Transition from the Late Roman Period to the Early Anglo-Saxon Period in the Upper Thames Valley Based on Stable Isotopes

YURIKA SAKAI
ST. CROSS COLLEGE
DOCTOR OF PHILOSOPHY IN ARCHAEOLOGICAL SCIENCE



Abstract

Following the argument of cultural change between the Romano-British and Anglo-Saxon periods in Britain, the purpose of this thesis is to find evidence of change in human diet and animal husbandry in the Upper Thames Valley across this boundary. Research questions are set to find differences in human diet, animal diet, and birth seasonality of herbivores at Horcott, a site showing human activity in both periods. Stable carbon and nitrogen isotope measurements on collagen from humans and livestock animals and enamel carbonate extracted from herbivores were analysed. Results showed changes in the diets of cattle, sheep/goats, pigs, and human, and birth seasonality of cattle and sheep/goats. These changes were argued to have been caused by differences in the intensity of fertilising crop fields, the amount of animal protein fed to adult pigs, the amount of non-local food in human diet, and the significance and purpose of livestock rearing and the preference of dairy products. The outcome of this thesis enhances the understanding of: a) the strategy and the amount of human effort put into crop cultivation and livestock management; b) the availability and preference of food for humans depending on the period; and c) the site-dependent differences in the extent of change in the course of transition between the Romano-British and Anglo-Saxon periods. This thesis demonstrates the importance of animal data in order to discuss human diet, and the advantage of modelling enamel carbonate sequential data when analysing worn and shortened teeth.

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Table of Contents

1. Introduction 1
    1.1. The Transition from the Roman to the Anglo-Saxon Period in Britain 1
    1.2. The Topic: Why the Upper Thames Valley? 9
    1.3. The Topic: Why Compare the Romano-British and the Anglo-Saxon Periods? 14
    1.4. The Site: Why Horcott? 15
    1.5. Stable Isotope Approaches 16
    1.6. Aims and Objectives 18
    1.7. Outline of Chapters 20
2. Animal Husbandry in the Romano-British and the Anglo-Saxon Periods 21
    2.1. Animal Bone Evidence 21
    2.2. Evidence of Livestock Management 52
    2.3. Evidence of Livestock Feed 59
    2.4. Summary 65
3. Human Diet in the Romano-British and the Anglo-Saxon Periods 66
    3.1. The Romano-British Period 66
    3.2. The Anglo-Saxon Period 78
    3.3. Summary 88
4. Stable Isotope Evidence of Animal husbandry and Human Diet 89
    4.1. Principles of Carbon and Nitrogen Stable Isotopes in Bone Collagen and Tooth Dentine 89
    4.2. Influences on Carbon Stable Isotope Composition in Terrestrial Ecosystems 91
    4.3. Factors Which Influence the Nitrogen Stable Isotopes 94
    4.4. Principles of Carbon and Oxygen Stable Isotopes from Tooth Enamel Carbonate 97
    4.5. Published Stable Isotope Data for Bone Collagen and Tooth Dentine 104
    4.6. Published Stable Isotope Data of Tooth Enamel Carbonate in Fauna 124
    4.7. Summary 131
5. Material and Methods 133
    5.1. Selected Site: Horcott 133
    5.2. Sampled Materials from Horcott 154
    5.3. Sample Preparation Methods 158
    5.4. Statistical Methods 161
    5.5. Programming Softwares Used 161
    5.6. Summary 163
6. Results 164
    6.1. Bone Collagen Results 164
    6.2. Sequential Enamel Carbonate Results 200
    6.3. Summary 218
7. Discussion 219
    7.1. Diet from Collagen Results 219
    7.2. Animal Husbandry from Enamel Carbonate Results 264
8. Conclusion 309
    8.1. Key Findings 310
9. Appendix 317

10. Bibliography 342

List of Figures

Figure 2.1: Averaged interspecies ratio by NISP of cattle, sheep/goats and pigs in Roman Britain
Figure 2.2: Interspecies ratio by NISP of cattle sheep/goats and pigs in the Roman Upper Thames Valley
Figure 2.3: Interspecies ratio by NISP of cattle, sheep/goats, and pigs in early Anglo-Saxon Britain, from Crabtree (2010)
Figure 2.4: Interspecies ratio by NISP of cattle, sheep/goats, and pigs in the Anglo-Saxon Upper Thames Valley
Figure 2.5: Mortality profile of cattle from aged mandibles and maxillae at Horcott
Figure 2.6: Mortality profile of sheep/goats from aged mandibles and maxillae at Horcott
Figure 2.7: Mortality profile of pigs from aged mandibles and maxillae at Horcott
Figure 4.1: Location of Upper Thames Valley sites with stable isotope data
Figure 4.2: Box plots of collagen data of human from the Upper Thames Valley sites
Figure 4.3: Sequential enamel carbonate data of GG839 (Bronze Age cow at Grimes Graves) from Towers et al. (2013)
Figure 4.4: Sequential enamel carbonate data of GGT10 (Bronze Age cow at Grimes Graves) from Towers et al. (2013)
Figure 4.5: Sequential enamel carbonate data of GG614 (Bronze Age cow at Grimes Graves) from Towers et al. (2013)
Figure 4.6: Sequential enamel carbonate data of GG120 (Bronze Age cow at Grimes Graves) from Towers et al. (2013)
Figure 5.1: Location of Horcott from Hayden et al. forthcoming
Figure 5.2: Site plan of Horcott from Hayden et al. forthcoming
Figure 5.3: Plan of Roman villa style part masonry building at Horcott from Hayden et al. forthcoming
Figure 5.4: Location of cemeteries at Horcott from Hayden et al. forthcoming
Figure 5.5: Age distribution of inhumations from the southern cemetery at Horcott from Hayden et al. forthcoming
Figure 5.6: Plan of the southern cemetery at Horcott from Hayden et al. forthcoming
Figure 5.7: Plan of Anglo-Saxon features in the western area at Horcott from Hayden et al. forthcoming
Figure 5.8: Plan of Anglo-Saxon features in the eastern area at Horcott from Hayden et al. forthcoming
Figure 5.9: Plan of the northern cemetery at Horcott from Hayden et al. forthcoming
Figure 5.10: Age distribution of inhumations from the northern cemetery at Horcott from Hayden et al. forthcoming
Figure 6.1: Comparison of distribution of cattle data at Horcott by period
Figure 6.2: Statistical significance of difference in mean and variance of cow data between the two periods
Figure 6.3: Correlation between age and stable isotope values of cow
Figure 6.4: Statistical significance of correlation between age and stable isotope values of cow
Figure 6.5: Comparison of distribution of sheep/goat data at Horcott by period
Figure 6.6: Statistical significance of difference in mean and variance of sheep/goat stable isotope values between the two periods
Figure 6.7: Correlation between age and stable isotope values of sheep/goat
Figure 6.8: Statistical significance of correlation between age and stable isotope values of

sheep/goat
Figure 6.9: Comparison of distribution of pig data at Horcott by period
Figure 6.10: Statistical significance of difference in mean and variance of pig stable isotope values between the two periods
Figure 6.11: Correlation between age and stable isotope values of pig
Figure 6.12: Statistical significance of correlation between age and stable isotope values of pig
Figure 6.13: Collagen results from Horcott
Figure 6.14: Statistical significance of inter-specific comparison of animals at Horcott
Figure 6.15: Comparison of distribution of human data at Horcott by period
Figure 6.16: Statistical significance of difference in mean and variance of human stable isotope values between the two periods
Figure 6.17: Statistical significance of comparison by period and phase
Figure 6.18: Comparison of collagen data by various burial characteristics
Figure 6.19: Collagen results of humans at Horcott by period and phase
Figure 6.20: Correlation between age and stable isotope values of human by period
Figure 6.21: Statistical significance of correlation between age and stable isotope values of human by period
Figure 6.22: Collagen data of humans at Horcott by age category
Figure 6.23: Correlation between age and stable isotope values of Anglo-Saxon human by phase
Figure 6.24: Statistical significance of correlation between age and stable isotope values of Anglo-Saxon human by phase
Figure 6.25: Sequential enamel carbonate data of cattle at Horcott
Figure 6.26: Sequential enamel carbonate data of sheep/goats at Horcott
Figure 6.27: Birth seasonality of cattle at Horcott from the method by Balasse et al. (2012 b)
Figure 6.28: Birth seasonality of cattle and sheep/goats at Horcott from the method by Towers et al. (2013)
Figure 6.29: Birth seasonality of sheep/goats at Horcott from the method by Balasse et al. (2012 b)
Figure 7.1: Box-plots of collagen data of cow from Horcott in comparison with other Upper Thames Valley sites
Figure 7.2: Statistical significance of difference in mean and variance of stable isotope values of cow between Horcott and other Upper Thames Valley sites
Figure 7.3: Box-plots of collagen data of sheep/goat from Horcott in comparison with other Upper Thames Valley sites
Figure 7.4: Statistical significance of difference in mean and variance of stable isotope values of sheep/goat between Horcott and other Upper Thames Valley sites
Figure 7.5: Box-plots of collagen data of pig from Horcott in comparison with other Upper Thames Valley sites
Figure 7.6: Statistical significance of difference in mean and variance of stable isotope values of pig between Horcott and other Upper Thames Valley sites
Figure 7.7: Collagen results from Horcott in comparison with other Upper Thames Valley sites
Figure 7.8: Box-plots of collagen data of human from Horcott in comparison with other Upper Thames Valley sites
Figure 7.9: Statistical significance of difference in human $\delta^{13}C$ values among Romano-British Upper Thames Valley sites
Figure 7.10: Statistical significance of difference in human $\delta^{15}N$ values among Romano-British Upper Thames Valley sites

Figure 7.11: Statistical significance of difference in human stable isotope values among Anglo-Saxon Upper Thames Valley sites
Figure 7.12: Collagen results from Horcott in comparison with other Upper Thames Valley sites
Figure 7.13: Sequential enamel carbonate data of cattle from British sites
Figure 7.14: Sequential enamel carbonate data of cattle from continental sites
Figure 7.15: Sequential enamel carbonate data of sheep/goats from Bercy, Paris, France by Balasse et al. (2012)
Figure 7.16: Birth seasonality of cattle from British sites and Er Yoh from the method by Balasse et al. (2012)
Figure 7.17: Birth seasonality of cattle from continental sites from the method by Balasse et al. (2012)
Figure 7.18: Birth seasonality of sheep/goats from British sites and Er Yoh from the method by Balasse et al. (2012)
Figure 7.19: Birth seasonality of sheep/goats from non-British sites from the method by Balasse et al. (2012)
Figure 7.20: Sequential enamel carbonate data of cattle from Bercy, Paris, France by Balasse et al. (2012)
Figure 7.21: Sequential enamel carbonate data of cattle from Er Yoh, Brittany, France and Knap of Howar, Orkneys, Britain by Balasse and Tresset (2007)
Figure 7.22: Sequential enamel carbonate data of sheep/goats from Er Yoh, Brittany, France and Knap of Howar, Orkneys, Britain by Balasse and Tresset (2007)

List of Tables

Table 4.1: Majority and minority groups by various burial characteristics of Romano-British humans at Horcott and the statistical significances of the difference between each two groups by Cheung (2009)
Table 5.1: Sampled bone and dentine from Horcott for collagen analyses
Table 6.1: Values calculated from collagen data of cattle at Horcott
Table 6.2: Values calculated from collagen data of sheep/goats at Horcott
Table 6.3: Values calculated from collagen data of pigs at Horcott
Table 6.4: Values calculated from collagen data of humans at Horcott
Table 6.5: Majority and minority groups by various burial characteristics of Romano-British humans at Horcott
Table 6.6: Sampled cattle teeth at Horcott for enamel carbonate analysis
Table 6.7: Values calculated from enamel carbonate data of cattle at Horcott
Table 6.8: Sampled sheep/goat teeth at Horcott for enamel carbonate analysis
Table 6.9: Values calculated from enamel carbonate data of sheep/goats at Horcott
Table 7.1: Values calculated from collagen data of cattle from Upper Thames Valley sites
Table 7.2: Values calculated from collagen data of sheep/goats from Upper Thames Valley sites
Table 7.3: Values calculated from collagen data of pigs from Upper Thames Valley sites
Table 7.4: Values calculated from collagen data of humans from Upper Thames Valley sites
Table 7.5: List of enamel carbonate data of cattle from British sites
Table 7.6: Values calculated from enamel carbonate data of cattle from British sites
Table 7.7: List of enamel carbonate data of cattle from continental sites
Table 7.8: Values calculated from enamel carbonate data of cattle from continental sites
Table 7.9: List of enamel carbonate data of sheep from British sites
Table 7.10: Values calculated from enamel carbonate data of sheep from British sites
Table 7.11: List of enamel carbonate data of sheep and goat from non-British sites
Table 7.12: Values calculated from enamel carbonate data of sheep and goats from non-British sites
Table S1: Normalised results of cattle at Horcott
Table S2: Normalised results of sheep/goats at Horcott
Table S3: Normalised results of pigs at Horcott
Table S4: Normalised results of horses at Horcott
Table S5: Normalised results of dogs at Horcott
Table S6 a: Normalised results of tooth enamel carbonate of cattle at Horcott
Table S6 b: Normalised results of tooth enamel carbonate of sheep/goats at Horcott
Table S7 a: Burial characteristics of humans at Horcott and normalised collagen data from this study
Table S7 b: Burial characteristics of humans at Horcott and collagen data from Cheng (2009)

List of Abbreviations

Cato Agri.	Cato	On Agriculture
Col. Agri.	Columella	On Agriculture
Gal. Prop. Food.	Galen	On the Properties of Foodstuffs
Ori. Med. Comp.	Oribasius	Medical Compilations
Plaut. Capt.	Plautus	Captivi
Pliny NH	Pliny	Natural History
Varro Agri.	Varro	On Agriculture
Verg. Geor.	Vergil	Georgics

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Chapter 1. Introduction

The focus of this research is the transition from the Romano-British period to the Anglo-Saxon period in the Upper Thames Valley, England and its impact on human diet and animal husbandry practices as evidenced at Horcott, Gloucestershire, one of the few sites that are known to span the transition. The techniques used to investigate this topic are stable light isotopes in bone collagen and enamel carbonate, which were analysed using several statistical tests and model fitting.

