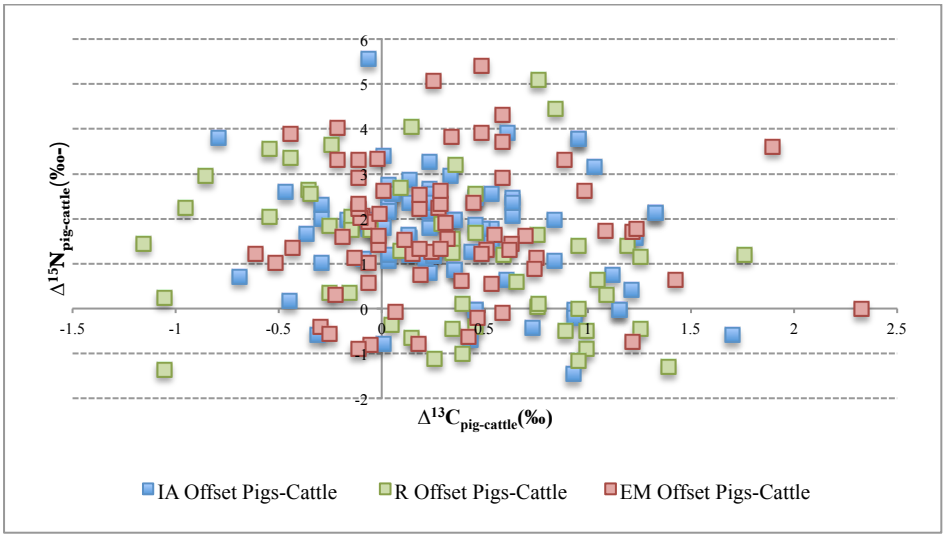


Figure 8.3. Comparisons of the pigs' $\Delta^{15}N_{pig\text{-}cattle}$ values in all three broad periods.

This suggests that these particular animals were likely kept on omnivorous diets, or that they seasonally fed on animal products (it is also worth acknowledging that the 'omnivorous' signal might also be younger animals showing a nursing signal). But overall, the pig data are systematically (and often significantly) ^{15}N enriched but not necessarily enriched in ^{13}C compared to cattle and sheep (see Chapter 6), which make pigs a good candidate for some of the isotopic profiles seen in the human data.

Another omnivorous animal worth considering are chicken and their eggs. The issue with chickens, much like with fish, is that they are not well represented in the archaeological record, which may or may not be an issue of bone survival. While unequivocally used for food today, whether for meat or eggs, chickens were probably introduced to Britain as exotic pets. First domesticated in East Asia in the 6th millennium B.C., the earliest

record of chicken in Britain dates to the early Iron Age, with possible indications than breeding was taking place. They became more common in the Late Iron Age, probably through Roman influence, although it is unclear how they were exploited (Yalden and Albarella 2009; Sykes 2011). An oft-quoted remark from the *Gallic Wars* seems to imply that native Britons did not consider chicken for eating: 'they have a taboo against eating hare, chicken and goose, but they rear them for amusement and pleasure' (*Gallic Wars*, 5,12) but butchery marks on domestic fowls dated to the Roman conquest directly contradict this statement. It is not clear if Caesar was reporting a religious taboo or a regional preference. Either way, his comment should probably not be understood as being true for the whole population. In the Middle Ages, chickens seem to have been regularly consumed too and became a dietary staple around the 11th century (Sykes 2011). Irremediably linked to the question of chickens is the question of eggs. In 1993 Benecke argued that eggs were not much of a motivation for domesticating chicken, since the ratio of cockerels to hens was 3:1 at some of the earliest sites. While this might indicate a preference towards cockerels, it could also indicate that cockerel bones were preferentially recovered because these birds were raised for fighting and the whole body was likely to be disposed of, thus resulting in better preservation, while hens were kept for egg production and consumption (Benecke 1993). The preservation of hens' bones might therefore have been specifically hampered by them being butchered and cooked. In 1995, Hobson showed that while eggs were enriched in ^{15}N by up to 3.4 ‰, the yolk was depleted in^{13}C by 2.6‰ due to lipids while the albumen was enriched in ^{13}C by

1.5‰ compared to the values of the bird that laid it. These are average values, and may differ according to birds, but this means that compared to birds, eggs would be ^{15}N-enriched but ^{13}C-depleted. Admittedly, Hobson's study did not include chicken eggs but relied on various species of captive birds (mallard, falcon and quails) whose diets would be closer to that of a domestic species than it would be to wild fowls. Based on the chicken data present in this data set, the following values can be hypothesised for eggs (Hobson, 1995 see Figure 8.4).

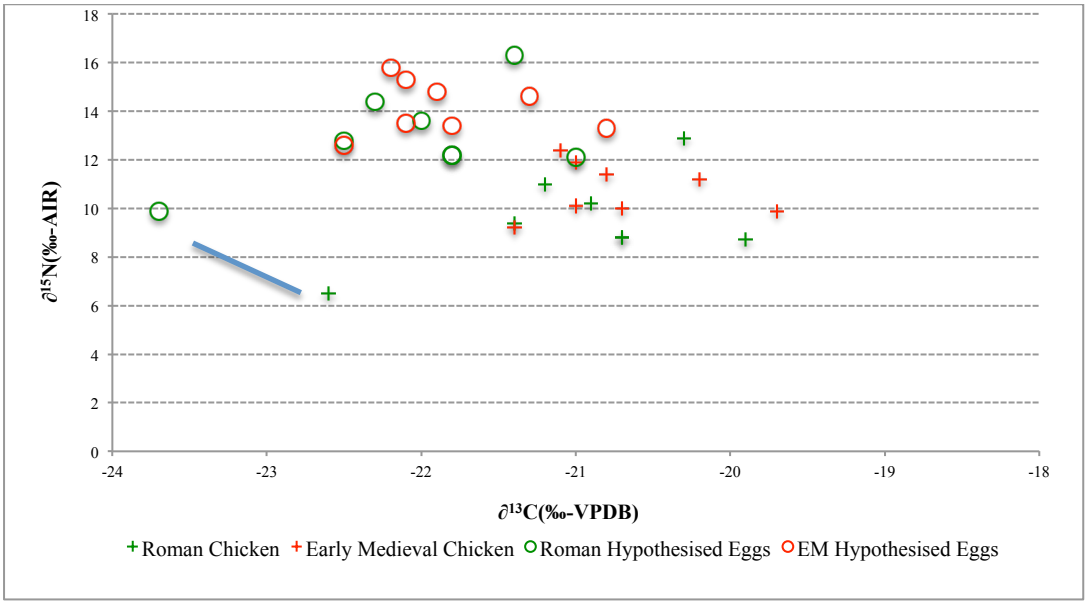


Figure 8.4. Hypothesised egg isotopic values based on the chicken data from Roman Britain and the Early Medieval Period. It uses the values from Hobson (1992): egg ∂^{15}N value = Chicken ∂^{15}N + 3.4; egg ∂^{13}C value = chicken ∂^{13}C + 1.5 -2.6. This is done on the assumption the whole egg was eaten. It is a very rough model.

Considerations about eggs have been raised in Müldner and Richards (2007a and b), and are still a food of interest to isotopic researchers (O'Connell and Hedges 2017; Mathilda Holmes, *pers. comm*). However, Müldner and Richards (2007a and b) pointed out that the 'low meat yield'

of eggs made it unlikely that they would cause the enrichment in ^{15}N seen in the data on their own (Müldner and Richards 2007b).

8.3.2.3 Younger animals

Finally, another possibility to explain these $\partial^{15}N$ ratios is the consumption of younger animals, because suckling animals would still retain a higher ^{15}N signal than the adult animals. Eating a significant amount of these animals would therefore lead to higher human values but the proportion of young animal that were sampled is not clear in the data, even in cases where the archaeological reports could be matched to the isotopic analyses. Furthermore, as was the case for freshwater fish or chicken, the bones of small animals, as well as the presence of dogs at these sites might have resulted in serious preservation issues (Jay and Richards 2007). Stevens *et al.* (2013b) recorded some different animal profiles at different sites, possibly suggesting ultra-localised agricultural practices with some sites focusing on meat, while others seemed to have favoured traction and secondary products. Stevens *et al*.'s data confirms that younger animals were eaten, and it seems likely that this would have been in case in the later periods too. Therefore, consumption of younger animals might have been a factor for some of the high $\partial^{15}N$ ratios in the human data.

8.3.2.4. Cereals

After considering how the consumption of meat or animal products may have affected the $\partial^{15}N$ ratios of the human population, it is worth considering the cereals component of the diet, and specifically manuring. This practice has been observed to result in an increase of the $\partial^{15}N$ values of the soil, primarily due to bacterially-mediated reactions where the lighter

^{14}N is preferentially lost leading to ^{15}N enrichment (See Chapter 2 for a fuller discussion; Heaton 1986. Fraser *et al*. 2011). Bogaard *et al.*'s pioneering study in 2007 showed that manuring cereal crops could raise $\partial^{15}N$ values by up to 8 ‰ compared with the non-manured fields at the same sites. The only grain data available that are relevant to this study come from Danebury (n= 34) and their $\partial^{15}N$ values have been compared to the $\partial^{15}N$ values of cattle from the same region and phases from Danebury. Figure 8.5 shows that the barley and cattle distribution from Southern Britain in the Iron Age are extremely close and not statistically different (p = 0.82). Wheat is the most different from both barley (p = 0.04) and cattle (p = 0.00). It can therefore be argued that a diet drawing its protein from barley would be virtually indistinguishable form a diet drawing its protein from beef in the isotopic record. Furthermore, these results also give an insight into faunal diets. It is indeed unlikely that cattle would have been foddered on barley considering how close their $\partial^{15}N$ values are: cattle $\partial^{15}N$ ratios would be higher if they had consumed the barley. The implication of this, if confirmed by further studies, could change our understanding of past grains as it is often argued that barley is grown mostly for brewing or foddering livestock.

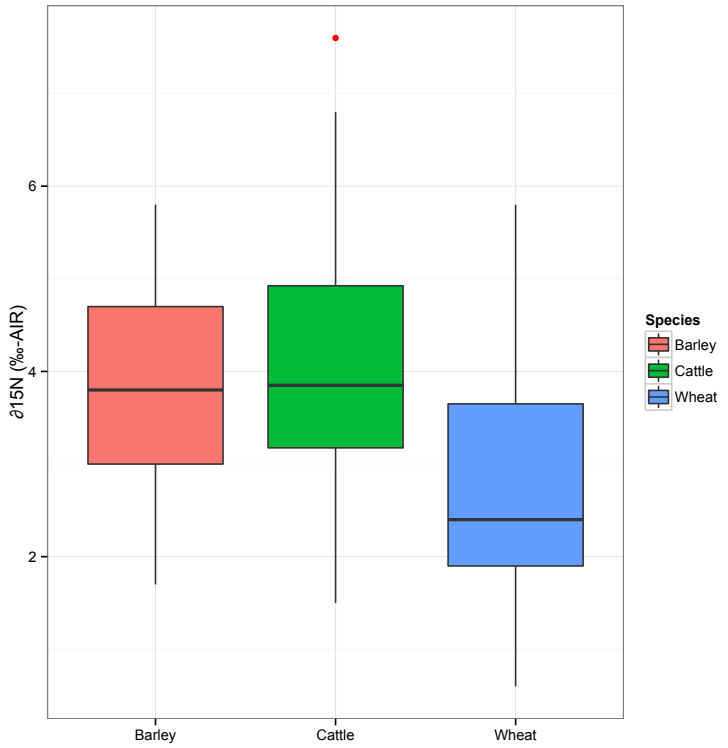


Figure 8.5. Boxplot distribution of the charred grain and cattle ∂^{15}N values in the Iron Age. All the data are from the Ceramic Phases 3 and 7 of Danebury and nearby settlements of similar dates (Lightfoot and Stevens, 2012; Stevens *et al.* 2013b). Barley ∂^{15}N average : 3.82 ‰, wheat ∂^{15}N average: 2.77 ‰.

Taking into account the intensification of agriculture in the Roman period, which would raise the nitrate contents in the soils (Fraser *et al.* 2011) as well as the well-attested manuring practices both in the Roman and Early Medieval period, it seems reasonable that the Iron Age values shown above could even be considered to be low relative to the other periods investigated here.

Manuring is important to consider (Hall and Kenward 1998; Jones 2012). The importance of this practice is well attested in the Mediterranean. Classical authors interested in the natural world like Pliny and Cato described the practice and extolled its virtue, and even Virgil wrote verses about it:

‘Yet shall thy lands from pleasure rear
Abundant harvest each alternate year
If rich manure fresh life and nurture yield
And ashes renovate th’exhausted fields’

*(*Virgil, *Georgics,* Book 1, trans. Sotheby, 1808, also Jones*,* 2012, 6*,)*.

Whether the practice was common in Britain is more difficult to assess. Settlement mounds in southern England in the Late Bronze Age and Iron Age seem to indicate that animal dung was gathered and piled rather than spread on the fields, with only minimal evidence for *in situ* cultivation (Waddington 2012, 44, 48). While there is not much evidence for or against manuring in the Later Iron Age, it can be argued without much doubt that fields are likely to have been manured in Roman Britain. Either the Romans would have brought the practice with them, which seems likely considering the importance given to it in Classical sources – or manuring did actually occur before the Conquest. Indeed, while the main component of the settlement mounds is dung, this does not necessarily mean that *all* the dung was gathered in this way. It is also possible that only part of it was collected for the mounds, while another part was spread into the fields.

Early Medieval sources as well as place-names evidence also suggest that manuring were likely continued after the end of Roman Britain (Jones 2012; Cullen and Jones 2012, 97-108). Furthermore, long-term field experiments have shown an ‘historical’ effect, where cereals grown in previously manured fields still displayed some level of nitrogen enrichment compared to non-manured fields, so even if there was a lull in manuring practices

following the end of Roman administration, it may not have resulted in an immediate drop in soil nitrogen values (Figure 8.7; Fraser *et al.* 2011).

So, while there seems to be little doubt that manuring occurred from the Roman period onwards and possibly earlier, questions concerning its scale and intensity remain. One of the most common arguments against manuring, at least in relation to these particular data, is that it would require large flocks or herds to maintain an effective manuring regime (Hull and O'Connell 2011). Figure 8.6 shows the Danebury grain data against data from a long-term field experiment in England. While it is true that the Iron Age grains do not plot near the intensively manured crops, barley clearly falls within the moderately manured range.

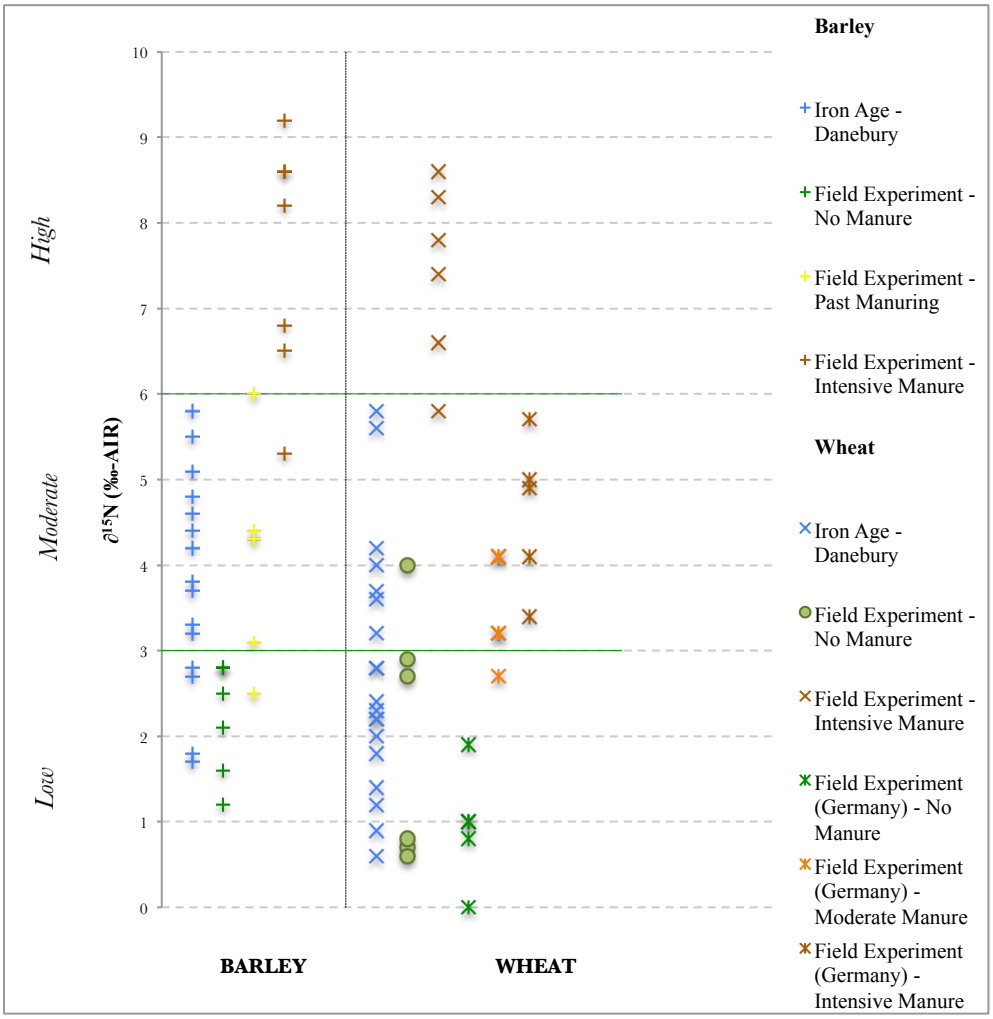


Figure 8.6 ∂^{15}N values for charred barley and wheat from Danebury (from Lightfoot and Stevens 2012) compared with data from long-term field experiments from England and Germany showing different levels of manuring (Intensive, 35 t/ha per year; moderate, 20 t/ha per year; data from Fraser *et al.* 2011 and Bogaard *et al.* 2007).

In modern agricultural practices, moderate amounts of manure are considered to be between ten and fifteen tons per hectare (Bogaard *et al.* 2013). While this does require a certain number of animals, it must be remembered that manure is not applied everyday. A modern cow will excrete about ~30 kilograms of waste (urine and faeces NRSC 2018;) per day, which means that, theoretically, even a household owning no more than a single cow and a hectare of land would have an annual access to ten tons

of manure. Besides, it must also be remembered that manure is not necessarily composed entirely of animal waste. The line from Virgil's *Georgics* quoted above also refers to 'ashes' as soil nutriments. As mentioned in Chapter 6 and 7, seaweed is also a known fertiliser and practices such as middening (the use of organic waste as fertiliser, Bogaard 2012) would have allowed for the fertilization of soil without relying on manure entirely composed of animal waste. Furthermore, the practice of marling (spreading clay and chalk on soils), well attested in Roman Britain, may also have had an effect on the isotopic values of the soils, although recent investigation of on the effects of chalk geology on the $\partial^{15}N$ of plants would suggest that marling would like result in ^{15}N-depleted soils (Bird 2016, 94; Schulting *et al.* 2019). It is therefore possible to argue that moderate amounts of manuring, can be achieved without presupposing the presence of many animals in any given settlement.

Summarily, it is argued here that cereals enriched in ^{15}N because of manuring, may be one of the causes of values enriched in ^{15}N for humans and could partially explain the high $\partial^{15}N$ values with terrestrial carbon seen in the data here.

This brief review of the possible causes for high $\partial^{15}N$ and low $\partial^{13}C$ signatures in the population highlights the need to integrate different hypotheses. While it might be appropriate for some site analyses to assume that similar trends in individuals' diets can be explained by the same behaviour, it is unlikely to be relevant here where the scale of analyses is so much larger. Indeed, a group with high $\partial^{15}N$ and low $\partial^{13}C$ signatures in the Iron Age might have favoured the consumption of young animals when a

group with the same values in the Roman period was actually consuming fresh water fish.

8.3.3. Regional patterns

The only significant difference visible in the data at the regional level is between Hampshire on the one hand and Norfolk and Oxfordshire on the other in the Early Medieval period, with the Hampshire data displaying much lower $\partial^{15}N$ values than in the other regions. The faunal data in both the Iron Age and the Early Medieval period in Hampshire were also significantly different to the other regions so it is interesting that this difference should only be visible in the Early Medieval human data. However, as was shown in section 7.5, investigating the offsets between a restricted, regional Hampshire baseline and the human data reveal a relationship between cattle and human similar to what is expected for a C_3-terrestrial diet, so it is likely that the human data appears to have such $\partial^{15}N$ values in part because of the fauna rather than because of a particular 'Hampshire diet'. It is particularly interesting to see some continuity between the Iron Age and the Early Medieval period, and to some lesser extent to the Roman period. It also shows the limitations of using modern counties as units of analyses. Indeed, it is highly unlikely that modern Hampshire would have had a strikingly different environment resulting in these low $\partial^{15}N$ values. It is more likely that what is seen in Hampshire is a regional trend in wider sense, one that must include soils, vegetation, climate into consideration. While such analyses were not undertaken here

due to time and space constraints, it is certainly a possible future avenue for research.

While there are only limited differences between the regions, this cannot be understood as a lack of regionality in the data. Rather, the scale of analyses here might not have been appropriate to pick up on small difference. It must also be pointed out that the criteria for regional analyses were stricter than those of previous studies. Therefore, while wide regional trends could not be conclusively identified, it is likely that there are complex patterns of hyper-localised regional trends both at the site level, and between different species. However, three important regional divisions related to diets can be pointed out: the differences between the North and the South, inland and riverine sites, as well as between urban centres and rural settlements in the Roman period, which are discussed below.

8.3.3.1 North/South divide

While there was no significant difference in the cattle data between the South and the North, there is one in the human data (section 6.6.5 and 7.7.5) with the data from the South being depleted in ^{15}N compared to the northern data. Two models can be suggested to explain this difference between the South and the North: (1) populations in the South consumed food with low $\partial^{15}N$ values, particularly pulses; and (2) crops $\partial^{15}N$ were enriched due to the increased anthropogenic influence in the North, which is consistent with van der Veen's suggestion that the North was more intensively farmed due to overall poorer agricultural conditions, raising the $\partial^{15}N$ values of the soil and the crops consumed by the humans (van der Veen 1992). Consumption of

pulses is a possible explanation since a distribution map of Celtic peas and beans shows them to be concentrated in the South, while they are absent from northern grain assemblages, especially in the Roman data (Lodwick 2017).

The second proposition seems unlikely since such an impact would likely have raised the values of the domesticated fauna as well. It cannot be ruled out either, though, since it is possible that the lack of significant pattern in the faunal data between the North and the South is due to the distribution of the data and that, should there be more samples from both the North and South, the comparison would be more striking. But for now, on the basis of the data available here, an environmental cause appears less likely than the consumption of pulses.

8.3.3.2 Urban and Rural

A final interesting point to consider is the difference between urban and rural settlements. Section 6.2.4.4 showed that the cattle data from either rural or urban settlements have similar $\partial^{13}C$ and $\partial^{15}N$ ranges. While the opposition between the 'consumer' or 'producer' city models has been abandoned in favour of a mixed model that takes on aspects of both more recently (Wilson and Bowman 2013), the faunal data here suggest that urban and rural populations might have drawn from the same pool of animals for feeding or at least drew on animals living in the same environment. It should not be surprising that fauna in urban and rural sites should have the same isotopic values. While it is possible to keep some animals in urban settings, it is more likely that large animals such as cattle would have been raised and possibly even slaughtered outside the city walls,

leaving people in the city to deal only with the carcasses (Maltby 2014). Zooarchaeological evidence from urban sites indeed points towards the preference for smaller, mostly female, animals maybe indicating that farmers supplied towns with animals whose productivity had declined, which suggests that were sent to town mainly to be slaughtered but had spent their lives somewhere else (Maltby 2014). If it is correct to assume that there would be one herd from which both rural and urban settlements drew their animals, then no isotopic difference should be expected between the urban and the rural cattle.

The human ^{13}C-enrichment in cities has sometimes been explained by the presence of migrants as cities are more likely to have attracted a diverse population (Chenery *et al.* 2011). Another possibility is harvested grains from other parts of the Empire, which would have a different isotopic signature than that of crops grown in Britain. As plants tend to be ^{13}C depleted at higher latitudes relative to lower latitudes, there is a strong possibility that imported grains grown in Italy or in Turkey would have higher $\partial^{13}C$ ratio than native British crops and raise the isotopic profile of the consumer. The concentration of larger $\Delta^{13}C_{human\text{-}cattle}$ offsets in the cities might support this hypothesis, as urban centres might more likely to have been trade hubs, where exotic imports were more readily available. Maybe more likely, if the hypothesis that fish consumption is linked with status, marine fish consumption might have been more readily available to city dwellers than to the inhabitants of the more rural settlements.

8.3.4 Environmental pattern

8.3.4.1 Dry/Wet episodes

Finally, it is important to consider the climatic patterns, which had an influence on the data. Again, significant variation is not similar across the human and faunal data and human data, showing how difficult it is to disentangle environmental and dietary factors. The human data were significantly enriched in ^{15}N during the drier periods, while this was not true in the cattle data. This would suggest that the pattern seen in the human data is more likely to be dietary rather than environmental. This might indicate more reliance on ^{15}N-enriched food stuffs, such as those described in section 8.3.2. The positive correlation in the human data from the drier periods might point towards fish being a more important part of the diet in the drier periods, although the reasons behind this are not necessarily clear. It must be pointed out that the data from the drier periods are mostly dated to the later Anglo-Saxon periods, for which fish consumption is likely for both cultural and economics reasons. While the statistical model was designed to contain the 'Sub-Period' variable, the correlation between both isotopes might be an echo of this particular pattern in the later periods.

8.3.4.2 Temperatures

Finally, there was also a significant difference between the data from warmer and colder periods, in what was maybe the clearest 'climatic' pattern seen in these data. Section 7.6.3 showed the clear pattern of both enrichment in ^{13}C and ^{15}N in the warmer periods. It is particularly interesting here since the 'warm' data predominantly come from the Roman period, which was indeed warmer than the other periods (Wang *et al.* 2012,

Büntgen *et al.* 2011) but the statistical models were designed to contain the 'Sub-Period' and 'Archaeological Period' (not in the same model, due to issue of collinearity), therefore the difference seen here should not be due to Roman bias. Having said that, the enrichment in enrichment in ^{13}C in the Roman data might actually be due to the warmer conditions, since such a pattern is expected with warmer temperature. The enrichment in ^{15}N is harder to explain, since the correlation relation between ^{15}N and temperature is usually seen in more extreme cases of aridity unlikely to be seen in Britain.

8.3.5 Specifics of the human data

The main pattern within the human data was a difference between males and females in all three broad periods. This is particularly interesting, as site-by-site analyses had revealed a lack of significant differences between the different genders. It must be acknowledged here that the difference seen here might be due to effect size, since the sample sizes examined here are larger than those examined for the previous analyses. However, and maybe more interesting than the significant difference between males and females, is the correlations between $\partial^{13}C$ and $\partial^{15}N$ for the different groups. The negative correlation between $\partial^{13}C$ and $\partial^{15}N$ in the Iron Age is more marked and more significant in the male data than it is in the female data. Considering the negative correlation in the domesticated species, it might indicate that men relied more on animal products than females, which may suggest diet differentiation based on gender. In Roman Britain, the males displayed a significant correlation between $\partial^{13}C$ and $\partial^{15}N$, while the females did display a moderately significant negative correlation between $\partial^{13}C$ and

∂^{15}N. Again, one must be cautious in interpreting these results, but it could suggest diet differentiation between males and females, with males have more access to aquatic resources and animal products. It could also be interpreted that these males built up a collagen signal outside of Britain and reveal a difference between 'foreign' men and 'native' women. The discrepancy in numbers between males (n=192) and females (n=83) in the Roman period and the presence of data from military cemetery might indeed suggest that an 'army' effect. However, these results can only be tentative for now. Finally, in the Early Medieval data, both males and females display a significant positive correlation between ∂^{13}C and ∂^{15}N, but it is stronger in the male data. Again, this might be more suggestive of dietary difference between the genders than a straightforward statistical comparison, as it could indicate different access to resources, particularly meat and aquatic protein, which is consistent with some of the historical records (Bullough and Campbell 1980; Pearson 1997). Summarily, while the statistical results between males and females should be interpreted cautiously, the correlation in the data using Pearson' correlation coefficient might be more revealing of dietary difference between genders.

8.4. Conclusion

While the more general conclusions of this work will be reviewed in the final chapter, a few important points need to be raised here. The first conclusion is that the relationship between the human and the cattle data are complex and varies on different scales, making it difficult to conclusively assess the dietary patterns of the periods against all possible environmental effects.

While overall there is little variation between the three main periods investigated, the Roman period stands out due to its high $\partial^{13}C$ values but overall lower $\partial^{15}N$ values compared to the baseline. This suggests an economy turned towards agrarianism rather than pastoralism. Cities have a different isotopic profile, whether through the presence of non-natives, as important trade hubs, or because of the difference of social status for the urban population compared to rural ones.

Regionally, the data suggest complex, local practices. The proximity of sites, or the physical environment of the settlements, are not necessarily accurate predictors of either agricultural or dietary behaviours, Overall, the data show the dynamic behaviour of both humans and non-human agents, as well as the complexities of ancient subsistence.

CHAPTER 9. Further Areas of Research and Final Conclusion

9.1. General Conclusion

This thesis has four major conclusions. The first is that subsistence patterns did not change dramatically between broad periods, suggesting more gradual changes and small-scale variations, reflecting the complexity of agricultural and dietary practices. Some regional variation has been noted, with Hampshire being 'different' to the other regions, the reasons for which are likely to be environmental, although due to factors probably extending beyond the modern limits of the county. This raises the important question of how regionality can be defined, and which factors are likely to be relevant to subsistence on the one hand, and isotopic variation on the other. It is fully acknowledged here that modern county limits might not be the best regional unit to investigate these data. Rather, the regional analyses presented here should be seen as a broad investigation, that can –and should– be refined using a more holistic approach to 'regionality', taking into account soils and vegetation.

The second conclusion, derived from the first, posits that the faunal domesticated and wild data, as well as archaeobotanical remains, should be integrated as much as possible in dietary studies to more fully assess the environmental background.

The third important consideration concerns scales of analysis. Over the course of writing this thesis, there was a mistaken sense that the 'correct' scale of analysis could be found. However, working with a dataset so large showed that it was not necessarily possible to answer all of the questions it

raised at once. Here, this is understood as evidence for the dynamism of the data, which reveals different, complementary patterns at different scale, each allowing for a better understanding of the overall data.

The fourth conclusion is concerned with the comparability of the different sub-datasets and the state of isotopic research in Britain. It showed the southern bias in the data, as well as the over-representation of some periods over others. It also revealed the hidden difficulties for researchers working with samples that had been excavated decades prior to the analyses, and for which very little contextual information could be traced. However, the size of this dataset – which did not include 'Big Data' projects completed after 2014 (or made available after 2014) – show how ubiquitous isotopes have become in today's research and how much they have furthered our understanding of past behaviours.

9.2. Further Work

This thesis has been presented as both an in-depth study of *longue durée* isotopic trends and a review of the isotopic data currently available to researchers investigating diets in England between the Iron Age and the Early Medieval period and has opened new possible avenues of research.

In light of the conclusions of this thesis, it now seems crucial that systematic isotopic investigations of the British archaeobotanical and wild faunal data should be undertaken in order to assess more fully the diets of the British populations in the past. Isotopic analyses of cereals will not only allow for better palaeodietary reconstruction, they would also be a powerful tool with which we could investigate past agricultural practices. Knowing about how crops were grown would shed light on past agricultural practices and would

further the understanding of how certain types of grains were used.

In addition to gathering isotopic data for grains, it is also important to investigate further the isotopic profile of wild animals. Although this may prove more difficult as the bones of wild animals are not necessarily recovered in large numbers, it is necessary to include them as far as possible to be able to reconstruct past environments more fully. The isotopic values of wild animals would act as a proxy for the unmanaged environment, while grains would create a baseline for the managed environment. Thanks to these data, the division of landscape between 'wild' and 'domesticated' could be explored more extensively, as well as its implication for diets and social organisation. It is also crucial to further the understanding of the isotopic variation of the domesticated fauna. A further avenue of research should undertake the systematic comparison of the isotopic data through better defined regional units, taking into account soils, vegetation and climate, similar to Hamilton's approach to the Upper Thames Valley, but for the whole country (Hamilton 2016). This would likely yield crucially important results for the understanding of past subsistence.

Finally, some of the trends identified here have not been analysed in depth, but would warrant some more research. A more detailed analysis of the differences between urban and rural data, taking into account the different types of urbanised settlements would be fascinating. Similarly, differences within the human groups could be investigated more systematically on a broader scale.

Central to this thesis was the creation of a database. This work has integrated all of the carbon and nitrogen isotopic data from England

between the Iron Age and the Early Medieval period. However, this is only a fraction of the isotopic datasets actually available. Gathering data – with the added issues of cleaning and unification – is a complex and time-consuming task. Some of these datasets were not digitised and needed to be added by hand. Some were digitised but there was a distinct lack of uniformity between what was recorded and what was not. Because of time constraints, only the dietary elements relevant to the analyses were recorded here but a final database could include all the alternative isotopes (for example strontium and oxygen) to make information available for future researchers to have a direct access to the wealth of isotopic data that has been collected through the years to investigate diets, but also migration and ecological cycles, similar to what Salesse *et al*. (2018) have created for Greek data. Ideally, this database would be hosted online, where researchers could easily access and either upload their own data or investigate the existing dataset. A final point about this work is that it integrated data analysed at different times in different places, which raised issues of comparability across datasets. While differences were shown to be minimal, the possibility of analytical variation must be kept in mind and protocols to minimise such variation should be utilised as far as possible.

9.3 Closing remarks

This first systematic analysis of integrated isotopic results from English sites has shown how patterns of subsistence between the Iron Age and the Early Medieval period have fluctuated over time and space. Broad patterns have been identified but they are complex since they are caused by the interaction of many variables rather than any one variable. Therefore finding

causes is difficult as possible factors affecting variation are all connected. The legacy data/longue durée approach allowed to test these variations on a broader scale and has been a stepping stone to start understanding the delicate balance of the different factors affecting the isotopic data.

To conclude, broad patterns defined by periods and regions form the background of the isotopic trends present on the island at the time, against which hyper-localised behaviours and the nature and the locality of the settlements act as mitigating factors, alongside the overall climatic conditions. Only by the continued integration of all isotopic data can we hope to gain a fuller understanding of the complex interplay between identity, diets and agriculture.

APPENDIXES

Database example, summary of the data per site, site Information and detailed statistical results.

Appendix I.1 Database.

Table A1.1 Example of the database.

Ref	Date_of_ Study	Arch. Period	Date _of_Samp le	Sub_Period	Site	Region	Species	d13C	d15N	Sex	Age	Coastal_ Inland	Precipitation	Temp	Rain Regions	North _ South	Urban/ Rural	Element_ Sampled	Lab.
Hull	2007	Early Medieval	475-525 A.D.	Early Anglo-Saxon	Alton	Hampshire	Human	-20.63	11.21	F	Adult	Inland	Wet	Cold	SEE	South	N/A	Long Bone	RLAHA, Oxford
Hull	2007	Early Medieval	475-525 A.D.	Early Anglo-Saxon	Alton	Hampshire	Human	-20.55	8.77	F	Adult	Inland	Wet	Cold	SEE	South	N/A	Rib	RLAHA, Oxford
Hull	2007	Early Medieval	475-525 A.D.	Early Anglo-Saxon	Alton	Hampshire	Human	-20.49	9.36	F	Adult	Inland	Wet	Cold	SEE	South	N/A	Long Bone	RLAHA, Oxford
Hull	2007	Early Medieval	475-525 A.D.	Early Anglo-Saxon	Alton	Hampshire	Human	-20.4	9.02	F	Adult	Inland	Wet	Cold	SEE	South	N/A	Rib	RLAHA, Oxford
Hull	2007	Early Medieval	475-525 A.D.	Early Anglo-Saxon	Alton	Hampshire	Human	-20.28	9.46	F	Adult	Inland	Wet	Cold	SEE	South	N/A	Rib	RLAHA, Oxford
Hull	2007	Early Medieval	475-525 A.D.	Early Anglo-Saxon	Alton	Hampshire	Human	-20.23	8.6	F	Adult	Inland	Wet	Cold	SEE	South	N/A	Rib	RLAHA, Oxford
Hull	2007	Early Medieval	475-525 A.D.	Early Anglo-Saxon	Alton	Hampshire	Human	-20.2	9.86	F	Adult	Inland	Wet	Cold	SEE	South	N/A	Ulna	RLAHA, Oxford
Hull	2007	Early Medieval	475-525 A.D.	Early Anglo-Saxon	Alton	Hampshire	Human	-20.05	8.1	F	Adult	Inland	Wet	Cold	SEE	South	N/A	Rib	RLAHA, Oxford
Hull	2007	Early Medieval	475-525 A.D.	Early Anglo-Saxon	Alton	Hampshire	Human	-19.8	8.06	F	Adult	Inland	Wet	Cold	SEE	South	N/A	Rib	RLAHA, Oxford
Hull	2007	Early Medieval	475-525 A.D.	Early Anglo-Saxon	Alton	Hampshire	Human	-20.7	10.51	F	Young Adult	Inland	Wet	Cold	SEE	South	N/A	Rib	RLAHA, Oxford
Hull	2007	Early Medieval	475-525 A.D.	Early Anglo-Saxon	Alton	Hampshire	Human	-20.49	9.09	F	Young Adult	Inland	Wet	Cold	SEE	South	N/A	Rib	RLAHA, Oxford
Hull	2007	Early Medieval	475-525 A.D.	Early Anglo-Saxon	Alton	Hampshire	Human	-20.38	8.37	F	Young Adult	Inland	Wet	Cold	SEE	South	N/A	Rib	RLAHA, Oxford
Hull	2007	Early Medieval	475-525 A.D.	Early Anglo-Saxon	Alton	Hampshire	Human	-20.89	9.5	M	Adult	Inland	Wet	Cold	SEE	South	N/A	Rib	RLAHA, Oxford
Hull	2007	Early Medieval	475-525 A.D.	Early Anglo-Saxon	Alton	Hampshire	Human	-20.75	8.34	M	Adult	Inland	Wet	Cold	SEE	South	N/A	Rib	RLAHA, Oxford

Appendix 1.2. Number of samples for each site.