In this chapter the historical background to the transition will be reviewed first followed by the reasoning behind the topic and approach. Finally, the objective and research questions of this study will be presented, followed by an outline of the following chapters.

1.1. The Transition from the Roman to the Anglo-Saxon Period in Britain

One of the most significant current discussions in the transition from the late Roman period to the early Anglo-Saxon period in Britain concerns what aspects of Romano-British culture diminished after the end of the Roman period and what other aspects continued into the Anglo-Saxon period (Esmonde Cleary 2011). Equally, the argument regarding the arrival of the Anglo-Saxon tribes has drawn significant interest focussing on both the scale of migration and its impact on indigenous British culture.

In the following sections, the cultural impact of Roman rule and its subsequent decline on southern Britain, and the arrival of the Anglo-Saxons is explored.

1.1.1. ‘Romanisation’

The Romanisation of Britain was a complex and diverse process. For example, it involved people of different cultures, social statuses, and ethnic backgrounds (Freeman 1993, Hill 2001, Hingley 1996, 1997, James 2001, 2003, Mattingly 2006, Millett 1990 a, 1990 b, Woolf 1997). It is for this reason that the term ‘Romanisation’ has been challenged by researchers who argue that it overlooks the regional difference in the influence of Roman culture across the Roman Empire and the impact on indigenous cultures (Alcock 2001, Carr 2003, Lucas 2002, Mattingly 2004, Terrenato 1998, Webster 2001). Other terms such as ‘creolisation’ (Carr 2003, Hawkes 2001, Webster 2001), ‘cross-culturalisation’ (Crowe 2001), and ‘globalisation’ (Hingley 2005) have been proposed as alternatives. Although the author is aware of the controversiality of using the term ‘Romanisation’, it will be used in this thesis simply to refer to the apparent change that occurred after the Iron Age and before the Anglo-Saxon period.

Improvement in Agriculture

Nevertheless, in Britain, a number of consistent features of Romanisation can be detected. A clear example is agriculture, in which the effect of Roman culture has been demonstrated. Many researchers have argued that Roman farming was sophisticated and productive (e.g. Dickson 1788, Forni 2006, Kolendo 1980, Marcone 2006, Pleket 1990). Compared to the Iron Age, the level of land-use intensified (Dark and Dark 1998, Grant 2004). In addition, manufactured metal tools such as the iron plough coulter were introduced (Lambrick 1992: 97, Kron 2012). Fertilisation of arable land was widely applied, increasing productivity, and as a result, the yield of wheat in Roman Italy has been argued to be equivalent or higher than

the medieval or modern agriculture in Italy up till the 1970s (Spurr 1986: 82–8, Erdkamp 2005: 34–46).

Notably, the intensification of agriculture in the Roman period was prominent where there were urban markets and trade networks (Kron 2012). Taxation to support the needs of the Roman military and administrative communities also caused a rise in demand for cereal grains and further encouraged the intensification and efficiency improvement in agricultural activities (Rivet 1969: 189–98, Young 1986).

Roman Trading Network and Food Availability

Another common feature of Romanisation is the extensive trading network. Several lines of evidence shows that there was a significant increase in the scale and level of trade in the territory occupied by the Roman Empire (Bang 2008: 32). The Roman economy was driven by fiscal integration and the state's needs of transporting goods using road and oversea networks (Loseby 2012). This is because the state was involved in food provisioning systems of grains and later also olive oil and pork (Rickman 1980, Garnsey 1983, Aldrete and Mattingly 1999, HA Sept. Sev. 18.3, Aurel. 35.2, 48.1.), which were not only for Rome but also for other major Roman cities and military communities (Wilson 2012, Silver 2012). The centralised taxation and state-induced transportation networks also stimulated surplus production, market activities, and transport means for private demands (Wickham 1988: 189–93, Morley 2012, Loseby 2012).

In addition, the vast trading network connecting various regions in the Roman Empire increased the accessibility to a wide variety of non-local foods across the territory. For example, the scale of wine trade was deduced from the distribution of Italian amphorae found across Gaul in the second and first century BC and also in Britain (Loughton 2003). Other frequently traded commodities were cereal grains, processed fish, fine table wares, textiles, and olive oil (Silver 2012), which can be found ubiquitously in the western provinces of the Roman Empire (Wilson 2012, Morley 2012).

There is also evidence that new foods were introduced in the Roman period. Condiments and spices were imported from outside the Roman territory, such as from the Near East, India, and East Asia (Kron 2012). Pepper was one of the many imported goods and was available across the territory as far north as Vindolanda near the Hadrian's Wall, and its availability was not limited to those of high social status (Tomber 2008: 16, 55, 174, Bowman 1994: 70, Cool 2006: 32, 64, 67).

Moreover, the ubiquity of availability of goods essential for leading a Romanised lifestyle such as wine and olive oil has been argued to have enabled the inhabitants across the Empire to lead a relatively homogeneous Roman lifestyle (Pitts 2008, Morley 2012) and express a sense of common identity as Romans by consuming these goods (Wilson 2012). Some researchers have interpreted this economic integration as 'Roman globalization' (Hingley 2005, Morley 2010: 107–27).

In Roman Britain however, the extent of these changes varied depending on the location and the types of settlements (details in Chapter 3). In the Romano-British period, various settlement types emerged besides rural sites in the Iron Age, resulting in a society with social

differentiation (Young 1986). The level of Romanisation varied from highly Romanised urban sites to scarcely Romanised rural sites where their lifestyle shows little change from the Iron Age (Hingley 1989: 121–32).

1.1.2. The End of Roman Rule

As with Romanisation, the decline in Roman influence triggered by the collapse of Roman rule was a complex process which varied in time and space (Loseby 2012), which becomes apparent by regional comparison (Wickham 2005: 1–14, 825–31). For instance, studies of pottery distribution indicate that circulation of products became more limited to local and regional areas within the Roman territory (Loseby 2007: 10–12).

In Britain, the collapse of the Roman system was relatively rapid compared to other regions of the Roman Empire (Loseby 2012). In 407 AD, most of the Roman troops deployed in Britain were transferred to the continental territories and Emperor Honorius took no further action to defend the frontier in Britain (Welch 1992: 101). In the latter half of the fourth century AD, quantitative and qualitative decline of characteristic Roman features became apparent (Esmonde Cleary 2011).

Collapse of the Roman Trading Network

The Roman trading network supported by the state rapidly ceased to function in Britain as a result of the disintegration of Roman rule (Esmonde Cleary 1989: 138–61). The loss of the army led to a significant fall in demand for markets in post-Roman Britain because the military demand had been a major driver for economic production and circulation until the end of the Romano-British period. For example, wheel-thrown pottery ceased to be produced

in post-Roman Britain by the AD 420s or 430s (Welch 1992: 102, Wilson 2006: 233–4), and the amount of pottery and its quality also declined (Esmonde Cleary 2011). The decline of the market economy is probably due to the rise in costs and risk as well as the decline in demand, and consequently the profit from the extensive and complex trade system was no longer sufficient to maintain the large-scale production and circulation of goods supplied to markets (Wickham 2005: 693–824). In addition, no Roman coins issued after 402 AD are found in Britain, suggesting the decline of monetary system (Esmonde Cleary 2011).

The decline in the Roman trading network meant that non-local and imported foods became scarce, as shown by the archaeological and botanical evidence in the Anglo-Saxon period (details in Chapter 3).

Pockets of Continuity

Not just the complex economy, but also the social structure and culture of the Roman Empire deteriorated by the latter half of the fifth century AD, resulting in a reduction in resources, social hierarchy, and variety of commodities (Esmonde Cleary 2011). However, it should be noted that the qualitative and quantitative deterioration of various characteristic Roman features was most apparent at highly Romanised sites such as towns and military sites. Unsurprisingly, rural sites that showed little evidence of Romanisation in the Romano-British period in the first place showed little signs of change by its end (Esmonde Cleary 2011). Moreover, re-examination of the chronology of the material culture of late Roman Britain revealed the possibility of settlements, structures, burials, and artefacts of Romano-British culture continuing into the first third of the fifth century (Esmonde Cleary 2011).

1.1.3. Arrival of the Anglo-Saxons

Even before Roman rule ended, Britain became exposed to the invasion of tribes that had been kept outside of the Roman Empire. There has been a long debate over what happened in the fifth century AD in Britain, where various types of evidence have been adopted to analyse the migration of the Anglo-Saxons. Grave-goods and burial practices in early Anglo-Saxon Britain show a more complex cultural influence from the continent than what the Venerable Bede described, since they show connections with Frisia and Frankia in addition to southern Scandinavia and northern Germany, the homelands of the Germanic tribes according to the Venerable Bede (Brugmann 2011).

It has been noted by many researchers that architectural evidence such as timber hall structures and sunken feature buildings, artefactual evidence such as pottery styles and grave-goods, and burial customs such as cremation burials exhibit similarities with the evidence in contemporaneous north-western continental Europe (see Williams 2006: 7–8). Archaeological evidence has been used to argue for both a large scale migration resulting in a population replacement and a small scale migration of elite warriors (see for example Arnold 1984: 139, Scull 1995: 71–2, Härke 2003: 15–6). Higham (1992: 233) argued that the reason why Anglo-Saxon material culture became so prevalent in Britain was because ambitious indigenous Britons preferred to express their close links to the elite Anglo-Saxons by adapting themselves to their material culture in order to gain authority.

However, the characteristic cremation burial practice which emerged in Britain in the fifth century AD suggests that the Anglo-Saxon cultural influence was more than acquiring characteristic objects, and when the newcomers died they were buried in Britain following their traditional burial practice (Welch 1992: 12). This leads to the argument that the

movement of people across the channel was carried out by families and whole communities rather than a small number of elite warriors (Welch 1992: 12).

Still, the influence of Anglo-Saxon material culture varied depending on the region. It is most obvious in south-east Britain, while settlements in other regions show signs of both continuity and change in architectural patterns (see Hamerow 1999, 2002: 48–51).

Nevertheless, economic and vegetation change in the post-Roman period was detected from the pollen-data in south-east England which suggest that woodland regeneration, increase in pasture, and decline in arable land occurred. Dark (2000: 156) argues that overall, many of the regions that had undergone the greatest change in vegetation and agriculture in the Romano-British period seem to have experienced a reduction in the intensity of land use in the post-Roman period; the most productive soils were probably maintained for arable, while less fertile soils were converted to pasture or even allowed to revert to woodland.

1.2. The Topic: Why the Upper Thames Valley?

The Upper Thames Valley is a region which a number of studies have produced evidence for both change and continuity from the Romano-British to the Anglo-Saxon period. The evidence provided by these studies can be classified as: environmental, archaeological, and historical. This ample evidence is useful when analysing human diet and animal husbandry from stable isotope data, because a more detailed discussion is possible by comparing stable isotope data with other types of evidence reflecting various aspects of human activity and the environment.

1.2.1. Environmental Evidence

As suggested above, there was a significant increase in evidence of human activity in the Romano-British period such as the intensification of arable agriculture (Lambrick 1992). Intensification of land-use is also suggested from the increase in alluvium in the floodplain in the Romano-British period (Robinson 1992b: 55). Equally, change in vegetation and land use is indicated from botanical evidence. On the one hand, pollen evidence from Sidlings Copse, Oxfordshire show a decline in the amount of pollen of main tree species such as oak, alder and hazel in the Romano-British period (Henig and Booth 2000: 111). On the other hand, plant species common in damp environments become more frequently mixed in charred cereal remains, suggesting that more damp, marginal land was utilised in the Romano-British period (Lambrick 1992). This indicates that crop fields were extended onto the damp floodplain areas in the Thames Valley which had historically been grassland (Lambrick 1992). Since cereals are considered to provide a larger amount of nutrition compared to livestock (Lambrick 1992), focusing on arable agriculture at the expense of pastoral agriculture in the

Romano-British period has been regarded as a consequence of a demand for feeding a larger population.

However, the water table in the Thames valley continued to rise, causing frequent flooding on the floodplain and affecting the land-use of low lands by the late Romano-British period (Booth et al. 2007: 17–32). Botanical evidence from several sites in the Upper Thames Valley testifies that the higher, drier gravel terraces and clay soils remained in use for arable farming, while the lower wet lands reverted to pasture land and hay meadow (Booth et al. 2007: 26–8).

After the end of Roman rule in Britain, botanical evidence indicates that reforestation took place to some extent (Robinson 1981: 274). In addition, the alluvial deposition from the fifth to the eighth century AD greatly declined compared to the Romano-British period, which suggests that the scale of land exploitation in the Thames Valley became less intensive in the Anglo-Saxon period (Robinson 1981: 274, Robinson and Lambrick 1984: 813, Robinson 1992 a: 200–2). This may also suggest that some land used for arable farming in the Romano-British period reverted to pasture, since evidence of farming activity concentrates on the best quality land for crop cultivation, in contrast to the Romano-British period (Blair 1994: 25, xvii).

Settlement patterns also show a reduction in scale and the location of settlements concentrates on higher ground on the second gravel terrace (Robinson 1981: 274, Robinson and Lambrick 1984: 813, Robinson 1992a: 200–2, Blair 1994: 23), similar to where Neolithic and Bronze Age settlements are located (Hamerow 1992: 41).

Nevertheless, despite the decrease in the scale of arable farming, there is evidence of continuity in agricultural activity from the late Romano-British to the early Anglo-Saxon period (Booth et al. 2007: 317).

1.2.2. Archaeological Evidence

The decline of the Roman economy can also be observed from archaeological evidence. The Roman-influenced pottery industry in the area between Romano-British towns of Alchester and Dorchester-on-Thames show a decrease in the amount of pottery found around the end of the fourth century AD (Young 1977, Young 1986). One of the explanations argued is that the Oxford pottery industry declined as a result of the disintegration of the monetary market economy possibly related to the cessation of coin exportation to Britain (Henig and Booth 2000: 179–80). Although the latest coins minted in 402 AD are frequently found at town sites such as Dorchester, Alchester, Asthall and other sites which may indicate that the monetary market economy was at least still in function to some extent at the end of the fourth century AD (Henig and Booth 2000: 182), it probably declined after new coins ceased to arrive in Britain.

Archaeological evidence also shows the appearance of Germanic material culture in the Upper Thames Valley. The river Thames is considered to have played a crucial role in linking the Upper Thames Valley and the continental homelands of the Anglo-Saxons, where similarities in material culture are detected (Blair 1994:8). It has been argued that the early Anglo-Saxon burials in Oxfordshire reflect the intense human activity in the fifth century AD (Henig and Booth 2000: 192). For example, characteristic burial rites attributed to the Anglo-Saxons appear by the second half of the fifth century AD, and are regarded as evidence of Anglo-Saxon tribes that settled in the region (Blair 1994: 7). However, unlike East Anglia and northern England where cremation burials are more common, inhumation burials are more commonly found in the Upper Thames Valley (Kirk 1956).

Moreover, metal objects give further evidence of the presence of continental migrants. For example, Hawkes (1986) indicates that the Roman 'military' belt fittings found in burials at the Roman Villa of Shakenoak (Brodribb et al. 2005) show similarities with Böhme's (1974) Type A belt found in contemporary Rhineland and France. Hawkes (1986) refers to another example of Roman belt fitting set found at Dyke Hills, Dorchester-on-Thames and notes its similarity to those found in the Lower Rhine region classified by Böhme (1974). Also, the material culture of the Germanic tribes who arrived in the Upper Thames Valley, especially female brooches and cremation pottery, show a strong similarity to those in Old Saxony between the rivers Elbe and Weser in northern Germany (Hawkes 1986).

Conversely, archaeological evidence also shows continuity of indigenous British culture in the Anglo-Saxon period. For example, Dickinson (1976) argues that the belt fittings and buckles from Blewburton Hill grave 20, Abingdon I grave 30 and Minster Lovell grave 3 were produced by British workshops trying to create a military belt by copying the style attributed to the migrants. In addition, Dickinson (1979) argues that the cast saucer brooch, the most common brooch type found in the Oxford region, was possibly created by local workshops as a more robust version of applied brooches originally from Northern Germany.

1.2.3. Historical Evidence

Historical documents also provide information about the situation between the two different cultural groups in the region. The Romano-British town of Cirencester, not far from Horcott, is referred to in the Anglo-Saxon Chronicle, when Ceawlin and his son Cuthwine killed three

British rulers, Coinmagil, Candidan, and Farinmagil, at the battle against the Britons at Dyrham and took Cirencester as well as Gloucester and Bath in the year 577 (Swanton 2000). Although this suggests that the three Romano-British towns were still under control of the Britons until 577 AD, the archaeological evidence suggests otherwise. Wacher (1976: 321) argues that evidence of activity indicating that Cirencester functioned as a town ceased by the middle of the fifth century AD. Anglo-Saxon style burials from the beginning of the sixth century AD were found at the Roman villa at Barton Mill close to the Gloucester gate of Cirencester (Brown 1976). Another contemporary Anglo-Saxon cemetery was found at Kemble, four miles south-west of Cirencester, suggesting that Anglo-Saxon migration had already reached Cirencester by the beginning of the sixth century AD (Hawkes 1986).

1.3. The Topic: Why Compare the Romano-British and the Anglo-Saxon Periods?

As observed above, artefactual evidence has formed the basis of the argument that there was a large change in material culture after the arrival of the Anglo-Saxons. However, chronological studies of artefacts seem to be biased by assumptions that Romano-British materials cannot be dated later than AD 410, and Anglo-Saxon objects cannot be dated earlier than AD 450, which somewhat exaggerates how sudden or marked the change in the fifth century AD was, and understates the possibility of an overlap in time between the two cultures when they could have co-existed and interacted (Brugmann 2011). In addition, how this cultural change affected the lifestyles of the inhabitants has not been investigated in detail. Since there is some evidence to suggest partial continuity rather than an abrupt change, it is possible that the cultural change was not deep enough to affect the lifestyle of inhabitants. In order to assess whether or how lifestyles changed between the two periods, more direct evidence that reflects daily activities is necessary. Investigating habits such as diet and how they managed their livestock will make it possible to explore the extent of change from a different perspective (see Chapter 2 and 3 for archaeological evidence of livestock management and diet).

1.4. The Site: Why Horcott?

The site selected for analysis was excavated at Horcott Quarry, near Fairford, Gloucestershire. Horcott is one of only three sites in the Upper Thames Valley where archaeological evidence shows human activity in the Romano-British and the Anglo-Saxon periods and the only site where there were animal bone assemblages from both periods (see Chapter 5). Archaeological evidence shows that Horcott is located at the western edge of the early Anglo-Saxon cultural influence, where British presence seems to have been significant as testified by apparently locally produced metal objects. Clearly, the location and evidence of continuity is ideal for testing the extent of change in human diet and animal husbandry between the Romano-British and the Anglo-Saxon periods (detailed description of the site in Chapter 5).

1.5. Stable Isotope Approaches

Over the latest few decades, stable isotope analyses of bones and tooth dentine have attracted much attention as a mean for investigating diet in the past. The advantage of stable isotope analyses is that it can show individual difference in the food one consumed, which makes it possible to examine the relation between stable isotopes and various characteristics such as sex, age, and social status. This is not possible by investigating other archaeological evidence, because it can only tell the general availability of each type of food, and not the difference in food consumed by each individual.

This method has been used to investigate diet across time and place. Indeed, there are quite a few research studies published on human diet in the Romano-British and the Anglo-Saxon periods (details in Chapter 4). Yet, very few studies have examined the transition from the Romano-British to the Anglo-Saxon period. Moreover, studies of the transition in diet in a single site from the Romano-British to the Anglo-Saxon period are rare to find in literature. Equally, although analysing food stuffs consumed by humans such as plant food and animal protein is crucial when arguing the cause of the difference in diet patterns, this has not always been carried out. In addition, the research to date tends to focus on human diet rather than animal diet. Not all sites have corresponding animal data, and even for sites with animal data, the number of animals analysed for each site tend to be too small for arguing about animal diet.

Notably, in recent years, there has been an increasing amount of literature on stable isotopes of tooth enamel in order to investigate livestock management. The past decade has seen the rapid development of sequential sampling of tooth enamel, a relatively new way of sampling

which can show seasonal change in food consumption and difference in birth seasons (details in Chapter 4). However, studies which carried out sequential sampling of tooth enamel have been relatively few and no study has been found so far which use Romano-British and Anglo-Saxon livestock species.

Realising the gap in the extant literature, more research is needed for discussing livestock management in the Romano-British and Anglo-Saxon periods.

1.6. Aims and Objectives

Since the aim of this study was only briefly mentioned at the beginning of this chapter, it will be explained here in detail. The aim is to explore the difference in human diet and livestock management from the Romano-British period to the Anglo-Saxon period in order to reveal how the cultural and economic differences impacted on daily eating habits and farming practices of the inhabitants. This study also aims to develop a more rigorous understanding of previously overlooked aspects of livestock management regarding feeding and breeding in the Romano-British and the Anglo-Saxon periods.

The objective is to produce and analyse stable isotope data of bone collagen and tooth enamel carbonate of humans and animals at Horcott to investigate the change in human diet and animal husbandry between the Romano-British and Anglo-Saxon periods in the Upper Thames Valley. While this study focuses on the change in a single site, the long term implications of this study will impact the level of understanding of cultural change affecting daily activities concerning food and livestock management.

This study has two main research questions:

1. What does the animal husbandry evidence reveal about change at Horcott?

a) Did the Roman livestock have isotopically different diets from that in the Anglo-Saxon period at Horcott? If this is the case it could suggest that animals were fed or managed

differently, or the conditions under which their food was grown changed depending on the period.

b) Are there any isotopic differences among different species? Did pigs have an isotopically different diet from herbivores such as cattle and sheep/goat? If this is the case, pigs had a high proportion of food which did not derive from plants in their diet.

c) Are there any isotopic differences that relate to seasonality among cattle and sheep/goats? If there are, it could suggest that their fodder changed seasonally. If there is seasonal isotopic change in cattle and sheep/goats, is it different between the Romano-British and the Anglo-Saxon periods? If it is, it could suggest that the seasonal change of fodder varied depending on the period.

d) Did the cattle and sheep/goats have different birth seasonality between the Romano-British and the Anglo-Saxon periods? If they did, it could suggest that the extent of livestock management by humans, including breeding control, varied depending on the period.

2. What does the human diet evidence reveal about change at Horcott?

a) Did the Anglo-Saxon humans have an isotopically restricted diet compared to the Romano-British individuals at Horcott? If this is the case, it could suggest that imported non-local food (see Chapter 3) available in the Romano-British period ceased to be consumed in the Anglo-Saxon period.

b) Are there any intra-site isotopic differences at Horcott correlating to skeletal and burial characteristics? If there are, it could suggest that diet varied depending on physical characteristics or social status of the individual.

1.7. Outline of Chapters

In order to address these questions and fill in gaps in our understanding of the effects of cultural change on daily activities of inhabitants at Horcott, this thesis takes the following format. Firstly, archaeological, faunal, and botanical evidence in Roman and Anglo-Saxon Britain is explored in Chapter 2 for animal husbandry and Chapter 3 for human diet. Archaeological evidence at Horcott is compared to other sites in the Upper Thames Valley and the rest of Britain to see how representative it is.