Table A1.2.1 Distribution of the number of faunal samples by sites.

Site	N of faunal samples
6DT_York	14
Abbot's Worthy	83
Alchester	13
Asthall	17
Bellevue_York	21
Berinsfield	7
Black Gate Cemetery_Newcastle	17
Bloodmoor Hill	17
Blossom Street_York	25
Bradley Hill	14
Bury Hill	16
Butler's Field Lechlade	8
Catterick	25
Cirencester	28
Danebury	126
East Kent Access Road	2
Fishbourne	34
Fishergate_York	78
Fordington Bottom	1
Gloucester	18
Harlyn Bay	3
Houghton Down	52
Hucclecote	7
Lechlade	35
London Bridge	1
Manor Farm	3
Masham	8
Minster	3
Monkton	8
Nettlebank Copse	125
New Buildings	55
ShavardsFarm	63
Silvester Street	1
Suddern Farm	106
Tolpuddle Ball	2
Trethellan Farm	23
Trevelgue Head	29
WestStow	150
Wetwang Garton-Slack	70
Whitton	9
Winchester	37
Winnall Down	24
Yarnton	83
York	41

Table A1.2.2. Distribution of the number of human samples by sites

Site	N of human samples
3DT_York	50
6DT_York	29
Alchester	21
Alington Avenue	5
Alton	37
Appledown Compton	3
Asthall	9
Aston Clinton	1
Barton upon Humber	9
Bellevue_York	37
BerghApton	13
Berinsfield	95
Black Gate Cemetary_Newcastle	55
Bloodmoor Hill	15
Blossom Street_York	18
Bradley Hill	42
BurghCastle	28
Butler's Field Lechlade	119
Buttermarket	1
Caister-by-Yarmouth	21
Casteldyke South	7
Catterick	41
Cirencester	145
Coddenham	1
Coppergate	3
Costwolds Community	24
Danebury	56
Dover Buckland	6
Droxford	34
Edix Hill	8
Fillingham	2
Fishergate_York	51
Flagstones	2
Ford Lavestock	1
Fordington Bottom	10
Galley Hill	1
Gloucester	65
Gravesend	12
Gussage All Saints	5
Harlyn Bay	20
Horcott Quarry	22
Hucclecote	8
Kilton Hill	2
Lakenheath	1
Lechlade	24
London Road_Gloucester	25
Manor Farm	4
Marina Drive	2
Masham	30
Melbourn Water Lane	9
MichelDewer Wood	3
Mill Hill	8
Morningthorpe	19
Norwich	17

Site	N of human samples
Portway	69
Poundbury	49
Queenford	87
Raunds Furnell	19
ShavardsFarm	13
SouthAcre	12
SpongHill	6
St JohnsCollege	38
St Peter's Tip	12
Stanton Court	27
Suddern Farm	37
Swaffham	10
Tolpuddle Ball	2
Trentholme Drive_York	43
Trethellan Farm	4
Wasperton	7
West Heslerton	1
Westerfield Farm	11
WestgarthGardens	67
Wetwang Garton-Slack	74
Whitcombe Farm	7
Whitton	2
Winchester	107
Winnall	37
Winnall Down	26
Worthy_Park	35
Yarnton	42
York	7

Appendix 1.3. Summary of the data

A1.3.1 Iron Age

Table A1.3.1 Summary of the Iron Age data by site.

Site	Regions	Date	Species	n	Average $\partial^{13}C$ (‰)	Average $\partial^{15}N$ (‰)	Min $\partial^{13}C$ (‰)	Max $\partial^{13}C$ (‰)	range $\partial^{13}C$ (‰)	Min $\partial^{15}N$ (‰)	Max $\partial^{15}N$ (‰)	range $\partial^{15}N$ (‰)	Reference
Harlyn Bay	Cornwall	Iron Age	Cattle	2	-21.85 ± 0.7	5.8 ± 0							Jay (2005)
Harlyn Bay	Cornwall	Iron Age	Humans	20	-20.51 ± 0.39	10.88 ± 0.43	-21.1	-19.6	1.5	10.1	11.8	1.7	Jay (2005)
Harlyn Bay	Cornwall	Iron Age	Pig	1	-22.4	5.7							Jay (2005)
Trethellan Farm	Cornwall	Iron Age	Humans	4	-20.52 ± 0.32	10 ± 0.33	-20.8	-20.2	0.6	9.5	10.2	0.7	Jay (2005)
Trevelgue Head	Cornwall	Iron Age	Cattle	7	-22.01 ± 0.34	5.57 ± 0.63	-22.5	-21.5	1	4.8	6.7	1.9	Jay (2005)
Trevelgue Head	Cornwall	Iron Age	Deer	4	-22 ± 0.16	5.35 ± 0.45	-22.2	-21.8	0.4	4.8	5.9	1.1	Jay (2005)
Trevelgue Head	Cornwall	Iron Age	Horses	2	-22.7 ± 0.28	4.5 ± 0.56							Jay (2005)
Trevelgue Head	Cornwall	Iron Age	Pigs	8	-21.45 ± 0.36	7.12 ± 1.34	-21.9	-20.8	1.1	5.5	9.3	3.8	Jay (2005)
Trevelgue Head	Cornwall	Iron Age	Sheep	8	-21.8 ± 0.29	5.75 ± 0.53	-22.1	-21.3	0.8	4.8	6.5	1.7	Jay (2005); Jay and Richards (2007)

Site	Regions	Date	Species	n	Average $\partial^{13}C$ (‰)	Average $\partial^{15}N$ (‰)	Min $\partial^{13}C$ (‰)	Max $\partial^{13}C$ (‰)	range $\partial^{13}C$ (‰)	Min $\partial^{15}N$ (‰)	Max $\partial^{15}N$ (‰)	range $\partial^{15}N$ (‰)	Reference
Alington Avenue	Dorset	100-50 B.C.	Humans	5	-19.7 ± 0.58	9.84 ± 0.32	-20.5	-19	1.5	9.5	10.3	0.8	Redfern *et al.* (2008)
Flagstones	Dorset	100-50 B.C.	Humans	2	-20 ± 0.14	9.2 ± .70							Redfern *et al.* (2008)
Fordington Bottom	Dorset	100-50 B.C.	Cattle	1	-21.3	4.4							Redfern *et al.* (2008)
Fordington Bottom	Dorset	100-50 B.C.	Humans	10	-19.83 ± 0.22	9.17 ± 0.29	-20.1	-19.4	0.7	8.7	9.5	0.8	Redfern *et al.* (2008)
Manor Farm	Dorset	100-50 B.C.	Humans	4	-19.7 ± 0.50	9.22 ± 0.37	-20.2	-19	1.2	8.7	9.6	0.9	Redfern *et al.* (2008)
Manor Farm	Dorset	100-50 B.C.	Pigs	2	-21.05 ± 0.35	6.45 ± 0.35							Redfern *et al.* (2008)
Manor Farm	Dorset	100-50 B.C.	Sheep	1	-22.3	7.5							Redfern *et al.* (2008)
Gussage All Saints	Dorset	100-50 B.C.	Humans	5	-20.3 ± 0.17	8.78 ± 0.29	-20.6	-20.2	0.4	8.3	9	0.7	Redfern *et al.* (2008)
Tolpuddle Ball	Dorset	100-50 B.C.	Humans	2	-20.2 ± 0.14	9.7 ± 0.0							Redfern *et al.* (2008)
Tolpuddle Ball	Dorset	100-50 B.C.	Pig	1	-21.5	7.4							Redfern *et al.* (2008)
Tolpuddle Ball	Dorset	100-50 B.C.	Sheep	1	-21.2	4.6							Redfern *et al.* (2008)
Whitcombe Farm	Dorset	100-50 B.C.	Humans	7	-20 ± 0.11	9.62 ± 0.17	-20.2	-19.8	0.4	9.4	9.9	0.5	Redfern *et al.* (2008)
Lechlade	Gloucestershire	Iron Age	Cattle	10	-21.65 ± 0.28	7.32 ± 1.67	-22.04	-21.21	0.83	4.81	9.6	4.79	Sinh (2007)
Lechlade	Gloucestershire	Iron Age	Humans	15	-19.84 ± 0.15	10.24 ± 0.64	-20.16	-19.61	0.55	9.04	11.26	2.22	Sinh (2007)
Lechlade	Gloucestershire	Iron Age	Pigs	9	-20.85 ±	8.04	-21.96	-19.95	2.01	5.87	9.45	3.58	Sinh

Site	Regions	Date	Species	n	Average $\partial^{13}C$ (‰)	Average $\partial^{15}N$ (‰)	Min $\partial^{13}C$ (‰)	Max $\partial^{13}C$ (‰)	range $\partial^{13}C$ (‰)	Min $\partial^{15}N$ (‰)	Max $\partial^{15}N$ (‰)	range $\partial^{15}N$ (‰)	Reference
					0.64	± 1.32							(2007)
Lechlade	Gloucestershire	Iron Age	Sheep	16	-21.47 ± 0.41	7.4 ± 1.43	-22.72	-20.92	1.8	4.95	10.03	5.08	Sinh (2007)
Bury Hill	Hampshire	470. B.C - 50 A.D	Horses	16	-22.33 ± 0.31	4.55 ± 1.08	-23	-21.9	1.1	2.6	6.3	3.7	Stevens *et al.* (2013)
Danebury	Hampshire	470. BC. 40 A.D	Cattle	39	-21.59 ± 1.22	4.3 ± 1.24	-22.4	-20.7	1.7	2	6.7	4.7	Stevens *et al.* (2010)
Danebury	Hampshire	470. BC. 40 A.D	Humans	56	-20.12 ± 0.32	8.31 ± 0.81	-21.8	-19.6	2.2	5.5	10.6	5.1	Stevens *et al.* (2010)
Danebury	Hampshire	470. BC. 40 A.D	Pigs	30	-21.29 ± 0.35	6.52 ± 0.98	-21.8	-20.4	1.4	3.9	9.9	6	Stevens *et al.* (2010)
Danebury	Hampshire	470. BC. 40 A.D	Sheep	57	-21.22 ± 0.36	4.23 ± 0.76	-22.2	-20.3	1.9	2.6	6	3.4	Stevens *et al.* (2010)
Houghton Down	Hampshire	600-400	Cattle	18	-21.48 ± 0.44	3.89 ± 0.89	-22.8	-21	1.8	2.3	5.8	3.5	Stevens *et al.* (2013)
Houghton Down	Hampshire	600-400	Dog	1	-20.2	9							Stevens *et al.* (2013)
Houghton Down	Hampshire	600-400	Horses	7	-21.14 ± 0.32	3.5 ± 0.93	-22.6	-21.7	0.9	2.5	5.3	2.8	Stevens *et al.* (2013)
Houghton Down	Hampshire	600-400	Pigs	8	-21.18 ± 0.32	6.81 ± 0.73	-21.5	-20.5	1	5.2	7.7	2.5	Stevens *et al.* (2013)
Houghton Down	Hampshire	600-400	Sheep	18	-21.04 ± 0.20	4.51 ± 0.54	-21.4	-20.7	0.7	3.5	5.7	2.2	Stevens *et al.* (2013)
Nettlebank Copse	Hampshire	600-50 B.C	Cattle	35	-21.3 ± 0.35	3.85 ± 1.10	-22.1	-20.6	1.5	2.1	6.5	4.4	Stevens *et al.* (2013)
Nettlebank Copse	Hampshire	600-100 A.D	Dogs	3	-19.7 ± 0.36	7.3 ± 1.17	-20.1	-19.4	0.7	6.3	8.6	2.3	Stevens *et al.* (2013)
Nettlebank Copse	Hampshire	100-50 B.C.	Horses	18	-22.03 ± 0.38	3.7 ± 0.96	-22.5	-20.8	1.7	2.1	5.6	3.5	Stevens *et al.* (2013)

Site	Regions	Date	Species	n	Average $\partial^{13}C$ (‰)	Average $\partial^{15}N$ (‰)	Min $\partial^{13}C$ (‰)	Max $\partial^{13}C$ (‰)	range $\partial^{13}C$ (‰)	Min $\partial^{15}N$ (‰)	Max $\partial^{15}N$ (‰)	range $\partial^{15}N$ (‰)	Reference
Nettlebank Copse	Hampshire	600-50 B.C	Pigs	35	-21.14 ± 0.51	6.60 ± 0.92	-22	-19.9	2.1	5.2	8.9	3.7	Stevens *et al.* (2013)
Nettlebank Copse	Hampshire	600-50 B.C	Sheep	34	-21.07 ± 0.50	4.1 ±. 0.81	-22.1	-20	2.1	2.7	6.2	3.5	Stevens *et al.* (2013)
New Buildings	Hampshire	600-50 B.C	Cattle	17	-21.7 ± 0.45	4.68 ± 1.17	-22.7	-21	1.7	2.9	7.6	4.7	Stevens *et al.* (2013)
New Buildings	Hampshire	600-400	Dogs	1	-20.2	8.4							Stevens *et al.* (2013)
New Buildings	Hampshire	600-400	Horses	13	-22.48 ± 0.63	4.76 ± 1.10	-24	-21.1	2.9	3	7.2	4.2	Stevens *et al.* (2013)
New Buildings	Hampshire	600-50 B.C	Pigs	5	-21.24 + 0.36	6.4 ± 1.06	-21.6	-20.8	0.8	4.8	7.7	2.9	Stevens *et al.* (2013)
New Buildings	Hampshire	600-50 B.C	Sheep	19	-21.32 ± 0.31	4.8 ± 0.77	-22	-20.8	1.2	3.7	6.6	2.9	Stevens *et al.* (2013)
Suddern Farm	Hampshire	600-100 A.D	Cattle	39	-21.43 ± 0.32	3.66 ± 1.36	-22.1	-20.7	1.4	1.5	6.8	5.3	Stevens *et al.* (2013)
Suddern Farm	Hampshire	600-400	Dogs	1	-203	9.3							Stevens *et al.* (2013)
Suddern Farm	Hampshire	600-50 B.C	Horses	26	-22.07 ± 0.30	3.85 ± 1.40	-23	-21.6	1.4	1.7	7.1	5.4	Stevens *et al.* (2013)
Suddern Farm	Hampshire	600-100 A.D	Humans	37	-19.99 ± 0.35	8.84 ± 0.72	-20.5	-18.9	1.6	7.9	10.4	2.5	Stevens *et al.* (2014)
Suddern Farm	Hampshire	600-100 A.D	Pigs	8	-21.21 ± 0.29	5.95 ± 0.66	-21.6	-20.7	0.9	5.1	6.9	1.8	Stevens *et al.* (2013)
Suddern Farm	Hampshire	600-100 A.D	Sheep	32	-21.22 ± 0.37	4.12 ± 0.67	-21.9	-20.4	1.5	2.9	6.5	3.6	Stevens *et al.* (2013)
Winnal Down	Hampshire	Iron Age	Cattle	11	-21.8 ± 0.39	4.43 ± 1.12	-22.5	-21.3	1.2	3.6	7.3	3.7	Jay (2005); Jay and Richards

Site	Regions	Date	Species	n	Average $\partial^{13}C$ (‰)	Average $\partial^{15}N$ (‰)	Min $\partial^{13}C$ (‰)	Max $\partial^{13}C$ (‰)	range $\partial^{13}C$ (‰)	Min $\partial^{15}N$ (‰)	Max $\partial^{15}N$ (‰)	range $\partial^{15}N$ (‰)	Reference
													(2007)
Winnal Down	Hampshire	Iron Age	Humans	26	-20.48 ± 0.48	8.46 ± 1.76	-21.8	-19.9	1.9	7.4	12.3	4.9	Jay (2005); Jay and Richards (2007)
Winnal Down	Hampshire	Iron Age	Pigs	4	-21.35 ± 0.56	5.72 ± 0.97	-22	-20.7	1.3	4.3	6.5	2.2	Jay (2005); Jay and Richards (2007)
Winnal Down	Hampshire	Iron Age	Sheep	9	-21.59 ± 0.44	4.21 ± 0.76	-22.4	-21.1	1.3	3	5.2	2.2	Jay (2005); Jay and Richards (2007)
Gravesend	Kent	401-231 B.C.	Humans	2	-19.65 ± 0.21	10.1 ± 0.14							Redfern *et al.* (2008)
Yarnton	Oxfordshire	470. B.C - 50 B.D	Cattle	7	-21.76 ± 0.30	6.51 ± 1.54	-22.1	-21.3	0.8	4.2	9.1	4.9	Lightfoot *et al.* (2009)
Yarnton	Oxfordshire	470. B.C - 50 B.D	Horses	5	-22.38 ± 0.17	5.26 ± 1.02	-22.5	-22.1	0.4	3.9	6.7	2.8	Lightfoot *et al.* (2009)
Yarnton	Oxfordshire	400 -250 B.C.	Humans	27	-20.1 ± 0.36	11.09 ± 1	-20.9	-19.4	1.5	9.5	13.1	3.6	Lightfoot *et al.* (2009)
Yarnton	Oxfordshire	401 -250 B.C.	Pigs	5	-21.7 ± 0.66	8.42 ± 0.7	-22.2	-21.5	0.7	7.7	9.5	1.8	Lightfoot *et al.* (2009)
Yarnton	Oxfordshire	470. B.C -	Sheep	8	-21.44 ±	6.75 ±	-21.7	-21.2	0.5	4.5	8.6	4.1	Lightfoot

Site	Regions	Date	Species	n	Average $\partial^{13}C$ (‰)	Average $\partial^{15}N$ (‰)	Min $\partial^{13}C$ (‰)	Max $\partial^{13}C$ (‰)	range $\partial^{13}C$ (‰)	Min $\partial^{15}N$ (‰)	Max $\partial^{15}N$ (‰)	range $\partial^{15}N$ (‰)	Reference
		50 B.D			0.21	1.39							*et al.* (2009)
Wetwang Garton-Slack	Yorkshire	Iron Age	Cattle	13	-21.61 ± 0.42	4.69 ± 1.08	-22.3	-20.8	1.5	3.3	7.1	3.8	Jay (2005); Jay and Richards (2007)
Wetwang Garton-Slack	Yorkshire	Iron Age	Deer	3	-21.13 ± 0.40	5.73 ± 0.90	-21.6	-20.9	0.7	4.7	6.4	1.7	Jay (2005); Jay and Richards (2007)
Wetwang Garton-Slack	Yorkshire	Iron Age	Dogs	6	-20.76 ± 0.59	7.6 ± 1.23	-21.8	-20	1.8	5.3	8.8	3.5	Jay (2005); Jay and Richards (2007)
Wetwang Garton-Slack	Yorkshire	Iron Age	Horses	16	-22.01 ± 0.78	4.17 ± 2.09	-22.9	-20.2	2.7	2.2	6.2	4	Jay (2005); Jay and Richards (2007)
Wetwang Garton-Slack	Yorkshire	Iron Age - Middle Iron Age	Humans	74	-20.57 ± 0.32	9.67 ± 0.62	-21.4	-19.9	1.5	4.8	12.3	7.5	Jay (2005); Jay and Richards (2007)
Wetwang Garton-Slack	Yorkshire	Iron Age - Middle Iron Age	Pigs	12	-21.64 ± 0.66	6.42 ± 2.17	-22.4	-20.4	2	3.9	8.6	4.7	Jay (2005); Jay and Richards (2007)
Wetwang Garton-Slack	Yorkshire	Iron Age - Middle Iron Age	Sheep	19	-21.56 ± 0.72	4.91 ± 2.46	-22.8	-20.3	2.5	3.3	7.3	4	Jay (2005); Jay and Richards (2007)

A1.3.2 Roman Data

Table A1.3.2. Summary of the Roman data by site.

Site	Regions	Date A.D	Species	n	Average $\partial^{13}C$ (‰)	Average $\partial^{15}N$ (‰)	Min $\partial^{13}C$ (‰)	Max $\partial^{13}C$ (‰)	range $\partial^{13}C$ (‰)	Min $\partial^{15}N$ (‰)	Max $\partial^{15}N$ (‰)	range $\partial^{15}N$ (‰)	Reference
Poundbury	Dorset	43-400	Human	49	-19.25 ± 0.77	9.2 ± 1.2	-20.6	-17.8	2.8	6.7	12.1	5.4	Richards *et al.* 1998
Cirencester	Gloucestershire	275-400	Cattle	9	-21.9 ± 0.28	5.08 ± 1.68	-22.4	-21.5	0.9	2.9	7.4	4.5	Cummings 2008
Cirencester	Gloucestershire	275-400	Human	145	-19.74 ± 0.49	9.75 ± 1.01	-21.2	-18.6	2.6	7	11.9	4.9	Cummings 2008
Cirencester	Gloucestershire	275-400	Pig	8	-21.05 ± 0.45	7.21 ± 1.98	-21.6	-20.1	1.5	4.8	11	6.2	Cummings 2008
Cirencester	Gloucestershire	275-400	Sheep	11	-21.5 ± 0.57	5.51 ± 1.52	-22.8	-20.7	2.1	2.6	8	5.4	Cummings 2008
Costwolds Community	Gloucestershire	214-436	Human	24	-20.57 ± 0.39	9.77 ± 1	-21.5	-19.8	1.7	7.3	11.3	4	Cheung *et al.* 2011
GambierParryLodge	Gloucestershire	100-300	Cattle	7	-21.93 ± 0.24	5.17 ± 1.02	-22.2	-21.6	0.6	4.2	7.4	3.2	Cummings 2008
GambierParryLodge	Gloucestershire	100-200	Chicken	1	-20.7	8.8							Cummings 2008
GambierParryLodge	Gloucestershire	100-200	Horse	2	-22 ± 0.22	5.95 ± 1.76							Cummings 2008
GambierParryLodge	Gloucestershire	100-300	Human	32	-19.31 ± 0.55	10.78 ± 0.78	-20.3	-18.4	1.9	9.3	12.6	3.3	Cummings 2008
GambierParryL	Gloucestershire	100-200	Pig	1	-21.4	7.6							Cummings

Site	Regions	Date A.D	Species	n	Average $\partial^{13}C$ (‰)	Average $\partial^{15}N$ (‰)	Min $\partial^{13}C$ (‰)	Max $\partial^{13}C$ (‰)	range $\partial^{13}C$ (‰)	Min $\partial^{15}N$ (‰)	Max $\partial^{15}N$ (‰)	range $\partial^{15}N$ (‰)	Reference
odge													2008
GambierParryLodge	Gloucestershire	100-200	Sheep	2	-21.75 ± 0.35	5.15 ± 1.20							Cummings 2008
Horcott Quarry	Gloucestershire	247-400	Human	22	-20.11 ± 0.33	9.31 ± 0.73	-20.7	-19.5	1.2	7.8	10.9	3.1	Cheung *et al.* 2011
Hucclecote	Gloucestershire	50-100	Cattle	4	-21.85 ± 0.4	7.32 ± 1.07	-22.2	-21.5	0.7	6.5	8.9	2.4	Cummings 2008
Hucclecote	Gloucestershire	50-100	Human	8	-20.04 ± 0.18	10.79 ± 0.53	-20.3	-19.8	0.5	10.2	11.9	1.7	Cummings 2008
Hucclecote	Gloucestershire	50-100	Sheep	3	-21.3 ± 0.51	6.23 ± 1.88	-21.6	-20.7	0.9	5	8.4	3.4	Cummings 2008
LondonRoad_Gloucester (Cemetery)	Gloucestershire	43-300	Human	25	-19.78 ± 0.42	10.64 ± 0.81	-20.8	-19	1.8	8.8	12	3.2	Cheung *et al.* 2011
LondonRoad_Gloucester (Pit)	Gloucestershire	100-300	Cattle	4	-21.65 ± 0.33	6.62 ± 0.36	-22.2	-21.8	0.4	4.2	7.4	3.2	Chenery *et al.* 2010
LondonRoad_Gloucester (Pit)	Gloucestershire	150 - 250	Human	33	-19.74 ± 0.48	10.91 ± 1.21	-20.5	-18.8	1.7	8.7	12.6	3.9	Chenery *et al.* 2010; Cheung *et al.* 2011
LondonRoad_Gloucester (Pit)	Gloucestershire	100-300	Pig	1	-21.4	5.5							Chenery *et al.* 2010
LondonRoad_Gloucester (Pit)	Gloucestershire	200-400	Sheep	1	-21.4	5.4							Chenery *et al.* 2010
Winchester	Hampshire	200-300	Cattle	11	-21.89 ± 0.42	5.5 ± 1.06	-22.7	-21.1	1.6	4.5	7.8	3.3	Cummings 2008
Winchester	Hampshire	200-300	Human	107	-19.13 ± 0.42	8.7 ± 0.98	-20.1	-18.2	1.9	6.8	12.2	5.4	Cummings 2008
Winchester	Hampshire	200-300	Pig	12	-21.19 ±	5.89 ± 1.28	-21.8	-20.5	1.3	4.2	8.2	4	Cummings

Site	Regions	Date A.D	Species	n	Average $\partial^{13}C$ (‰)	Average $\partial^{15}N$ (‰)	Min $\partial^{13}C$ (‰)	Max $\partial^{13}C$ (‰)	range $\partial^{13}C$ (‰)	Min $\partial^{15}N$ (‰)	Max $\partial^{15}N$ (‰)	range $\partial^{15}N$ (‰)	Reference
					0.44								2008
Winchester	Hampshire	200-300	Sheep	14	-21.55 ± 0.53	4.55 ± 1.52	-22.2	-20.6	1.6	2.2	6.9	4.7	Cummings 2008
Gravesend	Kent	250-350	Human	10	-19.33 ± 1.48	9.43 ± 1.33	-20.4	-15.2	5.2	7.6	12	4.4	Pollard *et al.* 2011
Minster Road	Kent	50-250	Deer	3	-21.77 ± 1.33	5.4 ± 1.21	-22.9	-20.3	2.6	4.3	6.7	2.4	Madgwick *et al.* 2013
Monkton	Kent	43-410	Deer	8	-20.98 ± 0.50	6.51 ± 0.96	-21.8	-20	1.8	5.5	8.5	3	Madgwick *et al.* 2013
Alchester	Oxfordshire	350-410	Cattle	8	-21.54 ± 0.31	6.27 ± 0.36	-22	-21.1	0.9	5.7	6.8	1.1	Cummings 2008
Alchester	Oxfordshire	350-410	Human	13	-19.98 ± 0.59	9.53 ± 0.84	-20.9	-19	1.9	8	10.8	2.8	Cummings 2008
Alchester	Oxfordshire	350-410	Pig	1	-20.3	7.5							Cummings 2008
Alchester	Oxfordshire	350-410	Sheep	4	-21.7 ± 0.57	7.67 ± 2.26	-22.4	-21	1.4	5.6	10.5	4.9	Cummings 2008
Asthall	Oxfordshire	200-300	Cattle	8	-21.66 ± 0.29	5.55 ± 2.33	-22.1	-21.3	0.8	2.4	8.5	6.1	Cummings 2008
Asthall	Oxfordshire	200-300	Human	9	-19.13 + 0.45	9.35 ± 1.12	-20	-18.5	1.5	7.9	11.4	3.5	Cummings 2008
Asthall	Oxfordshire	200-300	Pig	2	-20.45 ± 0.21	5.5 ± 0.49							Cummings 2008
Asthall	Oxfordshire	200-300	Sheep	7	-21.03 ± 0.51	7.11 ± 1.04	-21.3	-19.9	1.4	5.5	8.3	2.8	Cummings 2008

Site	Regions	Date A.D	Species	n	Average $\partial^{13}C$ (‰)	Average $\partial^{15}N$ (‰)	Min $\partial^{13}C$ (‰)	Max $\partial^{13}C$ (‰)	range $\partial^{13}C$ (‰)	Min $\partial^{15}N$ (‰)	Max $\partial^{15}N$ (‰)	range $\partial^{15}N$ (‰)	Reference
Queenford	Oxfordshire	375-550	Human	87	-19.86 ± 0.40	10.44 ± 1.1	-20.8	-18.9	1.9	7.9	13.6	5.7	Fuller *et al.* 2006
Stanton Court	Oxfordshire	250-350	Human	27	-19.95 ± 0.27	10.92 ± 0.74	-20.6	-19.3	1.3	9.1	12	2.9	Cummings 2008
Yarnton	Oxfordshire	43-400	Cattle	13	-21.5 ± 0.36	6.89 ± 1.92	-22.4	-21	1.4	3.8	10.4	6.6	Lightfoot *et al.* 2009
Yarnton	Oxfordshire	43-400	Dog	5	-20.24 ± 0.20	11.02 ± 10.6	-20.5	-20	0.5	9.4	12.4	3	Lightfoot *et al.* 2009
Yarnton	Oxfordshire	43-400	Horse	8	-22.31 ± 0.30	7.31 ± 1.36	-22.8	-21.8	1	4.8	9.5	4.7	Lightfoot *et al.* 2009
Yarnton	Oxfordshire	43-410	Human	7	-19.66 ± 0.28	11.76 ± 2.11	-19.9	-19.1	0.8	8.1	14	5.9	Lightfoot *et al.* 2009
Yarnton	Oxfordshire	43-410	Pig	10	-21.6 ± 0.50	8.67 ± 1.08	-22.1	-20.8	1.3	6.4	10	3.6	Lightfoot *et al.* 2009
Yarnton	Oxfordshire	43-410	Sheep	12	-21.44 ± 0.26	7.34 ± 1.75	-21.9	-20.9	1	4.9	10	5.1	Lightfoot *et al.* 2009
Bradley Hill	Somerset	320-360	Cattle	5	-20.02 ± 0.42	6.72 ± 0.61	-22.5	-21.5	1	5.7	7.2	1.5	Cummings 2008
Bradley Hill	Somerset	320-360	Human	42	-20.63 ± 0.54	10.32 ± 0.78	-21.6	-19.1	2.5	8.5	11.8	3.3	Cummings 2008
Bradley Hill	Somerset	320-360	Pig	2	-21.2 ± 0.98	6.9 ± 0.29							Cummings 2008
Bradley Hill	Somerset	320-360	Sheep	7	-21.64 ± 0.57	7.05 ± 1.42	-22.7	-21	1.7	4.9	8.7	3.8	Cummings 2008
Fishbourne	Sussex	100-200	Deer	34	-21.94 ± 0.4	6.45 ± 1.18	-22.8	-20.9	1.9	3.8	10.1	6.3	Madgwick *et al.* 2013

Site	Regions	Date A.D	Species	n	Average $\partial^{13}C$ (‰)	Average $\partial^{15}N$ (‰)	Min $\partial^{13}C$ (‰)	Max $\partial^{13}C$ (‰)	range $\partial^{13}C$ (‰)	Min $\partial^{15}N$ (‰)	Max $\partial^{15}N$ (‰)	range $\partial^{15}N$ (‰)	Reference
3DT	Yorkshire	200-400	Human	50	-19.49 ± 0.65	10.85 ± 0.79	-20.4	-16.3	4.1	9.3	12.9	3.6	Müldner *et al.* 2010
6DT	Yorkshire	200-400	Human	18	-19.60 ± 1.07	11.08 ± 0.78	-20.9	-16.8	4.1	9.6	12.8	3.2	Müldner *et al.* 2011
Blossom Street	Yorkshire	200-300	Human	17	-19.86 ± 0.73	11.36 ± 0.47	-21.8	-18.8	3	10.4	12	1.6	Müldner 2005
Catterick	Yorkshire	200-400	Cattle	7	-21.6 ± 0.14	5.14 ± 0.62	-21.8	-21.4	0.4	4.3	6.1	1.8	Chenery *et al.* 2011
Catterick	Yorkshire	200-400	Dog	3	-20.23 ± 0.15	9.86 ± 0.05	-20.4	-20.1	0.3	9.8	9.8	0	Chenery *et al.* 2011
Catterick	Yorkshire	200-400	Horse	1	-22.6	6.7	N/A	N/A	N/A	N/A	N/A	N/A	Chenery *et al.* 2011
Catterick	Yorkshire	200-400	Human	20	-19.96 ± 0.54	10.77 ± 0.65	-20.8	-19	1.8	9.5	11.9	2.4	Chenery *et al.* 2011
Catterick	Yorkshire	200-400	Pig	5	-21.16 ± 0.43	8.02 ± 2.1	-21.6	-20.6	1	5.6	10.4	4.8	Chenery *et al.* 2011
Catterick	Yorkshire	200-400	Sheep	9	-21.66 ± 0.22	6.15 ± 1	-22	-21.3	0.7	5	7.8	2.8	Chenery *et al.* 2011
Catterick Bridge	Yorkshire	200-400	Human	8	-20.23 ± 0.42	9.75 ± 0.80	-20.9	-19.7	1.2	9.8	11.6	1.8	Chenery *et al.* 2011
Dere Street Catterick	Yorkshire	200-400	Human	1	-20.8	11.8							Chenery *et al.* 2011
Honey Pot Road (Catterick)	Yorkshire	200-400	Human	2	-20.35 ± 0.21	11.15 ± 0.35							Chenery *et al.* 2011
Trentholme Drive	Yorkshire	150-300	Human	42	-19.47 ± 0.59	11.13 ± 0.84	-20.5	-17.1	3.4	9.2	14.1	4.9	Müldner 2005
York	Yorkshire	200-400	Cattle	6	-21.70 ± 0.39	6.9 ± 1.03	-22.1	-21	1.1	5.4	8.6	3.2	Müldner 2005
York	Yorkshire	200-400	Chicken	7	-21 + 0.87	9.64 + 2.01	-22.6	-19.9	2.7	6.5	12.9	6.4	Müldner

Site	Regions	Date A.D	Species	n	Average $\partial^{13}C$ (‰)	Average $\partial^{15}N$ (‰)	Min $\partial^{13}C$ (‰)	Max $\partial^{13}C$ (‰)	range $\partial^{13}C$ (‰)	Min $\partial^{15}N$ (‰)	Max $\partial^{15}N$ (‰)	range $\partial^{15}N$ (‰)	Reference
													2005
York	Yorkshire	200-400	Goose	2	-21.95 ± 0.21	6.95 ± 2.88	N/A	N/A	N/A	N/A	N/A	N/A	Müldner 2005
York	Yorkshire	200-400	Human	7	-19.83 + 0.65	11.27 ± 0.44	-20.8	-18.9	1.9	10.5	11.8	1.3	Müldner 2005
York	Yorkshire	200-400	Pig	13	-22.05 + 0.54	6.92 ± 1.33	-22.8	-21.3	1.5	4.6	8.9	4.3	Müldner 2005
York	Yorkshire	200-400	Sheep	5	-21.62 ± 0.39	5.92 ± 1.47	-22.3	-21.3	1	4	7.9	3.9	Müldner 2005
York	Yorkshire	200-400	Dog	3	-20.16 ± 0.28	9.66 ± 0.2	-20.5	-20	0.5	9.5	9.9	0.4	Müldner 2005
York	Yorkshire	200-400	Swan	2	-22.1 ± 0.14	11.2 ± 0.84							
York	Yorkshire	200-400	wild boar	1	-20.1	6.4							
York	Yorkshire	200-400	wild duck	1	-19.7	8.9							
York	Yorkshire	200-400	wood pigeon	1	-21.3	4.8							

A1.3.3 Early Medieval

Table A1.3.3 Summary of the Early Medieval data by site

Site	Regions	Date	Species	n	Average $\partial^{13}C$ (‰)	Average $\partial^{15}N$ (‰)	Min $\partial^{13}C$ (‰)	Max $\partial^{13}C$ (‰)	range $\partial^{13}C$ (‰)	Min $\partial^{15}N$ (‰)	Max $\partial^{15}N$ (‰)	range $\partial^{15}N$ (‰)	Reference
Marina Drive	Bedfordshire	400-600	Humans	2	-20.35 ± 0.07	10.4 ± 0.91							Mayes and Beavan (2012)
Aston Clinton	Buckinghamshire	400-600	Humans	1	-20.8	9.4							Mayes and Beavan (2012)
Edix Hill	Cambridgeshire	400-600	Humans	8	-20.26 ± 0.18	9.91 ± 0.63	-20.6	-20	0.6	8.8	10.9	2.1	Mayes and Beavan (2012)
Melbourne	Cambridgeshire	400-600	Humans	9	-20.2 ± 0.13	9.53 ± 0.5	-20.4	-20	0.4	8.9	10.4	1.5	Mayes and Beavan (2012)
Lechlade	Gloucestershire	400-600	Humans	9	20.22 ± 0.38	9.43 ± 1.09	-20.7	-19.6	1.1	8	11.4	3.4	Mayes and Beavan (2012)
Abbot's Worthy	Hampshire	400 - 500	Cattle	22	-21.68 ± 0.79	4.7 ± 1.03	-23.02	-20.31	2.71	1.75	6.35	4.6	Hull (2007)
Abbot's Worthy	Hampshire	400 - 500	Sheep	54	-21.61 ± 0.58	4.37 ± 0.82	-23.54	-20.43	3.11	2.92	6.45	3.53	Hull (2007)

Site	Regions	Date	Species	n	Average $\partial^{13}C$ (‰)	Average $\partial^{15}N$ (‰)	Min $\partial^{13}C$ (‰)	Max $\partial^{13}C$ (‰)	range $\partial^{13}C$ (‰)	Min $\partial^{15}N$ (‰)	Max $\partial^{15}N$ (‰)	range $\partial^{15}N$ (‰)	Reference
Abbot's Worthy	Hampshire	400 - 500	Pig	7	21.25 ± 0.87	6.05 ± 1.41	-22.19	-19.77	2.42	4.5	8.52	4.02	Hull (2007)
Alton	Hampshire	475-625	Humans	37	-20.48 ± 0.27	9.11 ± 0.82	-21.04	-19.8	1.24	7.9	11.21	3.31	Hull (2007)
Droxford	Hampshire	400-625	Humans	34	'-20.18 ± 0.37	8.87 ± 0.74	-20.88	-19.02	1.86	7.47	10.41	2.94	Hull (2007)
Portway	Hampshire	500 -600	Humans	70	-19.84 ± 0.60	8.32 ± 0.91	-21.32	-18.37	2.95	7.32	11.08	3.76	Hull (2007)
Shavards Farm	Hampshire	450 -650 A.D	Humans	13	-19.63 ± 0.21	8.77 ± 0.45	-20.03	-19.33	0.7	8.21	9.8	1.59	Hull (2007)
Shavards Farm	Hampshire	450 -650 A.D	Cattle	30	-22.40 ± 0.47	4.51 ± 0.81	-23.29	-20.93	2.36	2.7	6.9	4.2	Hull (2007)
Shavards Farm	Hampshire	450 -650 A.D	Sheep	26	-22.01 ± 0.61	4.86 ± 1.13	-23.37	-20.61	2.76	1.97	7.67	5.7	Hull (2007)
Shavards Farm	Hampshire	451 -650 A.D	Pig	7	21.88 ± 0.55	4.5 ± 0.92	-22.39	-20.88	1.51	3.7	6.31	2.61	Hull (2007)
Winnall	Hampshire	600 -700	Humans	37	--20.20 ± 0.25	9.01 ± 0.93	-20.66	-19.83	0.83	6.66	11.01	4.35	Hull (2007)
Worthy_Park	Hampshire	450-650	Humans	35	-20.37 ± 0.33	8.65 ± 1.16	-21.6	-19.84	1.77	6.88	12.31	5.43	Hull (2007)

Site	Regions	Date	Species	n	Average $\partial^{13}C$ (‰)	Average $\partial^{15}N$ (‰)	Min $\partial^{13}C$ (‰)	Max $\partial^{13}C$ (‰)	range $\partial^{13}C$ (‰)	Min $\partial^{15}N$ (‰)	Max $\partial^{15}N$ (‰)	range $\partial^{15}N$ (‰)	Reference
							1						
Dover Buckland	Kent	400-600	Humans	6	-19.77 ± 0.05	9.6 ± 0.51	-19.8	-19.7	0.1	8.9	10.4	1.5	Mayes and Beavan (2012)
Mill Hill	Kent	400-600	Humans	8	-19.76 ± 0.41	9.65 ± 0.46	-20.3	-19.1	1.2	8.8	10.1	1.3	Mayes and Beavan (2012)
St Peter's Tip	Kent	400-600	Humans	12	-19.86 ± 0.22	9.52 ± 0.65	-20.1	-19.4	0.7	8.3	10.6	2.3	Mayes and Beavan (2012)
BerghApton	Norfolk	450 -650 A.D	Humans	13	-20.86 ± 0.46	9.72 ± 0.57	-21.71	-20	1.71	9.1	10.68	1.58	Hull (2007)
BurghCastle	Norfolk	630-850	Humans	28	-19.77 ± 0.62	10.89 ± 1.18	-21.7	-18.59	3.11	6.79	12.76	5.97	Hull (2007)
Caister-by-Yarmouth	Norfolk	720 -870	Humans	21	-19.48 ± 0.78	12.27 ± 1.43	-22.12	-18.76	3.36	7.34	13.63	6.29	Hull (2007)
Morningthorpe	Norfolk	450-550 A.D	Humans	19	-20.68 ± 0.34	10.42 ± 0.63	-21.29	-20.05	1.24	9.51	11.77	2.26	Hull (2007)
Norwich	Norfolk	800 - 1000	Humans	17	-19.21 ± 0.97	11.15 ± 0.87	-20.6	-17	3.6	9.8	13.5	3.7	Bayliss *et al.* (2004)
SouthAcre	Norfolk	450 -850 A.D	Humans	12	-19.14 ± 0.34	11.67 ± 0.76	-19.74	-18.76	0.98	10.88	13.64	2.76	Hull (2007)
SpongHill	Norfolk	450-550 A.D	Humans	6	-20.80 ± 0.45	10.54 ± 0.45	-21.62	-20.29	1.33	9.92	10.93	1.01	Hull (2007)

Site	Regions	Date	Species	n	Average $\partial^{13}C$ (‰)	Average $\partial^{15}N$ (‰)	Min $\partial^{13}C$ (‰)	Max $\partial^{13}C$ (‰)	range $\partial^{13}C$ (‰)	Min $\partial^{15}N$ (‰)	Max $\partial^{15}N$ (‰)	range $\partial^{15}N$ (‰)	Reference
Swaffham	Norfolk	475 - 600	Humans	10	-20.33 ± 0.53	9.65 ± 1.02	-21.75	-19.91	1.84	9	12.26	3.26	Hull (2007)
Barton upon Humber	North Lincolnshire	Anglo-Saxon	Humans	9	-20.48 ± 0.42	11.32 ± 1.55	-21.32	-19.79	1.53	7.6	12.6	5	McPherson (2005)
Casteldyke South	North Lincolnshire	400-600	Humans	7	-20.8 ± 0.36	10.24 ± 0.82	-21.3	-20.3	1	8.9	11.5	2.6	Mayes and Beavan (2012)
Fillingham	North Lincolnshire	660-1160 A.D	Humans	2	-20.76 ± 0.19	11.15 ± 0.96							McPherson (2005)
Kilton Hill	North Lincolnshire	Anglo-Saxon	Humans	2	-20.48 ± 0.04	12.90 ± 0.14							McPherson (2005)
Whitton	North Lincolnshire	560-960	Humans	2	-20.55 ± 0.18	11.15 ± 0.35							McPherson (2005)
Whitton	North Lincolnshire	560-960	Cattle	3	-21.89 ± 0.8	6.4 ± 2.58	-22.81	-21.33	1.48	3.91	9.08	5.17	McPherson (2005)
Whitton	North Lincolnshire	560-960	Dog	1	-20.63	11.44							McPherson (2005)
Whitton	North Lincolnshire	560-960	Pig	2	-21.66 ± 0.07	11.35 ± 1.01							McPherson (2005)
Whitton	North Lincolnshire	560-960	Sheep	3	-21.83 ± 0.41	8.97 ± 0.84	-22.6	-21.44	1.16	8	9.48	1.48	McPherson (2005)
Black Gate Cemetary_Newcastle	Northumberland	600 - 1100	Humans	55	-20.49 ± 0.55	5.75 ± 1.08	-21.59	-19.12	2.47	9.06	14.94	5.88	McPherson (2005)
Black Gate Cemetary_Newcas	Northumberland	600 - 1100	Cattle	6	-21.96 ± 0.36	6.45 ± 1.16	-22.4	-21.6	0.83	8.44	5.19	8.44	McPherson (2005)

Site	Regions	Date	Species	n	Average $\partial^{13}C$ (‰)	Average $\partial^{15}N$ (‰)	Min $\partial^{13}C$ (‰)	Max $\partial^{13}C$ (‰)	range $\partial^{13}C$ (‰)	Min $\partial^{15}N$ (‰)	Max $\partial^{15}N$ (‰)	range $\partial^{15}N$ (‰)	Reference
tle							3						
Black Gate Cemetary_Newcastle	Northumberland	600 - 1100	Sheep	4	-21.97 ± 0.11	6.53 ± 1.57	-22.06	-21.81	0.25	5.29	8.65	8.44	McPherson (2005)
Black Gate Cemetary_Newcastle	Northumberland	601 - 1100	Pig	6	-21.33 ± 0.52	8.42 ± 1.42	-22.06	-20.79	1.27	6.9	10.34	8.44	McPherson (2005)
Black Gate Cemetary_Newcastle	Northumberland	601 - 1100	Dog	1	-19.8	11.27							McPherson (2005)
Alchester	Oxfordshire	410-450	Humans	8	-19.94 ± 0.55	9.11 ± 0.95	-20.5	-18.8	1.7	8	10.9	2.9	Cummings (2008)
Berinsfield	Oxfordshire	450-700	Humans	95	-20.09 ± 0.25	9.83 ± 0.89	-20.7	-19.1	1.6	8.4	12.8	4.4	Privat *et al.* (2002)
Berinsfield	Oxfordshire	450-700	Cattle	4	-21.57 ± 0.20	5.75 ± 0.42	-21.8	-21.4	0.4	5.3	6.3	1	Privat *et al.* (2002)
Berinsfield	Oxfordshire	450-700	Sheep		-21.3 ± 0.14	6.1 ± 0.42							Privat *et al.* (2002)
Berinsfield	Oxfordshire	450-700	Pig	1	-20.9	6							Privat *et al.* (2002)
St JohnsCollege	Oxfordshire	1002 ?	Humans	38	-19.65 ± 0.35	12.02 ± 0.73	-20.57	-18.69	1.88	10.6	13.41	2.81	Pollard *et al.* (2012)
Yarnton	Oxfordshire	Anglo-Saxon	Humans	8	-19.81 ± 0.26	11.79 ± 1.34	-20.2	-19.5	0.7	9.99	13.5	3.51	Lightfoot *et al.* 2009
Buttermarket	Suffolk	400-600	Humans	1	-20.2	10.7							Mayes and Beavan (2012)

Site	Regions	Date	Species	n	Average $\partial^{13}C$ (‰)	Average $\partial^{15}N$ (‰)	Min $\partial^{13}C$ (‰)	Max $\partial^{13}C$ (‰)	range $\partial^{13}C$ (‰)	Min $\partial^{15}N$ (‰)	Max $\partial^{15}N$ (‰)	range $\partial^{15}N$ (‰)	Reference
Coddenham	Suffolk	400-600	Humans	1	-20.4	10.3							Mayes and Beavan (2012)
Lakenheath	Suffolk	400-600	Humans	1	-19.8	9.2							Mayes and Beavan (2012)
WestgarthGardens	Suffolk	400-650	Humans	67	-20.16 ± 0.3	10.04 ± 0.91	-20.85	-18.64	2.21	8.4	14.09	5.69	Mayes and Beavan (2012); Hull (2007)
WestStow	Suffolk	Anglo-Saxon	Cattle	46	-21.48 ± 0.64	5.45 ± 1.04	-22.95	-20.43	2.52	3.4	7.84	4.44	Hull (2007)
WestStow	Suffolk	Anglo-Saxon	Sheep	71	-21.22 ± 0.65	6.08 ± 0.89	-24.48	-20.02	4.46	3.81	8.14	4.33	Hull (2007)
WestStow	Suffolk	Anglo-Saxon	Pig	33	-21.20 ± 0.46	7.04 ± 1.32	-21.92	-19.58	2.34	4.67	10.53	5.86	Hull (2007)
Galley Hill	Surrey	400-600	Humans	1	-20.2	10.4							Mayes and Beavan (2012)
Appledown Compton	Sussex	400-600	Humans	3	-20.36 ± 0.20	8.2 ± 0.43	-20.6	-20.2	0.4	7.9	8.7	0.8	Mayes and Beavan (2012)
Wasperton	Warwickshire	400 - 700	Humans	7	-20.11 ± 0.41	11.18 ± 0.87	-20.6	-19.5	1.1	10	12.3	2.3	Müldner (2006)
Ford Lavestock	Wiltshire	400-600	Humans	1	-20.4	9							Mayes and Beavan

Site	Regions	Date	Species	n	Average $\partial^{13}C$ (‰)	Average $\partial^{15}N$ (‰)	Min $\partial^{13}C$ (‰)	Max $\partial^{13}C$ (‰)	range $\partial^{13}C$ (‰)	Min $\partial^{15}N$ (‰)	Max $\partial^{15}N$ (‰)	range $\partial^{15}N$ (‰)	Reference
													(2012)
Bellevue_York	Yorkshire	650 -750	Humans	37	-20.04 ± 0.3	10.16 ± 0.95	-20.7	-19.4	1.3	7.7	12	4.3	Müldner (2005)
Bellevue_York	Yorkshire	720-870	Cattle	3	-22.17 ± 0.61	4.76 ± 0.51	-22.7	-21.5	1.2	4.2	5.2	1	Müldner (2005)
Bellevue_York	Yorkshire	750 -850	Sheep	4	-21.90 ± 0.33	5.50 ± 0.76	-21.9	-21.1	0.8	4.4	6.1	1.7	Müldner (2005)
Bellevue_York	Yorkshire	750 -850	Pig	6	-21.65 ± 0.20	7.43 ± 1.01	-21.9	-21.4	0.5	5.9	8.6	2.7	Müldner (2005)
Bellevue_York	Yorkshire	751 -850	Freshwater Fish	4	-23.93 ± 1.01	10.32 ± 1.75	-25	-22.7	2.3	8.8	12.5	3.7	Müldner (2005)
Bellevue_York	Yorkshire	752 -850	Marine Fish	1	-15.2	11							Müldner (2005)
Bellevue_York	Yorkshire	752 -850	Salmonid	1	-14.7	12.9							Müldner (2005)
Fishergate_York	Yorkshire	950-1200 A.D	Humans	48	-19.7 ± 0.63	11.37 ± 1.23	-20.9	-18.1	2.8	8.8	14.9	6.1	Müldner (2005)
Fishergate_York	Yorkshire	950-1200 A.D	Cattle	10	-21.67 ± 0.41	5.43 ± 1.02	-22.4	-21	1.4	4	7.2	3.2	Müldner (2005)
Fishergate_York	Yorkshire	950-1200 A.D	Sheep	8	-21.71 ± 0.35	5.16 ± 1.78	-22.1	-21	1.1	2.7	8.5	5.8	Müldner (2005)
Fishergate_York	Yorkshire	950-1200 A.D	Pig	19	21.54 ± 0.48	7.84 ± 1.21	-22.4	-20.7	1.7	6.3	10.7	4.4	Müldner (2005)
Fishergate_York	Yorkshire	950-1200 A.D	Bird	2	-20.35 ± 0.35	10 ± 0.70							Müldner (2005)
Fishergate_York	Yorkshire	950-1200 A.D	Cat	5	-20.3 ± 0.49	9.54 ± 0.35	-20.7	-19.5	1.2	9.1	9.9	0.8	Müldner (2005)
Fishergate_York	Yorkshire	950-1200 A.D	Chicken	8	-20.57 ± 0.54	10.76 ± 1.11	-21.4	-19.7	1.7	9.2	12.4	3.2	Müldner (2005)

Site	Regions	Date	Species	n	Average $\partial^{13}C$ (‰)	Average $\partial^{15}N$ (‰)	Min $\partial^{13}C$ (‰)	Max $\partial^{13}C$ (‰)	range $\partial^{13}C$ (‰)	Min $\partial^{15}N$ (‰)	Max $\partial^{15}N$ (‰)	range $\partial^{15}N$ (‰)	Reference
Fishergate_York	Yorkshire	950-1200 A.D	Freshwater Fish	7	-21.1 ± 4.32	12.6 ± 1.34	-25.7	-13.1	12.6	11.2	14.9	3.7	Müldner (2005)
Fishergate_York	Yorkshire	950-1200 A.D	Goose	3	-21.63 ± 0.3	11.93 ± 3.03	-21.9	-21.3	0.6	9.4	15.3	5.9	Müldner (2005)
Fishergate_York	Yorkshire	950-1200 A.D	Marine Fish	12	-14.32 ± 1.14	12.93 ± 1.64	-15.8	-12.4	3.4	10.6	15.4	4.8	Müldner (2005)
Fishergate_York	Yorkshire	950-1200 A.D	Salmonid	5	-15.1 ± 0.63	10.9 ± 2.63							Müldner (2005)
West Heslerton	Yorkshire	400-600	Humans	1	-20.3	8.9							Mayes and Beavan (2012)

Appendixes I.4 – Location of the sites within England.

Table A1.4.1 Location of the sites in England.

Site	Archaeological_Period	Region	Latitude	Longitude
Abbot's Worthy	Early Medieval	Hampshire	51.09	-1.28
Alchester	Roman/Early Medieval	Oxfordshire	51.87	-1.17
Alington Avenue	Iron Age	Dorset	50.71	-2.44
Alton	Early Medieval	Hampshire	51.15	-0.97
Appledown Compton	Early Medieval	Sussex	50.83	-0.77
Asthall	Roman	Oxfordshire	51.79	-1.58
Aston Clinton	Early Medieval	Buckinghamshire	51.79	-0.72
Barton-upon-Humber	Early Medieval	Lincolnshire	53.68	-0.44
Bergh Apton	Early Medieval	Norfolk	52.55	1.4
Berinsfield	Early Medieval	Oxfordshire	51.66	-1.17
Black Gate Cemetery	Early Medieval	Northumberland	54.97	-1.61
Bloodmoor Hill	Early Medieval	Suffolk	52.45	1.69
Bradley hill	Roman	Somerset	51.05	-2.73
BurghCastle	Early Medieval	Norfolk	52.58	1.65
Bury Hill	Iron Age	Hampshire	51.18	-1.49
Butler's Field	Early Medieval	Gloucestershire	51.69	-1.69
Buttermarket	Early Medieval	Suffolk	52.05	1.14
Caister-by-Yarmouth	Early Medieval	Norfolk	52.64	1.72
Casteldyke South	Early Medieval	Lincolnshire	53.67	-0.44
Catterick	Roman	Yorkshire	54.37	-1.62
Cirencester	Roman	Gloucestershire	51.71	-1.96
Coddenham	Early Medieval	Suffolk	52.14	1.11
Cotswolds Community	Roman	Gloucestershire	51.87	-1.76
Danebury	Iron Age	Hampshire	51.13	-1.53
Dover Buckland	Early Medieval	Kent	51.12	1.31
Droxford	Early Medieval	Hampshire	50.95	-1.13
East Kent Access Road	Roman	Kent	51.36	1.34
Edix Hill	Early Medieval	Cambridgeshire	52.13	0.03
Fillingham	Early Medieval	North Lincolnshire	53.36	-0.57
Fishbourne	Roman	Sussex	50.83	-0.81
Flagstones	Iron Age	Dorset	50.71	-2.44
Ford Lavestock	Early Medieval	Wiltshire	51.07	-1.77
Fordington Bottom	Iron Age	Dorset	50.71	-2.47
Galley Hill	Early Medieval	Surrey	51.32	-0.2

Site	Archaeological_Period	Region	Latitude	Longitude
Glastonbury Lake Village	Iron Age	Somerset	51.16	-2.72
Gloucester	Roman	Gloucestershire	51.86	-2.23
Gravesend	Iron Age/Roman	Kent	51.44	0.37
Gussage All Saints	Iron Age	Dorset	50.9	-1.99
Harlyn Bay	Iron Age	Cornwall	50.53	-4.99
Horcott Quarry	Roman	Gloucestershire	51.67	-1.77
Houghton Down	Iron Age	Hampshire	51.09	-1.52
Hucclecote	Roman	Gloucestershire	51.85	-2.17
Kilton Hill	Early Medieval	Northamptonshire	53.3	-1.12
Lakenheath	Early Medieval	Suffolk	52.41	0.52
Lechlade	Iron Age/Early Medieval	Gloucestershire	51.69	-1.69
London Bridge	Roman	London	51.5	-0.12
Manor Farm	Iron Age	Dorset	50.67	-2.56
Marina Drive	Early Medieval	Bedfordshire	51.88	-0.52
Masham	Early Medieval	Yorkshire	54.22	-1.655
Melbourn Water Lane	Early Medieval	Cambridgeshire	52.08	0.02
Michel Dewer Wood	Iron Age	Hampshire	51.13	-1.23
Mill Hill	Early Medieval	Kent	51.22	1.4
Minster	Roman	Kent	51.33	1.31
Monkton	Roman	Kent	51.33	1.27
Morningthorpe	Early Medieval	Norfolk	52.5	1.25
Nettlebank Copse	Iron Age	Hampshire	51.14	-1.51
New Buildings	Iron Age	Hampshire	51.12	-1.54
Norwich	Early Medieval	Norfolk	52.63	1.29
Portway	Early Medieval	Hampshire	51.21	-1.49
Poundbury	Roman	Dorset	50.71	-2.46
Queenford	Roman/Early Medieval	Oxfordshire	51.64	-1.16
Raunds Furnell	Early Medieval	Northamptonshire	52.34	-0.53
Shavard	Early Medieval	Hampshire	50.97	-1.12
Silvester Street	Roman/Early Medieval	London	51.5	-0.12
South Acre	Early Medieval	Norfolk	52.69	0.67
Spong Hill	Early Medieval	Norfolk	52.75	0.94
St John's College	Early Medieval	Oxfordshire	51.75	-1.25
St Peter's Tip	Early Medieval	Kent	51.35	1.43
Stanton Harcourt	Roman/Early Medieval	Oxfordshire	51.74	-1.4
Suddern Farm	Iron Age	Hampshire	51.14	-1.59
Swaffham	Early Medieval	Norfolk	52.64	0.68
Tolpuddle Ball	Iron Age	Dorset	50.75	-2.26
Trethellan Farm	Iron Age	Cornwall	50.2	-5.19
Trevelgue Head	Iron Age	Cornwall	50.25	-5.03

Site	Archaeological_Period	Region	Latitude	Longitude
Wasperton	Early Medieval	Warwickshire	52.23	-1.59
West Heslerton	Early Medieval	Yorkshire	54.17	-0.6
West Stow	Early Medieval	Suffolk	52.3	0.66
Westfield Farm	Early Medieval	Cambridgeshire	52.39	0.02
Westgarth Gardens	Early Medieval	Suffolk	52.24	0.71
Wetwang Garton-Slack	Iron Age	Yorkshire	54.01	-0.34
Whitcombe Farm	Iron Age	Dorset	50.81	-2.74
Whitton	Early Medieval	North Lincolnshire	53.7	-0.63
Winchester	Roman/Early Medieval	Hampshire	51.05	-1.31
Winnall	Early Medieval	Hampshire	51.06	-1.27
Worthy Park	Early Medieval	Hampshire	51.1	-1.29
Yarnton	Roman/Early Medieval	Oxfordshire	51.8	-1.31
York	Roman/Early Medieval	Yorkshire	53.96	-1.08

Appendix II.1 Differences between sites

The Levene test was used to test for homogeneity of variance. The null hypothesis (N_0) posited that there were no significant difference between the variances of the different groups and therefore that the ANOVA test could be used. If N_0 was rejected ($p < 0.05$), one-way ANOVA with a Welsh correction. The results of these tests are presented above the tables. The tables show the results of post-hoc testing.

A2.1.1.Iron Age

A2.1.1.1 HUMANS

Levene Test

∂^{13}C: (f(16, 282) = 1.665, p= 0.052)

∂^{15}N: (f(16, 282) = 2.619, p= 0.000)

ANOVAs

∂^{13}C: (f(16, 282) = 12.08, p= 0.000)

∂^{15}N: F = 12.056, num df = 16, denom df = 19.565, p = 0.00

i. Sites

Site	∂^{13}C	∂^{15}N
Test + Post-Hoc Test	ANOVA + TUKEY HSD	Pairwise T-Test (adjusted p-values)
Danebury-Alington Avenue	0.418	0.017
Flagstones-Alington Avenue	1.000	1.000
Fordington Bottom-Alington Avenue	1.000	1.000
Gravesend-Alington Avenue	1.000	1.000
Gussage All Saints-Alington Avenue	0.335	1.000
Harlyn Bay-Alington Avenue	0.001	1.000
Lechlade-Alington Avenue	0.999	1.000
Manor Farm-Alington Avenue	1.000	1.000
MichelDewer Wood-Alington Avenue	0.405	1.000
Suddern Farm-Alington Avenue	0.947	1.000
Tolpuddle Ball-Alington Avenue	0.950	1.000
Trethellan Farm-Alington Avenue	0.040	1.000
Wetwang Garton-Slack-Alington Avenue	0.000	1.000
Whitcombe Farm-Alington Avenue	0.998	1.000
Winnall Down-Alington Avenue	0.000	0.109
Yarnton-Alington Avenue	0.584	0.294
Flagstones-Danebury	1.000	1.000
Fordington Bottom-Danebury	0.529	0.389
Gravesend-Danebury	0.893	0.389

Site	$\partial^{13}C$	$\partial^{15}N$
Test + Post-Hoc Test	ANOVA + TUKEY HSD	Pairwise T-Test (adjusted p-values)
Gussage All Saints-Danebury	0.999	1.000
Harlyn Bay-Danebury	0.000	0.000
Lechlade-Danebury	0.289	0.000
Manor Farm-Danebury	0.609	1.000
MichelDewer Wood-Danebury	0.999	0.769
Suddern Farm-Danebury	0.907	0.399
Tolpuddle Ball-Danebury	1.000	1.000
Trethellan Farm-Danebury	0.696	0.018
Wetwang Garton-Slack-Danebury	0.000	0.000
Whitcombe Farm-Danebury	0.999	0.016
Winnall Down-Danebury	0.002	1.000
Yarnton-Danebury	1.000	0.000
Fordington Bottom-Flagstones	0.999	1.000
Gravesend-Flagstones	0.999	1.000
Gussage All Saints-Flagstones	0.999	1.000
Harlyn Bay-Flagstones	0.854	0.790
Lechlade-Flagstones	0.999	1.000
Manor Farm-Flagstones	0.999	1.000
MichelDewer Wood-Flagstones	0.999	1.000
Suddern Farm-Flagstones	1.000	1.000
Tolpuddle Ball-Flagstones	1.000	1.000
Trethellan Farm-Flagstones	0.944	1.000
Wetwang Garton-Slack-Flagstones	0.644	1.000
Whitcombe Farm-Flagstones	1.000	1.000
Winnall Down-Flagstones	0.896	1.000
Yarnton-Flagstones	1.000	0.280
Gravesend-Fordington Bottom	0.999	1.000
Gussage All Saints-Fordington Bottom	0.521	1.000
Harlyn Bay-Fordington Bottom	0.000	0.000
Lechlade-Fordington Bottom	1.000	0.233
Manor Farm-Fordington Bottom	0.999	1.000
MichelDewer Wood-Fordington Bottom	0.614	1.000
Suddern Farm-Fordington Bottom	0.997	1.000
Tolpuddle Ball-Fordington Bottom	0.994	1.000
Trethellan Farm-Fordington Bottom	0.060	1.000
Wetwang Garton-Slack-Fordington Bottom	0.000	1.000
Whitcombe Farm-Fordington Bottom	0.999	1.000
Winnall Down-Fordington Bottom	0.000	1.000
Yarnton-Fordington Bottom	0.768	0.000
Gussage All Saints-Gravesend	0.695	1.000

Site	$\partial^{13}C$	$\partial^{15}N$
Test + Post-Hoc Test	ANOVA + TUKEY HSD	Pairwise T-Test (adjusted p-values)
Harlyn Bay-Gravesend	0.070	1.000
Lechlade-Gravesend	0.999	1.000
Manor Farm-Gravesend	1.000	1.000
MichelDewer Wood-Gravesend	0.678	1.000
Suddern Farm-Gravesend	0.995	1.000
Tolpuddle Ball-Gravesend	0.976	1.000
Trethellan Farm-Gravesend	0.231	1.000
Wetwang Garton-Slack-Gravesend	0.020	1.000
Whitcombe Farm-Gravesend	0.997	1.000
Winnall Down-Gravesend	0.090	0.873
Yarnton-Gravesend	0.933	1.000
Harlyn Bay-Gussage All Saints	0.998	0.000
Lechlade-Gussage All Saints	0.451	0.106
Manor Farm-Gussage All Saints	0.443	1.000
MichelDewer Wood-Gussage All Saints	1.000	1.000
Suddern Farm-Gussage All Saints	0.893	1.000
Tolpuddle Ball-Gussage All Saints	1.000	1.000
Trethellan Farm-Gussage All Saints	0.999	1.000
Wetwang Garton-Slack-Gussage All Saints	0.953	1.000
Whitcombe Farm-Gussage All Saints	0.988	1.000
Winnall Down-Gussage All Saints	0.999	1.000
Yarnton-Gussage All Saints	0.999	0.000
Lechlade-Harlyn Bay	0.000	1.000
Manor Farm-Harlyn Bay	0.003	0.040
MichelDewer Wood-Harlyn Bay	0.999	1.000
Suddern Farm-Harlyn Bay	0.000	0.000
Tolpuddle Ball-Harlyn Bay	0.998	1.000
Trethellan Farm-Harlyn Bay	1.000	1.000
Wetwang Garton-Slack-Harlyn Bay	0.999	0.000
Whitcombe Farm-Harlyn Bay	0.075	0.099
Winnall Down-Harlyn Bay	1.000	0.000
Yarnton-Harlyn Bay	0.009	1.000
Manor Farm-Lechlade	0.999	1.000
MichelDewer Wood-Lechlade	0.576	1.000
Suddern Farm-Lechlade	0.994	0.000
Tolpuddle Ball-Lechlade	0.994	1.000
Trethellan Farm-Lechlade	0.040	1.000
Wetwang Garton-Slack-Lechlade	0.000	1.000
Whitcombe Farm-Lechlade	0.999	1.000
Winnall Down-Lechlade	0.000	0.000

Site	$\partial^{13}C$	$\partial^{15}N$
Test + Post-Hoc Test	ANOVA + TUKEY HSD	Pairwise T-Test (adjusted p-values)
Yarnton-Lechlade	0.606	0.237
MichelDewer Wood-Manor Farm	0.489	1.000
Suddern Farm-Manor Farm	0.979	1.000
Tolpuddle Ball-Manor Farm	0.963	1.000
Trethellan Farm-Manor Farm	0.072	1.000
Wetwang Garton-Slack-Manor Farm	0.000	1.000
Whitcombe Farm-Manor Farm	0.994	1.000
Winnall Down-Manor Farm	0.004	1.000
Yarnton-Manor Farm	0.742	0.006
Suddern Farm-MichelDewer Wood	0.920	1.000
Tolpuddle Ball-MichelDewer Wood	1.000	1.000
Trethellan Farm-MichelDewer Wood	0.999	1.000
Wetwang Garton-Slack-MichelDewer Wood	0.998	1.000
Whitcombe Farm-MichelDewer Wood	0.983	1.000
Winnall Down-MichelDewer Wood	1.000	1.000
Yarnton-MichelDewer Wood	0.998	0.643
Tolpuddle Ball-Suddern Farm	0.999	1.000
Trethellan Farm-Suddern Farm	0.213	0.956
Wetwang Garton-Slack-Suddern Farm	0.000	0.000
Whitcombe Farm-Suddern Farm	1.000	1.000
Winnall Down-Suddern Farm	0.000	1.000
Yarnton-Suddern Farm	0.996	0.000
Trethellan Farm-Tolpuddle Ball	0.999	1.000
Wetwang Garton-Slack-Tolpuddle Ball	0.985	1.000
Whitcombe Farm-Tolpuddle Ball	0.999	1.000
Winnall Down-Tolpuddle Ball	0.999	1.000
Yarnton-Tolpuddle Ball	1.000	1.000
Wetwang Garton-Slack-Trethellan Farm	1.000	1.000
Whitcombe Farm-Trethellan Farm	0.565	1.000
Winnall Down-Trethellan Farm	1.000	0.090
Yarnton-Trethellan Farm	0.676	1.000
Whitcombe Farm-Wetwang Garton-Slack	0.004	1.000
Winnall Down-Wetwang Garton-Slack	0.999	0.000
Yarnton-Wetwang Garton-Slack	0.000	0.000
Winnall Down-Whitcombe Farm	0.090	0.150
Yarnton-Whitcombe Farm	0.999	0.007
Yarnton-Winnall Down	0.010	0.000

A2.1.1.2 Cattle

Levene Test
∂^{13}C: (f(12, 193) = 0.475, *p*= 0.927)
∂^{15}N: (f(12, 193) = 1.558, *p*= 0.106)

ANOVAs
∂^{13}C: (f(12, 193) = 4.695, *p*= 0.000)
∂^{15}N: (f(12, 193) = 10.34, *p*= 0.000)

Site	∂^{13}C	∂^{15}N
Test + Post-Hoc Test	ANOVA + TUKEY HSD	ANOVA + TUKEY HSD
Fordington Bottom-Danebury	0.999	1.000
Harlyn Bay-Danebury	0.998	0.884
Houghton Down-Danebury	0.998	0.992
Lechlade-Danebury	0.999	0.000
Nettlebank Copse-Danebury	0.052	0.919
New Buildings-Danebury	0.997	0.996
Suddern Farm-Danebury	0.817	0.473
Trevelgue Head-Danebury	0.191	0.335
Wetwang Garton-Slack-Danebury	1.000	0.998
Winnall Down-Danebury	0.890	1.000
Yarnton-Danebury	0.995	0.000
Harlyn Bay-Fordington Bottom	0.991	0.999
Houghton Down-Fordington Bottom	0.999	0.999
Lechlade-Fordington Bottom	0.999	0.501
Nettlebank Copse-Fordington Bottom	1.000	0.999
New Buildings-Fordington Bottom	0.997	1.000
Suddern Farm-Fordington Bottom	1.000	0.999
Trevelgue Head-Fordington Bottom	0.834	0.999
Wetwang Garton-Slack-Fordington Bottom	0.999	1.000
Winnall Down-Fordington Bottom	0.984	1.000
Yarnton-Fordington Bottom	0.994	0.910
Houghton Down-Harlyn Bay	0.980	0.938
Lechlade-Harlyn Bay	0.999	0.914
Nettlebank Copse-Harlyn Bay	0.693	0.566
New Buildings-Harlyn Bay	0.999	0.990
Suddern Farm-Harlyn Bay	0.936	0.408
Trevelgue Head-Harlyn Bay	0.999	1.000
Wetwang Garton-Slack-Harlyn Bay	0.999	0.991
Winnall Down-Harlyn Bay	1.000	0.958
Yarnton-Harlyn Bay	1.000	0.999
Lechlade-Houghton Down	0.995	0.000
Nettlebank Copse-Houghton Down	0.892	1.000

Site	$\partial^{13}C$	$\partial^{15}N$
Test + Post-Hoc Test	ANOVA + TUKEY HSD	ANOVA + TUKEY HSD
New Buildings-Houghton Down	0.870	0.757
Suddern Farm-Houghton Down	0.999	0.999
Trevelgue Head-Houghton Down	0.063	0.090
Wetwang Garton-Slack-Houghton Down	0.999	0.831
Winnall Down-Houghton Down	0.547	0.993
Yarnton-Houghton Down	0.900	0.000
Nettlebank Copse-Lechlade	0.304	0.000
New Buildings-Lechlade	1.000	0.000
Suddern Farm-Lechlade	0.912	0.000
Trevelgue Head-Lechlade	0.707	0.143
Wetwang Garton-Slack-Lechlade	1.000	0.000
Winnall Down-Lechlade	0.999	0.000
Yarnton-Lechlade	0.999	0.977
New Buildings-Nettlebank Copse	0.018	0.479
Suddern Farm-Nettlebank Copse	0.947	0.999
Trevelgue Head-Nettlebank Copse	0.000	0.035
Wetwang Garton-Slack-Nettlebank Copse	0.339	0.624
Winnall Down-Nettlebank Copse	0.007	0.972
Yarnton-Nettlebank Copse	0.132	0.000
Suddern Farm-New Buildings	0.375	0.154
Trevelgue Head-New Buildings	0.786	0.914
Wetwang Garton-Slack-New Buildings	0.999	1.000
Winnall Down-New Buildings	0.999	0.999
Yarnton-New Buildings	1.000	0.044
Trevelgue Head-Suddern Farm	0.009	0.009
Wetwang Garton-Slack-Suddern Farm	0.957	0.274
Winnall Down-Suddern Farm	0.154	0.803
Yarnton-Suddern Farm	0.624	0.000
Yarnton-Trethellan Farm	0.983	0.960
Wetwang Garton-Slack-Trevelgue Head	0.469	0.937
Winnall Down-Trevelgue Head	0.992	0.756
Yarnton-Trevelgue Head	0.983	0.960
Winnall Down-Wetwang Garton-Slack	0.986	0.999
Yarnton-Wetwang Garton-Slack	0.999	0.068
Yarnton-Winnall Down	1.000	0.024