In Chapter 4, in order to review the methodological background of this thesis, the principles of stable isotopes are outlined, followed by a discussion of stable isotope evidence of animal husbandry and human diet.

Chapter 5 summarises the archaeological background for Horcott, the materials selected for stable isotope analysis, the criteria for sample selection, and the practical procedures used to extract samples and measure samples. Notably, modelling of oxygen stable isotope value sequences of tooth enamel carbonate was carried out in order to concatenate sequences from different teeth from an individual. This procedure will be also explained in this chapter.

Chapter 6 presents the results; it analyses the data, and the trends observed from the results are tested for significance.

Chapter 7 discusses about the significant trends detected in Chapter 6, and their relevance for the research questions listed above.

Finally, Chapter 8 summarises the key findings of this study, and points to possibilities for future research.

Chapter 2. Animal Husbandry in the Romano-British and the Anglo-Saxon Periods

This chapter reviews the archaeological and historical evidence for animal husbandry in order to reveal how typical Horcott was compared to other contemporaneous sites especially in the Upper Thames Valley. The main periods of focus are the Romano-British and Anglo-Saxon periods, but when there is not enough evidence from these two periods, evidence in later periods are referred to.

The discussion is divided into three parts: animal bone evidence for investigating the purpose of rearing each species; historical and modern evidence of the strategy of managing births and weaning of new born individuals; and various forms of archaeological evidence of the diet of each species.

2.1. Animal Bone Evidence

The influence of Roman culture on Romano-British animal husbandry can be observed in various aspects of animal bone assemblages. For example, an increase in livestock body size has been detected in the Romano-British period, especially in cattle and sheep (Albarella 2007, Dobney 2001, Grant 1989, Maltby 1981, O'Connor and van der Veen 1998). In addition, an increase in tooth size of cattle and sheep was detected at Elms Farm, Heybridge, Essex, which was attributed to the introduction of new stock, since teeth are more resistant to change due to artificial selection or nutritional improvement (Albarella et al. 2008) and less prone to sexual difference (Degerbøl and Fredskild 1970) compared to bones.

Yet, there is difference in the timing and extent of the size increase depending on sites and regions (Maltby 1981, Noddle 1984). Furthermore, there are sites in western Britain which do not show any evidence of size change throughout the Romano-British period (Maltby 1979, 1981). This diversity in timing and extent of livestock size increase or lack of size change may reflect site-specific reactions to the market economy, technological innovation, and political and social change (Albarella et al. 2008).

The following sections will focus on interspecies ratios and mortality profiles. The species of interest are cattle, sheep, goats, and pigs, since these livestock are higher in proportion in animal bone assemblages compared to the rest of the animal species that contributed to the human diet.

2.1.1. Importance of Livestock from Interspecies Ratio

The interspecies ratio deduced from the number of identified specimens (NISP) shows which livestock was predominant. A change in the proportion can suggest discontinuity in the preference of species between different periods.

2.1.1.1. The Romano-British Period

Britain

Generally speaking, the predominant species in Britain changed from sheep in the late Iron Age (Hambleton 1999) to cattle in the Romano-British period (Albarella 2007). On the one hand, King (1978 a, 1984, 1999) argues that the intensity of 'Romanisation' was the main factor that influenced the proportion of livestock species in Britain. He argues that

Romanised towns, villas, roadside settlements, and military sites have a higher proportion of cattle, whereas Iron Age and indigenous Romano-British rural sites have a higher proportion of sheep (Fig. 2.1). For example, at the late Romano-British site with a bathhouse at Icklingham, Suffolk, which seems to have functioned as a market centre, cattle were the predominant species in the third and fourth centuries AD (Crabtree 1994).

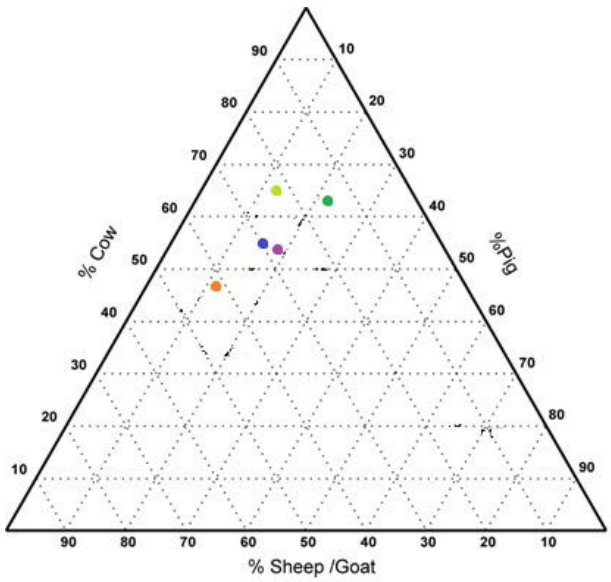


Fig. 2.1 Averaged interspecies ratio by NISP of cattle, sheep/goats and pigs in Roman Britain; dark green: legionary sites, light green: auxiliary sites, purple: town sites, blue: villa sites, orange: rural sites. Data from King (1999).

On the other hand, it has been argued that the higher proportion of cattle was a response to the Roman market economy based on consumer oriented demands, which induced intensification in both arable and pastoral agriculture (Halstead 1985, Albarella 2007, Dobney 2001, Grant 1989, Luff 1993). Indeed, Crabtree (1994) argues that the animals at Icklingham were provided through the Roman market since the cattle, red deer and horse bones show the same standardised butchery marks. Similarly, by analysing the animal bone assemblages from Winchester, and Dorchester, Dorset, as well as from rural sites in the same

region, Maltby (1994) concludes that the higher proportion of adult cattle was the result of exploiting them for their economic benefits rather than a result of military influence.

Alternatively, the rise in the proportion of cattle may correlate with the intensification of arable agriculture. Lambrick (1992) argues that arable fields were extended onto the flooded areas of the floodplain in the Thames Valley which had been grassland. The increase in alluvium in the floodplain during the Romano-British period indicates the intensification of land-use (Robinson 1992b: 55). Albarella (2007) argues that the increase in the proportion of mature cattle may have been a result of the intensification of arable cultivation, since cattle are useful for pulling the plough. However, this trend towards a high proportion of mature cattle was not observed across Roman Britain and there are site-dependent and chronological variations in the composition of cattle (Albarella 2007, Gidney 1999, Grant 1989, 2002, Hamshaw-Thomas 2000).

Equally, the proportion of pigs changed depending on the level of Romanisation. King (1984, 1991) argues that the proportion of pigs was higher in Romano-British towns than in less Romanised sites (Fig. 2.1). For example, a high percentage of pigs was found at the Romano-British towns of Exeter (Maltby 1979), York (O'Connor 1988), and Colchester (Luff 1993). The high proportion of pigs may be explained as a dietary preference or a husbandry preference for pigs in towns (King 1984, Maltby 1994). Furthermore, Maltby (1994) argues that the high proportion in urban sites reflects not just where pigs were consumed, but also where they were raised. Other sites with a high proportion of pigs show a strong influence of Roman culture, such as: the large and exceptionally Mediterranean style villa at Fishbourne, West Sussex (Grant 1971); the early industrial site at Leicester (Brown 1985); the early pottery industry settlement at Ower, Poole harbour Dorset (Coy 1987); and the late fourth

century AD villa at Great Bedwyn, Wiltshire (Payne 1997). However, apart from such highly Romanised sites, pig husbandry in Romano-British sites shows little change from the Iron Age pattern (Albarella 2007).

The Upper Thames Valley

Overall, the predominant species in the Upper Thames Valley sites was either cattle or sheep while pigs were low in proportion (Fig. 2.2). Particularly in urban sites, the proportion of cattle tended to increase at the expense of sheep in the course of the Romano-British period (Hesse 2011). Not only was cattle the predominant species at urban sites such as Cirencester (Maltby 1998) and Dorchester-on-Thames (Grant 1979), and at the small roadside settlement of Wilcote to the north of the Upper Thames Valley (Hamshaw-Thomas et al. 2004), but also at rural sites. For example, at Yarnton (Mulville et al. 2011: Table 17.4), Watkins Farm (Wilson and Allison 1990), Old Shifford Farm, Standlake (Lange 1995), Farmoor (Wilson 1979), Appleford (Wilson 1980), Barton Court Farm (Wilson 1984), and the extramural site of Alchester (Powell and Clark 2001), cattle is the predominant species followed by sheep and a low proportion of pigs. Similarly, cattle is the predominant species at the rural sites near Cirencester or adjacent to the River Thames such as Claydon Pike (Sykes 2007a), Neigh Bridge, Somerford Keynes (Sykes 2007 b), Cotswold Community (Strid 2010), Thornhill farm (Charles 2004), and Whelford Bowmoor (Harman 2007), although compared to Cirencester, the proportion of sheep at these sites was higher whereas the proportion of pigs was lower.

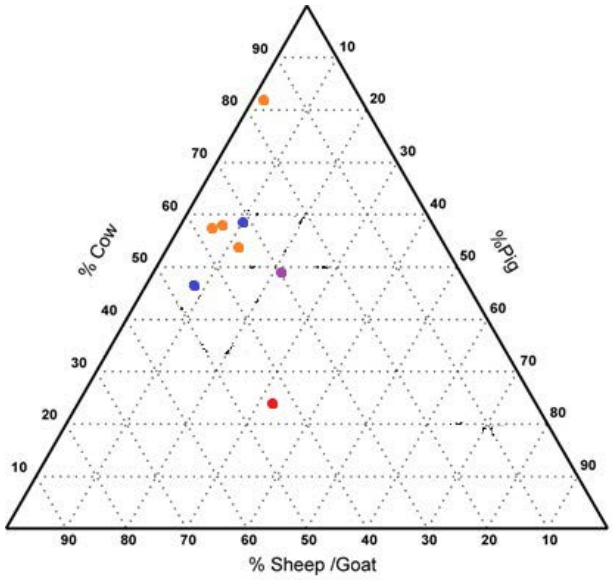


Fig. 2.2 Interspecies ratio by NISP of cattle sheep/goats and pigs in the Roman Upper Thames Valley; purple: St. Michael's Field, Cirencester 3rd c. AD (Maltby 1998), blue: villae at Barton Court Farm 3rd–4th c. AD (Wilson 1984) and Claydon Pike 2nd–3rd c. AD (Sykes 2007 a), orange: rural sites at Cotswold Community Middle Roman (Strid 2010), Neigh Bridge, Somerford Keynes 2nd–3rd c. AD (Sykes 2007 b), Whelford Bowmoor 2nd–3rd c. AD (Harman 2007), and Old Shifford Farm 3rd–4th c. AD (Lange 1995), red: Horcott (Hayden et al. forthcoming).

Hesse (2011) argues that the increase in the proportion of cattle could have been a response to environmental change. In the Thames Valley, the water table in the Romano-British period constantly rose, causing frequent flooding of the floodplain and affecting the land-use of low lands by the late Romano-British period (Booth et al. 2007: 17–32). Botanical evidence from several sites in the Upper Thames Valley testifies that the higher dry lands of gravel terraces and clay soils continued to be used for arable farming, while the lower wet lands were reverted to pasture land and hay meadow (Booth et al. 2007: 26–8). Since sheep are prone to disease common on wetlands such as foot rot and liver fluke (Wilson 1993, Mulville and Levitan 2004), the pasture land and hay meadow on increasingly wet floodplains were more suitable for rearing cattle.

However, there are Romano-British rural sites in the Upper Thames Valley where the predominant species is not cattle. Some rural sites from the surrounding region of Cirencester have a higher percentage of sheep/goats at the expense of cattle compared to Cirencester (King 1984), such as at Frocester Court villa (Noddle 1979) and at Bagendon (Reilly 1990). Other examples are Abingdon (Wilson and Wallis 1991, Wilson 1978), and Gravelly Guy (Muville and Levitan 2004), the small roadside town of Asthall to the north of the Upper Thames Valley (Powell et al. 1997), and the villa at North Leigh (Pinter-Bellows 1999), where cattle were the second most common species and pigs remained relatively rare throughout the Romano-British period.

As with other regions across Roman Britain, pigs are normally not found in a high proportion in the Upper Thames Valley sites except for urban sites, such as Cirencester (Maltby 1998). Exceptionally, despite being a low status rural site, the percentage of pigs at Yarnton is 16.4%, which is a high proportion for a non-urban settlement (Mulville et al. 2011). At Longdoles Field, Claydon Pike, although the proportion of pigs increased in the Roman period at Claydon Pike, it was still not drastic enough to attribute to Romanisation (Sykes 2007b).

2.1.1.2. The Anglo-Saxon Period

Britain

In the early Anglo-Saxon period in Britain, cattle or sheep/goats remained the predominant species (Fig 2.3). Animal husbandry in the early Anglo-Saxon period (fifth to seventh centuries AD) seems to have aimed for local consumption rather than exporting to markets (Crabtree 2010). However, from the middle Anglo-Saxon period, some sites suggest the introduction of more specialised husbandry practices, which seems to be corresponding to the period when formal markets re-emerged (Crabtree 2010). The discussion here will focus on the early Anglo-Saxon period until the seventh century AD, the same period to which the animal bone assemblages from Anglo-Saxon Horcott were dated.

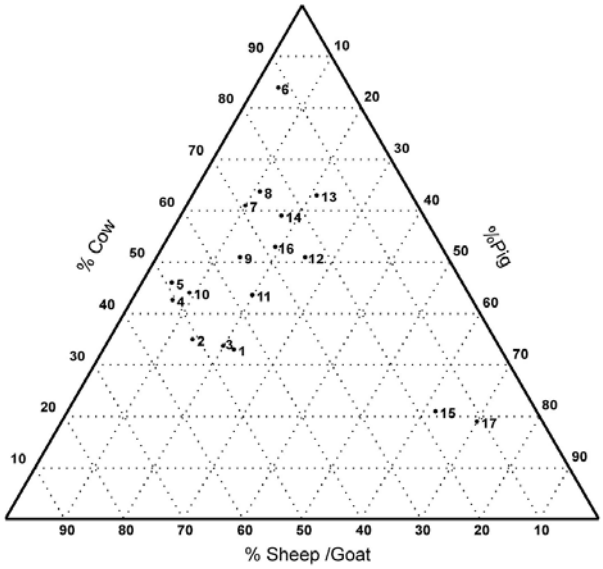


Fig. 2.3 Interspecies ratio by NISP of cattle, sheep/goats, and pigs in early Anglo-Saxon Britain, from Crabtree (2010); 1. West Stow Phase 1; 2. West Stow Phase 2; 3. West Stow Phase 3; 4. West Stow new excavations; 5. Kilham; 6. Spong Hill; 7. Melford Meadows; 8. Quarrington Early Saxon; 9. Redcastle Furze; 10. West Heslerton Early Saxon; 11. Station Road, Gamlingay; 12. Oakley Road, Clapham; 13. Mucking; 14. Oxford Science Park; 15. Wicken Bonhunt Early Saxon; 16. Harrold; 17. St. Albans Abbey 5th–8th/9th centuries.

King (1978 a) argues that after the Roman influence faded away following the end of the Roman rule in Britain, the proportion of cattle and pork declined and the predominant

livestock gradually reverted to sheep as in the Iron Age. Examples of sites where sheep/goats were the predominant species are early Anglo-Saxon West Stow, Suffolk (Crabtree 1990a) and early Anglo-Saxon West Heslerton, North Yorkshire (Dobney et al. 2007: 223). Still, sites where sheep/goats predominate the animal bone assemblage are a minority in early Anglo-Saxon Britain. The inter-species ratio of livestock by NISP counts from a number of Anglo-Saxon sites show that cattle were commonly the most abundant species (Clutton-Brock 1976), even in East Anglia, a region traditionally associated with sheep production (Crabtree 2010). Examples of sites dominated by cattle are: the high-status site at early Anglo-Saxon Yeavering, Northumberland (Higgs and Jarman 1977), early Anglo-Saxon Spong Hill, Norfolk (Bond 1995), and early Anglo-Saxon Mucking, Essex (Done 1993).

Although documentary evidence shows that pig was important in the Anglo-Saxon economy (Clutton-Brock 1976), pigs only existed as a minor component in the animal bone assemblages at most of the Anglo-Saxon sites (Mulville and Ayres 2004), a proportion of 20 % of animal assemblages at most (Fig. 2.3). Exceptionally, in the late sixth to seventh century AD contexts at Wicken Bonhunt, Essex, pigs were the predominant species unlike other early Anglo-Saxon sites (Crabtree 2010). Another exceptional example of pigs as the predominant species comes from the remains dated from the fifth to ninth century AD at St. Albans Abbey, Hertfordshire (Crabtree 2010). Since there is also a high proportion of deer, the high proportion of pigs seems to reflect the high status of the Abbey (Crabtree 2010).

The Upper Thames Valley

The animal bone assemblages of Upper Thames Valley sites tended to be dominated by cattle (Fig 2.4), as at Lechlade (Maltby 2003) and Cresswell Field (Mulville and Ayres 2004). Exceptional sites where sheep/goats were the predominant species are: early Anglo-Saxon Barton Court Farm (Wilson 1984), where the predominant livestock from the villa in the Romano-British period was cattle but was replaced by sheep/goats in the Anglo-Saxon period; and Eynsham throughout the Anglo-Saxon period (Mulville in Ayres et al. 2003: Table 10.1). Moreover, at Eynsham, in addition to sheep/goats being the predominant species, a relatively high proportion of pigs at around 20% of the animal bone assemblage was found in the early Anglo-Saxon period (Fig. 2.4) and especially in the mid/late eighth century AD and later (Mulville 2003). In addition to the wild animals such as roe deer which are constantly found, the increase in the proportion of pigs seems to reflect the high status of the site, as a minster was founded possibly in the middle Anglo-Saxon period (Mulville 2003). A relatively high proportion of pigs in the early Anglo-Saxon period may suggest that Eynsham was a high status site even before the minster was founded.

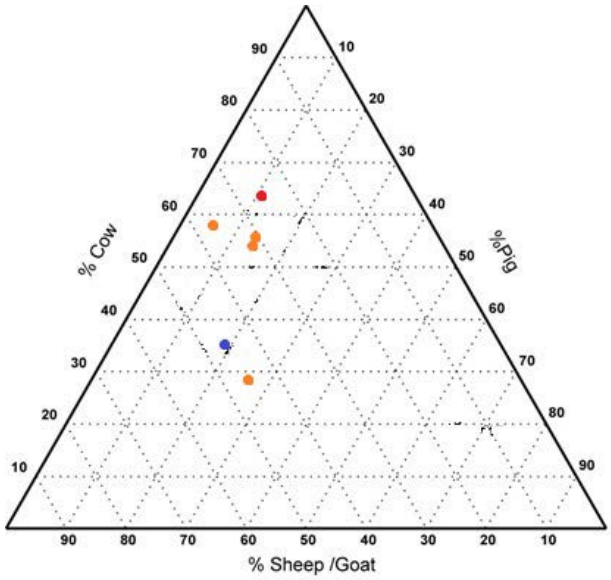


Fig. 2.4 Interspecies ratio by NISP of cattle, sheep/goats, and pigs in the Anglo-Saxon Upper Thames Valley; blue: Eynsham Early Saxon (Ayers et al. 2003), orange: rural sites at Barton Court Farm (Wilson 1984), Lechlade (Maltby 2003), and Yarnton (Mulville and Ayers 2004), red: Horcott (Hayden et al. forthcoming).

2.1.1.3. Horcott

Following the pattern observed in the Upper Thames Valley, the animal bone assemblage of Horcott analysed by Strid (in Hayden et al. forthcoming) will be discussed. From Romano-British contexts, a total of 808 fragments were recovered, of which 606 were identified to species, while the Anglo-Saxon contexts yielded a total of 4752 fragments, of which 1063 were identified to species (Hayden et al.forthcoming: Table 11.1).

As in the Iron Age, sheep/goats continued to be the predominant species by NISP (excluding horse from the horse burial) at Horcott in the Romano-British period (Fig. 2.3). Surprisingly, the proportion of cattle is much lower while that of pigs is much higher than any other site in the Upper Thames Valley. In contrast, cattle became the predominant species in the Anglo-Saxon period (Fig. 2.4). However, Strid (in Hayden et al. forthcoming) argues that the Romano-British assemblage is too small to discuss species proportions (Hayden et al. forthcoming: Table 11.1) and dismisses that the Anglo-Saxon assemblage does not show

much difference from the Romano-British assemblage, suggesting that the animal husbandry practice were similar between the two periods.

NISP can be biased by difference in fragmentation and recovery depending on the size of the taxa (Crabtree 1994). Since bones of larger animals tend to break into pieces more often than those of smaller animals, the number of cattle bones tends to be exaggerated in NISP (Sykes 2007a). On the contrary, the number of cattle bones by NISP at Romano-British Horcott was smaller compared to sheep/goats and pigs animals which could be under-represented by NISP being smaller in size than cattle.

However, there is a huge bias towards horse at Romano-British Horcott, because a semi-articulated horse skeleton was found which was considered to be a horse burial. In fact, 539 out of 606 Romano-British animal bones identified to species were identified as horse (Hayden et al. forthcoming: Table 11.1). The sum of bones identified as cattle (13), sheep/goats (23), and pigs (17) is only 53, which explains why Strid (in Hayden et al. forthcoming) argues that the Romano-British sample size is too small for detailed discussion.

The author only counted the minimum number of individuals (MNI) of mandibles and maxillae of the animal bone assemblage at Horcott (discussed in section 2.1.2). Discrepancies between results by NISP and MNI counts can be caused by differences in fragmentation between species of different size (Mulville and Ayres 2004), but this was not the case for cattle at Romano-British Horcott since they were the least frequent of the three main livestock types by MNI as well as by NISP. Thus, the small number of Romano-British cattle was probably not caused by destruction but instead may reflect the actual scarcity of cattle at Romano-British Horcott.

In contrast, although the proportion of pigs is higher in the Romano-British period than in the Anglo-Saxon period both by NISP and MNI, the number of mandibles and maxillae of

Romano-British pigs (n=6) was similar to that of Anglo-Saxon pigs (n=7) (see section 2.1.2). Therefore, it seems that the reason for the apparent high proportion of pigs in the Romano-British period was a skew caused by the unusually low proportion of cattle rather than an actual increase in the number of pigs.

Therefore, although Strid (in Hayden et al. forthcoming) argues the Anglo-Saxon assemblage does not show much difference from the Romano-British assemblage, interspecies ratios suggests that the importance of cattle varied between the two periods.

The predominance of cattle at Anglo-Saxon Horcott agrees with other Anglo-Saxon sites in the Upper Thames Valley such as Lechlade, Yarnton, and Cresswell Field, but differs from Barton Court Farm and Eynsham where sheep/goats were the predominant species (Fig. 2.4). Regarding topography, Wilson (1978: 136) argues that the Upper Thames Valley sites on the second gravel terrace tend to have higher proportions of sheep compared to those on the first gravel terrace. This may be because the second gravel terrace is drier and more suitable for sheep rearing, since they are prone to foot rot and liver fluke in wet conditions (Wilson 1993, Mulville and Levitan 2004). Horcott is located on the second gravel terrace of the River Thames, so this argument supports the fact that sheep/goat was the predominant species at Iron Age and Romano-British Horcott, but does not explain why cattle became the predominant species in the Anglo-Saxon period. Thus, other factors besides topography affected the animal proportions at Anglo-Saxon Horcott.

Change or Continuity at Horcott?

The animal bone assemblage does not indicate that livestock were exported or imported, suggesting that it was a self-sufficient rural site in both periods (Strid in Hayden et al. forthcoming). The predominance of sheep/goats in the Romano-British period at Horcott fits the characteristics of indigenous sites argued by King (1978 a). Thus, animal husbandry practices at Romano-British Horcott were not significantly affected by the demands of the Roman market economy and the occupants of Horcott were not involved in the trade of their livestock. Interestingly, cattle became the predominant species in the Anglo-Saxon period after the cessation of Romanised economy, suggesting a change in livestock preference between the two periods.

2.1.2. Purpose of Livestock Rearing from Slaughter Patterns

The age at death of animals can be evaluated from the timing of epiphyseal fusion, dental eruption, and dental attrition. Mortality profiles of livestock created from the age at death of individuals reflect the slaughter patterns of each site. The slaughter pattern will vary depending on what the livestock were valued for: meat, milk, traction power, hide, and horns for cattle; and meat, milk, and wool for sheep (Crabtree 1990a). For example, if meat consumption is the main purpose of livestock rearing, the mortality profile shows a large number of young animals which reached their full body size and a smaller number of adult animals for breeding (Crabtree 1990a). Equally, if the main purpose of rearing is milk and dairy products, the mortality profile shows a large number of adult female animals at producer sites and a large number of calves at consumer sites (Hesse 2011). Furthermore, if

the main purpose of rearing is other secondary products, such as breeding, manure, and traction for cattle, and breeding, manure, and wool for sheep, the age at death peaks at an older age (Hesse 2011).