A2.1.1.3 Sheep

Levene Test
∂^{13}C: (f(10, 217) = 1.938, p= 0.041)
∂^{15}N: (f(10, 217) = 2.6177, p= 0.005)

ANOVAs
∂^{13}C: F = 8.77, num df = 10, denom df = 52.982, p= 0.000)
∂^{15}N: F = 10.029, num df = 10, denom df = 52.274, p= 0.000)

3.1.1 Sites

Site	∂^{13}C	∂^{15}N
Test + Post-Hoc Test	T-Test (adjusted p-values)	T-Test (adjusted p-values)
Houghton Down-Danebury	1.000	1.000
Lechlade-Danebury	1.000	0.000
Nettlebank Copse-Danebury	1.000	1.000
New Buildings-Danebury	1.000	0.266
Suddern Farm-Danebury	1.000	1.000
Trevelgue Head-Danebury	0.008	0.000
Wetwang Garton-Slack-Danebury	0.064	0.070
Winnall Down-Danebury	0.425	1.000
Yarnton-Danebury	1.000	0.000
Lechlade-Houghton Down	0.092	0.000
Nettlebank Copse-Houghton Down	1.000	1.000
New Buildings-Houghton Down	1.000	1.000
Suddern Farm-Houghton Down	1.000	1.000
Trevelgue Head-Houghton Down	0.000	0.020
Wetwang Garton-Slack-Houghton Down	0.005	1.000
Winnall Down-Houghton Down	0.042	1.000
Yarnton-Houghton Down	0.722	0.000
Nettlebank Copse-Lechlade	0.058	0.000
New Buildings-Lechlade	1.000	0.000
Suddern Farm-Lechlade	1.000	0.000
Trevelgue Head-Lechlade	1.000	0.000
Wetwang Garton-Slack-Lechlade	1.000	0.000
Winnall Down-Lechlade	1.000	0.000
Yarnton-Lechlade	1.000	1.000
New Buildings-Nettlebank Copse	1.000	0.126
Suddern Farm-Nettlebank Copse	1.000	1.000
Trevelgue Head-Nettlebank Copse	0.000	0.000
Wetwang Garton-Slack-Nettlebank Copse	0.000	0.033
Winnall Down-Nettlebank Copse	0.031	1.000
Yarnton-Nettlebank Copse	0.722	0.000

Site	$\partial^{13}C$	$\partial^{15}N$
Test + Post-Hoc Test	T-Test (adjusted p-values)	T-Test (adjusted p-values)
Suddern Farm-New Buildings	1.000	0.016
Trevelgue Head-New Buildings	0.202	0.231
Wetwang Garton-Slack-New Buildings	1.000	1.000
Winnall Down-New Buildings	1.000	1.000
Yarnton-New Buildings	1.000	0.000
Trevelgue Head-Suddern Farm	0.016	0.000
Wetwang Garton-Slack-Suddern Farm	0.150	0.045
Winnall Down-Suddern Farm	0.592	1.000
Yarnton-Suddern Farm	1.000	0.000
Wetwang Garton-Slack-Trevelgue Head	1.000	0.435
Winnall Down-Trevelgue Head	1.000	0.009
Yarnton-Trevelgue Head	1.000	0.435
Winnall Down-Wetwang Garton-Slack	1.000	0.743
Yarnton-Wetwang Garton-Slack	1.000	0.000
Yarnton-Winnall Down	1.000	0.000

A2.1.1.4 Pig

Levene Test
$\partial^{13}C$: (f(13, 127) = 1.103, p= 0.362)
$\partial^{15}N$: (f(13, 127) = 1.442, p= 0.148)

ANOVAs
$\partial^{13}C$: (f(13, 127) = 3.198, p= 0.000)
$\partial^{15}N$: (f(13, 127) = 3.417, p= 0.000)

3.1.2 Sites

Site	$\partial^{13}C$	$\partial^{15}N$
Test + Post-Hoc Test	ANOVA + TUKEY HSD	ANOVA + TUKEY HSD
Harlyn Bay-Danebury	0.427	0.999
Houghton Down-Danebury	0.999	0.999
Lechlade-Danebury	0.280	0.015
Manor Farm-Danebury	0.999	1.000
Nettlebank Copse-Danebury	0.983	1.000
New Buildings-Danebury	1.000	1.000
Suddern Farm-Danebury	0.999	0.982
Tolpuddle Ball-Danebury	0.999	0.999
Trevelgue Head-Danebury	0.999	0.975
Wetwang Garton-Slack-Danebury	0.528	2.000
Winnall Down-Danebury	1.000	0.975
Yarnton-Danebury	0.269	0.009
Houghton Down-Harlyn Bay	0.334	0.999
Lechlade-Harlyn Bay	0.056	0.687
Manor Farm-Harlyn Bay	0.411	0.999
Nettlebank Copse-Harlyn Bay	0.225	0.999
New Buildings-Harlyn Bay	0.480	0.999
Suddern Farm-Harlyn Bay	0.385	1.000
Tolpuddle Ball-Harlyn Bay	0.974	0.996
Trevelgue Head-Harlyn Bay	0.741	0.990
Wetwang Garton-Slack-Harlyn Bay	0.926	0.999
Winnall Down-Harlyn Bay	0.675	1.000
Yarnton-Harlyn Bay	0.973	0.686
Lechlade-Houghton Down	0.945	0.479
Manor Farm-Houghton Down	1.000	1.000
Nettlebank Copse-Houghton Down	1.000	0.999
New Buildings-Houghton Down	1.000	0.999
Suddern Farm-Houghton Down	1.000	0.930
Tolpuddle Ball-Houghton Down	0.999	0.999
Trevelgue Head-Houghton Down	0.992	0.999
Wetwang Garton-Slack-Houghton Down	0.539	0.999

Site	$\partial^{13}C$	$\partial^{15}N$
Test + Post-Hoc Test	ANOVA + TUKEY HSD	ANOVA + TUKEY HSD
Winnall Down-Houghton Down	0.999	0.914
Yarnton-Houghton Down	0.313	0.451
Manor Farm-Lechlade	0.999	0.800
Nettlebank Copse-Lechlade	0.847	0.022
New Buildings-Lechlade	0.929	0.235
Suddern Farm-Lechlade	0.887	0.005
Tolpuddle Ball-Lechlade	0.976	0.999
Trevelgue Head-Lechlade	0.202	0.873
Wetwang Garton-Slack-Lechlade	0.004	0.040
Winnall Down-Lechlade	0.796	0.022
Yarnton-Lechlade	0.001	1.000
Nettlebank Copse-Manor Farm	1.000	1.000
New Buildings-Manor Farm	0.999	1.000
Suddern Farm-Manor Farm	0.999	0.999
Tolpuddle Ball-Manor Farm	0.999	0.999
Trevelgue Head-Manor Farm	0.996	0.999
Wetwang Garton-Slack-Manor Farm	0.888	1.000
Winnall Down-Manor Farm	0.999	0.999
Yarnton-Manor Farm	0.766	0.796
New Buildings-Nettlebank Copse	0.999	1.000
Suddern Farm-Nettlebank Copse	1.000	0.947
Tolpuddle Ball-Nettlebank Copse	0.999	0.999
Trevelgue Head-Nettlebank Copse	0.872	0.991
Wetwang G-Slack-Nettlebank Copse	0.513	0.999
	0.999	0.991
Yarnton-Nettlebank Copse	0.018	0.991
Suddern Farm-New Buildings	1.000	0.999
Tolpuddle Ball-New Buildings	0.999	0.947
Trevelgue Head-New Buildings	0.999	0.999
Wetwang Garton-Slack-New Buildings	0.906	0.999
Winnall Down-New Buildings	1.000	0.995
Yarnton-New Buildings	0.742	0.995
Tolpuddle Ball-Suddern Farm	0.999	1.000
Trethellan Farm-Suddern Farm	0.998	0.999
Trevelgue Head-Suddern Farm	0.998	0.219
Wetwang Garton-Slack-Suddern Farm	0.673	0.989
Winnall Down-Suddern Farm	0.999	0.600
Yarnton-Suddern Farm	0.429	0.600
Trethellan Farm-Tolpuddle Ball	1.000	0.999
Trevelgue Head-Tolpuddle Ball	1.000	0.100
Wetwang Garton-Slack-Tolpuddle Ball	1.000	0.004

Site	$\partial^{13}C$	$\partial^{15}N$
Test + Post-Hoc Test	ANOVA + TUKEY HSD	ANOVA + TUKEY HSD
Winnall Down-Tolpuddle Ball	1.000	1.000
Yarnton-Tolpuddle Ball	0.999	1.000
Wetwang Garton-Slack-Trevelgue Head	0.999	0.971
Winnall Down-Trevelgue Head	1.000	0.643
Yarnton-Trevelgue Head	0.986	0.862
Winnall Down-Wetwang Garton-Slack	0.996	0.996
Yarnton-Wetwang Garton-Slack	0.999	0.031
Yarnton-Winnall Down	0.971	0.020

A2.1.2 Roman Britain

A2.1.2.1 Humans

Levene Test
∂^{13}C: (f(24, 793) = 3.2301, p= 0.000)
∂^{15}N: (f(24, 793) = 2.736, p= 0.000)

ANOVAs
∂^{13}C: F = 16.63, num df = 24, denom df = 5.393, p = 0.00
∂^{15}N: F = 22.55, num df = 24, denom df = 21.176, p = 0.00

Site	∂^{13}C	∂^{15}N
Test + Post-Hoc Test	T-Test (adjusted p-values)	T-Test (adjusted p-values)
6DT_York3DT_York	1.000	1.000
Alchester-3DT_York	0.903	0.003
Asthall-3DT_York	1.000	0.004
Blossom Street_York-3DT_York	1.000	1.000
Bradley Hill-3DT_York	0.000	1.000
Catterick-3DT_York	0.339	1.000
CatterickBridge_Catterick-3DT_York	0.139	1.000
Cirencester-3DT_York	1.000	0.000
Costwolds Community-3DT_York	0.000	0.002
GambierParryLodge_Gloucester-3DT_York	1.000	1.000
Gravesend-3DT_York	1.000	0.005
HoneyPotRoad_Catterick-3DT_York	1.000	1.000
Horcott Quarry-3DT_York	0.004	0.000
Hucclecote-3DT_York	1.000	1.000
London Road_Gloucester-3DT_York	1.000	1.000
LondonRoad_Gloucester-3DT_York	1.000	1.000
Poundbury-3DT_York	1.000	0.000
Queenford-3DT_York	0.048	1.000
Stanton Court-3DT_York	0.134	1.000
Trentholme Drive_York-3DT_York	1.000	1.000
Winchester-3DT_York	0.060	0.000
Yarnton-3DT_York	1.000	1.000
York-3DT_York	1.000	1.000
Alchester-6DT_York	1.000	0.000
Asthall-6DT_York	1.000	0.000
Blossom Street_York-6DT_York	1.000	1.000
Bradley Hill-6DT_York	0.000	0.036
Catterick-6DT_York	1.000	1.000

Site	$\partial^{13}C$	$\partial^{15}N$
Test + Post-Hoc Test	T-Test (adjusted p-values)	T-Test (adjusted p-values)
CatterickBridge_Catterick-6DT_York	1.000	1.000
Cirencester-6DT_York	1.000	0.000
Costwolds Community-6DT_York	0.000	0.000
GambierParryLodge_Gloucester-6DT_York	1.000	1.000
Gravesend-6DT_York	1.000	0.000
HoneyPotRoad_Catterick-6DT_York	1.000	1.000
Horcott Quarry-6DT_York	0.363	0.000
Hucclecote-6DT_York	1.000	1.000
London Road_Gloucester-6DT_York	1.000	1.000
LondonRoad_Gloucester-6DT_York	1.000	1.000
Poundbury-6DT_York	1.000	0.000
Queenford-6DT_York	1.000	0.048
Stanton Court-6DT_York	1.000	1.000
Trentholme Drive_York-6DT_York	1.000	1.000
Winchester-6DT_York	0.014	0.000
Yarnton-6DT_York	1.000	1.000
York-6DT_York	1.000	1.000
Asthall-Alchester	0.119	1.000
Blossom Street_York-Alchester	1.000	0.000
Bradley Hill-Alchester	0.071	1.000
Catterick-Alchester	1.000	0.690
CatterickBridge_Catterick-Alchester	1.000	0.246
Cirencester-Alchester	1.000	1.000
Costwolds Community-Alchester	0.487	1.000
GambierParryLodge_Gloucester-Alchester	0.064	0.018
Gravesend-Alchester	1.000	1.000
HoneyPotRoad_Catterick-Alchester	1.000	1.000
Horcott Quarry-Alchester	1.000	1.000
Hucclecote-Alchester	1.000	0.638
London Road_Gloucester-Alchester	1.000	0.146
LondonRoad_Gloucester-Alchester	1.000	0.003
Poundbury-Alchester	0.008	1.000
Queenford-Alchester	1.000	0.296
Stanton Court-Alchester	1.000	0.005
Trentholme Drive_York-Alchester	0.778	0.000
Winchester-Alchester	0.000	1.000
Yarnton-Alchester	1.000	0.000
York-Alchester	1.000	0.026
Blossom Street_York-Asthall	0.363	0.000
Bradley Hill-Asthall	0.000	0.085

Site	$\partial^{13}C$	$\partial^{15}N$
Test + Post-Hoc Test	T-Test (adjusted p-values)	T-Test (adjusted p-values)
Catterick-Asthall	0.065	0.054
CatterickBridge_Catterick-Asthall	0.019	0.161
Cirencester-Asthall	0.352	1.000
Costwolds Community-Asthall	0.000	1.000
GambierParryLodge_Gloucester-Asthall	1.000	0.018
Gravesend-Asthall	1.000	1.000
HoneyPotRoad_Catterick-Asthall	1.000	1.000
Horcott Quarry-Asthall	0.003	1.000
Hucclecote-Asthall	0.218	0.377
London Road_Gloucester-Asthall	0.638	0.110
LondonRoad_Gloucester-Asthall	0.867	0.004
Poundbury-Asthall	1.000	1.000
Queenford-Asthall	0.057	0.239
Stanton Court-Asthall	0.043	0.005
Trentholme Drive_York-Asthall	1.000	0.000
Winchester-Asthall	1.000	1.000
Yarnton-Asthall	1.000	0.000
York-Asthall	1.000	0.018
Bradley Hill-Blossom Street_York	0.000	0.028
Catterick-Blossom Street_York	1.000	1.000
CatterickBridge_Catterick-Blossom Street_York	1.000	1.000
Cirencester-Blossom Street_York	1.000	0.000
Costwolds Community-Blossom Street_York	0.012	0.000
GambierParryLodge_Gloucester-Blossom Street_York	0.214	1.000
Gravesend-Blossom Street_York	1.000	0.000
HoneyPotRoad_Catterick-Blossom Street_York	1.000	1.000
Horcott Quarry-Blossom Street_York	1.000	0.000
Hucclecote-Blossom Street_York	1.000	1.000
London Road_Gloucester-Blossom Street_York	1.000	1.000
LondonRoad_Gloucester-Blossom Street_York	1.000	1.000
Poundbury-Blossom Street_York	0.026	0.000
Queenford-Blossom Street_York	1.000	0.043
Stanton Court-Blossom Street_York	1.000	1.000
Trentholme Drive_York-Blossom Street_York	1.000	1.000
Winchester-Blossom Street_York	0.000	0.000
Yarnton-Blossom Street_York	1.000	1.000
York-Blossom Street_York	1.000	1.000
Catterick-Bradley Hill	0.003	1.000
CatterickBridge_Catterick-Bradley Hill	1.000	1.000
Cirencester-Bradley Hill	0.000	0.145

Site	$\partial^{13}C$	$\partial^{15}N$
Test + Post-Hoc Test	T-Test (adjusted p-values)	T-Test (adjusted p-values)
Costwolds Community-Bradley Hill	1.000	1.000
GambierParryLodge_Gloucester-Bradley Hill	0.000	1.000
Gravesend-Bradley Hill	0.000	1.000
HoneyPotRoad_Catterick-Bradley Hill	1.000	1.000
Horcott Quarry-Bradley Hill	0.110	0.016
Hucclecote-Bradley Hill	1.000	1.000
London Road_Gloucester-Bradley Hill	0.000	1.000
LondonRoad_Gloucester-Bradley Hill	0.000	1.000
Poundbury-Bradley Hill	0.000	0.000
Queenford-Bradley Hill	0.000	1.000
Stanton Court-Bradley Hill	0.000	1.000
Trentholme Drive_York-Bradley Hill	0.000	0.025
Winchester-Bradley Hill	0.000	0.000
Yarnton-Bradley Hill	0.006	0.054
York-Bradley Hill	0.113	1.000
CatterickBridge_Catterick-Catterick	1.000	1.000
Cirencester-Catterick	1.000	0.003
Costwolds Community-Catterick	0.077	0.137
GambierParryLodge_Gloucester-Catterick	0.013	1.000
Gravesend-Catterick	0.770	0.068
HoneyPotRoad_Catterick-Catterick	1.000	1.000
Horcott Quarry-Catterick	1.000	0.000
Hucclecote-Catterick	1.000	1.000
London Road_Gloucester-Catterick	1.000	1.000
LondonRoad_Gloucester-Catterick	1.000	1.000
Poundbury-Catterick	0.000	0.000
Queenford-Catterick	1.000	1.000
Stanton Court-Catterick	1.000	1.000
Trentholme Drive_York-Catterick	0.290	1.000
Winchester-Catterick	0.000	0.000
Yarnton-Catterick	1.000	1.000
York-Catterick	1.000	1.000
Cirencester-CatterickBridge_Catterick	1.000	0.172
Costwolds Community-CatterickBridge_Catterick	1.000	0.641
GambierParryLodge_Gloucester-CatterickBridge_Catterick	0.011	1.000
Gravesend-CatterickBridge_Catterick	0.188	0.210
HoneyPotRoad_Catterick-CatterickBridge_Catterick	1.000	1.000
Horcott Quarry-CatterickBridge_Catterick	1.000	0.013
Hucclecote-CatterickBridge_Catterick	1.000	1.000
London Road_Gloucester-CatterickBridge_Catterick	1.000	1.000

Site	$\partial^{13}C$	$\partial^{15}N$
Test + Post-Hoc Test	T-Test (adjusted p-values)	T-Test (adjusted p-values)
LondonRoad_Gloucester-CatterickBridge_Catterick	1.000	1.000
Poundbury-CatterickBridge_Catterick	0.001	0.000
Queenford-CatterickBridge_Catterick	1.000	1.000
Stanton Court-CatterickBridge_Catterick	1.000	1.000
Trentholme Drive_York-CatterickBridge_Catterick	0.119	1.000
Winchester-CatterickBridge_Catterick	0.000	0.000
Yarnton-CatterickBridge_Catterick	1.000	1.000
York-CatterickBridge_Catterick	1.000	1.000
Costwolds Community-Cirencester	0.000	1.000
GambierParryLodge_Gloucester-Cirencester	0.020	0.000
Gravesend-Cirencester	1.000	1.000
HoneyPotRoad_Catterick-Cirencester	1.000	1.000
Horcott Quarry-Cirencester	0.807	1.000
Hucclecote-Cirencester	1.000	0.530
London Road_Gloucester-Cirencester	1.000	0.005
LondonRoad_Gloucester-Cirencester	1.000	0.000
Poundbury-Cirencester	0.000	0.095
Queenford-Cirencester	1.000	0.000
Stanton Court-Cirencester	1.000	0.000
Trentholme Drive_York-Cirencester	0.988	0.000
Winchester-Cirencester	0.000	0.000
Yarnton-Cirencester	1.000	0.000
York-Cirencester	1.000	0.011
GambierParryLodge_Gloucester-Costwolds Community	0.000	0.024
Gravesend-Costwolds Community	0.000	1.000
HoneyPotRoad_Catterick-Costwolds Community	1.000	1.000
Horcott Quarry-Costwolds Community	1.000	1.000
Hucclecote-Costwolds Community	1.000	1.000
London Road_Gloucester-Costwolds Community	0.000	0.292
LondonRoad_Gloucester-Costwolds Community	0.000	0.003
Poundbury-Costwolds Community	0.000	1.000
Queenford-Costwolds Community	0.000	0.510
Stanton Court-Costwolds Community	0.022	0.005
Trentholme Drive_York-Costwolds Community	0.000	0.000
Winchester-Costwolds Community	0.000	0.007
Yarnton-Costwolds Community	0.040	0.000
York-Costwolds Community	0.431	0.062
Gravesend-GambierParryLodge_Gloucester	1.000	0.023
HoneyPotRoad_Catterick-GambierParryLodge_Gloucester	1.000	1.000
Horcott Quarry-GambierParryLodge_Gloucester	0.000	0.000

Site	$\partial^{13}C$	$\partial^{15}N$
Test + Post-Hoc Test	T-Test (adjusted p-values)	T-Test (adjusted p-values)
Hucclecote-GambierParryLodge_Gloucester	0.231	1.000
London Road_Gloucester-GambierParryLodge_Gloucester	0.352	1.000
LondonRoad_Gloucester-GambierParryLodge_Gloucester	0.438	1.000
Poundbury-GambierParryLodge_Gloucester	1.000	0.000
Queenford-GambierParryLodge_Gloucester	0.000	1.000
Stanton Court-GambierParryLodge_Gloucester	0.003	1.000
Trentholme Drive_York-GambierParryLodge_Gloucester	1.000	1.000
Winchester-GambierParryLodge_Gloucester	1.000	0.000
Yarnton-GambierParryLodge_Gloucester	1.000	1.000
York-GambierParryLodge_Gloucester	1.000	1.000
HoneyPotRoad_Catterick-Gravesend	1.000	1.000
Horcott Quarry-Gravesend	0.067	1.000
Hucclecote-Gravesend	1.000	0.498
London Road_Gloucester-Gravesend	1.000	0.142
LondonRoad_Gloucester-Gravesend	1.000	0.005
Poundbury-Gravesend	1.000	1.000
Queenford-Gravesend	0.906	0.300
Stanton Court-Gravesend	0.586	0.006
Trentholme Drive_York-Gravesend	1.000	0.000
Winchester-Gravesend	1.000	1.000
Yarnton-Gravesend	1.000	0.000
York-Gravesend	1.000	0.023
Horcott Quarry-HoneyPotRoad_Catterick	1.000	1.000
Hucclecote-HoneyPotRoad_Catterick	1.000	1.000
London Road_Gloucester-HoneyPotRoad_Catterick	1.000	1.000
LondonRoad_Gloucester-HoneyPotRoad_Catterick	1.000	1.000
Poundbury-HoneyPotRoad_Catterick	1.000	0.812
Queenford-HoneyPotRoad_Catterick	1.000	1.000
Stanton Court-HoneyPotRoad_Catterick	1.000	1.000
Trentholme Drive_York-HoneyPotRoad_Catterick	1.000	1.000
Winchester-HoneyPotRoad_Catterick	0.517	0.169
Yarnton-HoneyPotRoad_Catterick	1.000	1.000
York-HoneyPotRoad_Catterick	1.000	1.000
Hucclecote-Horcott Quarry	1.000	0.043
London Road_Gloucester-Horcott Quarry	1.000	0.000
LondonRoad_Gloucester-Horcott Quarry	1.000	0.000
Poundbury-Horcott Quarry	0.000	1.000
Queenford-Horcott Quarry	1.000	0.000
Stanton Court-Horcott Quarry	1.000	0.000
Trentholme Drive_York-Horcott Quarry	0.004	0.000

Site	$\partial^{13}C$	$\partial^{15}N$
Test + Post-Hoc Test	T-Test (adjusted p-values)	T-Test (adjusted p-values)
Winchester-Horcott Quarry	0.000	1.000
Yarnton-Horcott Quarry	1.000	0.000
York-Horcott Quarry	1.000	0.000
London Road_Gloucester-Hucclecote	1.000	1.000
LondonRoad_Gloucester-Hucclecote	1.000	1.000
Poundbury-Hucclecote	0.062	0.004
Queenford-Hucclecote	1.000	1.000
Stanton Court-Hucclecote	1.000	1.000
Trentholme Drive_York-Hucclecote	1.000	1.000
Winchester-Hucclecote	0.004	0.000
Yarnton-Hucclecote	1.000	1.000
York-Hucclecote	1.000	1.000
LondonRoad_Gloucester-London Road_Gloucester	1.000	1.000
Poundbury-London Road_Gloucester	0.034	0.000
Queenford-London Road_Gloucester	1.000	1.000
Stanton Court-London Road_Gloucester	1.000	1.000
Trentholme Drive_York-London Road_Gloucester	1.000	1.000
Winchester-London Road_Gloucester	0.000	0.000
Yarnton-London Road_Gloucester	1.000	1.000
York-London Road_Gloucester	1.000	1.000
Poundbury-LondonRoad_Gloucester	0.336	0.000
Queenford-LondonRoad_Gloucester	1.000	1.000
Stanton Court-LondonRoad_Gloucester	1.000	1.000
Trentholme Drive_York-LondonRoad_Gloucester	1.000	1.000
Winchester-LondonRoad_Gloucester	0.000	0.000
Yarnton-LondonRoad_Gloucester	1.000	1.000
York-LondonRoad_Gloucester	1.000	1.000
Queenford-Poundbury	0.000	0.000
Stanton Court-Poundbury	0.000	0.000
Trentholme Drive_York-Poundbury	1.000	0.000
Winchester-Poundbury	1.000	1.000
Yarnton-Poundbury	1.000	0.000
York-Poundbury	1.000	0.000
Stanton Court-Queenford	1.000	1.000
Trentholme Drive_York-Queenford	0.005	0.025
Winchester-Queenford	0.000	0.000
Yarnton-Queenford	1.000	0.094
York-Queenford	1.000	1.000
Trentholme Drive_York-Stanton Court	0.119	1.000
Winchester-Stanton Court	0.000	0.000

Site	$\partial^{13}C$	$\partial^{15}N$
Test + Post-Hoc Test	T-Test (adjusted p-values)	T-Test (adjusted p-values)
Yarnton-Stanton Court	1.000	1.000
York-Stanton Court	1.000	1.000
Winchester-Trentholme Drive_York	0.223	0.000
Yarnton-Trentholme Drive_York	1.000	1.000
York-Trentholme Drive_York	1.000	1.000
Yarnton-Winchester	1.000	0.000
York-Winchester	0.348	0.000
York-Yarnton	1.000	1.000

A2.1.2.2 Cattle

Levene Test
∂^{13}C: (f(10, 70) = 0.756, p= 0.669)
∂^{15}N: (f(10, 70) = 3.0595, p= 0.002)

ANOVAs
∂^{13}C: (f(10, 70) = 2.004, p= 0.045)
∂^{15}N: F =3.8479, num df = 10, denom df = 23.179, p = 0.003

Site	∂^{13}C	∂^{15}N
Test + Post-Hoc Test	ANOVA + TUKEY HSD	T-Test (adjusted p-values)
Asthall-Alchester	0.999	1.000
Bradley Hill-Alchester	0.366	1.000
Catterick-Alchester	0.999	1.000
Cirencester-Alchester	0.555	1.000
GambierParryLodge_Gloucester-Alchester	0.581	1.000
Hucclecote-Alchester	0.927	1.000
LondonRoad_Gloucester-Alchester	0.999	1.000
Winchester-Alchester	0.526	1.000
Yarnton-Alchester	1.000	1.000
York-Alchester	0.998	1.000
Bradley Hill-Asthall	0.777	1.000
Catterick-Asthall	0.999	1.000
Cirencester-Asthall	0.944	1.000
GambierParryLodge_Gloucester-Asthall	0.934	1.000
Hucclecote-Asthall	0.998	1.000
LondonRoad_Gloucester-Asthall	1.000	1.000
Winchester-Asthall	0.942	1.000
Yarnton-Asthall	0.993	1.000
York-Asthall	1.000	1.000
Catterick-Bradley Hill	0.612	1.000
Cirencester-Bradley Hill	0.999	1.000
GambierParryLodge_Gloucester-Bradley Hill	0.999	1.000
Hucclecote-Bradley Hill	0.999	1.000
LondonRoad_Gloucester-Bradley Hill	0.885	1.000
Winchester-Bradley Hill	0.999	1.000
Yarnton-Bradley Hill	0.168	1.000
York-Bradley Hill	0.910	1.000
Cirencester-Catterick	0.827	1.000
GambierParryLodge_Gloucester-Catterick	0.821	1.000
Hucclecote-Catterick	0.986	0.770
LondonRoad_Gloucester-Catterick	0.100	1.000

Site	$\partial^{13}C$	$\partial^{15}N$
Test + Post-Hoc Test	ANOVA + TUKEY HSD	T-Test (adjusted p-values)
Winchester-Catterick	0.818	1.000
Yarnton-Catterick	0.999	0.500
York-Catterick	0.999	1.000
GambierParryLodge_Gloucester-Cirencester	1.000	1.000
Hucclecote-Cirencester	1.000	0.500
LondonRoad_Gloucester-Cirencester	0.981	1.000
Winchester-Cirencester	1.000	1.000
Yarnton-Cirencester	0.247	0.210
York-Cirencester	0.990	0.820
Hucclecote-GambierParryLodge_Gloucester	0.999	1.000
LondonRoad_Gloucester-GambierParryLodge_Gloucester	0.972	1.000
Winchester-GambierParryLodge_Gloucester	1.000	1.000
Yarnton-GambierParryLodge_Gloucester	0.313	1.000
York-GambierParryLodge_Gloucester	0.984	1.000
LondonRoad_Gloucester-Hucclecote	0.999	1.000
Winchester-Hucclecote	1.000	1.000
Yarnton-Hucclecote	0.802	1.000
York-Hucclecote	0.999	1.000
Winchester-LondonRoad_Gloucester	0.982	1.000
Yarnton-LondonRoad_Gloucester	0.999	1.000
York-LondonRoad_Gloucester	1.000	1.000
Yarnton-Winchester	0.206	0.860
York-Winchester	0.991	1.000
York-Yarnton	0.984	1.000

A2.1.2.3 Sheep

Levene Test
$\partial^{13}C$: (f(10, 64) = 0.649, p= 0.765)
$\partial^{15}N$: (f(10, 64) = 1.057, p= 0.408)

ANOVAs
$\partial^{13}C$: (f(10, 64) = 1.122, p= 0.360)
$\partial^{15}N$: (f(10, 64) = 3.554, p= 0.000)

Site	$\partial^{13}C$	$\partial^{15}N$
Test + Post-Hoc Test	ANOVA + TUKEY HSD	ANOVA + TUKEY HSD
Asthall-Alchester	0.458	0.999
Bradley Hill-Alchester	1.000	0.999
Catterick-Alchester	1.000	0.845
Cirencester-Alchester	0.999	0.360
GambierParryLodge_Gloucester-Alchester	1.000	0.700
Hucclecote-Alchester	0.988	0.974
LondonRoad_Gloucester-Alchester	0.999	0.957
Winchester-Alchester	0.999	0.021
Yarnton-Alchester	0.996	0.999
York-Alchester	1.000	0.816
Bradley Hill-Asthall	0.353	1.000
Catterick-Asthall	0.245	0.972
Cirencester-Asthall	0.597	0.528
GambierParryLodge_Gloucester-Asthall	0.704	0.869
Hucclecote-Asthall	0.998	0.998
LondonRoad_Gloucester-Asthall	0.999	0.992
Winchester-Asthall	0.397	0.020
Yarnton-Asthall	0.745	0.999
York-Asthall	0.545	0.956
Catterick-Bradley Hill	1.000	0.982
Cirencester-Bradley Hill	0.999	0.582
GambierParryLodge_Gloucester-Bradley Hill	1.000	0.889
Hucclecote-Bradley Hill	0.992	0.999
LondonRoad_Gloucester-Bradley Hill	0.999	0.994
Winchester-Bradley Hill	0.999	0.026
Yarnton-Bradley Hill	0.997	0.999
York-Bradley Hill	1.000	0.968
Cirencester-Catterick	0.999	0.997
GambierParryLodge_Gloucester-Catterick	1.000	0.998
Hucclecote-Catterick	0.986	1.000
LondonRoad_Gloucester-Catterick	0.999	0.999
Winchester-Catterick	0.999	0.336
Yarnton-Catterick	0.993	0.790

Site	$\partial^{13}C$	$\partial^{15}N$
Test + Post-Hoc Test	ANOVA + TUKEY HSD	ANOVA + TUKEY HSD
York-Catterick	1.000	1.000
GambierParryLodge_Gloucester-Cirencester	0.999	0.999
Hucclecote-Cirencester	0.999	0.999
LondonRoad_Gloucester-Cirencester	1.000	1.000
Winchester-Cirencester	1.000	0.882
Yarnton-Cirencester	0.999	0.152
York-Cirencester	0.999	0.999
Hucclecote-GambierParryLodge_Gloucester	0.992	0.999
LondonRoad_Gloucester-GambierParryLodge_Gloucester	0.999	1.000
Winchester-GambierParryLodge_Gloucester	0.999	0.999
Yarnton-GambierParryLodge_Gloucester	0.998	0.719
York-GambierParryLodge_Gloucester	0.999	0.999
LondonRoad_Gloucester-Hucclecote	1.000	0.999
Winchester-Hucclecote	0.999	0.806
Yarnton-Hucclecote	0.999	0.987
York-Hucclecote	0.997	1.000
Winchester-LondonRoad_Gloucester	0.999	0.999
Yarnton-LondonRoad_Gloucester	1.000	0.976
York-LondonRoad_Gloucester	0.999	0.999
Yarnton-Winchester	0.999	0.000
York-Winchester	0.999	0.812
York-Yarnton	0.999	0.797

A2.1.2.4 Pig

Levene Test
∂^{13}C: (f(9, 45) = 1.1025, p= 0.380)
∂^{15}N: (f((9, 45) = 1.349, p= 0.239)

ANOVAs
∂^{13}C: (f((9, 45) = 4.761, p= 0.000)
∂^{15}N: (f((9, 45) = 2.863, p= 0.009)

Site	∂^{13}C	∂^{15}N
Test + Post-Hoc Test	ANOVA + TUKEY HSD	ANOVA + TUKEY HSD
Asthall-Alchester	0.999	0.983
Bradley Hill-Alchester	0.899	0.999
Catterick-Alchester	0.859	0.999
Cirencester-Alchester	0.918	1.000
GambierParryLodge_Gloucester-Alchester	0.865	1.000
LondonRoad_Gloucester-Alchester	0.865	0.992
Winchester-Alchester	0.787	0.986
Yarnton-Alchester	0.314	0.998
York-Alchester	0.045	0.999
Bradley Hill-Asthall	0.888	0.995
Catterick-Asthall	0.796	0.586
Cirencester-Asthall	0.881	0.906
GambierParryLodge_Gloucester-Asthall	0.867	0.976
LondonRoad_Gloucester-Asthall	0.867	1.000
Winchester-Asthall	0.648	0.999
Yarnton-Asthall	0.121	0.180
York-Asthall	0.004	0.961
Catterick-Bradley Hill	1.000	0.995
Cirencester-Bradley Hill	0.999	0.999
GambierParryLodge_Gloucester-Bradley Hill	0.999	0.999
LondonRoad_Gloucester-Bradley Hill	0.999	0.998
Winchester-Bradley Hill	1.000	0.996
Yarnton-Bradley Hill	0.988	0.856
York-Bradley Hill	0.448	1.000
Cirencester-Catterick	0.999	0.992
GambierParryLodge_Gloucester-Catterick	0.999	0.999
LondonRoad_Gloucester-Catterick	0.999	0.851
Winchester-Catterick	1.000	0.188
Yarnton-Catterick	0.842	0.997

Site	$\partial^{13}C$	$\partial^{15}N$
Test + Post-Hoc Test	ANOVA + TUKEY HSD	ANOVA + TUKEY HSD
York-Catterick	0.043	0.911
GambierParryLodge_Gloucester-Cirencester	0.999	0.999
LondonRoad_Gloucester-Cirencester	0.999	0.981
Winchester-Cirencester	0.999	0.613
Yarnton-Cirencester	0.405	0.532
York-Cirencester	0.002	0.999
LondonRoad_Gloucester-GambierParryLodge_Gloucester	1.000	0.989
Winchester-GambierParryLodge_Gloucester	0.999	0.979
Yarnton-GambierParryLodge_Gloucester	0.999	0.999
York-GambierParryLodge_Gloucester	0.958	0.999
Winchester-LondonRoad_Gloucester	0.999	0.999
Yarnton-LondonRoad_Gloucester	0.999	0.554
York-LondonRoad_Gloucester	0.958	0.994
Yarnton-Winchester	0.671	0.002
York-Winchester	0.003	0.751
York-Yarnton	0.506	0.151

A2.1.3 Early Medieval

A2.1.3.1 Human

Levene Test
$\partial^{13}C$: (f(42, 758) = 3.884, p= 0.000)
$\partial^{15}N$: (f((42, 758) = 1.271, p= 0.119)

ANOVAs
$\partial^{13}C$: F = 12.3, num df = 42, denom df = 103.7, p = 0.000
$\partial^{15}N$: (f((42, 758) = 28.52, p= 0.000)

Site	$\partial^{13}C$	$\partial^{15}N$
Test + Post-Hoc Test	T-Test (adjusted p-values)	ANOVA + TUKEY HSD
Alton-Alchester	0.793	0.705
Appledown Compton-Alchester	1.000	0.478
Barton upon Humber-Alchester	1.000	0.768
Bellevue_York-Alchester	1.000	1.000
BerghApton-Alchester	0.002	1.000
Berinsfield-Alchester	1.000	1.000
Black Gate Cemetary_Newcastle-Alchester	0.527	0.009
BurghCastle-Alchester	1.000	0.985
Caister-by-Yarmouth-Alchester	1.000	0.000
Casteldyke South-Alchester	0.009	1.000
Dover Buckland-Alchester	1.000	1.000
Droxford-Alchester	1.000	0.256
Edix Hill-Alchester	1.000	1.000
Fillingham -Alchester	1.000	0.999
Fishergate_York-Alchester	1.000	0.155
Kilton Hill-Alchester	1.000	0.074
Lechlade-Alchester	1.000	0.999
Marina Drive-Alchester	1.000	1.000
Melbourne-Alchester	1.000	0.999
Mill Hill-Alchester	1.000	1.000
Morningthorpe-Alchester	0.041	1.000
Norwich-Alchester	0.078	0.819
Portway-Alchester	1.000	0.000
ShavardsFarm-Alchester	1.000	0.350
SouthAcre-Alchester	0.045	0.109
SpongHill-Alchester	0.187	1.000
St JohnsCollege-Alchester	1.000	0.000
St Peter's Tip-Alchester	1.000	0.999
Swaffham-Alchester	1.000	1.000

Site	$\partial^{13}C$	$\partial^{15}N$
Test + Post-Hoc Test	T-Test (adjusted p-values)	ANOVA + TUKEY HSD
Wasperton-Alchester	1.000	0.966
WestgarthGardens-Alchester	1.000	1.000
Whitton-Alchester	1.000	0.999
Winnall-Alchester	1.000	0.486
Worthy_Park-Alchester	1.000	0.035
Yarnton-Alchester	1.000	0.131
Appledown Compton-Alton	1.000	0.999
Barton upon Humber-Alton	1.000	0.000
Bellevue_York-Alton	0.009	0.001
BerghApton-Alton	1.000	0.990
Berinsfield-Alton	0.003	0.039
Black Gate Cemetary_Newcastle-Alton	1.000	0.000
BurghCastle-Alton	0.000	0.000
Caister-by-Yarmouth-Alton	0.000	0.000
Casteldyke South-Alton	1.000	0.550
Dover Buckland-Alton	0.131	0.990
Droxford-Alton	1.000	1.000
Edix Hill-Alton	1.000	0.970
Fillingham -Alton	1.000	0.487
Fishergate_York-Alton	0.000	0.000
Kilton Hill-Alton	1.000	0.000
Lechlade-Alton	1.000	1.000
Marina Drive-Alton	1.000	0.994
Melbourne-Alton	1.000	0.999
Mill Hill-Alton	0.019	0.999
Morningthorpe-Alton	1.000	0.000
Norwich-Alton	0.000	0.000
Portway-Alton	0.000	0.018
ShavardsFarm-Alton	0.000	1.000
SouthAcre-Alton	0.000	0.000
SpongHill-Alton	1.000	0.179
St JohnsCollege-Alton	0.000	0.000
St Peter's Tip-Alton	0.014	0.999
Swaffham-Alton	1.000	0.999
Wasperton-Alton	1.000	0.000
WestgarthGardens-Alton	0.186	0.001
Whitton-Alton	1.000	0.493
Winnall-Alton	1.000	1.000
Worthy_Park-Alton	1.000	0.984
Yarnton-Alton	0.060	0.000
Barton upon Humber-Appledown Compton	1.000	0.000

Site	$\partial^{13}C$	$\partial^{15}N$
Test + Post-Hoc Test	T-Test (adjusted p-values)	ANOVA + TUKEY HSD
Bellevue_York-Appledown Compton	1.000	0.165
BerghApton-Appledown Compton	1.000	0.842
Berinsfield-Appledown Compton	1.000	0.517
Black Gate Cemetary_Newcastle-Appledown Compton	1.000	0.000
BurghCastle-Appledown Compton	1.000	0.001
Caister-by-Yarmouth-Appledown Compton	0.556	0.000
Casteldyke South-Appledown Compton	1.000	0.364
Dover Buckland-Appledown Compton	1.000	0.982
Droxford-Appledown Compton	1.000	0.999
Edix Hill-Appledown Compton	1.000	0.734
Fillingham -Appledown Compton	1.000	0.183
Fishergate_York-Appledown Compton	1.000	0.000
Kilton Hill-Appledown Compton	1.000	0.000
Lechlade-Appledown Compton	1.000	0.993
Marina Drive-Appledown Compton	1.000	0.783
Melbourne-Appledown Compton	1.000	9.790
Mill Hill-Appledown Compton	1.000	0.949
Morningthorpe-Appledown Compton	1.000	0.062
Norwich-Appledown Compton	0.020	0.000
Portway-Appledown Compton	1.000	1.000
ShavardsFarm-Appledown Compton	1.000	1.000
SouthAcre-Appledown Compton	0.011	0.000
SpongHill-Appledown Compton	1.000	0.148
St JohnsCollege-Appledown Compton	1.000	0.000
St Peter's Tip-Appledown Compton	1.000	0.970
Swaffham-Appledown Compton	1.000	0.926
Wasperton-Appledown Compton	1.000	0.002
WestgarthGardens-Appledown Compton	1.000	0.250
Whitton-Appledown Compton	1.000	0.185
Winnall-Appledown Compton	1.000	0.999
Worthy_Park-Appledown Compton	1.000	1.000
Yarnton-Appledown Compton	1.000	0.000
Bellevue_York-Barton upon Humber	1.000	0.258
BerghApton-Barton upon Humber	1.000	0.042
Berinsfield-Barton upon Humber	1.000	0.003
Black Gate Cemetary_Newcastle-Barton upon Humber	1.000	1.000
BurghCastle-Barton upon Humber	0.002	0.999
Caister-by-Yarmouth-Barton upon Humber	0.000	0.842
Casteldyke South-Barton upon Humber	1.000	0.950
Dover Buckland-Barton upon Humber	0.958	0.170
Droxford-Barton upon Humber	1.000	0.000

Site	$\partial^{13}C$	$\partial^{15}N$
Test + Post-Hoc Test	T-Test (adjusted p-values)	ANOVA + TUKEY HSD
Edix Hill-Barton upon Humber	1.000	0.410
Fillingham -Barton upon Humber	1.000	1.000
Fishergate_York-Barton upon Humber	0.000	1.000
Kilton Hill-Barton upon Humber	1.000	0.976
Lechlade-Barton upon Humber	1.000	0.012
Marina Drive-Barton upon Humber	1.000	0.999
Melbourne-Barton upon Humber	1.000	0.028
Mill Hill-Barton upon Humber	0.397	0.100
Morningthorpe-Barton upon Humber	1.000	0.924
Norwich-Barton upon Humber	0.000	1.000
Portway-Barton upon Humber	0.022	0.000
ShavardsFarm-Barton upon Humber	0.000	0.000
SouthAcre-Barton upon Humber	1.000	1.000
SpongHill-Barton upon Humber	1.000	0.999
St JohnsCollege-Barton upon Humber	0.000	0.992
St Peter's Tip-Barton upon Humber	0.634	0.009
Swaffham-Barton upon Humber	1.000	0.053
Wasperton-Barton upon Humber	1.000	1.000
WestgarthGardens-Barton upon Humber	1.000	0.057
Whitton-Barton upon Humber	1.000	1.000
Winnall-Barton upon Humber	1.000	0.000
Worthy_Park-Barton upon Humber	1.000	0.000
Yarnton-Barton upon Humber	0.842	1.000
BerghApton-Bellevue_York	0.000	0.999
Berinsfield-Bellevue_York	1.000	0.998
Black Gate Cemetary_Newcastle-Bellevue_York	0.001	0.000
BurghCastle-Bellevue_York	1.000	0.398
Caister-by-Yarmouth-Bellevue_York	0.003	0.000
Casteldyke South-Bellevue_York	0.018	1.000
Dover Buckland-Bellevue_York	1.000	0.999
Droxford-Bellevue_York	1.000	0.000
Edix Hill-Bellevue_York	1.000	1.000
Fillingham -Bellevue_York	1.000	0.999
Fishergate_York-Bellevue_York	0.336	0.000
Kilton Hill-Bellevue_York	1.000	0.031
Lechlade-Bellevue_York	1.000	0.983
Marina Drive-Bellevue_York	1.000	1.000
Melbourne-Bellevue_York	1.000	0.998
Mill Hill-Bellevue_York	1.000	0.999
Morningthorpe-Bellevue_York	0.000	1.000
Norwich-Bellevue_York	0.000	0.130

Site	$\partial^{13}C$	$\partial^{15}N$
Test + Post-Hoc Test	T-Test (adjusted p-values)	ANOVA + TUKEY HSD
Portway-Bellevue_York	1.000	0.000
ShavardsFarm-Bellevue_York	1.000	0.003
SouthAcre-Bellevue_York	0.000	0.001
SpongHill-Bellevue_York	0.059	1.000
St JohnsCollege-Bellevue_York	0.083	0.000
St Peter's Tip-Bellevue_York	1.000	0.988
Swaffham-Bellevue_York	1.000	0.999
Wasperton-Bellevue_York	1.000	0.775
WestgarthGardens-Bellevue_York	1.000	1.000
Whitton-Bellevue_York	1.000	0.999
Winnall-Bellevue_York	1.000	0.000
Worthy_Park-Bellevue_York	0.654	0.000
Yarnton-Bellevue_York	1.000	0.006
Berinsfield-BerghApton	0.000	1.000
Black Gate Cemetary_Newcastle-BerghApton	1.000	0.000
BurghCastle-BerghApton	0.000	0.082
Caister-by-Yarmouth-BerghApton	0.000	0.000
Casteldyke South-BerghApton	1.000	0.999
Dover Buckland-BerghApton	0.000	1.000
Droxford-BerghApton	0.002	0.714
Edix Hill-BerghApton	1.000	1.000
Fillingham -BerghApton	1.000	0.991
Fishergate_York-BerghApton	0.000	0.000
Kilton Hill-BerghApton	1.000	0.005
Lechlade-BerghApton	0.477	1.000
Marina Drive-BerghApton	1.000	1.000
Melbourne-BerghApton	0.327	1.000
Mill Hill-BerghApton	0.000	1.000
Morningthorpe-BerghApton	1.000	0.986
Norwich-BerghApton	0.000	0.021
Portway-BerghApton	0.000	0.000
ShavardsFarm-BerghApton	0.000	0.815
SouthAcre-BerghApton	0.000	0.000
SpongHill-BerghApton	1.000	0.999
St JohnsCollege-BerghApton	0.000	0.000
St Peter's Tip-BerghApton	0.000	1.000
Swaffham-BerghApton	1.000	1.000
Wasperton-BerghApton	0.190	0.250
WestgarthGardens-BerghApton	0.000	1.000
Whitton-BerghApton	1.000	0.992
Winnall-BerghApton	0.003	0.931

Site	$\partial^{13}C$	$\partial^{15}N$
Test + Post-Hoc Test	T-Test (adjusted p-values)	ANOVA + TUKEY HSD
Worthy_Park-BerghApton	0.367	0.151
Yarnton-BerghApton	0.000	0.000
Black Gate Cemetary_Newcastle-Berinsfield	0.000	0.000
BurghCastle-Berinsfield	0.510	0.000
Caister-by-Yarmouth-Berinsfield	0.000	0.000
Casteldyke South-Berinsfield	0.028	1.000
Dover Buckland-Berinsfield	1.000	1.000
Droxford-Berinsfield	1.000	0.000
Edix Hill-Berinsfield	1.000	1.000
Fillingham -Berinsfield	1.000	0.993
Fishergate_York-Berinsfield	0.000	0.000
Kilton Hill-Berinsfield	1.000	0.003
Lechlade-Berinsfield	1.000	0.999
Marina Drive-Berinsfield	1.000	1.000
Melbourne-Berinsfield	1.000	1.000
Mill Hill-Berinsfield	1.000	1.000
Morningthorpe-Berinsfield	0.000	0.851
Norwich-Berinsfield	0.000	0.000
Portway-Berinsfield	0.144	0.000
ShavardsFarm-Berinsfield	0.237	0.063
SouthAcre-Berinsfield	0.000	0.000
SpongHill-Berinsfield	0.094	0.998
St JohnsCollege-Berinsfield	0.000	0.000
St Peter's Tip-Berinsfield	1.000	1.000
Swaffham-Berinsfield	1.000	1.000
Wasperton-Berinsfield	1.000	0.092
WestgarthGardens-Berinsfield	1.000	0.999
Whitton-Berinsfield	1.000	0.993
Winnall-Berinsfield	1.000	0.004
Worthy_Park-Berinsfield	0.715	0.000
Yarnton-Berinsfield	1.000	0.000
BurghCastle-Black Gate Cemetary_Newcastle	0.000	0.019
Caister-by-Yarmouth-Black Gate Cemetary_Newcastle	0.000	0.814
Casteldyke South-Black Gate Cemetary_Newcastle	1.000	0.082
Dover Buckland-Black Gate Cemetary_Newcastle	0.091	0.000
Droxford-Black Gate Cemetary_Newcastle	0.817	0.000
Edix Hill-Black Gate Cemetary_Newcastle	1.000	0.000
Fillingham -Black Gate Cemetary_Newcastle	1.000	1.000
Fishergate_York-Black Gate Cemetary_Newcastle	0.000	0.999
Kilton Hill-Black Gate Cemetary_Newcastle	1.000	0.997
Lechlade-Black Gate Cemetary_Newcastle	1.000	0.000

Site	$\partial^{13}C$	$\partial^{15}N$
Test + Post-Hoc Test	T-Test (adjusted p-values)	ANOVA + TUKEY HSD
Marina Drive-Black Gate Cemetary_Newcastle	1.000	0.999
Melbourne-Black Gate Cemetary_Newcastle	1.000	0.000
Mill Hill-Black Gate Cemetary_Newcastle	0.011	0.000
Morningthorpe-Black Gate Cemetary_Newcastle	1.000	0.000
Norwich-Black Gate Cemetary_Newcastle	0.000	0.996
Portway-Black Gate Cemetary_Newcastle	0.000	0.000
ShavardsFarm-Black Gate Cemetary_Newcastle	0.000	0.000
SouthAcre-Black Gate Cemetary_Newcastle	0.000	1.000
SpongHill-Black Gate Cemetary_Newcastle	1.000	0.699
St JohnsCollege-Black Gate Cemetary_Newcastle	0.000	0.997
St Peter's Tip-Black Gate Cemetary_Newcastle	0.006	0.000
Swaffham-Black Gate Cemetary_Newcastle	1.000	0.000
Wasperton-Black Gate Cemetary_Newcastle	1.000	0.999
WestgarthGardens-Black Gate Cemetary_Newcastle	0.031	0.000
Whitton-Black Gate Cemetary_Newcastle	1.000	1.000
Winnall-Black Gate Cemetary_Newcastle	1.000	0.000
Worthy_Park-Black Gate Cemetary_Newcastle	1.000	0.000
Yarnton-Black Gate Cemetary_Newcastle	0.036	1.000
Caister-by-Yarmouth-BurghCastle	1.000	0.000
Casteldyke South-BurghCastle	0.000	0.999
Dover Buckland-BurghCastle	1.000	0.429
Droxford-BurghCastle	0.188	0.000
Edix Hill-BurghCastle	1.000	0.792
Fillingham -BurghCastle	1.000	1.000
Fishergate_York-BurghCastle	1.000	0.980
Kilton Hill-BurghCastle	1.000	0.555
Lechlade-BurghCastle	1.000	0.025
Marina Drive-BurghCastle	1.000	1.000
Melbourne-BurghCastle	1.000	0.060
Mill Hill-BurghCastle	1.000	0.258
Morningthorpe-BurghCastle	0.000	0.999
Norwich-BurghCastle	0.211	1.000
Portway-BurghCastle	1.000	0.000
ShavardsFarm-BurghCastle	1.000	0.000
SouthAcre-BurghCastle	0.017	0.913
SpongHill-BurghCastle	0.000	1.000
St JohnsCollege-BurghCastle	1.000	0.001
St Peter's Tip-BurghCastle	1.000	0.013
Swaffham-BurghCastle	0.372	0.124
Wasperton-BurghCastle	1.000	1.000
WestgarthGardens-BurghCastle	0.079	0.027

Site	$\partial^{13}C$	$\partial^{15}N$
Test + Post-Hoc Test	T-Test (adjusted p-values)	ANOVA + TUKEY HSD
Whitton-BurghCastle	1.000	1.000
Winnall-BurghCastle	0.082	0.000
Worthy_Park-BurghCastle	0.000	0.000
Yarnton-BurghCastle	1.000	0.920
Casteldyke South-Caister-by-Yarmouth	0.000	0.000
Dover Buckland-Caister-by-Yarmouth	1.000	0.000
Droxford-Caister-by-Yarmouth	0.000	0.000
Edix Hill-Caister-by-Yarmouth	0.013	0.000
Fillingham -Caister-by-Yarmouth	0.051	0.999
Fishergate_York-Caister-by-Yarmouth	1.000	0.103
Kilton Hill-Caister-by-Yarmouth	1.000	1.000
Lechlade-Caister-by-Yarmouth	0.016	0.000
Marina Drive-Caister-by-Yarmouth	1.000	0.790
Melbourne-Caister-by-Yarmouth	0.026	0.000
Mill Hill-Caister-by-Yarmouth	1.000	0.000
Morningthorpe-Caister-by-Yarmouth	0.000	0.000
Norwich-Caister-by-Yarmouth	1.000	0.101
Portway-Caister-by-Yarmouth	0.536	0.000
ShavardsFarm-Caister-by-Yarmouth	1.000	0.000
SouthAcre-Caister-by-Yarmouth	1.000	0.999
SpongHill-Caister-by-Yarmouth	0.000	0.035
St JohnsCollege-Caister-by-Yarmouth	1.000	1.000
St Peter's Tip-Caister-by-Yarmouth	1.000	0.000
Swaffham-Caister-by-Yarmouth	0.000	0.000
Wasperton-Caister-by-Yarmouth	0.487	0.774
WestgarthGardens-Caister-by-Yarmouth	0.000	0.000
Whitton-Caister-by-Yarmouth	0.525	0.999
Winnall-Caister-by-Yarmouth	0.000	0.000
Worthy_Park-Caister-by-Yarmouth	0.000	0.000
Yarnton-Caister-by-Yarmouth	1.000	0.999
Dover Buckland-Casteldyke South	0.018	0.999
Droxford-Casteldyke South	0.411	0.172
Edix Hill-Casteldyke South	1.000	1.000
Fillingham -Casteldyke South	1.000	0.999
Fishergate_York-Casteldyke South	0.000	0.510
Kilton Hill-Casteldyke South	1.000	0.146
Lechlade-Casteldyke South	1.000	0.995
Marina Drive-Casteldyke South	1.000	1.000
Melbourne-Casteldyke South	1.000	0.999
Mill Hill-Casteldyke South	0.004	0.999
Morningthorpe-Casteldyke South	1.000	1.000

Site	$\partial^{13}C$	$\partial^{15}N$
Test + Post-Hoc Test	T-Test (adjusted p-values)	ANOVA + TUKEY HSD
Norwich-Casteldyke South	0.000	0.977
Portway-Casteldyke South	0.000	0.002
ShavardsFarm-Casteldyke South	0.000	0.241
SouthAcre-Casteldyke South	0.000	0.334
SpongHill-Casteldyke South	1.000	1.000
St JohnsCollege-Casteldyke South	0.000	0.003
St Peter's Tip-Casteldyke South	0.005	0.999
Swaffham-Casteldyke South	1.000	0.999
Wasperton-Casteldyke South	1.000	0.997
WestgarthGardens-Casteldyke South	0.152	1.000
Whitton-Casteldyke South	1.000	0.999
Winnall-Casteldyke South	0.518	0.350
Worthy_Park-Casteldyke South	1.000	0.023
Yarnton-Casteldyke South	0.011	0.346
Droxford-Dover Buckland	1.000	0.999
Edix Hill-Dover Buckland	1.000	1.000
Fillingham -Dover Buckland	1.000	0.990
Fishergate_York-Dover Buckland	1.000	0.008
Kilton Hill-Dover Buckland	1.000	0.010
Lechlade-Dover Buckland	1.000	1.000
Marina Drive-Dover Buckland	1.000	1.000
Melbourne-Dover Buckland	1.000	1.000
Mill Hill-Dover Buckland	1.000	1.000
Morningthorpe-Dover Buckland	0.007	0.997
Norwich-Dover Buckland	1.000	0.172
Portway-Dover Buckland	1.000	0.327
ShavardsFarm-Dover Buckland	1.000	0.998
SouthAcre-Dover Buckland	1.000	0.006
SpongHill-Dover Buckland	0.036	0.999
St JohnsCollege-Dover Buckland	1.000	0.000
St Peter's Tip-Dover Buckland	1.000	1.000
Swaffham-Dover Buckland	1.000	1.000
Wasperton-Dover Buckland	1.000	0.456
WestgarthGardens-Dover Buckland	1.000	1.000
Whitton-Dover Buckland	1.000	0.990
Winnall-Dover Buckland	1.000	0.999
Worthy_Park-Dover Buckland	0.960	0.946
Yarnton-Dover Buckland	1.000	0.009
Edix Hill-Droxford	1.000	0.675
Fillingham -Droxford	1.000	0.255
Fishergate_York-Droxford	0.000	0.000

Site	$\partial^{13}C$	$\partial^{15}N$
Test + Post-Hoc Test	T-Test (adjusted p-values)	ANOVA + TUKEY HSD
Kilton Hill-Droxford	1.000	0.000
Lechlade-Droxford	1.000	0.999
Marina Drive-Droxford	1.000	0.948
Melbourne-Droxford	1.000	0.998
Mill Hill-Droxford	1.000	0.987
Morningthorpe-Droxford	0.051	0.000
Norwich-Droxford	0.000	0.000
Portway-Droxford	0.102	0.564
ShavardsFarm-Droxford	0.077	1.000
SouthAcre-Droxford	0.000	0.000
SpongHill-Droxford	0.863	0.036
St JohnsCollege-Droxford	0.000	0.000
St Peter's Tip-Droxford	1.000	0.991
Swaffham-Droxford	1.000	0.953
Wasperton-Droxford	1.000	0.000
WestgarthGardens-Droxford	1.000	0.000
Whitton-Droxford	1.000	0.259
Winnall-Droxford	1.000	1.000
Worthy_Park-Droxford	1.000	1.000
Yarnton-Droxford	1.000	0.000
Fillingham -Edix Hill	1.000	0.999
Fishergate_York-Edix Hill	0.487	0.256
Kilton Hill-Edix Hill	1.000	0.029
Lechlade-Edix Hill	1.000	1.000
Marina Drive-Edix Hill	1.000	1.000
Melbourne-Edix Hill	1.000	1.000
Mill Hill-Edix Hill	1.000	1.000
Morningthorpe-Edix Hill	1.000	0.999
Norwich-Edix Hill	0.000	0.431
Portway-Edix Hill	1.000	0.003
ShavardsFarm-Edix Hill	0.725	0.731
SouthAcre-Edix Hill	0.000	0.022
SpongHill-Edix Hill	1.000	0.999
St JohnsCollege-Edix Hill	0.191	0.000
St Peter's Tip-Edix Hill	1.000	1.000
Swaffham-Edix Hill	1.000	1.000
Wasperton-Edix Hill	1.000	0.787
WestgarthGardens-Edix Hill	1.000	1.000
Whitton-Edix Hill	1.000	0.999
Winnall-Edix Hill	1.000	0.885
Worthy_Park-Edix Hill	1.000	0.191

Site	$\partial^{13}C$	$\partial^{15}N$
Test + Post-Hoc Test	T-Test (adjusted p-values)	ANOVA + TUKEY HSD
Yarnton-Edix Hill	1.000	0.003
Fishergate_York-Fillingham	0.461	1.000
Kilton Hill-Fillingham	1.000	0.997
Lechlade-Fillingham	1.000	0.929
Marina Drive-Fillingham	1.000	1.000
Melbourne-Fillingham	1.000	0.966
Mill Hill-Fillingham	1.000	0.990
Morningthorpe-Fillingham	1.000	1.000
Norwich-Fillingham	0.002	1.000
Portway-Fillingham	1.000	0.014
ShavardsFarm-Fillingham	0.389	0.241
SouthAcre-Fillingham	0.001	1.000
SpongHill-Fillingham	1.000	1.000
St JohnsCollege-Fillingham	0.267	0.999
St Peter's Tip-Fillingham	1.000	0.951
Swaffham-Fillingham	1.000	0.987
Wasperton-Fillingham	1.000	1.000
WestgarthGardens-Fillingham	1.000	0.999
Whitton-Fillingham	1.000	1.000
Winnall-Fillingham	1.000	0.374
Worthy_Park-Fillingham	1.000	0.097
Yarnton-Fillingham	1.000	1.000
Kilton Hill-Fishergate_York	1.000	0.955
Lechlade-Fishergate_York	0.630	0.000
Marina Drive-Fishergate_York	1.000	0.999
Melbourne-Fishergate_York	0.961	0.000
Mill Hill-Fishergate_York	1.000	0.001
Morningthorpe-Fishergate_York	0.000	0.080
Norwich-Fishergate_York	0.050	1.000
Portway-Fishergate_York	1.000	0.000
ShavardsFarm-Fishergate_York	1.000	0.000
SouthAcre-Fishergate_York	0.040	1.000
SpongHill-Fishergate_York	0.000	0.988
St JohnsCollege-Fishergate_York	1.000	0.355
St Peter's Tip-Fishergate_York	1.000	0.000
Swaffham-Fishergate_York	0.030	0.000
Wasperton-Fishergate_York	1.000	1.000
WestgarthGardens-Fishergate_York	0.000	0.000
Whitton-Fishergate_York	1.000	1.000
Winnall-Fishergate_York	0.000	0.000
Worthy_Park-Fishergate_York	0.000	0.000

Site	$\partial^{13}C$	$\partial^{15}N$
Test + Post-Hoc Test	T-Test (adjusted p-values)	ANOVA + TUKEY HSD
Yarnton-Fishergate_York	1.000	1.000
Lechlade-Kilton Hill	1.000	0.001
Marina Drive-Kilton Hill	1.000	0.794
Melbourne-Kilton Hill	1.000	0.003
Mill Hill-Kilton Hill	1.000	0.007
Morningthorpe-Kilton Hill	1.000	0.139
Norwich-Kilton Hill	0.076	0.862
Portway-Kilton Hill	1.000	0.000
ShavardsFarm-Kilton Hill	1.000	0.000
SouthAcre-Kilton Hill	0.043	0.999
SpongHill-Kilton Hill	1.000	0.421
St JohnsCollege-Kilton Hill	1.000	0.999
St Peter's Tip-Kilton Hill	1.000	0.001
Swaffham-Kilton Hill	1.000	0.005
Wasperton-Kilton Hill	1.000	0.950
WestgarthGardens-Kilton Hill	1.000	0.013
Whitton-Kilton Hill	1.000	0.997
Winnall-Kilton Hill	1.000	0.000
Worthy_Park-Kilton Hill	1.000	0.000
Yarnton-Kilton Hill	1.000	0.999
Marina Drive-Lechlade	1.000	0.999
Melbourne-Lechlade	1.000	1.000
Mill Hill-Lechlade	1.000	1.000
Morningthorpe-Lechlade	1.000	0.795
Norwich-Lechlade	0.000	0.006
Portway-Lechlade	1.000	0.236
ShavardsFarm-Lechlade	0.966	0.999
SouthAcre-Lechlade	0.000	0.000
SpongHill-Lechlade	1.000	0.960
St JohnsCollege-Lechlade	0.244	0.000
St Peter's Tip-Lechlade	1.000	1.000
Swaffham-Lechlade	1.000	1.000
Wasperton-Lechlade	1.000	0.080
WestgarthGardens-Lechlade	1.000	0.998
Whitton-Lechlade	1.000	0.931
Winnall-Lechlade	1.000	0.999
Worthy_Park-Lechlade	1.000	0.961
Yarnton-Lechlade	1.000	0.000
Melbourne-Marina Drive	1.000	0.999
Mill Hill-Marina Drive	1.000	1.000
Morningthorpe-Marina Drive	1.000	1.000

Site	$\partial^{13}C$	$\partial^{15}N$
Test + Post-Hoc Test	T-Test (adjusted p-values)	ANOVA + TUKEY HSD
Norwich-Marina Drive	0.312	1.000
Portway-Marina Drive	1.000	0.357
ShavardsFarm-Marina Drive	1.000	0.927
SouthAcre-Marina Drive	0.183	0.999
SpongHill-Marina Drive	1.000	1.000
St JohnsCollege-Marina Drive	1.000	0.943
St Peter's Tip-Marina Drive	1.000	0.999
Swaffham-Marina Drive	1.000	1.000
Wasperton-Marina Drive	1.000	1.000
WestgarthGardens-Marina Drive	1.000	1.000
Whitton-Marina Drive	1.000	1.000
Winnall-Marina Drive	1.000	0.982
Worthy_Park-Marina Drive	1.000	0.776
Yarnton-Marina Drive	1.000	0.998
Mill Hill-Melbourne	1.000	1.000
Morningthorpe-Melbourne	1.000	0.929
Norwich-Melbourne	0.000	0.017
Portway-Melbourne	1.000	0.103
ShavardsFarm-Melbourne	1.000	0.997
SouthAcre-Melbourne	0.000	0.000
SpongHill-Melbourne	1.000	0.989
St JohnsCollege-Melbourne	0.387	0.000
St Peter's Tip-Melbourne	1.000	1.000
Swaffham-Melbourne	1.000	1.000
Wasperton-Melbourne	1.000	0.162
WestgarthGardens-Melbourne	1.000	0.999
Whitton-Melbourne	1.000	0.967
Winnall-Melbourne	1.000	0.999
Worthy_Park-Melbourne	1.000	0.851
Yarnton-Melbourne	1.000	0.000
Morningthorpe-Mill Hill	0.000	0.994
Norwich-Mill Hill	1.000	0.083
Portway-Mill Hill	1.000	0.065
ShavardsFarm-Mill Hill	1.000	0.985
SouthAcre-Mill Hill	0.901	0.001
SpongHill-Mill Hill	0.011	0.999
St JohnsCollege-Mill Hill	1.000	0.000
St Peter's Tip-Mill Hill	1.000	1.000
Swaffham-Mill Hill	1.000	1.000
Wasperton-Mill Hill	1.000	0.359
WestgarthGardens-Mill Hill	1.000	1.000

Site	$\partial^{13}C$	$\partial^{15}N$
Test + Post-Hoc Test	T-Test (adjusted p-values)	ANOVA + TUKEY HSD
Whitton-Mill Hill	1.000	0.990
Winnall-Mill Hill	1.000	0.999
Worthy_Park-Mill Hill	0.252	0.717
Yarnton-Mill Hill	1.000	0.003
Norwich-Morningthorpe	0.000	0.941
Portway-Morningthorpe	0.000	0.000
ShavardsFarm-Morningthorpe	0.000	0.000
SouthAcre-Morningthorpe	0.000	0.121
SpongHill-Morningthorpe	1.000	1.000
St JohnsCollege-Morningthorpe	0.000	0.000
St Peter's Tip-Morningthorpe	0.000	0.802
Swaffham-Morningthorpe	1.000	0.983
Wasperton-Morningthorpe	1.000	0.998
WestgarthGardens-Morningthorpe	0.000	0.999
Whitton-Morningthorpe	1.000	1.000
Winnall-Morningthorpe	0.070	0.000
Worthy_Park-Morningthorpe	1.000	0.000
Yarnton-Morningthorpe	0.002	0.184
Portway-Norwich	0.000	0.000
ShavardsFarm-Norwich	1.000	0.000
SouthAcre-Norwich	1.000	0.999
SpongHill-Norwich	0.000	0.999
St JohnsCollege-Norwich	0.403	0.350
St Peter's Tip-Norwich	0.065	0.003
Swaffham-Norwich	0.000	0.034
Wasperton-Norwich	0.004	1.000
WestgarthGardens-Norwich	0.000	0.009
Whitton-Norwich	0.034	1.000
Winnall-Norwich	0.000	0.000
Worthy_Park-Norwich	0.000	0.000
Yarnton-Norwich	0.748	0.999
ShavardsFarm-Portway	1.000	0.999
SouthAcre-Portway	0.000	0.000
SpongHill-Portway	0.000	0.000
St JohnsCollege-Portway	1.000	0.000
St Peter's Tip-Portway	1.000	0.221
Swaffham-Portway	0.485	0.152
Wasperton-Portway	1.000	0.000
WestgarthGardens-Portway	0.014	0.000
Whitton-Portway	1.000	0.153
Winnall-Portway	0.033	0.106

Site	$\partial^{13}C$	$\partial^{15}N$
Test + Post-Hoc Test	T-Test (adjusted p-values)	ANOVA + TUKEY HSD
Worthy_Park-Portway	0.000	0.999
Yarnton-Portway	1.000	0.000
SouthAcre-ShavardsFarm	1.000	0.000
SpongHill-ShavardsFarm	0.000	0.062
St JohnsCollege-ShavardsFarm	1.000	0.000
St Peter's Tip-ShavardsFarm	1.000	0.992
Swaffham-ShavardsFarm	0.099	0.961
Wasperton-ShavardsFarm	1.000	0.000
WestgarthGardens-ShavardsFarm	0.051	0.005
Whitton-ShavardsFarm	1.000	0.245
Winnall-ShavardsFarm	0.041	1.000
Worthy_Park-ShavardsFarm	0.000	1.000
Yarnton-ShavardsFarm	1.000	0.000
SpongHill-SouthAcre	0.000	0.906
St JohnsCollege-SouthAcre	0.266	1.000
St Peter's Tip-SouthAcre	0.040	0.000
Swaffham-SouthAcre	0.000	0.000
Wasperton-SouthAcre	0.002	1.000
WestgarthGardens-SouthAcre	0.000	0.000
Whitton-SouthAcre	0.019	1.000
Winnall-SouthAcre	0.000	0.000
Worthy_Park-SouthAcre	0.000	0.000
Yarnton-SouthAcre	0.413	1.000
St JohnsCollege-SpongHill	0.000	0.127
St Peter's Tip-SpongHill	0.016	0.974
Swaffham-SpongHill	1.000	0.998
Wasperton-SpongHill	1.000	0.999
WestgarthGardens-SpongHill	0.392	0.999
Whitton-SpongHill	1.000	1.000
Winnall-SpongHill	1.000	0.091
Worthy_Park-SpongHill	1.000	0.003
Yarnton-SpongHill	0.026	0.881
St Peter's Tip-St JohnsCollege	1.000	0.000
Swaffham-St JohnsCollege	0.009	0.000
Wasperton-St JohnsCollege	1.000	0.976
WestgarthGardens-St JohnsCollege	0.000	0.000
Whitton-St JohnsCollege	1.000	0.999
Winnall-St JohnsCollege	0.000	0.000
Worthy_Park-St JohnsCollege	0.000	0.000
Yarnton-St JohnsCollege	1.000	1.000
Swaffham-St Peter's Tip	1.000	1.000

Site	$\partial^{13}C$	$\partial^{15}N$
Test + Post-Hoc Test	T-Test (adjusted p-values)	ANOVA + TUKEY HSD
Wasperton-St Peter's Tip	1.000	0.083
WestgarthGardens-St Peter's Tip	1.000	0.999
Whitton-St Peter's Tip	1.000	0.953
Winnall-St Peter's Tip	1.000	0.999
Worthy_Park-St Peter's Tip	0.296	0.663
Yarnton-St Peter's Tip	1.000	0.000
Wasperton-Swaffham	1.000	0.259
WestgarthGardens-Swaffham	1.000	0.999
Whitton-Swaffham	1.000	0.987
Winnall-Swaffham	1.000	0.996
Worthy_Park-Swaffham	1.000	0.498
Yarnton-Swaffham	1.000	0.001
WestgarthGardens-Wasperton	1.000	0.429
Whitton-Wasperton	1.000	1.000
Winnall-Wasperton	1.000	0.000
Worthy_Park-Wasperton	1.000	0.000
Yarnton-Wasperton	1.000	0.999
Whitton-WestgarthGardens	1.000	0.999
Winnall-WestgarthGardens	1.000	0.000
Worthy_Park-WestgarthGardens	1.000	0.000
Yarnton-WestgarthGardens	1.000	0.000
Winnall-Whitton	1.000	0.380
Worthy_Park-Whitton	1.000	0.099
Yarnton-Whitton	1.000	1.000
Worthy_Park-Winnall	1.000	0.999
Yarnton-Winnall	1.000	0.000
Yarnton-Worthy_Park	0.644	0.000

A2.1.3.2 Cattle

Levene Test
$\partial^{13}C$: (f(7, 116) = 1.524, p= 0.165)
$\partial^{15}N$: (f((7, 116) = 1.981, p= 0.063)