Moreover, according to Wapnish and Hesse (1988), patterns of the age at death of livestock can be categorised into three types depending on livestock production and consumption strategies:

1) self-sufficient sites where produced livestock is consumed at the same place, exhibit 'all of the mortality experienced by a domestic herd' (Wapnish and Hesse 1988:84). This applies to rural sites.

2) consumption sites where more livestock are consumed than produced, exhibit more animals killed at market-age and less animals at reproductive age. This applies to urban sites.

3) producer sites where more livestock are produced than those consumed, exhibit animals that died at perinatal age and older animals killed from the breeding stock. This applies to rural sites which supply livestock to urban sites.

Therefore, by analysing the pattern of the age at death of livestock, the purpose of livestock rearing of each site can be deduced. However, the difference in the type of sites can be unclear, and in reality many sites may display more than one role of these patterns (Booth et al. 2007: 283).

2.1.2.1. Cattle

The Romano-British Period

Generally speaking, the peak in the age at death of cattle gradually became older in the Romano-British period compared to the Iron Age (Mulville and Powell in Booth et al. 2007: 296, Fig. 6.9). This indicates that young cattle were slaughtered commonly in the Iron Age probably for meat, while in the course of the Romano-British period, more cattle were slaughtered after they were four years or older, probably exploited for various secondary products and later killed for meat (Hesse 2011). Keeping them until later for traction and eventually slaughtering at an old age is an optimal strategy to rear cattle for traction rather than for meat.

Additionally, the lack of emphasis on dairy production is observed from cattle bone assemblages across Roman Britain (Malty 1998). The mortality profiles of cattle in the Romano-British period do not show a high proportion of calves, indicating that cattle were not reared primarily for their milk (Cool 2006:93). Other evidence of dairy production will be discussed in Chapter 3 section 3.1.1.3.

Rearing cattle for various purposes is generally a consistent trend among Romano-British rural sites in the Upper Thames Valley (Strid 2010: 228, Booth et al. 2007: 295). The mortality profile of cattle aged by dental eruption and wear at the extramural site of Alchester shows two peaks, one at around three years, probably slaughtered for meat and another as senile adults, probably killed after being exploited for secondary products (Powell and Clark 2001: Fig. 9.7). At the roadside town of Asthall, the mortality profile of cattle suggests that not only cattle at around three years that had reached full body size were slaughtered for meat

but also suckling calves, while some were spared for secondary products and killed as mature adults between six and eight years (Powell et al. 1997). At Dorchester-on-Thames, slightly more than 50% of cattle survived until at least the age of four, suggesting that the focus of cattle rearing was more on secondary products than meat (Grant 1979).

However, mortality profiles of other sites indicate that there was site-dependent preference in what cattle were exploited for. Sites where cattle mortality profiles suggest that meat production was preferred are Yarnton (Mulville et al. 2011) and early Romano-British rural sites adjacent to Cirencester such as Claydon Pike (Sykes 2007a: 84), Thornhill Farm (Levine 2004: 129), and Neigh Bridge, Somerford Keynes (Evans 2007: 267). In contrast, at several sites in Cirencester, aged cattle mandibles show that adult cattle were dominant while no calves were found (Maltby 1998: 361), suggesting that cattle supplied to the market in Cirencester were exploited for secondary products such as milk, traction, and manure before eventually slaughtered for meat.

In addition, as in other parts of Britain, a trend towards older cattle is observed in the Romano-British period in the Upper Thames Valley (Hesse 2011). In Cirencester and nearby sites, as well as sites by the river, the peak in the age at death of cattle continued to become older from the Iron Age to the Romano-British period (Hesse 2011). Furthermore, at Claydon Pike, not only an increase in the proportion of older aged cattle throughout the Romano-British period (Sykes 2007b) but also an increase in the proportion of adult male cattle was detected (Sykes 2007c: 203–4), suggesting their rise in importance. This means that cattle were not necessarily primarily reared for milk at Claydon Pike. Since male cattle are more robust and more resistant to hard labour than female cattle, it seems that they were exploited for traction. Indeed, pathological evidence of cattle bones supports this. For example,

exostosis on the lower limbs, which is caused by pulling heavy weight over a period of time, were found from cattle bones in the region, such as those at the villa site of Barton Court Farm dated from the third to the fifth centuries AD (Wilson 1984) and the extramural site of Alchester (Powell and Clark 2001). Furthermore, sites where botanical evidence suggests that crop cultivation was focused on cereals, such as Barton Court Farm and Cotswold Water Park sites, contemporaneous animal bone assemblages were dominated by older male cattle (Wilson 1984, Miles et al. 2007: 354). As Ingrem (2007: 355) concluded, the predominance of male old cattle seems to correspond to a rising demand for traction as a result of intensification in crop cultivation.

Among other secondary products of cattle, milk production was often not the main focus, since male adult cattle were more common in rural sites, and calves (which would be a surplus where dairy production was important) were a minority in animal bone assemblages from both urban and rural sites (Hesse 2011). Exceptionally, at the roadside settlement of Wilcote to the north of the Upper Thames Valley, the cattle mortality profile shows a high proportion of calves less than one month old as well as senile adults older than the optimum age for beef production, suggesting that milk production was preferred (Hamshaw-Thomas et al. 2004). This is supported by the sex ratio deduced from pelvic bones which was 1 male to 4 female. Similar cases are found at late Romano-British sites on the first gravel terrace of the Upper Thames Valley, such as at Farmoor (Wilson 1979), Appleford (Wilson 1980), and Watkins Farm, Northmoor (Wilson and Allison 1990), where there were a high proportion of older cows, possibly reflecting herds for milk production (see Chapter 3 for other evidence).

The Anglo-Saxon Period

In contrast to the Romano-British period, the common age at death of cattle became younger in the Anglo-Saxon period, as in the Iron Age (Hesse 2011). Although Hesse (2011) generalises that this indicates that the purpose of rearing cattle reverted to meat production, the mortality profiles do not always support this, since they suggest that livestock rearing did not focus on certain products, probably because most settlements were largely self-sufficient in terms of food production in the early Anglo-Saxon period when the Roman trading network had declined and Anglo-Saxon market had not been emerged yet.

As Maltby (1981:182) argued, the proportion of young cattle which have not reached the market-age, breeding-age or working-age is high at rural self-sufficient sites. For example, at early Anglo-Saxon West Stow, the mortality profile of cattle shows several peaks corresponding to perinatal deaths and autumn culls, but also show constant slaughtering at other ages, indicating that cattle rearing was not focused on either milk or meat production but were reared for various purposes (Crabtree 1990a: 69–6). Crabtree (1994) argues that the Anglo-Saxon West Stow cattle mortality profile is most similar to cattle assemblages from small self-sufficient Iron Age sites in southern Britain.

Likewise, in the Upper Thames Valley where most sites were rural settlements, the mortality profiles tend to suggest that cattle rearing did not focus on one purpose, such as at Yarnton (Mulville and Ayres 2004) and early Anglo-Saxon Barrow Hills, Radley (Barnetson 2007). Similarly, at Eynsham in the early Anglo-Saxon period, the mortality profile of cattle shows a bigger peak when they are immature and a smaller peak when they are old, suggesting that cattle were reared for meat as well as secondary products (Mulville 2003). This pattern also indicates that cattle at these sites were reared for self-sufficient purposes.

Conversely, there are other cases which suggest that more weight was put on certain products. For instance, at Barton Court Farm, more cattle were killed before they became 1.5 years old (Wilson 1984: Fig. 155), at a younger age compared to the animal assemblages from the Roman villa contexts at the same site, and since most of the young animals were male – bulls or steers – they were possibly killed so as to enable surplus milk production. Another example is Lechlade, where a higher proportion of cattle killed at an immature age was attributed to the cull of immature males common in herds reared for milk production (Maltby 2003: 74).

Horcott

The mortality profile of cattle at Horcott was created using all the mandibles found by the author while sampling. The age at death of individuals were estimated by the author following Halstead (1985), Payne (1973), and O'Connor (1988) after evaluating the tooth eruption stage following Hillson (2005: 229–242) and Schmid (1972) and the tooth wear stage following Grant (1982 in Hillson 2005: Appendix A). Strid (in Hayden et al. forthcoming) argues that most cattle were aged as sub-adult or adult by epiphyseal fusion, tooth eruption and wear, but the author found only three cattle mandibles from Romano-British contexts. Their teeth were heavily worn and they were all aged as older than three years old (Fig. 2.5). There was also a limited number of loose cattle teeth, which were also heavily worn. Unfortunately, it is not possible to present a meaningful argument on slaughtering strategy when only three cattle mandibles could be aged. Strid (in Hayden et al. forthcoming) argues that the Romano-British ditches where the animal bones were found could have been used as waste dumps of primary butcher waste (see Chapter 5).Thus, regarding the three old cattle at Romano-British Horcott, it can be suggested that they were

exploited until their old age and eventually slaughtered for meat. However, the sample size is too small for any further discussion on Romano-British cattle.

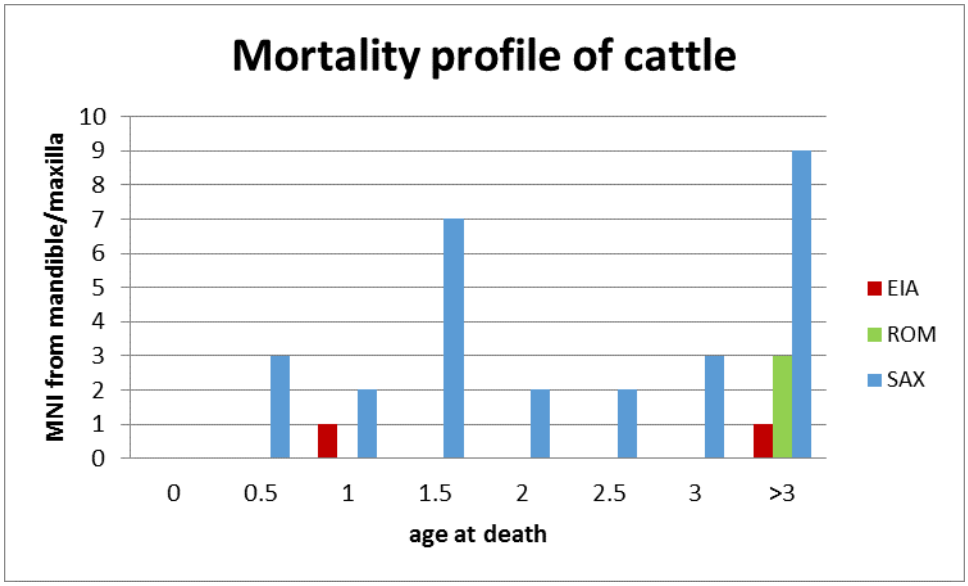


Fig. 2.5 Mortality profile of cattle from aged mandibles and maxillae at Horcott; x-axis: age at death from tooth eruption and wear, y-axis: minimum number of individuals (MNI) of mandible/maxilla.

In contrast, there were more mandibles available from the Anglo-Saxon period. The mortality profile created from 28 Anglo-Saxon individuals shows a peak at around 1.5 years and another peak at older than three years, but the ages at death are dispersed between the minimum age of six months and the maximum age of older than three years (Fig 2.5). This indicates that cattle at Anglo-Saxon Horcott were killed annually with some peaks at certain ages. Interestingly, a peak at a similar age was observed from the mortality profile of cattle from Iron Age Barton Court Farm (Wilson 1984: Fig.155).

Among the aged cattle at Anglo-Saxon Horcott, 32% of cattle reached the age of three. This percentage is similar to that of early Anglo-Saxon West Stow, Suffolk, where 39 % of cattle lived beyond the age of four, which Crabtree (1994) argues that it was a self-sufficient or rural producer site. Since the kill pattern of Anglo-Saxon Horcott more or less follows that of

West Stow, Horcott was probably also a self-sufficient or rural producer site in the Anglo-Saxon period (Strid in Heyden et al. forthcoming).

2.1.2.2. Sheep and Goats

According to kill pattern models by Payne (1973), when sheep are reared for meat, the majority are killed when they reach the age of mature body size, which is approximately 2–3 years of age. When they are reared for milk, excess male lambs are killed within a year of their birth. And when they are reared for wool, the majority survive until older ages and then are eventually slaughtered.

The Romano-British Period

Noddle (1987) argues that while the Iron Age and the early Romano-British sheep/goats are more commonly killed at around 1 year after birth, more sheep/goats tend to be killed at an older age between 1.5 and 4 years in the late Romano-British period, possibly a result of an increase in demand of meat and/or wool.