ANOVAs
$\partial^{13}C$: (f((7, 116) = 6.596, p= 0.000)
$\partial^{15}N$: (f((7, 116) = 5.215, p= 0.000)

Site	$\partial^{13}C$	$\partial^{15}N$
Test + Post-Hoc Test	ANOVA + TUKEY HSD	ANOVA + TUKEY HSD
Bellevue_York-Abbot's Worthy	0.892	1.000
Berinsfield-Abbot's Worthy	0.999	0.570
Black Gate Cemetary_Newcastle-Abbot's Worthy	0.968	0.007
Fishergate_York-Abbot's Worthy	1.000	0.586
ShavardsFarm-Abbot's Worthy	0.001	0.997
WestStow-Abbot's Worthy	0.907	0.101
Whitton-Abbot's Worthy	0.999	0.135
Berinsfield-Bellevue_York	0.904	0.912
Black Gate Cemetary_Newcastle-Bellevue_York	0.999	0.282
Fishergate_York-Bellevue_York	0.916	0.975
ShavardsFarm-Bellevue_York	0.998	0.999
WestStow-Bellevue_York	0.549	0.949
Whitton-Bellevue_York	0.999	0.514
Black Gate Cemetary_Newcastle-Berinsfield	0.973	0.961
Fishergate_York-Berinsfield	0.999	0.999
ShavardsFarm-Berinsfield	0.179	0.322
WestStow-Berinsfield	0.999	0.999
Whitton-Berinsfield	0.997	0.990
Fishergate_York-Black Gate Cemetary_Newcastle	0.981	0.523
ShavardsFarm-Black Gate Cemetary_Newcastle	0.740	0.001
WestStow-Black Gate Cemetary_Newcastle	0.586	0.323
Whitton-Black Gate Cemetary_Newcastle	0.999	1.000
ShavardsFarm-Fishergate_York	0.026	0.230
WestStow-Fishergate_York	0.984	1.000
Whitton-Fishergate_York	0.999	0.834
WestStow-ShavardsFarm	0.000	0.003
Whitton-ShavardsFarm	0.856	0.056
Whitton-WestStow	0.946	0.774

A2.1.3.3 Sheep

Levene Test
$\partial^{13}C$: (f(7, 164) = 1.022, p= 0.417)
$\partial^{15}N$: (f((7, 164) = 1.346, p= 0.231)

ANOVAs
$\partial^{13}C$: (f((7, 164) = 5.774, p= 0.000)
$\partial^{15}N$: (f((7, 164) = 21.18, p= 0.000)

Site	$\partial^{13}C$	$\partial^{15}N$
Test + Post-Hoc Test	ANOVA + TUKEY HSD	ANOVA + TUKEY HSD
Bellevue_York-Abbot's Worthy	0.999	0.344
Berinsfield-Abbot's Worthy	0.996	0.226
Black Gate Cemetary_Newcastle-Abbot's Worthy	0.942	0.000
Fishergate_York-Abbot's Worthy	0.999	0.400
ShavardsFarm-Abbot's Worthy	0.117	0.420
WestStow-Abbot's Worthy	0.008	0.000
Whitton-Abbot's Worthy	0.998	0.000
Berinsfield-Bellevue_York	0.999	0.996
Black Gate Cemetary_Newcastle-Bellevue_York	0.965	0.812
Fishergate_York-Bellevue_York	0.999	0.999
ShavardsFarm-Bellevue_York	0.813	0.927
WestStow-Bellevue_York	0.974	0.941
Whitton-Bellevue_York	0.997	0.000
Black Gate Cemetary_Newcastle-Berinsfield	0.901	0.999
Fishergate_York-Berinsfield	0.988	0.928
ShavardsFarm-Berinsfield	0.750	0.674
WestStow-Berinsfield	0.999	1.000
Whitton-Berinsfield	0.978	0.033
Fishergate_York-Black Gate Cemetary_Newcastle	0.996	0.310
ShavardsFarm-Black Gate Cemetary_Newcastle	1.000	0.037
WestStow-Black Gate Cemetary_Newcastle	0.227	0.986
Whitton-Black Gate Cemetary_Newcastle	0.999	0.029
ShavardsFarm-Fishergate_York	0.929	0.994
WestStow-Fishergate_York	0.351	0.194
Whitton-Fishergate_York	0.999	0.000
WestStow-ShavardsFarm	0.000	0.000
Whitton-ShavardsFarm	0.999	0.000
Whitton-WestStow	0.667	0.000

A2.1.3.4 Pigs

Levene Test
∂^{13}C: (f(7, 73) = 1.718, *p*= 0.117)
∂^{15}N: (f((7, 73) = 1.491, *p*= 0.837)

ANOVAs
∂^{13}C: (f((7, 73) = 2.326, *p*= 0.033)
∂^{15}N: (f((7, 73) = 10.14, *p*= 0.000)

Site	∂^{13}C	∂^{15}N
Test + Post-Hoc Test	ANOVA + TUKEY HSD	ANOVA + TUKEY HSD
Bellevue_York-Abbot's Worthy	0.857	0.518
Berinsfield-Abbot's Worthy	0.998	1.000
Black Gate Cemetary_Newcastle-Abbot's Worthy	0.999	0.025
Fishergate_York-Abbot's Worthy	0.904	0.041
ShavardsFarm-Abbot's Worthy	0.311	0.313
WestStow-Abbot's Worthy	0.999	0.573
Whitton-Abbot's Worthy	0.974	0.000
Berinsfield-Bellevue_York	0.874	0.965
Black Gate Cemetary_Newcastle-Bellevue_York	0.958	0.872
Fishergate_York-Bellevue_York	0.999	0.997
ShavardsFarm-Bellevue_York	0.991	0.002
WestStow-Bellevue_York	0.500	0.996
Whitton-Bellevue_York	1.000	0.006
Black Gate Cemetary_Newcastle-Berinsfield	0.993	0.638
Fishergate_York-Berinsfield	0.923	0.845
ShavardsFarm-Berinsfield	0.628	0.954
WestStow-Berinsfield	0.999	0.991
Whitton-Berinsfield	0.926	0.019
Fishergate_York-Black Gate Cemetary_Newcastle	0.986	0.975
ShavardsFarm-Black Gate Cemetary_Newcastle	0.533	0.000
WestStow-Black Gate Cemetary_Newcastle	0.999	0.227
Whitton-Black Gate Cemetary_Newcastle	0.993	0.102
ShavardsFarm-Fishergate_York	0.806	0.000
WestStow-Fishergate_York	0.294	0.368
Whitton-Fishergate_York	0.999	0.008
WestStow-ShavardsFarm	0.040	0.000
Whitton-ShavardsFarm	0.999	0.000
Whitton-WestStow	0.918	0.000

Appendix II.2. Difference between sub-periods

A2.2.1 Cattle

a. Output for the 'lsmeans' function when the **carbon** isotopic values of cattle are analysed by sub-period, with region and site as random effects.

$lsmeans

Sub_Period	lsmean	SE	df	lower.CL	upper.CL
Anglo-Saxon	-21.73103	0.13729449	23.27	-22.01486	-21.44720
Early Anglo-Saxon	-21.89774	0.14295685	12.78	-22.20711	-21.58837
Early Iron Age	-21.66095	0.12542294	4.30	-21.99988	-21.32201
Early Roman	-21.59860	0.16130488	104.89	-21.91845	-21.27876
Iron Age	-21.64012	0.17968208	57.61	-21.99984	-21.28039
Late Iron Age	-21.50210	0.12692325	7.76	-21.79637	-21.20783
Late Roman	-21.54822	0.18186594	46.71	-21.91415	-21.18229
Late Saxon_Norman	-21.67000	0.26598885	21.47	-22.22242	-21.11758
Latest Iron Age	-21.52772	0.15915604	29.64	-21.85293	-21.20251
LIA/Roman	-21.37512	0.28588827	331.64	-21.93750	-20.81273
Middle Anglo-Saxon	-22.39703	0.20718124	38.45	-22.81628	-21.97777
Middle Iron Age	-21.71466	0.10712887	13.85	-21.94467	-21.48466
Middle Roman	-21.79869	0.09883769	19.59	-22.00513	-21.59224
Roman	-21.49756	0.19564916	26.28	-21.89952	-21.09560

Confidence level used: 0.95

$contrasts

contrast	estimate	SE	df	t.ratio	p.value
Anglo-Saxon - Early Anglo-Saxon	0.166705245	0.2003119	18.15	0.832	0.9997
Anglo-Saxon - Early Iron Age	-0.070084798	0.1877666	15.38	-0.373	1.0000
Anglo-Saxon - Early Roman	-0.132426417	0.2118635	53.17	-0.625	1.0000
Anglo-Saxon - Iron Age	-0.090913538	0.2276869	39.53	-0.399	1.0000
Anglo-Saxon - Late Iron Age	-0.228934235	0.1886526	19.43	-1.214	0.9906
Anglo-Saxon - Late Roman	-0.182811893	0.2287858	37.02	-0.799	0.9999
Anglo-Saxon - Late Saxon_Norman	-0.061030619	0.2963179	22.91	-0.206	1.0000
Anglo-Saxon - Latest Iron Age	-0.203311104	0.2116613	34.58	-0.961	0.9992
Anglo-Saxon - LIA/Roman	-0.355913225	0.3177732	191.07	-1.120	0.9976
Anglo-Saxon - Middle Anglo-Saxon	0.665996551	0.2455616	32.28	2.712	0.3169
Anglo-Saxon - Middle Iron Age	-0.016368951	0.1749948	23.23	-0.094	1.0000
Anglo-Saxon - Middle Roman	0.067657042	0.1692139	23.80	0.400	1.0000
Anglo-Saxon - Roman	-0.233472635	0.2363666	31.44	-0.988	0.9989
Early Anglo-Saxon - Early Iron Age	-0.236790043	0.1532675	21.49	-1.545	0.9427
Early Anglo-Saxon - Early Roman	-0.299131662	0.2161614	54.65	-1.384	0.9800
Early Anglo-Saxon - Iron Age	-0.257618783	0.2180750	41.59	-1.181	0.9947
Early Anglo-Saxon - Late Iron Age	-0.395639479	0.1578311	26.08	-2.507	0.4399
Early Anglo-Saxon - Late Roman	-0.349517138	0.2298427	42.39	-1.521	0.9559
Early Anglo-Saxon - Late Saxon_Norman	-0.227735864	0.3123062	19.69	-0.729	0.9999
Early Anglo-Saxon - Latest Iron Age	-0.370016349	0.1852146	49.54	-1.998	0.7614

contrast	estimate	SE	df	t.ratio	p.value
Early Anglo-Saxon - LIA/Roman	-0.522618470	0.3144305	226.33	-1.662	0.9267
Early Anglo-Saxon - Middle Anglo-Saxon	0.499291306	0.2565574	28.05	1.946	0.7855
Early Anglo-Saxon - Middle Iron Age	-0.183074196	0.1625719	25.69	-1.126	0.9958
Early Anglo-Saxon - Middle Roman	-0.099048203	0.1738602	22.03	-0.570	1.0000
Early Anglo-Saxon - Roman	-0.400177880	0.2518380	22.09	-1.589	0.9314
Early Iron Age - Early Roman	-0.062341619	0.1986899	71.41	-0.314	1.0000
Early Iron Age - Iron Age	-0.020828740	0.1984181	87.62	-0.105	1.0000
Early Iron Age - Late Iron Age	-0.158849436	0.0938606	409.04	-1.692	0.9178
Early Iron Age - Late Roman	-0.112727095	0.2127218	47.32	-0.530	1.0000
Early Iron Age - Late Saxon_Norman	0.009054179	0.3015663	20.09	0.030	1.0000
Early Iron Age - Latest Iron Age	-0.133226306	0.1387176	418.28	-0.960	0.9995
Early Iron Age - LIA/Roman	-0.285828427	0.2966934	346.61	-0.963	0.9995
Early Iron Age - Middle Anglo-Saxon	0.736081349	0.2459465	28.33	2.993	0.1985
Early Iron Age - Middle Iron Age	0.053715847	0.1309636	63.34	0.410	1.0000
Early Iron Age - Middle Roman	0.137741840	0.1610658	20.58	0.855	0.9997
Early Iron Age - Roman	-0.163387837	0.2387281	19.58	-0.684	1.0000
Early Roman - Iron Age	0.041512879	0.2387877	109.25	0.174	1.0000
Early Roman - Late Iron Age	-0.096507818	0.2007631	93.72	-0.481	1.0000
Early Roman - Late Roman	-0.050385477	0.2234842	170.91	-0.225	1.0000
Early Roman - Late Saxon_Norman	0.071395798	0.3049100	34.28	0.234	1.0000
Early Roman - Latest Iron Age	-0.070884688	0.2242710	140.43	-0.316	1.0000

contrast	estimate	SE	df	t.ratio	p.value
Early Roman - LIA/Roman	-0.223486808	0.3044317	421.49	-0.734	1.0000
Early Roman - Middle Anglo-Saxon	0.798422967	0.2609654	59.37	3.059	0.1468
Early Roman - Middle Iron Age	0.116057466	0.1936373	98.81	0.599	1.0000
Early Roman - Middle Roman	0.200083458	0.1854346	69.96	1.079	0.9981
Early Roman - Roman	-0.101046218	0.2225241	126.36	-0.454	1.0000
Iron Age - Late Iron Age	-0.138020696	0.1962677	108.54	-0.703	1.0000
Iron Age - Late Roman	-0.091898355	0.2578326	71.83	-0.356	1.0000
Iron Age - Late Saxon_Norman	0.029882919	0.3284580	29.28	0.091	1.0000
Iron Age - Latest Iron Age	-0.112397566	0.2153521	166.35	-0.522	1.0000
Iron Age - LIA/Roman	-0.264999687	0.3351549	297.55	-0.791	0.9999
Iron Age - Middle Anglo-Saxon	0.756910089	0.2777935	46.24	2.725	0.2980
Iron Age - Middle Iron Age	0.074544587	0.1981847	83.31	0.376	1.0000
Iron Age - Middle Roman	0.158570580	0.2023798	53.15	0.784	0.9999
Iron Age - Roman	-0.142559097	0.2718207	44.58	-0.524	1.0000
Late Iron Age - Late Roman	0.046122341	0.2154659	55.77	0.214	1.0000
Late Iron Age - Late Saxon_Norman	0.167903616	0.3014153	22.07	0.557	1.0000
Late Iron Age - Latest Iron Age	0.025623130	0.1338932	418.94	0.191	1.0000
Late Iron Age - LIA/Roman	-0.126978990	0.2996233	362.17	-0.424	1.0000
Late Iron Age - Middle Anglo-Saxon	0.894930785	0.2463877	32.68	3.632	**0.0480**
Late Iron Age - Middle Iron Age	0.212565284	0.1291796	103.09	1.646	0.9293
Late Iron Age - Middle Roman	0.296591276	0.1620788	28.90	1.830	0.8452

contrast	estimate	SE	df	t.ratio	p.value
Late Iron Age - Roman	-0.004538400	0.2389681	23.91	-0.019	1.0000
Late Roman - Late Saxon_Norman	0.121781274	0.3259138	29.07	0.374	1.0000
Late Roman - Latest Iron Age	-0.020499211	0.2383646	79.72	-0.086	1.0000
Late Roman - LIA/Roman	-0.173101331	0.3073381	419.54	-0.563	1.0000
Late Roman - Middle Anglo-Saxon	0.848808444	0.2775815	44.60	3.058	0.1563
Late Roman - Middle Iron Age	0.166442942	0.2120294	50.25	0.785	0.9999
Late Roman - Middle Roman	0.250468935	0.2085515	53.55	1.201	0.9942
Late Roman - Roman	-0.050660741	0.2670180	43.72	-0.190	1.0000
Late Saxon_Norman - Latest Iron Age	-0.142280485	0.3159841	28.86	-0.450	1.0000
Late Saxon_Norman - LIA/Roman	-0.294882606	0.3927209	86.05	-0.751	1.0000
Late Saxon_Norman - Middle Anglo-Saxon	0.727027170	0.3242618	28.20	2.242	0.6051
Late Saxon_Norman - Middle Iron Age	0.044661668	0.2862916	23.86	0.156	1.0000
Late Saxon_Norman - Middle Roman	0.128687661	0.2771613	23.29	0.464	1.0000
Late Saxon_Norman - Roman	-0.172442016	0.2958111	24.54	-0.583	1.0000
Latest Iron Age - LIA/Roman	-0.152602120	0.3172528	369.51	-0.481	1.0000
Latest Iron Age - Middle Anglo-Saxon	0.869307655	0.2643180	45.90	3.289	**0.0924**
Latest Iron Age - Middle Iron Age	0.186942153	0.1557972	245.13	1.200	0.9954
Latest Iron Age - Middle Roman	0.270968146	0.1883299	63.32	1.439	0.9732
Latest Iron Age - Roman	-0.030161531	0.2575268	37.45	-0.117	1.0000
LIA/Roman - Middle Anglo-Saxon	1.021909775	0.3543125	156.84	2.884	0.1959
LIA/Roman - Middle Iron Age	0.339544274	0.3016663	334.22	1.126	0.9976

contrast	estimate	SE	df	t.ratio	p.value
LIA/Roman - Middle Roman	0.423570266	0.3028903	300.86	1.398	0.9816
LIA/Roman - Roman	0.122440590	0.3437637	191.88	0.356	1.0000
Middle Anglo-Saxon - Middle Iron Age	-0.682365502	0.2338860	37.18	-2.918	0.2154
Middle Anglo-Saxon - Middle Roman	-0.598339509	0.2277543	37.02	-2.627	0.3585
Middle Anglo-Saxon - Roman	-0.899469186	0.2734752	43.08	-3.289	**0.0944**
Middle Iron Age - Middle Roman	0.084025993	0.1470589	30.03	0.571	1.0000
Middle Iron Age - Roman	-0.217103684	0.2229165	35.38	-0.974	0.9991
Middle Roman - Roman	-0.301129677	0.2119456	39.83	-1.421	0.9735

P value adjustment: tukey method for comparing a family of 14 estimates

b. Output for the 'lsmeans' function when the **nitrogen** isotopic values of cattle are analysed by sub-period, with region and site as random effects.

$lsmeans

Sub_Period	lsmean	SE	df	lower.CL	upper.CL
Anglo-Saxon	6.099089	0.4425805	18.83	5.172190	7.025989
Early Anglo-Saxon	5.499837	0.4054223	18.92	4.651048	6.348627
Early Iron Age	5.131703	0.3646252	16.61	4.361024	5.902381
Early Roman	6.940880	0.4795124	54.23	5.979611	7.902150
Iron Age	6.623876	0.5154470	48.20	5.587614	7.660138
Late Iron Age	5.236561	0.3718278	20.01	4.460969	6.012153
Late Roman	5.394249	0.5436364	50.62	4.302656	6.485843
Late Saxon_Norman	5.466750	0.6663359	25.36	4.095380	6.838121
Latest Iron Age	5.248366	0.4527845	44.05	4.335870	6.160862
LIA/Roman	6.779533	0.7967887	235.12	5.209776	8.349290
Middle Anglo-Saxon	4.470553	0.5988025	39.86	3.260192	5.680914
Middle Iron Age	5.053352	0.3594405	15.34	4.288703	5.818002
Middle Roman	5.820776	0.3328233	14.69	5.110059	6.531493
Roman	6.110214	0.5329665	44.54	5.036461	7.183968

Confidence level used: 0.95

$contrasts

contrast	estimate	SE	df	t.ratio	p.value
Anglo-Saxon - Early Anglo-Saxon	0.59925207	0.5925062	24.58	1.011	0.9985
Anglo-Saxon - Early Iron Age	0.96738676	0.5641158	25.88	1.715	0.8923
Anglo-Saxon - Early Roman	-0.84179082	0.6353520	47.89	-1.325	0.9857
Anglo-Saxon - Iron Age	-0.52478633	0.6714269	41.27	-0.782	0.9999
Anglo-Saxon - Late Iron Age	0.86252831	0.5686369	28.27	1.517	0.9529
Anglo-Saxon - Late Roman	0.70484013	0.6943620	43.62	1.015	0.9988
Anglo-Saxon - Late Saxon_Norman	0.63233898	0.7623095	28.25	0.830	0.9998
Anglo-Saxon - Latest Iron Age	0.85072325	0.6239511	42.12	1.363	0.9813
Anglo-Saxon - LIA/Roman	-0.68044378	0.9050107	151.29	-0.752	1.0000
Anglo-Saxon - Middle Anglo-Saxon	1.62853596	0.6219033	27.58	2.619	0.3733
Anglo-Saxon - Middle Iron Age	1.04573716	0.5553246	24.95	1.883	0.8170
Anglo-Saxon - Middle Roman	0.27831323	0.5344910	25.24	0.521	1.0000
Anglo-Saxon - Roman	-0.01112502	0.6540365	43.38	-0.017	1.0000
Early Anglo-Saxon - Early Iron Age	0.36813469	0.3666658	17.15	1.004	0.9982
Early Anglo-Saxon - Early Roman	-1.44104289	0.5207796	56.38	-2.767	0.2705
Early Anglo-Saxon - Iron Age	-1.12403840	0.5348181	39.94	-2.102	0.6957
Early Anglo-Saxon - Late Iron Age	0.26327624	0.3837955	21.40	0.686	1.0000
Early Anglo-Saxon - Late Roman	0.10558806	0.5674458	56.30	0.186	1.0000
Early Anglo-Saxon - Late Saxon_Norman	0.03308690	0.7309189	21.65	0.045	1.0000
Early Anglo-Saxon - Latest Iron Age	0.25147118	0.4631986	43.98	0.543	1.0000

contrast	estimate	SE	df	t.ratio	p.value
Early Anglo-Saxon - LIA/Roman	-1.27969586	0.8111343	251.15	-1.578	0.9504
Early Anglo-Saxon - Middle Anglo-Saxon	1.02928388	0.7008512	37.44	1.469	0.9653
Early Anglo-Saxon - Middle Iron Age	0.44648509	0.4154490	24.13	1.075	0.9972
Early Anglo-Saxon - Middle Roman	-0.32093884	0.4026899	21.02	-0.797	0.9999
Early Anglo-Saxon - Roman	-0.61037709	0.6049624	38.84	-1.009	0.9988
Early Iron Age - Early Roman	-1.80917758	0.4864862	165.79	-3.719	**0.0186**
Early Iron Age - Iron Age	-1.49217309	0.4991895	109.19	-2.989	0.1584
Early Iron Age - Late Iron Age	-0.10485845	0.2481000	365.89	-0.423	1.0000
Early Iron Age - Late Roman	-0.26254663	0.5358623	132.22	-0.490	1.0000
Early Iron Age - Late Saxon_Norman	-0.33504779	0.7062174	25.20	-0.474	1.0000
Early Iron Age - Latest Iron Age	-0.11666351	0.3672310	385.39	-0.318	1.0000
Early Iron Age - LIA/Roman	-1.64783055	0.7776586	425.65	-2.119	0.6879
Early Iron Age - Middle Anglo-Saxon	0.66114919	0.6762804	46.14	0.978	0.9992
Early Iron Age - Middle Iron Age	0.07835040	0.3444495	89.90	0.227	1.0000
Early Iron Age - Middle Roman	-0.68907353	0.3741601	34.74	-1.842	0.8421
Early Iron Age - Roman	-0.97851178	0.5757515	60.40	-1.700	0.9080
Early Roman - Iron Age	0.31700449	0.6048267	90.71	0.524	1.0000
Early Roman - Late Iron Age	1.70431913	0.4983707	179.00	3.420	**0.0472**
Early Roman - Late Roman	1.54663095	0.5880441	181.66	2.630	0.3291
Early Roman - Late Saxon_Norman	1.47412980	0.7453362	32.65	1.978	0.7695

contrast	estimate	SE	df	t.ratio	p.value
Early Roman - Latest Iron Age	1.69251407	0.5652367	225.74	2.994	0.1481
Early Roman - LIA/Roman	0.16134704	0.8071698	426.43	0.200	1.0000
Early Roman - Middle Anglo-Saxon	2.47032678	0.7295469	65.92	3.386	0.0646
Early Roman - Middle Iron Age	1.88752798	0.5135357	111.48	3.676	0.0238
Early Roman - Middle Roman	1.12010405	0.4705842	71.59	2.380	0.5042
Early Roman - Roman	0.83066580	0.5784131	193.03	1.436	0.9764
Iron Age - Late Iron Age	1.38731464	0.4990273	135.53	2.780	0.2474
Iron Age - Late Roman	1.22962646	0.6724883	99.30	1.828	0.8578
Iron Age - Late Saxon_Norman	1.15712530	0.7939135	30.48	1.457	0.9656
Iron Age - Latest Iron Age	1.37550958	0.5534745	203.57	2.485	0.4235
Iron Age - LIA/Roman	-0.15565745	0.8827624	315.78	-0.176	1.0000
Iron Age - Middle Anglo-Saxon	2.15332228	0.7678532	54.23	2.804	0.2530
Iron Age - Middle Iron Age	1.57052349	0.5258533	97.09	2.987	0.1613
Iron Age - Middle Roman	0.80309956	0.5041558	44.40	1.593	0.9388
Iron Age - Roman	0.51366131	0.6792478	62.72	0.756	1.0000
Late Iron Age - Late Roman	-0.15768818	0.5500425	141.55	-0.287	1.0000
Late Iron Age - Late Saxon_Norman	-0.23018934	0.7099709	26.57	-0.324	1.0000
Late Iron Age - Latest Iron Age	-0.01180506	0.3561889	421.15	-0.033	1.0000
Late Iron Age - LIA/Roman	-1.54297210	0.7887107	424.97	-1.956	0.7937
Late Iron Age - Middle Anglo-Saxon	0.76600764	0.6800907	49.43	1.126	0.9968
Late Iron Age - Middle Iron Age	0.18320885	0.3432475	144.79	0.534	1.0000

contrast	estimate	SE	df	t.ratio	p.value
Late Iron Age - Middle Roman	-0.58421508	0.3855198	43.24	-1.515	0.9572
Late Iron Age - Roman	-0.87365333	0.5812084	65.49	-1.503	0.9623
Late Roman - Late Saxon_Norman	-0.07250115	0.8161830	35.75	-0.089	1.0000
Late Roman - Latest Iron Age	0.14588312	0.6149038	182.23	0.237	1.0000
Late Roman - LIA/Roman	-1.38528391	0.8108856	392.79	-1.708	0.9121
Late Roman - Middle Anglo-Saxon	0.92369583	0.7890424	60.15	1.171	0.9956
Late Roman - Middle Iron Age	0.34089703	0.5781752	98.87	0.590	1.0000
Late Roman - Middle Roman	-0.42652690	0.5445370	68.16	-0.783	0.9999
Late Roman - Roman	-0.71596515	0.6990106	89.67	-1.024	0.9989
Late Saxon_Norman - Latest Iron Age	0.21838428	0.7533129	33.87	0.290	1.0000
Late Saxon_Norman - LIA/Roman	-1.31278276	0.9986012	96.44	-1.315	0.9883
Late Saxon_Norman - Middle Anglo-Saxon	0.99619698	0.8225308	30.67	1.211	0.9925
Late Saxon_Norman - Middle Iron Age	0.41339818	0.6879847	22.13	0.601	1.0000
Late Saxon_Norman - Middle Roman	-0.35402574	0.6643174	21.82	-0.533	1.0000
Late Saxon_Norman - Roman	-0.64346400	0.7105698	22.45	-0.906	0.9995
Latest Iron Age - LIA/Roman	-1.53116704	0.8366568	423.43	-1.830	0.8614
Latest Iron Age - Middle Anglo-Saxon	0.77781270	0.7263373	64.78	1.071	0.9982
Latest Iron Age - Middle Iron Age	0.19501391	0.4128229	310.43	0.472	1.0000
Latest Iron Age - Middle Roman	-0.57241002	0.4635250	86.94	-1.235	0.9932
Latest Iron Age - Roman	-0.86184827	0.6344152	89.58	-1.358	0.9842
LIA/Roman - Middle Anglo-Saxon	2.30897974	0.9784419	170.30	2.360	0.5137

contrast	estimate	SE	df	t.ratio	p.value
LIA/Roman - Middle Iron Age	1.72618094	0.8129204	379.19	2.123	0.6847
LIA/Roman - Middle Roman	0.95875702	0.7974378	311.21	1.202	0.9954
LIA/Roman - Roman	0.66931876	0.9031807	290.64	0.741	1.0000
Middle Anglo-Saxon - Middle Iron Age	-0.58279880	0.6645914	42.83	-0.877	0.9997
Middle Anglo-Saxon - Middle Roman	-1.35022272	0.6446698	43.63	-2.094	0.7007
Middle Anglo-Saxon - Roman	-1.63966098	0.7270597	49.15	-2.255	0.5934
Middle Iron Age - Middle Roman	-0.76742393	0.3902799	33.86	-1.966	0.7764
Middle Iron Age - Roman	-1.05686218	0.5615074	44.37	-1.882	0.8248
Middle Roman - Roman	-0.28943825	0.5288463	44.10	-0.547	1.0000

P value adjustment: tukey method for comparing a family of 14 estimates

A2.2.2 Sheep

a. Output for the 'lsmeans' function when the **carbon** isotopic values of sheep are analysed by sub-period, with region and site as random effects

$lsmeans

Sub_Period	lsmean	SE	df	lower.CL	upper.CL
Anglo-Saxon	-21.56543	0.13551033	17.83	-21.85032	-21.28054
Early Anglo-Saxon	-21.69940	0.16096875	7.26	-22.07733	-21.32147
Early Iron Age	-21.23394	0.13169308	2.68	-21.68298	-20.78490
Early Roman	-21.38210	0.19962426	173.30	-21.77611	-20.98810
Iron Age	-21.36197	0.14484786	17.31	-21.66717	-21.05678
Late Iron Age	-21.25764	0.13974863	5.85	-21.60172	-20.91357
Late Roman	-21.43889	0.21228874	78.95	-21.86145	-21.01634
Late Saxon_Norman	-21.71250	0.27497011	26.13	-22.27757	-21.14743
Latest Iron Age	-21.25361	0.17828197	21.51	-21.62383	-20.88339
LIA_Roman	-21.43871	0.31163063	361.51	-22.05154	-20.82587
Middle Anglo-Saxon	-21.76886	0.21333454	49.85	-22.19739	-21.34033
Middle Iron Age	-21.67517	0.12427193	16.15	-21.93841	-21.41192
Middle Roman	-21.51203	0.09939607	20.34	-21.71915	-21.30492
Roman	-21.57893	0.18845983	15.28	-21.97998	-21.17788

Confidence level used: 0.95

$contrasts

contrast	estimate	SE	df	t.ratio	p.value
Anglo-Saxon - Early Anglo-Saxon	0.1339720263	0.21274923	11.81	0.630	1.0000
Anglo-Saxon - Early Iron Age	-0.3314934906	0.19128608	10.14	-1.733	0.8645
Anglo-Saxon - Early Roman	-0.1833271270	0.24180265	70.79	-0.758	1.0000
Anglo-Saxon - Iron Age	-0.2034559902	0.20055818	19.08	-1.014	0.9981
Anglo-Saxon - Late Iron Age	-0.3077876028	0.19686858	13.46	-1.563	0.9292
Anglo-Saxon - Late Roman	-0.1265370313	0.25288260	49.34	-0.500	1.0000
Anglo-Saxon - Late Saxon_Norman	0.1470694549	0.30310273	25.66	0.485	1.0000
Anglo-Saxon - Latest Iron Age	-0.3118170286	0.22594783	24.48	-1.380	0.9758
Anglo-Saxon - LIA_Roman	-0.1267237191	0.34054233	195.92	-0.372	1.0000
Anglo-Saxon - Middle Anglo-Saxon	0.2034310989	0.24841422	35.71	0.819	0.9999
Anglo-Saxon - Middle Iron Age	0.1097356739	0.18396551	18.68	0.597	1.0000
Anglo-Saxon - Middle Roman	-0.0533988755	0.16787237	20.43	-0.318	1.0000
Anglo-Saxon - Roman	0.0134991095	0.22861684	21.55	0.059	1.0000
Early Anglo-Saxon - Early Iron Age	-0.4654655169	0.15245607	14.59	-3.053	0.2208
Early Anglo-Saxon - Early Roman	-0.3172991534	0.25769452	66.07	-1.231	0.9931
Early Anglo-Saxon - Iron Age	-0.3374280165	0.18232959	21.39	-1.851	0.8304
Early Anglo-Saxon - Late Iron Age	-0.4417596291	0.16202494	18.83	-2.726	0.3350
Early Anglo-Saxon - Late Roman	-0.2605090576	0.26603678	49.95	-0.979	0.9992
Early Anglo-Saxon - Late Saxon_Norman	0.0130974286	0.32863584	19.87	0.040	1.0000
Early Anglo-Saxon - Latest Iron Age	-0.4457890549	0.19397574	36.24	-2.298	0.5664

contrast	estimate	SE	df	t.ratio	p.value
Early Anglo-Saxon - LIA_Roman	-0.2606957454	0.34417972	216.66	-0.757	1.0000
Early Anglo-Saxon - Middle Anglo-Saxon	0.0694590725	0.27281950	26.34	0.255	1.0000
Early Anglo-Saxon - Middle Iron Age	-0.0242363524	0.19490141	15.40	-0.124	1.0000
Early Anglo-Saxon - Middle Roman	-0.1873709018	0.18846496	16.52	-0.994	0.9983
Early Anglo-Saxon - Roman	-0.1204729168	0.25753087	12.07	-0.468	1.0000
Early Iron Age - Early Roman	0.1481663635	0.23429235	105.54	0.632	1.0000
Early Iron Age - Iron Age	0.1280375004	0.14378687	110.46	0.890	0.9998
Early Iron Age - Late Iron Age	0.0237058878	0.09929068	437.64	0.239	1.0000
Early Iron Age - Late Roman	0.2049564593	0.24292892	63.63	0.844	0.9999
Early Iron Age - Late Saxon_Norman	0.4785629455	0.31381874	20.79	1.525	0.9471
Early Iron Age - Latest Iron Age	0.0196764620	0.14470835	470.94	0.136	1.0000
Early Iron Age - LIA_Roman	0.2047697715	0.32309870	367.40	0.634	1.0000
Early Iron Age - Middle Anglo-Saxon	0.5349245895	0.25586360	28.00	2.091	0.7011
Early Iron Age - Middle Iron Age	0.4412291645	0.17157490	15.54	2.572	0.4234
Early Iron Age - Middle Roman	0.2780946151	0.16428851	17.12	1.693	0.8928
Early Iron Age - Roman	0.3449926001	0.23776688	10.13	1.451	0.9508
Early Roman - Iron Age	-0.0201288631	0.24408209	152.92	-0.082	1.0000
Early Roman - Late Iron Age	-0.1244604758	0.24100883	126.37	-0.516	1.0000
Early Roman - Late Roman	0.0567900957	0.27340654	298.01	0.208	1.0000
Early Roman - Late Saxon_Norman	0.3303965819	0.33809477	51.06	0.977	0.9992
Early Roman - Latest Iron Age	-0.1284899016	0.26565759	160.88	-0.484	1.0000

contrast	estimate	SE	df	t.ratio	p.value
Early Roman - LIA_Roman	0.0566034080	0.34670731	487.79	0.163	1.0000
Early Roman - Middle Anglo-Saxon	0.3867582259	0.29206317	92.05	1.324	0.9874
Early Roman - Middle Iron Age	0.2930628009	0.23688952	87.87	1.237	0.9931
Early Roman - Middle Roman	0.1299282516	0.22059296	117.92	0.589	1.0000
Early Roman - Roman	0.1968262365	0.26339150	89.64	0.747	1.0000
Iron Age - Late Iron Age	-0.1043316126	0.14333893	194.35	-0.728	1.0000
Iron Age - Late Roman	0.0769189589	0.25778726	78.76	0.298	1.0000
Iron Age - Late Saxon_Norman	0.3505254451	0.31977679	25.41	1.096	0.9967
Iron Age - Latest Iron Age	-0.1083610384	0.17565421	335.93	-0.617	1.0000
Iron Age - LIA_Roman	0.0767322711	0.33802941	353.48	0.227	1.0000
Iron Age - Middle Anglo-Saxon	0.4068870891	0.26294417	38.49	1.547	0.9491
Iron Age - Middle Iron Age	0.3131916641	0.18693904	25.32	1.675	0.9063
Iron Age - Middle Roman	0.1500571147	0.17397021	34.85	0.863	0.9998
Iron Age - Roman	0.2169550997	0.24670075	17.71	0.879	0.9995
Late Iron Age - Late Roman	0.1812505715	0.25040632	70.13	0.724	1.0000
Late Iron Age - Late Saxon_Norman	0.4548570577	0.31720778	23.00	1.434	0.9669
Late Iron Age - Latest Iron Age	-0.0040294258	0.14504004	488.10	-0.028	1.0000
Late Iron Age - LIA_Roman	0.1810638837	0.33000671	371.14	0.549	1.0000
Late Iron Age - Middle Anglo-Saxon	0.5112187017	0.26003244	32.58	1.966	0.7762
Late Iron Age - Middle Iron Age	0.4175232767	0.17835982	20.98	2.341	0.5461
Late Iron Age - Middle Roman	0.2543887273	0.17076933	25.26	1.490	0.9575

contrast	estimate	SE	df	t.ratio	p.value
Late Iron Age - Roman	0.3212867123	0.24274524	12.64	1.324	0.9765
Late Roman - Late Saxon_Norman	0.2736064862	0.35119816	41.80	0.779	0.9999
Late Roman - Latest Iron Age	-0.1852799973	0.27444653	91.93	-0.675	1.0000
Late Roman - LIA_Roman	-0.0001866877	0.34839547	480.70	-0.001	1.0000
Late Roman - Middle Anglo-Saxon	0.3299681302	0.30321562	67.53	1.088	0.9979
Late Roman - Middle Iron Age	0.2362727052	0.24898514	55.55	0.949	0.9994
Late Roman - Middle Roman	0.0731381559	0.23568116	90.26	0.310	1.0000
Late Roman - Roman	0.1400361408	0.28372151	45.98	0.494	1.0000
Late Saxon_Norman - Latest Iron Age	-0.4588864835	0.33638902	29.56	-1.364	0.9792
Late Saxon_Norman - LIA_Roman	-0.2737931740	0.41797755	106.12	-0.655	1.0000
Late Saxon_Norman - Middle Anglo-Saxon	0.0563616440	0.33108105	35.82	0.170	1.0000
Late Saxon_Norman - Middle Iron Age	-0.0373337810	0.29299839	27.22	-0.127	1.0000
Late Saxon_Norman - Middle Roman	-0.2004683303	0.28348702	28.61	-0.707	1.0000
Late Saxon_Norman - Roman	-0.1335703454	0.29247837	25.20	-0.457	1.0000
Latest Iron Age - LIA_Roman	0.1850933095	0.34851494	377.82	0.531	1.0000
Latest Iron Age - Middle Anglo-Saxon	0.5152481275	0.28284213	44.33	1.822	0.8545
Latest Iron Age - Middle Iron Age	0.4215527025	0.20958484	40.89	2.011	0.7519
Latest Iron Age - Middle Roman	0.2584181532	0.20339433	54.43	1.271	0.9904
Latest Iron Age - Roman	0.3253161381	0.26730662	20.77	1.217	0.9907
LIA_Roman - Middle Anglo-Saxon	0.3301548179	0.37914923	191.53	0.871	0.9998
LIA_Roman - Middle Iron Age	0.2364593929	0.33558671	241.58	0.705	1.0000

contrast	estimate	SE	df	t.ratio	p.value
LIA_Roman - Middle Roman	0.0733248436	0.32717370	327.92	0.224	1.0000
LIA_Roman - Roman	0.1402228286	0.36152531	179.82	0.388	1.0000
Middle Anglo-Saxon - Middle Iron Age	-0.0936954250	0.24382726	41.46	-0.384	1.0000
Middle Anglo-Saxon - Middle Roman	-0.2568299743	0.23195665	47.37	-1.107	0.9972
Middle Anglo-Saxon - Roman	-0.1899319894	0.26770740	43.57	-0.709	1.0000
Middle Iron Age - Middle Roman	-0.1631345493	0.15740977	23.74	-1.036	0.9980
Middle Iron Age - Roman	-0.0962365644	0.21622853	26.13	-0.445	1.0000
Middle Roman - Roman	0.0668979850	0.20259584	29.11	0.330	1.0000