However, mortality profiles of sheep/goats are different between self-sufficient sites and consumer sites. In highly Romanised sites, a high proportion of sheep/goats was killed at a young age. For example, at the market town of Exeter, there is evidence of high proportion of lambs compared to mutton (Maltby 1979). Similarly, at Icklingham, Suffolk, a late Romano-British site which seems to have functioned as a market centre, the animal assemblage dated mainly to the third and fourth centuries AD shows that the majority are killed as late adolescents and young adults, and fewer animals were killed as old adults (Crabtree 1994). In addition, there were no senile animals or animals less than one year old (Crabtree 1994),

suggesting that these sheep/goats were killed for meat production. The kill patterns at Exeter and Icklingham are what one would expect from consumer sites.

In contrast, in rural sites, sheep/goats were killed at various ages such as at early Romano-British West Stow, Suffolk. They were killed mainly between 6 to 12 months and between 2 to 6 years, a similar pattern to the Iron Age mortality profile at West Stow (Crabtree 1990b). Following Payne (1973), the sheep/goat killed within their first year were probably killed as surplus animals for milk production, while those killed between 2–3 years were probably killed for meat, and so were the older individuals after producing wool. Thus the mortality profile suggests that Romano-British West Stow was a self-sufficient site where sheep/goats were reared for various purposes.

Generally speaking, rearing sheep/goats for various purposes is a consistent trend among Romano-British rural sites in the Upper Thames Valley (Strid 2010: 228, Booth et al. 2007: 295). For example, at Barton Court Farm, sheep/goats younger than wear stage 5 by Grant (1982) (around 6 months old c.f. Crabtree 1990a) were absent from the late Romano-British assemblage (Wilson 1984). Following Payne (1973), the absence of lambs/kids suggests that Romano-British sheep/goats were not primarily reared for milk. However, sex ratio contradicts this since there were more ewes than wethers (castrated rams), a characteristic feature when livestock are reared for milk and reproduction (Wilson 1984). Alternatively, the lower proportion of males can be explained as a result of young males or wethers having been exported elsewhere, possibly for meat (Wilson 1984). Equally, the increase in the proportion of young sheep/goats (Wilson 1984: Fig. 153) which are older than wear stage 20 by Grant (1982) (between one and two years c.f. Crabtree 1990 a) may also reflect the focus on meat production for sheep/goat rearing at Romano-British Barton Court Farm. Therefore,

sheep/goats at Romano-British Barton Court Farm were reared for various purposes including milk and meat. Similarly, the mortality profile by dental condition at the extramural site of Alchester shows that sheep/goats were slaughtered at various ages for various purposes (Powell and Clark 2001: Fig. 9.8). However, in earlier phases dated from the mid first to mid third centuries AD, the highest peak is at three to four years, while in later phases dated from the mid third to late fourth centuries AD, the peak is earlier at one to two years, suggesting that the focus on sheep/goat rearing shifted from milk and/or wool to meat (Powell and Clark 2001: Fig. 9.8). Additionally, it was deduced from the mortality profiles of sheep/goats that they were reared for various purposes at Wilcote (Hamshaw-Thomas et al. 2004), wool as well as for meat at Asthall (Powell et al. 1997), and milk and meat at Dorchester-on-Thames (Grant 1979).

In contrast, mortality profiles of some rural sites in the Upper Thames Valley show an emphasis on meat production besides other products. For example, at Longdoles Field, Claydon Pike, the age at death peaked at Age Stage E after Payne (1973) (2–3 years c.f. Sykes 2007b), showing a mortality profile similar to that when reared for meat production (Sykes 2007b). Similarly, at Yarnton, the mortality profile shows a peak between six months and two years, suggesting that more focus was put on meat production in the Romano-British period at Yarnton (Mulville et al. 2011).

Notably, in Cirencester, the peak in the age at death becomes older in the course of the Romano-British period. This suggests that in later phases more sheep/goats were exploited for secondary products before killed off for meat. This is the opposite trend seen in highly Romanised sites in other regions in Roman Britain mentioned above, where sheep/goats were more commonly killed at a young age.

The Anglo-Saxon Period

Compared to the Romano-British period, less emphasis is put on meat production in the Anglo-Saxon period. At early Anglo-Saxon West Stow, Suffolk, there were two peaks of age at death. The first peak was between six and 12 months, probably reflecting the slaughter of surplus young sheep in fall or winter (Crabtree 1994). The second peak was between four and eight years, probably slaughtered from the breeding stock or wool-producing flock (Crabtree 1994). Fewer individuals are killed among late adolescents and young adults, probably killed for meat (Crabtree 1994). Thus, this kill pattern suggests that sheep/goat were not exclusively reared for a single purpose but for various purposes (Crabtree 1990a: 83). Crabtree (1994) indicates that this mortality profile resembles that from Iron Age sheep/goats at West Stow and suggests that this slaughter pattern can be expected from a self-sufficient or producer site.

Since there are no prominent Anglo-Saxon towns, the mortality profiles of the Upper Thames Valley sites do not show an emphasis on one product, suggesting that sheep/goats were reared for self-sufficient purposes. For example, the mortality profiles at Yarnton (Mulville and Ayres 2004), Barton Court Farm (Wilson 1984), early Saxon Barrow Hills (Barnetson 2007) and early Saxon Eynsham (Mulville 2003: Fig 10.3) show that sheep/goats were reared for various secondary products in addition to meat.

Horcott

The mortality profile of sheep/goats from 11 Romano-British and 17 Anglo-Saxon mandibles and maxillae available at Horcott was created by the author following the same procedures for cattle explained above. Sheep/goat assemblages at Horcott from both periods show similar slaughter patterns. The ages at death range between six months and four to six years old (Fig 2.6). This indicates that sheep/goat in both periods were killed annually probably for various purposes.

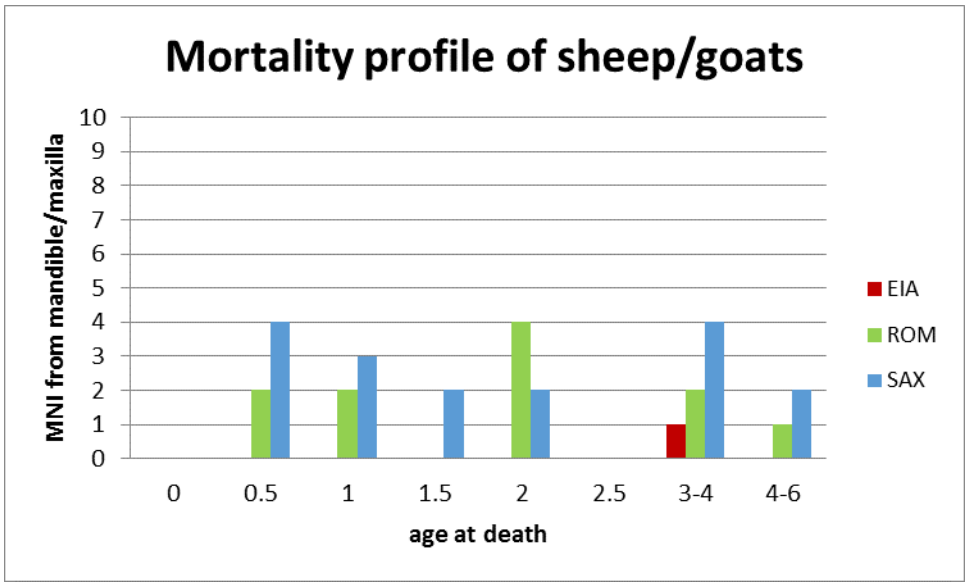


Fig. 2.6 Mortality profile of sheep/goats from aged mandibles and maxillae at Horcott; x-axis: age at death from tooth eruption and wear, y-axis: minimum number of individuals (MNI) of mandible/maxilla

Notably, in the Anglo-Saxon period, 40% of sheep/goats were killed in their first year. This percentage is similar to that of early Anglo-Saxon West Stow, where 40% of sheep were killed in their first year, which Crabtree (1994) conclude that it was a self-sufficient site. The similarity of kill pattern of sheep/goat at Horcott between the Romano-British and the Anglo-Saxon periods suggests that Horcott continued to be a self-sufficient rural site from the

Romano-British to the Anglo-Saxon period, without showing any drastic change in the purpose of sheep/goat husbandry.

2.1.2.3. Pigs

Since pigs are reared solely for meat, they are generally killed when they reach their full body size, and there is not much benefit in rearing pigs after their third year (Levine 2004). Consequently, there is not a large variation in mortality profiles for pigs in general.

The Romano-British Period

Pigs are commonly killed by the age of three years in the Romano-British period (Halstead 1985, Levine 1986, Levine 1995, Maltby 1996). For example, at the rural site of West Stow, although the sample size is small, the age at death spanned between juvenile and adult, showing that pigs were killed at various ages (Crabtree 1990b). Similarly, pigs from towns tend to show a peak in the age at death between one and three years (Maltby 1994). For the reason mentioned above, difference between self-sufficient sites and consumer sites are not clear. Although historical documents in the Romano-British period mention that suckling pigs were a delicacy and were served in luxurious meals (O'Connor 1988), they are rarely found from archaeological assemblages in Roman Britain (Maltby 1998). Exceptionally in York, a number of young pigs whose first molars were not yet worn were found, proving the existence of the custom of eating young pigs in Romano-British York (O'Connor 1988).

In the Upper Thames Valley, the slaughter patterns follow the general trend in Roman Britain. For example, At Chester Street and St. Michael's Field, Cirencester, pigs were mainly killed

by the age of three, with a few killed before the age of one at Chester Street (Maltby 1998) and some killed at a young age at St. Michael's Field (Levitan 1990). Despite being a Romanised town, the pig assemblages from Cirencester do not indicate the prevalence of the habit of eating suckling pigs or breeding of pigs, since the proportion of piglets are low (Maltby 1998).

In contrast, some other sites show a high proportion of young pigs. For instance, at the roadside town of Asthall, the mortality profile by dental stage of pigs shows that 50% of individuals were killed within a year after birth although only one individuals was aged as a neonatal (Powell et al. 1997). Similarly, a high proportion of pigs were killed by the end of their first year at the Roman villa of Barton Court Farm (Wilson 1984: fiche 8: E3), and at the roadside settlement of Wilcote (Hamshaw-Thomas et al. 2004). At Dorchester-on-Thames, the peak in the age at death was also relatively young and about 50% of aged pigs were killed in their second year (Grant 1979). Additionally, there are also rural sites such as at Claydon Pike (Sykes 2007b: Fig. 4.3.8) and Yarnton (Mulville et al. 2011), where pigs were mainly killed at a slightly younger age than three years. Moreover, at the extramural site of Alchester, the mortality profile of dental stage of pigs in the later phase (from the mid third to the late fourth centuries AD) shows that over two-thirds of the pigs died at a younger age when they were immature, and as sub-adults between the end of the first and second years, and only 20% of individuals were killed when they were older than two years (Powell and Clark 2001: Table 9.16).

The Anglo-Saxon Period

As with other livestock species, pig rearing seems to have been less closely managed in the early Anglo-Saxon period. For example, at early Anglo-Saxon West Stow, the mortality

profile shows that not only the majority of pigs were killed as young adults at around 3 year of age (Crabtree 1996, 1994), but also a relatively high proportion of pigs were culled during their first year, probably killed as surplus animals, which fits the pattern of a self-sufficient community (Crabtree 1994).

Although most Upper Thames Valley sites in the early Anglo-Saxon period were probably self-sufficient sites, there is some variation in the mortality profiles of pigs. For example, at Yarnton, pigs were mostly killed as sub-adults below the age of 2.5 years, slightly before reaching their full body size (Mulville and Ayres 2004). In contrast, at Eynsham, the majority of pigs were killed as adults in the early Anglo-Saxon period, which is at an older age compared to the pigs from later phases (Mulville 2003: Fig. 10.5). Equally, pigs from the barrow ditches at early Anglo-Saxon Barrow Hills mostly died at an age older than 24 months (Barnetson 2007). However, pigs from the sunken feature buildings at early Saxon Barrow Hills were killed constantly in all age groups except for pigs younger than 1 year (Barnetson 2007). Similarly, at Barton Court Farm, the mortality profile of Anglo-Saxon pigs is similar to that of the Iron Age Barton Court Farm, with no peak in the age at death of pigs (Wilson 1984: Fig. 157), indicating that pigs were reared for self-sufficient demand in the Anglo-Saxon period.

Horcott

The mortality profile of pigs from six Romano-British and seven Anglo-Saxon mandibles and maxillae available at Horcott was created by the author following the same procedures for cattle explained above.