P value adjustment: tukey method for comparing a family of 14 estimates

b. Output for the ‘lsmeans’ function when the **nitrogen** isotopic values of sheep are analysed by sub-period, with region and site as random effects

$lsmeans

Sub_Period	lsmean	SE	df	lower.CL	upper.CL
Anglo-Saxon	6.839903	0.5235340	19.69	5.746719	7.933087
Early Anglo-Saxon	6.087407	0.4996879	19.98	5.044998	7.129816
Early Iron Age	6.290545	0.4435390	15.48	5.347692	7.233399
Early Roman	7.641792	0.5637146	41.86	6.504060	8.779524
Iron Age	6.327577	0.4831148	20.72	5.322057	7.333097
Late Iron Age	5.768696	0.4538138	17.01	4.811278	6.726114
Late Roman	6.117493	0.6051984	47.96	4.900635	7.334350
Late Saxon_Norman	5.559166	0.7058613	28.30	4.113961	7.004370
Latest Iron Age	5.979260	0.5078233	26.89	4.937090	7.021431
LIA_Roman	5.914286	0.7509078	118.65	4.427369	7.401204
Middle Anglo-Saxon	5.895320	0.6222805	34.40	4.631233	7.159407
Middle Iron Age	5.569676	0.4897820	17.98	4.540607	6.598745
Middle Roman	6.172923	0.4197427	13.79	5.271380	7.074466
Roman	6.205673	0.5359376	29.59	5.110512	7.300834

Confidence level used: 0.95

$contrasts

contrast	estimate	SE	df	t.ratio	p.value
Anglo-Saxon - Early Anglo-Saxon	0.75249561	0.6588090	31.84	1.142	0.9957
Anglo-Saxon - Early Iron Age	0.54935767	0.6178207	36.24	0.889	0.9997
Anglo-Saxon - Early Roman	-0.80188907	0.6979530	65.98	-1.149	0.9964
Anglo-Saxon - Iron Age	0.51232604	0.6473699	39.26	0.791	0.9999
Anglo-Saxon - Late Iron Age	1.07120662	0.6274939	38.04	1.707	0.9006
Anglo-Saxon - Late Roman	0.72241050	0.7403970	67.59	0.976	0.9993
Anglo-Saxon - Late Saxon_Norman	1.28073733	0.7676644	28.37	1.668	0.9105
Anglo-Saxon - Latest Iron Age	0.86064296	0.6663675	48.99	1.292	0.9886
Anglo-Saxon - LIA_Roman	0.92561661	0.8615863	145.64	1.074	0.9984
Anglo-Saxon - Middle Anglo-Saxon	0.94458327	0.5966843	26.14	1.583	0.9355
Anglo-Saxon - Middle Iron Age	1.27022720	0.6274302	29.63	2.024	0.7414
Anglo-Saxon - Middle Roman	0.66698012	0.5809687	34.89	1.148	0.9956
Anglo-Saxon - Roman	0.63423032	0.6273547	38.56	1.011	0.9988
Early Anglo-Saxon - Early Iron Age	-0.20313794	0.3626408	14.69	-0.560	1.0000
Early Anglo-Saxon - Early Roman	-1.55438468	0.5390294	60.97	-2.884	0.2132
Early Anglo-Saxon - Iron Age	-0.24016957	0.4171441	21.90	-0.576	1.0000
Early Anglo-Saxon - Late Iron Age	0.31871101	0.3828613	18.03	0.832	0.9997
Early Anglo-Saxon - Late Roman	-0.03008511	0.5721470	69.81	-0.053	1.0000
Early Anglo-Saxon - Late Saxon_Norman	0.52824172	0.7415062	20.77	0.712	1.0000
Early Anglo-Saxon - Latest Iron Age	0.10814736	0.4399269	30.66	0.246	1.0000

contrast	estimate	SE	df	t.ratio	p.value
Early Anglo-Saxon - LIA_Roman	0.17312100	0.7221225	201.22	0.240	1.0000
Early Anglo-Saxon - Middle Anglo-Saxon	0.19208766	0.7049511	31.52	0.272	1.0000
Early Anglo-Saxon - Middle Iron Age	0.51773159	0.5104601	18.25	1.014	0.9981
Early Anglo-Saxon - Middle Roman	-0.08551549	0.4164679	18.43	-0.205	1.0000
Early Anglo-Saxon - Roman	-0.11826529	0.5686514	29.31	-0.208	1.0000
Early Iron Age - Early Roman	-1.35124674	0.4734069	215.10	-2.854	0.2064
Early Iron Age - Iron Age	-0.03703163	0.3043497	196.88	-0.122	1.0000
Early Iron Age - Late Iron Age	0.52184895	0.2088886	464.38	2.498	0.4115
Early Iron Age - Late Roman	0.17305283	0.5092094	217.37	0.340	1.0000
Early Iron Age - Late Saxon_Norman	0.73137966	0.7060585	23.26	1.036	0.9980
Early Iron Age - Latest Iron Age	0.31128529	0.3002444	478.73	1.037	0.9990
Early Iron Age - LIA_Roman	0.37625894	0.6621470	487.97	0.568	1.0000
Early Iron Age - Middle Anglo-Saxon	0.39522560	0.6671445	38.48	0.592	1.0000
Early Iron Age - Middle Iron Age	0.72086953	0.4601194	22.42	1.567	0.9377
Early Iron Age - Middle Roman	0.11762245	0.3561245	24.87	0.330	1.0000
Early Iron Age - Roman	0.08487265	0.5181306	45.95	0.164	1.0000
Early Roman - Iron Age	1.31421511	0.5168928	136.93	2.543	0.3874
Early Roman - Late Iron Age	1.87309569	0.4938240	216.64	3.793	**0.0136**
Early Roman - Late Roman	1.52429957	0.5893404	280.79	2.586	0.3539
Early Roman - Late Saxon_Norman	2.08262640	0.7705506	35.07	2.703	0.3187
Early Roman - Latest Iron Age	1.66253204	0.5412383	254.39	3.072	0.1210

contrast	estimate	SE	df	t.ratio	p.value
Early Roman - LIA_Roman	1.72750568	0.7202227	485.35	2.399	0.4828
Early Roman - Middle Anglo-Saxon	1.74647234	0.7386436	61.57	2.364	0.5165
Early Roman - Middle Iron Age	2.07211627	0.5874800	54.29	3.527	**0.0477**
Early Roman - Middle Roman	1.46886919	0.4878007	83.09	3.011	0.1553
Early Roman - Roman	1.43611939	0.5823016	134.26	2.466	0.4392
Iron Age - Late Iron Age	0.55888058	0.3021521	321.84	1.850	0.8514
Iron Age - Late Roman	0.21008446	0.5646471	173.51	0.372	1.0000
Iron Age - Late Saxon_Norman	0.76841129	0.7322634	24.45	1.049	0.9978
Iron Age - Latest Iron Age	0.34831693	0.3638842	426.92	0.957	0.9996
Iron Age - LIA_Roman	0.41329057	0.7091599	440.55	0.583	1.0000
Iron Age - Middle Anglo-Saxon	0.43225723	0.6947115	39.85	0.622	1.0000
Iron Age - Middle Iron Age	0.75790116	0.5043166	26.85	1.503	0.9554
Iron Age - Middle Roman	0.15465408	0.3967250	27.58	0.390	1.0000
Iron Age - Roman	0.12190428	0.5562860	45.71	0.219	1.0000
Late Iron Age - Late Roman	-0.34879612	0.5316525	224.46	-0.656	1.0000
Late Iron Age - Late Saxon_Norman	0.20953071	0.7161359	24.48	0.293	1.0000
Late Iron Age - Latest Iron Age	-0.21056366	0.2999006	481.99	-0.702	1.0000
Late Iron Age - LIA_Roman	-0.14559001	0.6809935	486.63	-0.214	1.0000
Late Iron Age - Middle Anglo-Saxon	-0.12662336	0.6769120	40.46	-0.187	1.0000
Late Iron Age - Middle Iron Age	0.19902058	0.4752625	25.38	0.419	1.0000
Late Iron Age - Middle Roman	-0.40422650	0.3752969	30.42	-1.077	0.9975

contrast	estimate	SE	df	t.ratio	p.value
Late Iron Age - Roman	-0.43697631	0.5333079	49.50	-0.819	0.9999
Late Roman - Late Saxon_Norman	0.55832683	0.8141912	37.98	0.686	1.0000
Late Roman - Latest Iron Age	0.13823246	0.5768154	260.90	0.240	1.0000
Late Roman - LIA_Roman	0.20320611	0.7265727	456.19	0.280	1.0000
Late Roman - Middle Anglo-Saxon	0.22217277	0.7813888	64.09	0.284	1.0000
Late Roman - Middle Iron Age	0.54781670	0.6333530	60.42	0.865	0.9998
Late Roman - Middle Roman	-0.05543038	0.5384368	88.84	-0.103	1.0000
Late Roman - Roman	-0.08818019	0.6482230	102.19	-0.136	1.0000
Late Saxon_Norman - Latest Iron Age	-0.42009436	0.7494732	28.99	-0.561	1.0000
Late Saxon_Norman - LIA_Roman	-0.35512072	0.9246309	71.94	-0.384	1.0000
Late Saxon_Norman - Middle Anglo-Saxon	-0.33615406	0.7897600	25.92	-0.426	1.0000
Late Saxon_Norman - Middle Iron Age	-0.01051013	0.6990041	18.43	-0.015	1.0000
Late Saxon_Norman - Middle Roman	-0.61375721	0.6626526	21.07	-0.926	0.9993
Late Saxon_Norman - Roman	-0.64650701	0.6772868	19.93	-0.955	0.9990
Latest Iron Age - LIA_Roman	0.06497364	0.7170820	485.03	0.091	1.0000
Latest Iron Age - Middle Anglo-Saxon	0.08394030	0.7126219	49.12	0.118	1.0000
Latest Iron Age - Middle Iron Age	0.40958423	0.5235553	37.03	0.782	0.9999
Latest Iron Age - Middle Roman	-0.19366285	0.4343588	52.08	-0.446	1.0000
Latest Iron Age - Roman	-0.22641265	0.5775092	65.68	-0.392	1.0000
LIA_Roman - Middle Anglo-Saxon	0.01896666	0.8964859	129.90	0.021	1.0000
LIA_Roman - Middle Iron Age	0.34461059	0.7687956	165.10	0.448	1.0000

contrast	estimate	SE	df	t.ratio	p.value
LIA_Roman - Middle Roman	-0.25863649	0.6995614	274.63	-0.370	1.0000
LIA_Roman - Roman	-0.29138629	0.7791444	267.88	-0.374	1.0000
Middle Anglo-Saxon - Middle Iron Age	0.32564393	0.6682394	28.66	0.487	1.0000
Middle Anglo-Saxon - Middle Roman	-0.27760315	0.6273236	35.88	-0.443	1.0000
Middle Anglo-Saxon - Roman	-0.31035295	0.6572598	32.99	-0.472	1.0000
Middle Iron Age - Middle Roman	-0.60324708	0.4528627	19.09	-1.332	0.9798
Middle Iron Age - Roman	-0.63599688	0.5333499	21.46	-1.192	0.9923
Middle Roman - Roman	-0.03274980	0.4736526	30.96	-0.069	1.0000

P value adjustment: tukey method for comparing a family of 14 estimates

A2.2.3 Pig

a. Output for the ‘lsmeans’ function when the **carbon** isotopic values of pigs are analysed by sub-period, with region and site as random effects

$lsmeans

Sub_Period	lsmean	SE	df	lower.CL	upper.CL
Anglo-Saxon	-21.47074	0.1895794	19.44	-21.86693	-21.07456
Early Anglo-Saxon	-21.43937	0.2295836	27.46	-21.91007	-20.96867
Early Iron Age	-21.32536	0.1514277	13.01	-21.65247	-20.99825
Early Roman	-21.57002	0.3269106	173.68	-22.21525	-20.92479
Iron Age	-21.17530	0.2122043	48.21	-21.60192	-20.74868
Late Iron Age	-21.28800	0.1741986	24.82	-21.64690	-20.92911
Late Roman	-21.04405	0.2575536	84.92	-21.55614	-20.53196
Late Saxon_Norman	-21.34915	0.3274453	13.25	-22.05522	-20.64308
Latest Iron Age	-20.90288	0.3114360	181.59	-21.51738	-20.28838
LIA/Roman	-21.12002	0.3793314	215.88	-21.86769	-20.37236
Middle Anglo-Saxon	-21.51547	0.2640661	23.24	-22.06141	-20.96952
Middle Iron Age	-21.39260	0.1523992	14.62	-21.71818	-21.06703
Middle Roman	-21.25522	0.1552823	18.04	-21.58140	-20.92903

Confidence level used: 0.95

$contrasts

contrast	estimate	SE	df	t.ratio	p.value
Anglo-Saxon - Early Anglo-Saxon	-0.03137624	0.3000561	25.00	-0.105	1.0000
Anglo-Saxon - Early Iron Age	-0.14538223	0.2443994	21.07	-0.595	1.0000
Anglo-Saxon - Early Roman	0.09927988	0.3792658	104.56	0.262	1.0000
Anglo-Saxon - Iron Age	-0.29544160	0.2860021	34.95	-1.033	0.9974
Anglo-Saxon - Late Iron Age	-0.18273942	0.2593502	26.38	-0.705	0.9999
Anglo-Saxon - Late Roman	-0.42669164	0.3215533	55.92	-1.327	0.9802
Anglo-Saxon - Late Saxon_Norman	-0.12159254	0.3627357	14.34	-0.335	1.0000
Anglo-Saxon - Latest Iron Age	-0.56786127	0.3650684	111.89	-1.555	0.9394
Anglo-Saxon - LIA/Roman	-0.35072012	0.4252815	145.37	-0.825	0.9998
Anglo-Saxon - Middle Anglo-Saxon	0.04472502	0.2976029	19.22	0.150	1.0000
Anglo-Saxon - Middle Iron Age	-0.07814048	0.2422957	21.86	-0.323	1.0000
Anglo-Saxon - Middle Roman	-0.21552607	0.2389328	22.44	-0.902	0.9991
Early Anglo-Saxon - Early Iron Age	-0.11400599	0.2264100	23.11	-0.504	1.0000
Early Anglo-Saxon - Early Roman	0.13065612	0.3725105	125.01	0.351	1.0000
Early Anglo-Saxon - Iron Age	-0.26406536	0.2813274	39.82	-0.939	0.9990
Early Anglo-Saxon - Late Iron Age	-0.15136318	0.2452399	30.11	-0.617	1.0000
Early Anglo-Saxon - Late Roman	-0.39531540	0.3156596	77.56	-1.252	0.9883
Early Anglo-Saxon - Late Saxon_Norman	-0.09021630	0.3994120	16.08	-0.226	1.0000
Early Anglo-Saxon - Latest Iron Age	-0.53648503	0.3586638	120.03	-1.496	0.9544
Early Anglo-Saxon - LIA/Roman	-0.31934388	0.4192683	167.13	-0.762	0.9999

contrast	estimate	SE	df	t.ratio	p.value
Early Anglo-Saxon - Middle Anglo-Saxon	0.07610126	0.3515215	25.72	0.216	1.0000
Early Anglo-Saxon - Middle Iron Age	-0.04676424	0.2464873	30.13	-0.190	1.0000
Early Anglo-Saxon - Middle Roman	-0.18414983	0.2569979	25.57	-0.717	0.9999
Early Iron Age - Early Roman	0.24466211	0.3067910	265.20	0.797	0.9999
Early Iron Age - Iron Age	-0.15005937	0.2128717	153.84	-0.705	1.0000
Early Iron Age - Late Iron Age	-0.03735719	0.1306492	268.79	-0.286	1.0000
Early Iron Age - Late Roman	-0.28130940	0.2390988	257.23	-1.177	0.9939
Early Iron Age - Late Saxon_Norman	0.02378969	0.3575092	14.84	0.067	1.0000
Early Iron Age - Latest Iron Age	-0.42247904	0.2978699	266.77	-1.418	0.9707
Early Iron Age - LIA/Roman	-0.20533789	0.3621361	261.69	-0.567	1.0000
Early Iron Age - Middle Anglo-Saxon	0.19010725	0.3043527	25.53	0.625	1.0000
Early Iron Age - Middle Iron Age	0.06724175	0.1577334	103.97	0.426	1.0000
Early Iron Age - Middle Roman	-0.07014384	0.1971073	28.08	-0.356	1.0000
Early Roman - Iron Age	-0.39472148	0.3674162	254.95	-1.074	0.9974
Early Roman - Late Iron Age	-0.28201930	0.3268691	269.81	-0.863	0.9997
Early Roman - Late Roman	-0.52597151	0.3368323	257.19	-1.562	0.9398
Early Roman - Late Saxon_Norman	-0.22087242	0.4614627	44.10	-0.479	1.0000
Early Roman - Latest Iron Age	-0.66714115	0.4244607	269.50	-1.572	0.9371
Early Roman - LIA/Roman	-0.45000000	0.4302431	248.86	-1.046	0.9980
Early Roman - Middle Anglo-Saxon	-0.05455486	0.4208708	86.90	-0.130	1.0000
Early Roman - Middle Iron Age	-0.17742036	0.3382660	253.29	-0.524	1.0000

contrast	estimate	SE	df	t.ratio	p.value
Early Roman - Middle Roman	-0.31480595	0.3515108	174.40	-0.896	0.9995
Iron Age - Late Iron Age	0.11270218	0.2350786	157.77	0.479	1.0000
Iron Age - Late Roman	-0.13125003	0.3105474	201.33	-0.423	1.0000
Iron Age - Late Saxon_Norman	0.17384906	0.3864457	18.70	0.450	1.0000
Iron Age - Latest Iron Age	-0.27241967	0.3341927	272.97	-0.815	0.9998
Iron Age - LIA/Roman	-0.05527852	0.4147487	267.85	-0.133	1.0000
Iron Age - Middle Anglo-Saxon	0.34016662	0.3383801	33.86	1.005	0.9979
Iron Age - Middle Iron Age	0.21730112	0.2197626	136.67	0.989	0.9987
Iron Age - Middle Roman	0.07991553	0.2406844	39.63	0.332	1.0000
Late Iron Age - Late Roman	-0.24395222	0.2635490	251.40	-0.926	0.9994
Late Iron Age - Late Saxon_Norman	0.06114688	0.3690474	16.84	0.166	1.0000
Late Iron Age - Latest Iron Age	-0.38512185	0.3192342	272.31	-1.206	0.9924
Late Iron Age - LIA/Roman	-0.16798070	0.3792957	266.99	-0.443	1.0000
Late Iron Age - Middle Anglo-Saxon	0.22746444	0.3169929	29.46	0.718	0.9999
Late Iron Age - Middle Iron Age	0.10459894	0.1903976	111.09	0.549	1.0000
Late Iron Age - Middle Roman	-0.03278665	0.2174071	38.91	-0.151	1.0000
Late Roman - Late Saxon_Norman	0.30509910	0.4158076	28.17	0.734	0.9999
Late Roman - Latest Iron Age	-0.14116964	0.3771485	269.22	-0.374	1.0000
Late Roman - LIA/Roman	0.07597151	0.3879147	255.30	0.196	1.0000
Late Roman - Middle Anglo-Saxon	0.47141666	0.3699261	52.47	1.274	0.9855
Late Roman - Middle Iron Age	0.34855115	0.2753408	178.55	1.266	0.9882

contrast	estimate	SE	df	t.ratio	p.value
Late Roman - Middle Roman	0.21116557	0.2886882	104.20	0.731	0.9999
Late Saxon_Norman - Latest Iron Age	-0.44626873	0.4463053	41.71	-1.000	0.9982
Late Saxon_Norman - LIA/Roman	-0.22912758	0.4999697	61.38	-0.458	1.0000
Late Saxon_Norman - Middle Anglo-Saxon	0.16631756	0.3815690	13.54	0.436	1.0000
Late Saxon_Norman - Middle Iron Age	0.04345206	0.3484636	13.55	0.125	1.0000
Late Saxon_Norman - Middle Roman	-0.09393353	0.3332019	12.05	-0.282	1.0000
Latest Iron Age - LIA/Roman	0.21714115	0.4660351	267.25	0.466	1.0000
Latest Iron Age - Middle Anglo-Saxon	0.61258629	0.4065659	88.96	1.507	0.9509
Latest Iron Age - Middle Iron Age	0.48972079	0.2985199	264.50	1.640	0.9154
Latest Iron Age - Middle Roman	0.35233520	0.3356371	180.40	1.050	0.9978
LIA/Roman - Middle Anglo-Saxon	0.39544514	0.4627678	119.42	0.855	0.9997
LIA/Roman - Middle Iron Age	0.27257964	0.3891603	266.68	0.700	1.0000
LIA/Roman - Middle Roman	0.13519405	0.4007265	218.94	0.337	1.0000
Middle Anglo-Saxon - Middle Iron Age	-0.12286550	0.2990473	24.44	-0.411	1.0000
Middle Anglo-Saxon - Middle Roman	-0.26025109	0.2900106	22.43	-0.897	0.9991
Middle Iron Age - Middle Roman	-0.13738559	0.1999485	26.86	-0.687	0.9999

P value adjustment: tukey method for comparing a family of 13 estimates

b. Output for the 'lsmeans' function when the **nitrogen** isotopic values of pigs are analysed by sub-period, with region and site as random effects

$lsmeans

Sub_Period	lsmean	SE	df	lower.CL	upper.CL
Anglo-Saxon	8.434845	0.5448249	17.90	7.289750	9.579940
Early Anglo-Saxon	5.810435	0.5864507	26.31	4.605659	7.015212
Early Iron Age	6.919152	0.4484573	15.25	5.964641	7.873662
Early Roman	8.270029	0.8655553	136.05	6.558346	9.981712
Iron Age	7.328436	0.5814257	36.22	6.149499	8.507374
Late Iron Age	7.414010	0.5012847	22.15	6.374810	8.453210
Late Roman	7.739993	0.7040666	70.55	6.335968	9.144018
Late Saxon_Norman	7.603956	0.7255879	12.43	6.029136	9.178776
Latest Iron Age	8.327569	0.8249210	139.07	6.696561	9.958577
LIA/Roman	7.403362	0.9938926	181.85	5.442318	9.364407
Middle Anglo-Saxon	6.461527	0.6593141	23.71	5.099884	7.823171
Middle Iron Age	6.828564	0.4569753	15.57	5.857630	7.799498
Middle Roman	6.701242	0.4388384	16.10	5.771413	7.631071

Confidence level used: 0.95

$contrasts

contrast	estimate	SE	df	t.ratio	p.value
Anglo-Saxon - Early Anglo-Saxon	2.62440975	0.7732880	26.82	3.394	0.0825
Anglo-Saxon - Early Iron Age	1.51569337	0.6743714	26.18	2.248	0.5691
Anglo-Saxon - Early Roman	0.16481599	1.0037672	108.68	0.164	1.0000
Anglo-Saxon - Iron Age	1.10640841	0.7656642	36.91	1.445	0.9592
Anglo-Saxon - Late Iron Age	1.02083476	0.7149814	30.12	1.428	0.9610
Anglo-Saxon - Late Roman	0.69485173	0.8692563	65.55	0.799	0.9998
Anglo-Saxon - Late Saxon_Norman	0.83088859	0.8113400	13.25	1.024	0.9959
Anglo-Saxon - Latest Iron Age	0.10727594	0.9617961	110.86	0.112	1.0000
Anglo-Saxon - LIA/Roman	1.03148266	1.1163267	147.91	0.924	0.9994
Anglo-Saxon - Middle Anglo-Saxon	1.97331739	0.6738317	17.03	2.929	0.2338
Anglo-Saxon - Middle Iron Age	1.60628078	0.6649884	24.90	2.416	0.4652
Anglo-Saxon - Middle Roman	1.73360303	0.6366492	24.69	2.723	0.2979
Early Anglo-Saxon - Early Iron Age	-1.10871638	0.5058554	19.87	-2.192	0.6068
Early Anglo-Saxon - Early Roman	-2.45959376	0.9037183	140.61	-2.722	0.2526
Early Anglo-Saxon - Iron Age	-1.51800135	0.6515527	36.88	-2.330	0.5113
Early Anglo-Saxon - Late Iron Age	-1.60357499	0.5645641	26.16	-2.840	0.2426
Early Anglo-Saxon - Late Roman	-1.92955803	0.7533426	89.80	-2.561	0.3490
Early Anglo-Saxon - Late Saxon_Norman	-1.79352116	0.8506067	12.04	-2.109	0.6586
Early Anglo-Saxon - Latest Iron Age	-2.51713381	0.8692246	120.82	-2.896	0.1749
Early Anglo-Saxon - LIA/Roman	-1.59292710	1.0272990	183.97	-1.551	0.9421

contrast	estimate	SE	df	t.ratio	p.value
Early Anglo-Saxon - Middle Anglo-Saxon	-0.65109236	0.8273664	22.41	-0.787	0.9998
Early Anglo-Saxon - Middle Iron Age	-1.01812897	0.5659396	26.14	-1.799	0.8334
Early Anglo-Saxon - Middle Roman	-0.89080672	0.5733307	20.36	-1.554	0.9252
Early Iron Age - Early Roman	-1.35087738	0.7777952	264.25	-1.737	0.8777
Early Iron Age - Iron Age	-0.40928496	0.5271743	128.64	-0.776	0.9999
Early Iron Age - Late Iron Age	-0.49485861	0.3344047	256.87	-1.480	0.9594
Early Iron Age - Late Roman	-0.82084165	0.6046605	272.66	-1.358	0.9794
Early Iron Age - Late Saxon_Norman	-0.68480478	0.7624741	11.31	-0.898	0.9985
Early Iron Age - Latest Iron Age	-1.40841743	0.7544356	266.84	-1.867	0.8130
Early Iron Age - LIA/Roman	-0.48421072	0.9184781	260.60	-0.527	1.0000
Early Iron Age - Middle Anglo-Saxon	0.45762402	0.7360206	24.16	0.622	1.0000
Early Iron Age - Middle Iron Age	0.09058741	0.3946897	102.37	0.230	1.0000
Early Iron Age - Middle Roman	0.21790966	0.4503955	22.39	0.484	1.0000
Early Roman - Iron Age	0.94159242	0.9254340	252.97	1.017	0.9984
Early Roman - Late Iron Age	0.85601877	0.8308621	270.88	1.030	0.9982
Early Roman - Late Roman	0.53003574	0.8529440	257.31	0.621	1.0000
Early Roman - Late Saxon_Norman	0.66607260	1.0679247	43.08	0.624	1.0000
Early Roman - Latest Iron Age	-0.05754004	1.0763835	269.26	-0.053	1.0000
Early Roman - LIA/Roman	0.86666667	1.0923291	249.25	0.793	0.9999
Early Roman - Middle Anglo-Saxon	1.80850140	1.0477191	89.37	1.726	0.8786
Early Roman - Middle Iron Age	1.44146480	0.8585656	263.84	1.679	0.9014

contrast	estimate	SE	df	t.ratio	p.value
Early Roman - Middle Roman	1.56878704	0.8683653	179.61	1.807	0.8440
Iron Age - Late Iron Age	-0.08557365	0.5900647	129.71	-0.145	1.0000
Iron Age - Late Roman	-0.41155668	0.7810701	217.58	-0.527	1.0000
Iron Age - Late Saxon_Norman	-0.27551982	0.8398970	14.63	-0.328	1.0000
Iron Age - Latest Iron Age	-0.99913246	0.8433235	267.50	-1.185	0.9936
Iron Age - LIA/Roman	-0.07492575	1.0464533	265.76	-0.072	1.0000
Iron Age - Middle Anglo-Saxon	0.86690899	0.8181656	30.25	1.060	0.9965
Iron Age - Middle Iron Age	0.49987238	0.5493596	125.24	0.910	0.9994
Iron Age - Middle Roman	0.62719462	0.5555010	31.67	1.129	0.9940
Late Iron Age - Late Roman	-0.32598303	0.6703440	270.76	-0.486	1.0000
Late Iron Age - Late Saxon_Norman	-0.18994617	0.8039996	13.27	-0.236	1.0000
Late Iron Age - Latest Iron Age	-0.91355881	0.8111887	265.88	-1.126	0.9959
Late Iron Age - LIA/Roman	0.01064790	0.9638300	267.31	0.011	1.0000
Late Iron Age - Middle Anglo-Saxon	0.95248263	0.7762444	27.69	1.227	0.9874
Late Iron Age - Middle Iron Age	0.58544603	0.4843210	97.16	1.209	0.9916
Late Iron Age - Middle Roman	0.71276827	0.5167811	31.97	1.379	0.9701
Late Roman - Late Saxon_Norman	0.13603686	0.9434955	26.97	0.144	1.0000
Late Roman - Latest Iron Age	-0.58757578	0.9566417	272.24	-0.614	1.0000
Late Roman - LIA/Roman	0.33663093	0.9829293	255.53	0.342	1.0000
Late Roman - Middle Anglo-Saxon	1.27846567	0.9201377	57.34	1.389	0.9717
Late Roman - Middle Iron Age	0.91142906	0.7011074	226.86	1.300	0.9855

contrast	estimate	SE	df	t.ratio	p.value
Late Roman - Middle Roman	1.03875130	0.7084827	119.91	1.466	0.9607
Late Saxon_Norman - Latest Iron Age	-0.72361264	1.0202080	37.95	-0.709	0.9999
Late Saxon_Norman - LIA/Roman	0.20059407	1.1743507	61.81	0.171	1.0000
Late Saxon_Norman - Middle Anglo-Saxon	1.14242880	0.8235081	11.22	1.387	0.9561
Late Saxon_Norman - Middle Iron Age	0.77539219	0.7379263	9.72	1.051	0.9936
Late Saxon_Norman - Middle Roman	0.90271444	0.6993923	8.98	1.291	0.9695
Latest Iron Age - LIA/Roman	0.92420671	1.1820482	267.20	0.782	0.9999
Latest Iron Age - Middle Anglo-Saxon	1.86604145	1.0031760	83.44	1.860	0.8129
Latest Iron Age - Middle Iron Age	1.49900484	0.7572233	265.16	1.980	0.7453
Latest Iron Age - Middle Roman	1.62632708	0.8241793	164.70	1.973	0.7486
LIA/Roman - Middle Anglo-Saxon	0.94183474	1.1560069	122.46	0.815	0.9998
LIA/Roman - Middle Iron Age	0.57479813	0.9878114	271.71	0.582	1.0000
LIA/Roman - Middle Roman	0.70212037	0.9963408	221.96	0.705	1.0000
Middle Anglo-Saxon - Middle Iron Age	-0.36703661	0.7187029	20.98	-0.511	1.0000
Middle Anglo-Saxon - Middle Roman	-0.23971436	0.6850996	19.75	-0.350	1.0000
Middle Iron Age - Middle Roman	0.12732224	0.4668950	21.27	0.273	1.0000

P value adjustment: tukey method for comparing a family of 13 estimates

A2.2.4 Human

a. Output for the 'lsmeans' function when the **carbon** isotopic values of cattle are analysed by sub-period, with region, site, sex and age as random effects.

$lsmeans

Sub_Period	lsmean	SE	df	lower.CL	upper.CL
Anglo-Saxon	-20.18858	0.15265251	68.43	-20.49316	-19.88401
Early Anglo-Saxon	-20.25705	0.09762117	30.99	-20.45615	-20.05794
Early Anglo-Saxon_Mid-Saxon	-19.00060	0.36104141	62.29	-19.72224	-18.27895
Early Iron Age	-20.35270	0.19572400	135.91	-20.73975	-19.96564
Early Roman	-20.55138	0.20453785	219.80	-20.95448	-20.14827
Iron Age	-20.13888	0.14497486	117.56	-20.42598	-19.85178
Late Iron Age	-20.20604	0.17071153	52.77	-20.54848	-19.86360
Late Roman	-19.87560	0.17654654	185.00	-20.22390	-19.52729
Late Roman/Early Anglo-Saxon	-19.95017	0.33740279	46.93	-20.62897	-19.27138
Late Saxon	-19.76140	0.18987156	93.56	-20.13842	-19.38438
Late Saxon_Norman	-19.70615	0.33521442	47.62	-20.38028	-19.03201
Latest Iron Age	-20.12776	0.49783676	1732.49	-21.10418	-19.15134
Middle Anglo-Saxon	-19.70388	0.16847824	73.54	-20.03961	-19.36814
Middle Iron Age	-20.44122	0.15104638	73.20	-20.74224	-20.14020
Middle Roman	-19.81812	0.12329584	43.94	-20.06661	-19.56962
Roman	-19.73435	0.17911696	144.12	-20.08839	-19.38032

Confidence level used: 0.95

$contrasts

contrast	estimate	SE	df	t.ratio	p.value
Anglo-Saxon - Early Anglo-Saxon	0.068462024	0.1563247	119.33	0.438	1.0000
Anglo-Saxon - Early Anglo-Saxon_Mid-Saxon	-1.187986949	0.3822219	66.75	-3.108	0.1555
Anglo-Saxon - Early Iron Age	0.164110916	0.2319506	169.03	0.708	1.0000
Anglo-Saxon - Early Roman	0.362792065	0.2363041	218.64	1.535	0.9771
Anglo-Saxon - Iron Age	-0.049704645	0.1498520	520.27	-0.332	1.0000
Anglo-Saxon - Late Iron Age	0.017456771	0.2121117	88.53	0.082	1.0000
Anglo-Saxon - Late Roman	-0.312986772	0.2134599	209.63	-1.466	0.9851
Anglo-Saxon - Late Roman/Early Anglo-Saxon	-0.238409864	0.3573484	50.87	-0.667	1.0000
Anglo-Saxon - Late Saxon	-0.427183395	0.2268185	108.79	-1.883	0.8777
Anglo-Saxon - Late Saxon_Norman	-0.482436980	0.3460820	48.23	-1.394	0.9883
Anglo-Saxon - Latest Iron Age	-0.060825021	0.5130781	1634.46	-0.119	1.0000
Anglo-Saxon - Middle Anglo-Saxon	-0.484705453	0.2081819	95.90	-2.328	0.6043
Anglo-Saxon - Middle Iron Age	0.252635376	0.1924264	111.85	1.313	0.9947
Anglo-Saxon - Middle Roman	-0.370468739	0.1630895	102.78	-2.272	0.6449
Anglo-Saxon - Roman	-0.454233688	0.1877821	326.09	-2.419	0.5347
Early Anglo-Saxon - Early Anglo-Saxon_Mid-Saxon	-1.256448973	0.3563640	57.02	-3.526	**0.0582**
Early Anglo-Saxon - Early Iron Age	0.095648893	0.1969255	206.64	0.486	1.0000
Early Anglo-Saxon - Early Roman	0.294330041	0.1965502	335.22	1.497	0.9822
Early Anglo-Saxon - Iron Age	-0.118166669	0.1350790	287.43	-0.875	1.0000
Early Anglo-Saxon - Late Iron Age	-0.051005253	0.1727223	84.16	-0.295	1.0000

contrast	estimate	SE	df	t.ratio	p.value
Early Anglo-Saxon - Late Roman	-0.381448796	0.1643289	403.91	-2.321	0.6081
Early Anglo-Saxon - Late Roman/Early Anglo-Saxon	-0.306871888	0.3352860	43.55	-0.915	0.9999
Early Anglo-Saxon - Late Saxon	-0.495645418	0.1900996	99.59	-2.607	0.4058
Early Anglo-Saxon - Late Saxon_Norman	-0.550899004	0.3355468	44.95	-1.642	0.9510
Early Anglo-Saxon - Latest Iron Age	-0.129287044	0.4984189	1915.30	-0.259	1.0000
Early Anglo-Saxon - Middle Anglo-Saxon	-0.553167477	0.1650208	71.37	-3.352	**0.0850**
Early Anglo-Saxon - Middle Iron Age	0.184173353	0.1529224	106.97	1.204	0.9978
Early Anglo-Saxon - Middle Roman	-0.438930763	0.1236136	74.27	-3.551	**0.0493**
Early Anglo-Saxon - Roman	-0.522695712	0.1773050	172.78	-2.948	0.2031
Early Anglo-Saxon_Mid-Saxon - Early Iron Age	1.352097865	0.4020130	77.43	3.363	**0.0809**
Early Anglo-Saxon_Mid-Saxon - Early Roman	1.550779014	0.4033261	75.86	3.845	**0.0207**
Early Anglo-Saxon_Mid-Saxon - Iron Age	1.138282304	0.3758715	65.32	3.028	0.1862
Early Anglo-Saxon_Mid-Saxon - Late Iron Age	1.205443720	0.3907487	68.56	3.085	0.1631
Early Anglo-Saxon_Mid-Saxon - Late Roman	0.875000177	0.3891624	71.18	2.248	0.6609
Early Anglo-Saxon_Mid-Saxon - Late Roman/Early Anglo-Saxon	0.949577085	0.4841618	49.93	1.961	0.8340
Early Anglo-Saxon_Mid-Saxon - Late Saxon	0.760803554	0.3831020	62.49	1.986	0.8235
Early Anglo-Saxon_Mid-Saxon - Late Saxon_Norman	0.705549969	0.4831803	50.39	1.460	0.9822
Early Anglo-Saxon_Mid-Saxon - Latest Iron Age	1.127161928	0.6089236	394.46	1.851	0.8958
Early Anglo-Saxon_Mid-Saxon - Middle Anglo-Saxon	0.703281496	0.3656047	53.99	1.924	0.8534
Early Anglo-Saxon_Mid-Saxon - Middle Iron Age	1.440622325	0.3820602	63.83	3.771	**0.0281**
Early Anglo-Saxon_Mid-Saxon - Middle Roman	0.817518210	0.3705446	58.87	2.206	0.6892
Early Anglo-Saxon_Mid-Saxon - Roman	0.733753261	0.3922531	67.34	1.871	0.8797
Early Iron Age - Early Roman	0.198681149	0.2555770	252.45	0.777	1.0000

contrast	estimate	SE	df	t.ratio	p.value
Early Iron Age - Iron Age	-0.213815562	0.2228863	258.11	-0.959	0.9999
Early Iron Age - Late Iron Age	-0.146654146	0.1363872	2053.25	-1.075	0.9995
Early Iron Age - Late Roman	-0.477097689	0.2342154	250.24	-2.037	0.8020
Early Iron Age - Late Roman/Early Anglo-Saxon	-0.402520781	0.3803164	61.55	-1.058	0.9994
Early Iron Age - Late Saxon	-0.591294311	0.2605128	147.77	-2.270	0.6463
Early Iron Age - Late Saxon_Norman	-0.646547896	0.3749601	62.39	-1.724	0.9321
Early Iron Age - Latest Iron Age	-0.224935937	0.4806049	2035.89	-0.468	1.0000
Early Iron Age - Middle Anglo-Saxon	-0.648816370	0.2446443	140.31	-2.652	0.3723
Early Iron Age - Middle Iron Age	0.088524460	0.1750867	1101.02	0.506	1.0000
Early Iron Age - Middle Roman	-0.534579655	0.2085134	195.00	-2.564	0.4302
Early Iron Age - Roman	-0.618344604	0.2484114	222.25	-2.489	0.4834
Early Roman - Iron Age	-0.412496711	0.2245798	260.35	-1.837	0.9007
Early Roman - Late Iron Age	-0.345335295	0.2342917	169.57	-1.474	0.9840
Early Roman - Late Roman	-0.675778837	0.1428755	1837.52	-4.730	**0.0003**
Early Roman - Late Roman/Early Anglo-Saxon	-0.601201929	0.3783529	58.28	-1.589	0.9641
Early Roman - Late Saxon	-0.789975460	0.2623573	156.29	-3.011	0.1767
Early Roman - Late Saxon_Norman	-0.845229045	0.3793739	59.29	-2.228	0.6746
Early Roman - Latest Iron Age	-0.423617086	0.5242862	1689.02	-0.808	1.0000
Early Roman - Middle Anglo-Saxon	-0.847497518	0.2477528	147.96	-3.421	**0.0606**
Early Roman - Middle Iron Age	-0.110156689	0.2296097	188.28	-0.480	1.0000
Early Roman - Middle Roman	-0.733260804	0.2109577	162.73	-3.476	**0.0507**
Early Roman - Roman	-0.817025753	0.2487980	196.08	-3.284	**0.0861**
Iron Age - Late Iron Age	0.067161416	0.2024754	136.10	0.332	1.0000

contrast	estimate	SE	df	t.ratio	p.value
Iron Age - Late Roman	-0.263282127	0.2003367	286.32	-1.314	0.9951
Iron Age - Late Roman/Early Anglo-Saxon	-0.188705219	0.3501522	48.17	-0.539	1.0000
Iron Age - Late Saxon	-0.377478749	0.2181889	126.02	-1.730	0.9347
Iron Age - Late Saxon_Norman	-0.432732335	0.3461070	49.02	-1.250	0.9960
Iron Age - Latest Iron Age	-0.011120375	0.5089999	1875.93	-0.022	1.0000
Iron Age - Middle Anglo-Saxon	-0.435000808	0.1996477	111.16	-2.179	0.7095
Iron Age - Middle Iron Age	0.302340022	0.1823240	154.17	1.658	0.9542
Iron Age - Middle Roman	-0.320764094	0.1522531	121.05	-2.107	0.7571
Iron Age - Roman	-0.404529042	0.1650699	505.59	-2.451	0.5102
Late Iron Age - Late Roman	-0.330443543	0.2108936	151.91	-1.567	0.9718
Late Iron Age - Late Roman/Early Anglo-Saxon	-0.255866635	0.3683319	53.50	-0.695	1.0000
Late Iron Age - Late Saxon	-0.444640165	0.2428767	96.12	-1.831	0.8988
Late Iron Age - Late Saxon_Norman	-0.499893751	0.3630528	54.50	-1.377	0.9899
Late Iron Age - Latest Iron Age	-0.078281791	0.4775927	2045.83	-0.164	1.0000
Late Iron Age - Middle Anglo-Saxon	-0.502162224	0.2257279	86.26	-2.225	0.6777
Late Iron Age - Middle Iron Age	0.235178606	0.1567345	374.11	1.500	0.9820
Late Iron Age - Middle Roman	-0.387925510	0.1866781	90.37	-2.078	0.7736
Late Iron Age - Roman	-0.471690458	0.2300213	139.65	-2.051	0.7921
Late Roman - Late Roman/Early Anglo-Saxon	0.074576908	0.3624960	52.76	0.206	1.0000
Late Roman - Late Saxon	-0.114196622	0.2403822	144.19	-0.475	1.0000
Late Roman - Late Saxon_Norman	-0.169450208	0.3656424	55.45	-0.463	1.0000
Late Roman - Latest Iron Age	0.252161752	0.5142425	1800.32	0.490	1.0000
Late Roman - Middle Anglo-Saxon	-0.171718681	0.2244492	135.31	-0.765	1.0000

contrast	estimate	SE	df	t.ratio	p.value
Late Roman - Middle Iron Age	0.565622149	0.2057001	179.48	2.750	0.3083
Late Roman - Middle Roman	-0.057481967	0.1869711	158.32	-0.307	1.0000
Late Roman - Roman	-0.141246916	0.2284327	204.55	-0.618	1.0000
Late Roman/Early Anglo-Saxon - Late Saxon	-0.188773530	0.3650369	47.45	-0.517	1.0000
Late Roman/Early Anglo-Saxon - Late Saxon_Norman	-0.244027116	0.4639295	42.68	-0.526	1.0000
Late Roman/Early Anglo-Saxon - Latest Iron Age	0.177584844	0.5948464	362.94	0.299	1.0000
Late Roman/Early Anglo-Saxon - Middle Anglo-Saxon	-0.246295589	0.3623709	47.05	-0.680	1.0000
Late Roman/Early Anglo-Saxon - Middle Iron Age	0.491045241	0.3595522	49.82	1.366	0.9905
Late Roman/Early Anglo-Saxon - Middle Roman	-0.132058875	0.3405073	43.38	-0.388	1.0000
Late Roman/Early Anglo-Saxon - Roman	-0.215823824	0.3659681	50.82	-0.590	1.0000
Late Saxon - Late Saxon_Norman	-0.055253585	0.3722952	52.05	-0.148	1.0000
Late Saxon - Latest Iron Age	0.366358374	0.5263396	1377.24	0.696	1.0000
Late Saxon - Middle Anglo-Saxon	-0.057522059	0.1867997	322.05	-0.308	1.0000
Late Saxon - Middle Iron Age	0.679818771	0.2279324	101.11	2.983	0.1955
Late Saxon - Middle Roman	0.056714656	0.2047255	87.90	0.277	1.0000
Late Saxon - Roman	-0.027050293	0.2437257	121.94	-0.111	1.0000
Late Saxon_Norman - Latest Iron Age	0.421611959	0.5922677	374.94	0.712	1.0000
Late Saxon_Norman - Middle Anglo-Saxon	-0.002268473	0.3575841	46.02	-0.006	1.0000
Late Saxon_Norman - Middle Iron Age	0.735072356	0.3497040	47.84	2.102	0.7547
Late Saxon_Norman - Middle Roman	0.111968241	0.3291925	41.39	0.340	1.0000
Late Saxon_Norman - Roman	0.028203292	0.3558086	48.23	0.079	1.0000
Latest Iron Age - Middle Anglo-Saxon	-0.423880433	0.5189460	1476.27	-0.817	1.0000
Latest Iron Age - Middle Iron Age	0.313460397	0.4899751	2096.43	0.640	1.0000

Latest Iron Age - Middle Roman	-0.309643718	0.5030756	1849.90	-0.616	1.0000	
Latest Iron Age - Roman	-0.393408667	0.5209998	1691.26	-0.755	1.0000	
Middle Anglo-Saxon - Middle Iron Age	0.737340830	0.2090849	86.50	3.527	**0.0503**	
Middle Anglo-Saxon - Middle Roman	0.114236714	0.1842149	69.72	0.620	1.0000	
Middle Anglo-Saxon - Roman	0.030471765	0.2259715	104.68	0.135	1.0000	
Middle Iron Age - Middle Roman	-0.623104115	0.1607537	105.73	-3.876	**0.0162**	
Middle Iron Age - Roman	-0.706869064	0.2119597	139.42	-3.335	**0.0779**	
Middle Roman - Roman	-0.083764949	0.1799934	98.27	-0.465	1.0000	

P value adjustment: tukey method for comparing a family of 16 estimates

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b. Output for the 'lsmeans' function when the **nitrogen** isotopic values of human are analysed by sub-period, with region, site, sex and age as random effects.

$lsmeans

Sub_Period	lsmean	SE	df	lower.CL	upper.CL
Anglo-Saxon	11.181084	0.3629138	40.62	10.447956	11.91421
Early Anglo-Saxon	10.059940	0.2740002	17.05	9.481976	10.63790
Early Anglo-Saxon_Mid-Saxon	11.547291	0.7325407	65.33	10.084448	13.01013
Early Iron Age	9.805525	0.4323017	75.94	8.944510	10.66654
Early Roman	9.295511	0.4432607	95.96	8.415640	10.17538
Iron Age	10.468773	0.3448639	40.27	9.771922	11.16562
Late Iron Age	9.787776	0.3939171	45.75	8.994745	10.58081
Late Roman	9.961534	0.3953555	66.93	9.172386	10.75068
Late Roman/Early Anglo-Saxon	10.240165	0.6902620	51.28	8.854588	11.62574
Late Saxon	11.015089	0.4233420	63.29	10.169184	11.86099
Late Saxon_Norman	11.231046	0.6841047	52.02	9.858301	12.60379
Latest Iron Age	9.395187	0.9769332	1173.68	7.478456	11.31192
Middle Anglo-Saxon	11.111238	0.3857883	48.28	10.335673	11.88680
Middle Iron Age	10.162511	0.3584648	40.32	9.438205	10.88682
Middle Roman	10.473669	0.3144659	26.19	9.827504	11.11983
Roman	10.975907	0.4009067	64.84	10.175202	11.77661

Confidence level used: 0.95

$contrasts

contrast	estimate	SE	df	t.ratio	p.value
Anglo-Saxon - Early Anglo-Saxon	1.121143617	0.3148407	134.91	3.561	0.0406
Anglo-Saxon - Early Anglo-Saxon_Mid-Saxon	-0.366207380	0.7506718	65.44	-0.488	1.0000
Anglo-Saxon - Early Iron Age	1.375558549	0.4601283	184.85	2.990	0.1839
Anglo-Saxon - Early Roman	1.885573399	0.4630796	227.44	4.072	**0.0063**
Anglo-Saxon - Iron Age	0.712311301	0.2923387	578.17	2.437	0.5206
Anglo-Saxon - Late Iron Age	1.393308268	0.4260350	109.80	3.270	**0.0962**
Anglo-Saxon - Late Roman	1.219550517	0.4200324	221.59	2.903	0.2219
Anglo-Saxon - Late Roman/Early Anglo-Saxon	0.940918787	0.7047106	51.14	1.335	0.9924
Anglo-Saxon - Late Saxon	0.165994636	0.4516959	113.86	0.367	1.0000
Anglo-Saxon - Late Saxon_Norman	-0.049961830	0.6775539	47.71	-0.074	1.0000
Anglo-Saxon - Latest Iron Age	1.785897484	0.9893027	1635.11	1.805	0.9147
Anglo-Saxon - Middle Anglo-Saxon	0.069846359	0.4141915	100.49	0.169	1.0000
Anglo-Saxon - Middle Iron Age	1.018573112	0.3842120	117.60	2.651	0.3748
Anglo-Saxon - Middle Roman	0.707415052	0.3242587	108.41	2.182	0.7076
Anglo-Saxon - Roman	0.205177398	0.3660740	360.44	0.560	1.0000
Early Anglo-Saxon - Early Anglo-Saxon_Mid-Saxon	-1.487350998	0.6954931	54.58	-2.139	0.7330
Early Anglo-Saxon - Early Iron Age	0.254414932	0.3881644	210.14	0.655	1.0000
Early Anglo-Saxon - Early Roman	0.764429782	0.3812335	358.82	2.005	0.8210
Early Anglo-Saxon - Iron Age	-0.408832317	0.2648996	268.52	-1.543	0.9763
Early Anglo-Saxon - Late Iron Age	0.272164651	0.3464094	104.23	0.786	1.0000
Early Anglo-Saxon - Late Roman	0.098406899	0.3185581	438.44	0.309	1.0000

contrast	estimate	SE	df	t.ratio	p.value
Early Anglo-Saxon - Late Roman/Early Anglo-Saxon	-0.180224831	0.6567854	42.49	-0.274	1.0000
Early Anglo-Saxon - Late Saxon	-0.955148981	0.3753327	101.28	-2.545	0.4484
Early Anglo-Saxon - Late Saxon_Norman	-1.171105447	0.6561997	44.02	-1.785	0.9089
Early Anglo-Saxon - Latest Iron Age	0.664753867	0.9581835	1904.25	0.694	1.0000
Early Anglo-Saxon - Middle Anglo-Saxon	-1.051297258	0.3232193	68.83	-3.253	0.1100
Early Anglo-Saxon - Middle Iron Age	-0.102570506	0.3052820	109.32	-0.336	1.0000
Early Anglo-Saxon - Middle Roman	-0.413728566	0.2452157	75.43	-1.687	0.9438
Early Anglo-Saxon - Roman	-0.915966219	0.3455257	169.91	-2.651	0.3714
Early Anglo-Saxon_Mid-Saxon - Early Iron Age	1.741765930	0.7873182	73.69	2.212	0.6858
Early Anglo-Saxon_Mid-Saxon - Early Roman	2.251780779	0.7865772	73.31	2.863	0.2590
Early Anglo-Saxon_Mid-Saxon - Iron Age	1.078518681	0.7343657	62.47	1.469	0.9822
Early Anglo-Saxon_Mid-Saxon - Late Iron Age	1.759515648	0.7678822	66.33	2.291	0.6310
Early Anglo-Saxon_Mid-Saxon - Late Roman	1.585757897	0.7591092	68.59	2.089	0.7653
Early Anglo-Saxon_Mid-Saxon - Late Roman/Early Anglo-Saxon	1.307126167	0.9465052	48.16	1.381	0.9893
Early Anglo-Saxon_Mid-Saxon - Late Saxon	0.532202016	0.7477709	61.16	0.712	1.0000
Early Anglo-Saxon_Mid-Saxon - Late Saxon_Norman	0.316245551	0.9444065	48.72	0.335	1.0000
Early Anglo-Saxon_Mid-Saxon - Latest Iron Age	2.152104865	1.1767794	357.21	1.829	0.9044
Early Anglo-Saxon_Mid-Saxon - Middle Anglo-Saxon	0.436053740	0.7122495	52.40	0.612	1.0000
Early Anglo-Saxon_Mid-Saxon - Middle Iron Age	1.384780492	0.7493606	61.56	1.848	0.8884
Early Anglo-Saxon_Mid-Saxon - Middle Roman	1.073622432	0.7248916	56.45	1.481	0.9804
Early Anglo-Saxon_Mid-Saxon - Roman	0.571384779	0.7659569	64.60	0.746	1.0000
Early Iron Age - Early Roman	0.510014850	0.4956602	237.41	1.029	0.9997

contrast	estimate	SE	df	t.ratio	p.value
Early Iron Age - Iron Age	-0.663247249	0.4369349	250.75	-1.518	0.9795
Early Iron Age - Late Iron Age	0.017749719	0.2614631	2072.72	0.068	1.0000
Early Iron Age - Late Roman	-0.156008032	0.4547048	230.78	-0.343	1.0000
Early Iron Age - Late Roman/Early Anglo-Saxon	-0.434639763	0.7470763	59.63	-0.582	1.0000
Early Iron Age - Late Saxon	-1.209563913	0.5149167	148.97	-2.349	0.5883
Early Iron Age - Late Saxon_Norman	-1.425520379	0.7334900	60.43	-1.943	0.8449
Early Iron Age - Latest Iron Age	0.410338935	0.9195748	2033.42	0.446	1.0000
Early Iron Age - Middle Anglo-Saxon	-1.305712190	0.4820358	138.82	-2.709	0.3361
Early Iron Age - Middle Iron Age	-0.356985438	0.3384116	1238.43	-1.055	0.9996
Early Iron Age - Middle Roman	-0.668143498	0.4099852	201.75	-1.630	0.9610
Early Iron Age - Roman	-1.170381151	0.4858787	218.91	-2.409	0.5431
Early Roman - Iron Age	-1.173262098	0.4346181	258.62	-2.700	0.3367
Early Roman - Late Iron Age	-0.492265131	0.4569938	161.99	-1.077	0.9994
Early Roman - Late Roman	-0.666022882	0.2739322	1838.84	-2.431	0.5239
Early Roman - Late Roman/Early Anglo-Saxon	-0.944654612	0.7400480	57.69	-1.276	0.9953
Early Roman - Late Saxon	-1.719578763	0.5131935	158.04	-3.351	**0.0732**
Early Roman - Late Saxon_Norman	-1.935535229	0.7391057	57.78	-2.619	0.4065
Early Roman - Latest Iron Age	-0.099675915	1.0064633	1636.28	-0.099	1.0000
Early Roman - Middle Anglo-Saxon	-1.815727040	0.4826643	146.97	-3.762	**0.0211**
Early Roman - Middle Iron Age	-0.867000288	0.4465181	183.86	-1.942	0.8528
Early Roman - Middle Roman	-1.178158347	0.4092729	160.06	-2.879	0.2377
Early Roman - Roman	-1.680396001	0.4818495	198.94	-3.487	**0.0475**

contrast	estimate	SE	df	t.ratio	p.value
Iron Age - Late Iron Age	0.680996967	0.4014369	151.84	1.696	0.9448
Iron Age - Late Roman	0.507239216	0.3880953	281.82	1.307	0.9954
Iron Age - Late Roman/Early Anglo-Saxon	0.228607486	0.6868942	47.09	0.333	1.0000
Iron Age - Late Saxon	-0.546316665	0.4292230	124.25	-1.273	0.9962
Iron Age - Late Saxon_Norman	-0.762273130	0.6749179	47.57	-1.129	0.9986
Iron Age - Latest Iron Age	1.073586184	0.9785844	1843.39	1.097	0.9994
Iron Age - Middle Anglo-Saxon	-0.642464942	0.3910757	105.87	-1.643	0.9563
Iron Age - Middle Iron Age	0.306261811	0.3587849	147.67	0.854	1.0000
Iron Age - Middle Roman	-0.004896249	0.2964365	115.37	-0.017	1.0000
Iron Age - Roman	-0.507133902	0.3180855	513.11	-1.594	0.9689
Late Iron Age - Late Roman	-0.173757751	0.4125107	143.60	-0.421	1.0000
Late Iron Age - Late Roman/Early Anglo-Saxon	-0.452389481	0.7263766	52.85	-0.623	1.0000
Late Iron Age - Late Saxon	-1.227313632	0.4845454	105.22	-2.533	0.4564
Late Iron Age - Late Saxon_Norman	-1.443270098	0.7127615	53.58	-2.025	0.8008
Late Iron Age - Latest Iron Age	0.392589216	0.9139231	2041.73	0.430	1.0000
Late Iron Age - Middle Anglo-Saxon	-1.323461909	0.4494690	94.80	-2.945	0.2137
Late Iron Age - Middle Iron Age	-0.374735156	0.3058868	525.64	-1.225	0.9978
Late Iron Age - Middle Roman	-0.685893216	0.3723218	110.38	-1.842	0.8951
Late Iron Age - Roman	-1.188130870	0.4538380	150.68	-2.618	0.3945
Late Roman - Late Roman/Early Anglo-Saxon	-0.278631730	0.7093442	52.08	-0.393	1.0000
Late Roman - Late Saxon	-1.053555881	0.4709882	145.74	-2.237	0.6698
Late Roman - Late Saxon_Norman	-1.269512347	0.7129106	54.06	-1.781	0.9125

contrast	estimate	SE	df	t.ratio	p.value
Late Roman - Latest Iron Age	0.566346968	0.9869716	1745.58	0.574	1.0000
Late Roman - Middle Anglo-Saxon	-1.149704158	0.4376128	133.68	-2.627	0.3893
Late Roman - Middle Iron Age	-0.200977405	0.4008797	174.17	-0.501	1.0000
Late Roman - Middle Roman	-0.512135465	0.3634691	154.86	-1.409	0.9896
Late Roman - Roman	-1.014373119	0.4426847	206.47	-2.291	0.6305
Late Roman/Early Anglo-Saxon - Late Saxon	-0.774924151	0.7162390	47.09	-1.082	0.9992
Late Roman/Early Anglo-Saxon - Late Saxon_Norman	-0.990880617	0.9076195	41.75	-1.092	0.9990
Late Roman/Early Anglo-Saxon - Latest Iron Age	0.844978698	1.1505997	329.54	0.734	1.0000
Late Roman/Early Anglo-Saxon - Middle Anglo-Saxon	-0.871072428	0.7097311	45.95	-1.227	0.9966
Late Roman/Early Anglo-Saxon - Middle Iron Age	0.077654325	0.7079720	49.39	0.110	1.0000
Late Roman/Early Anglo-Saxon - Middle Roman	-0.233503735	0.6681131	42.84	-0.349	1.0000
Late Roman/Early Anglo-Saxon - Roman	-0.735741389	0.7159021	49.40	-1.028	0.9995
Late Saxon - Late Saxon_Norman	-0.215956466	0.7293050	51.37	-0.296	1.0000
Late Saxon - Latest Iron Age	1.619902848	1.0153582	1328.37	1.595	0.9692
Late Saxon - Middle Anglo-Saxon	-0.096148277	0.3628441	353.04	-0.265	1.0000
Late Saxon - Middle Iron Age	0.852578476	0.4530022	102.20	1.882	0.8779
Late Saxon - Middle Roman	0.541420416	0.4046577	88.35	1.338	0.9932
Late Saxon - Roman	0.039182762	0.4781983	122.30	0.082	1.0000
Late Saxon_Norman - Latest Iron Age	1.835859314	1.1435617	344.90	1.605	0.9666
Late Saxon_Norman - Middle Anglo-Saxon	0.119808189	0.6996091	45.08	0.171	1.0000
Late Saxon_Norman - Middle Iron Age	1.068534941	0.6846263	46.96	1.561	0.9678
Late Saxon_Norman - Middle Roman	0.757376881	0.6426747	40.67	1.178	0.9977

contrast	estimate	SE	df	t.ratio	p.value
Late Saxon_Norman - Roman	0.255139228	0.6932508	47.12	0.368	1.0000
Latest Iron Age - Middle Anglo-Saxon	-1.716051125	0.9994376	1415.56	-1.717	0.9424
Latest Iron Age - Middle Iron Age	-0.767324373	0.9388848	2096.00	-0.817	1.0000
Latest Iron Age - Middle Roman	-1.078482433	0.9672054	1838.94	-1.115	0.9993
Latest Iron Age - Roman	-1.580720086	1.0020843	1648.16	-1.577	0.9723
Middle Anglo-Saxon - Middle Iron Age	0.948726752	0.4145591	85.97	2.289	0.6329
Middle Anglo-Saxon - Middle Roman	0.637568693	0.3629525	68.42	1.757	0.9228
Middle Anglo-Saxon - Roman	0.135331039	0.4418006	101.82	0.306	1.0000
Middle Iron Age - Middle Roman	-0.311158060	0.3186264	105.63	-0.977	0.9998
Middle Iron Age - Roman	-0.813395713	0.4156499	138.84	-1.957	0.8440
Middle Roman - Roman	-0.502237653	0.3499625	97.80	-1.435	0.9868

P value adjustment: tukey method for comparing a family of 16 estimates

Appendix II.3 Differences between the men and women groups, with different variable.

Table.A2.3.1. Statistical Differences between sex/age in the Iron Age.

	Multi-level model with 'site' and 'sub-periods' as random effect and 'Sex', 'Age' and 'Region' as fixed effects	Multi-level model with 'site' and 'sub-periods' as random effect and 'Sex', 'Age' and 'Region' as fixed effects
	p-value (^{13}C)	*p- value* (^{15}N)
Young Adult F - Young Adult M	0.775	0.999
Young Adult F - Adult M	0.563	1.000
Young Adult F - Mature Adult M	0.999	0.997
Adult F - Young Adult M	1.000	1.000
Adult F -Adult M	0.775	1.000
Adult F - Mature Adult M	1.000	1.000
Mature Adult F - Young Adult M	0.996	1.000
Mature Adult F - Adult M	0.741	1.000
Mature Adult F - Mature Adult M	0.775	1.000

Table.A2.3.2. Statistical Differences between sex/age in Roman Britain.

	Multi-level model with 'site' and 'Region' as random effect and 'Sex', 'Age' and 'Sub_Period' as fixed effects	Multi-level model with 'site' and 'Region' as random effect and 'Sex', 'Age' and 'Sub_Period' as fixed effects s
	p-value (^{13}C)	*p- value* (^{15}N)
Young Adult F - Young Adult M	0.143	0.421
Young Adult F - Adult M	0.973	0.881
Young Adult F - Mature Adult M	0.990	0.996
Young Adult F - Older Adult M	1.000	0.999
Adult F - Young Adult M	0.671	0.998
Adult F -Adult M	0.116	0.412
Adult F - Mature Adult M	0.996	0.999
Adult F - Older Adult M	1.000	1.000
Mature Adult F - Young Adult M	1.000	1.000
Mature Adult F - Adult M	1.000	1.000
Mature Adult F - Mature Adult M	0.117	0.421
Mature Adult F - Older Adult M	1.000	1.000
Older Adult F - Young Adult M	0.543	0.983
Older Adult F - Adult F	0.726	0.923
Older Adult F- Mature Adult M	0.721	0.978
Older Adult F - Older Adult M	0.143	0.421

Table.A2.3.3. Statistical Differences between sex/age in Early Medieval Britain.

	Multi-level model with 'site' and 'sub-periods' as random effect and 'Sex', 'Age' and 'Region' as fixed effects	Multi-level model with 'site' and 'Region' as random effect and 'Sex', 'Age' and 'Sub_Period' as fixed effects
	p-value (^{13}C)	*p- value* (^{15}N)
Young Adult F - Young Adult M	0.406	0.987
Young Adult F - Adult M	1.000	0.751
Young Adult F - Mature Adult M	1.000	1.000
Young Adult F - Older Adult M	0.999	1.000
Adult F - Young Adult M	0.963	1.000
Adult F -Adult M	0.406	0.987
Adult F - Mature Adult M	1.000	0.963
Adult F - Older Adult M	0.997	0.997
Mature Adult F - Young Adult M	0.527	0.947
Mature Adult F - Adult M	0.894	0.226
Mature Adult F - Mature Adult M	0.406	0.987
Mature Adult F - Older Adult M	0.695	1.000
Older Adult F - Young Adult M	1.000	0.996
Older Adult F - Adult F	1.000	0.735
Older Adult F- Mature Adult M	1.000	1.000
Older Adult F - Older Adult M	0.406	0.987

Table.A2.3.4. Statistical Differences between sex/region in Roman Britain.

	Multi-level model with 'site' and 'sub-periods' as random effect and 'Sex', and 'Region' as fixed effects	Multi-level model with 'site' and 'sub-periods' as random effect and 'Sex', and 'Region' as fixed effects
	p-value (^{13}C)	*p- value* (^{15}N)
F Gloucestershire - M Gloucestershire	0.029	0.369
F Gloucestershire - M Oxfordshire	0.912	0.999
F Gloucestershire - M Yorkshire	0.091	0.038
F Oxfordshire - M Gloucestershire	1.000	1.000
F Oxfordshire - M Oxfordshire	0.029	0.369
F Oxfordshire - M Yorkshire	0.999	0.587
F Yorkshire - M Gloucestershire	0.997	0.431
F Yorkshire - M Oxfordshire	0.997	0.979
F Yorkshire - M Yorkshire	0.029	0.369
F Gloucestershire - F Oxfordshire	0.995	1.000
F Gloucestershire - F Yorkshire	0.493	0.119
F Oxfordshire - F Yorkshire	1.000	0.829
M Gloucestershire - M Oxfordshire	0.995	1.000
M Gloucestershire - M Yorkshire	0.493	0.118
M Oxfordshire - M - Yorkshire	0.029	0.829
F Dorset - M Gloucestershire	0.990	0.612
F Dorset - M Oxfordshire	1.000	0.612
F Dorset - M Yorkshire	1.000	0.146
F Dorset - M Dorset	0.029	0.369
M Dorset - M Oxfordshire	1.000	0.612
M Dorset - M Gloucestershire	0.827	0.804
M Dorset - M Yorkshire	0.999	0.217
F Dorset - F Gloucestershire	0.827	0.804
F Dorset - F Oxfordshire	1.000	0.788
F Dorset - F Yorkshire	0.999	0.217
M Dorset - F Gloucestershire	0.552	0.957
M Dorset - F Oxfordshire	0.977	0.941
M Dorset - F Yorkshire	0.951	0.333

Table.A2.3.5. Statistical Differences between sex/sub-period in Roman Britain

	Multi-level model with 'site' and 'Region' as random effect and 'Sex' and 'Sub_Period' as fixed effects	Multi-level model with 'site' and 'Region' as random effect and 'Sex' and 'Sub_Period' as fixed effects
	p-value (^{13}C)	*p- value* (^{15}N)
F Early Roman - M Early Roman	0.035	0.368
F Early Roman - F Late Roman	0.015	0.039
F Early Roman - M Late Roman	0.000	0.003
F Early Roman - F Late Roman/Early Anglo-Saxon	1.000	0.687
F Early Roman - M Late Roman/Early Anglo-Saxon	0.995	0.561
F Early Roman - F Middle Roman	1.000	0.641
F Early Roman - M Middle Roman	0.999	0.511
M Early Roman - F Late Roman	0.681	0.596
M Early Roman - M Late Roman	0.015	0.039
M Early Roman - F Late Roman/Early Anglo-Saxon	1.000	0.823
M Early Roman - M Late Roman/Early Anglo-Saxon	1.000	0.687
M Early Roman - F Middle Roman	0.999	0.797
M Early Roman - M Middle Roman	1.000	0.641
F Late Roman - M Late Roman	0.035	0.368
F Late Roman - F Late Roman/Early Anglo-Saxon	0.089	0.981
F Late Roman - M Late Roman/Early Anglo-Saxon	1.000	0.924
F Late Roman - F Middle Roman	0.842	0.984
F Late Roman - M Middle Roman	0.987	0.919
M Late Roman - F Late Roman/Early Anglo-Saxon	0.904	0.998
M Late Roman - M Late Roman/Early Anglo-Saxon	0.989	0.981
M Late Roman - F Middle Roman	0.617	0.999
M Late Roman - R Middle Roman	0.842	0.984
F Late Roman/Early Anglo-Saxon - M Late Roman/Early Anglo-Saxon	0.053	0.369
F Late Roman/Early Anglo-Saxon - F Middle Roman	1.000	1.000
F Late Roman/Early Anglo-Saxon - M Middle Roman	1.000	1.000
M Late Roman/Early Anglo-Saxon - F Middle Roman	1.000	0.998
M Late Roman/Early Anglo-Saxon - M Middle Roman	0.999	1.000
F Middle Roman - M Middle Roman	0.0353	0.369

Appendix III.1 – Example of R script.

Figure A4.1. Example of R scripts to analyse the data through multivariate modeling. All variables can be changed to fixed or random [here (1|Site)] according to the factors of variability that are measured/constrained.

```
##### MULTIVARIATE  ALL PERIOD
cattle <- data[data$Species == "Cattle", ]
##13C
multicattle1  <-  lmer(d13C  ~  Archaeological_Period  +
(1|Site) , cattle)

multicattle2 <- lmer(d13C ~ Archaeological_Period + Region
+ (1|Site) , cattle)

multicattle4 <- lmer(d13C ~ Archaeological_Period +  Region
+ (1|Sub_Period) + (1|Site) , cattle)

multicattle3  <-  lmer(d13C  ~  Archaeological_Period  +
(1|Region) + Sub_Period + (1|Site) , cattle)


multicattle5  <-  lmer(d13C  ~  Archaeological_Period  +
(1|Sub_Period) + (1|Site) , cattle)

multicattle6  <-  lmer(d13C  ~  Archaeological_Period  +
(1|Sub_Period) +(1|Region) + (1|Site) , cattle)

multicattle7<-  lmer(d13C  ~  Archaeological_Period  +
Sub_Period + Region + (1|Site) , cattle)

###d15N
multicattle8  <-  lmer(d15N  ~  Archaeological_Period  +
(1|Site) , cattle)

multicattle9 <- lmer(d15N ~ Archaeological_Period + Region
+ (1|Site) , cattle)

multicattle10  <-  lmer(d15N  ~  Archaeological_Period  +
Region + (1|Sub_Period) + (1|Site) , cattle)

multicattle11  <-  lmer(d15N  ~  Archaeological_Period  +
(1|Region) + Sub_Period + (1|Site) , cattle)

multicattle12  <-  lmer(d15N  ~  Archaeological_Period  +
(1|Sub_Period) + (1|Site) , cattle)

multicattle13  <-  lmer(d15N  ~  Archaeological_Period  +
(1|Sub_Period) +(1|Region) + (1|Site) , cattle)

multicattle14  <-  lmer(d15N  ~  Archaeological_Period  +
Sub_Period + Region + (1|Site) , cattle)
```

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