Although only a small number of pigs were found from both periods, the ages at death understandably show the slaughter pattern for producing meat (Hagen 2006:115–117) and all individuals were killed before the age of 2.5 years and more than half of them were killed by the time when they became one year old (Fig. 2.7). The youngest pig from the Romano-British period had a first molar with no wear, but this was the only case with unworn first molar found from Iron Age, Romano-British and Anglo-Saxon contexts. Therefore, eating suckling pigs was not a common practice at Romano-British Horcott. Although more Romano-British pigs tend to be killed in the earlier years of their lives than Anglo-Saxon pigs, this difference could be due to the small sample size.

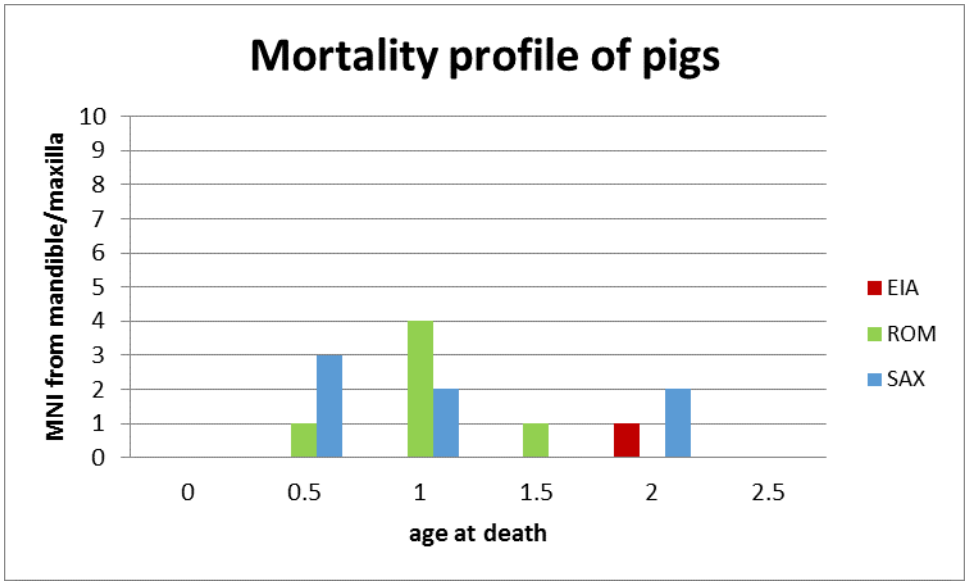


Fig. 2.7 Mortality profile of pigs from aged mandibles and maxillae at Horcott; x-axis: age at death from tooth eruption and wear, y-axis: minimum number of individuals (MNI) of mandible/maxilla.

2.1.2.4. Change or Continuity at Horcott?

Due to the scarcity of Romano-British cattle mandibles that could be aged, their slaughter pattern cannot be discussed whereas the mortality profile of Anglo-Saxon cattle suggests that they were reared for several purposes: meat, milk and traction. The mortality profile of

sheep/goats shows similar slaughter pattern between the two periods, suggesting that there was no change in the purpose of sheep/goat rearing. As with Anglo-Saxon cattle, the slaughtering pattern of sheep/goats suggests that they were reared for several purposes: meat, milk and wool. On the other hand, pigs from both periods are killed by the age of 2.5 years, slightly before they reached their full body size. Therefore the mortality profiles show continuity in at least sheep/goat and pig husbandry strategy.

2.2. Evidence of Livestock Management

Birth seasons and suckling periods of livestock can be restricted or extended by farmers depending on the food availability and the purpose of rearing. This section will describe what information is available about how the birth season and the timing of weaning were managed in the past, in order to compare later on with the data acquired for this study. The animals discussed here are cattle, sheep, goats, and pigs. Where historical evidence is insufficient, modern practice of livestock rearing in a free-range environment will also be explored.

2.2.1. Cattle

2.2.1.1. Birth Season

There are no Roman or Anglo-Saxon documents mentioning the birth seasons of cattle. What little information available is from the late medieval period. According to these few sources, the birth season of cattle in the late medieval period was common in spring. For example, Fitzherbert (1534: 57) states that calves are preferred to be born between Candlemas (2 Feb) and May to keep the milk for human consumption. Similarly, Mortimer (1712: 160) recommends calving to take place in March and April since it is the best time for dairy production. These birth seasons are slightly earlier than that of modern primitive breed cattle, which is from May to July in Normandy France, and from May to June in Scotland, both spanning over two to three months (Lecomte and Le Neveu 1986, Reinhart et al. 1986).

Moreover, there is evidence of calves being born in autumn at the Manor of North Curry, Somerset in 1325–6 AD (Thompson 2003). The amount of cheese production at North Curry

peaked in June but also increased in October, probably because there was a second birth season in late August or early September (Thompson 2003). However, Vancouver (1969: 326) notes that calves born later in the year were not generally approved of. Although autumn births are not surprising since cattle can breed all year round (King 1978 b: 124), in reality, their breeding can vary seasonally mainly because their nutritional level restricts their breeding ability (Ezanno et al. 2005, Mukasa-Mugerwa 1989).

Still, longer birth season is beneficial when livestock are reared for milk (Towers et al. 2011). This is because each cow will produce milk for a limited term, and the more variation there is in time when calves are born, the more variation there is in the period when the milk is available. If cattle are able to produce milk for 6 to 7 months after birth (Peske 1994), a birth season of 6 months results in the availability of milk throughout the year. Yet, the amount of milk produced by a cow is not the same throughout the year. Half of the total lactation yield will be produced in the first three months of lactation, reaching the maximum by its sixth week (Robinson 1972: 620). However, at the medieval manor of North Curry, Somerset, thanks to the two birth seasons, one in spring in another in autumn, cheese was produced all year round, and the amount of cheese produced bottomed in March instead of November (Thompson 2003).

Equally, shorter birth seasons also have benefits and it is easier to restrict the birth season than to expand it (Balasse and Tresset 2007). Restricting the birth season is beneficial for maximising the productivity when food availability is limited (Balasse and Tresset 2007). Another reason for birth season restriction is reducing the breeding frequency to save the females from exhaustion (Bernus 1988, Dahl and Hjort 1976, Mace 1993). Especially where

transhumance is practiced, the timing of giving birth can be crucial in order to ensure that the newborns and their mothers are strong enough to travel a long distance (Barth 1961, Bernus 1988, Digard 1981). Other benefits of restricting birth season are maximising the efficiency of time and labour invested in animal breeding such as mating, giving birth and nursing, as well as avoiding time conflicts with other farming activities (Digard 1981).

2.2.1.2. Weaning Age

There are examples of modern calves weaned at nine to ten months after birth, suckling right until the end of the lactation period (Balasse et al. 2001). Feral cattle at Chillingham, Northumberland, and in Maremma, Kenya have a suckling period of eight to 12 months after giving birth (Krohn 2001). However, calves can be weaned earlier when cattle are reared for milk for human consumption (Balasse and Tresset 2002). For example, at a farm in Auvergne, France, following traditional husbandry procedures, the calves of unimproved Salers breed reared for milk are weaned when they are four months old, long before the lactation period ends five months later (Bonal et al. 1985). Yet, the extended lactation period of modern European breeds may be a result of a long history of improvement, and a shorter lactation period of six to seven months has been assumed for Neolithic European cattle (Gregg 1988, Peske 1994).

Again, there are no contemporaneous documents mentioning the weaning age of cattle. The historical information available is from the late medieval period, which indicate that the suckling period of calves tended to last for a few months. For example, Tusser (1580: chapter

32, January's husbandry) state that calves should be weaned around 50 days after birth. Mortimer (1712: 160) states that calves were allowed to have milk for about 12 weeks, but after that they were given milk mixed with water until Lady-day (25 March) when they can start to be fed grass. Interestingly, according to Walter of Henley (Lamond 1890: 25), the weaning age changed according to the sex of calves. On the one hand, male calves were allowed to have all the milk for the first month, but the amount of milk given was reduced in the following month, and after that their food was switched from milk to solid food. On the other hand, female calves were allowed to have all the milk for the first three weeks, a week shorter than the male calves, and followed the same routine for male calves after that.

2.2.2. Sheep and Goats

2.2.2.1. Birth Season

Unlike cattle, sheep birth seasonality is strongly affected by the length of daylight (Karsch et al. 1984). This results in a shorter birth season in higher latitudes (Hafez 1952) whereas there is no fixed birth season in low latitudes due to less seasonal change (Mason 1980). In intermediate latitudes, sheep breed seasonally (Avdi et al. 2004, Dacheux et al. 1981, Hafez 1952, Thiéry et al. 2002).

Once again, the historical information available about the birth season of sheep is from the late medieval period. Normally, lambing months of sheep were March and April in the lowlands and April and May in the uplands (Biffen 1932: 550). However, according to the late medieval sources, the birth season of sheep was not only in spring but also in winter. For example, Mascall 1680: 298) mentioned that the preferable mating time depends on the season which the herder wants the lambs to be born in: "If ye will have your Lambs come in

the spring time, put the Ram to the Ewe in the midst of October; if ye will have them come in Winter, ye must put the Rams to the Ews in July".

In addition, the birth season apparently varied depending on how the sheep were managed. According to Mortimer (1712: 171), the best birth season was in April, unless there was abundant food in addition to grass. Alternatively, if the sheep were field sheep and the enclosure of sheep was not carried out, the birth season could be earlier, in January or February, but he notes that these early born lambs need to be taken well care of. Similarly, Markham (1657: 86) states that the best birth season was the latter end of April till the beginning of June for pasture sheep, and for field sheep it was from the beginning of January till the end of March. Notably, some cases of even earlier birth seasons are known. According to Mortimer (1712: 173), Way-Hill sheep bred in Hampshire, Wiltshire had a birth season which was usually before Christmas.

When compared to the birth dates of modern sheep from south-east France analysed by Blaise and Balasse (2011) which are January, February, April, and September, only the autumn birth is not referred to in the late medieval sources in Britain. The exception is the Dorset sheep which were claimed to be able to give birth in any season by Culley (1786: 86). Therefore, it might be the case that autumn birth was possible in south-east France and possibly in Dorset because these locations are in a relatively lower latitude which enables the sheep to have a longer birth season. Alternatively, sheep in locations with a diverse birth season were being reared for milk, since a longer birth season can provide milk for a longer period during the year (Towers et al. 2011).

As previously mentioned, there are several benefits in restricting the birth season. In lower latitudes where there is no fixed birth season, lambing season can still be restricted by not providing enough food during periods preceding mating seasons and during lactation (Bekure

et al. 1991, Mukasa-Mugerwa et al. 2002, Peacock 1982). Other ways of restricting birth seasons are; separating males from females when mating is not preferred; preventing males from mating by attaching an apron (Balasse et al. 2003, Peacock 1982); tying the penis to the scrotum (Bernus 1988); and preventing females from mating by attaching an apron (Jean-Brunhes-Delamarre 1970).

2.2.2.2. Weaning Age

Compared to calves, the suckling period of lambs is shorter. European mouflon and primitive sheep breeds in the Mediterranean region can produce milk for about five months (Toussaint 2001). In modern practice, sheep can yield milk as long as 16 weeks after giving birth (Animal Welfare Approved 2011) and spring born lambs on open range wean in early autumn (Ryder 1983: 13).

As before, the historical information available about the suckling period of sheep is from the late medieval period. Fitzherbert (1534: 44) states that in some cases lambs were not weaned and were always with their mothers, but lambs should be weaned at around 16 weeks to 18 weeks. However, he adds that when sheep milk was shared with the humans, the lambs were weaned earlier at around 12 weeks and the milk was consumed by humans for the remaining five to six weeks. Similarly, Mortimer (1712: 172) recommends that weaning be carried out when the lamb was 16 or 18 weeks old. Equally, Best (1641: 12) states that to keep milk for human consumption, it is recommended to ‘put theire lambes from them aboute St. Hellenmass’, although he did not specify when these sheep were born. St Helen´s feast day is 21 May in the Anglican Church calendar, so depending on the lambing season, they were weaned between one month (when born in April) and four months (when born in January) after birth.

2.2.3. Pigs

2.2.3.1. Breeding Season

Biologically, pigs can give birth several times per year. This is supported by the historical information available about the birth season of pigs from the late medieval period. These sources state that pigs can give birth up to three times per year (Lamond 1890: 29, Markham 1657: 100, Mascall 1680: 324, Mortimer 1712: 176,). Still, there were preferred birth timings depending on food availability. According to Lisle (1757: 475), farrowing was arranged in May in Wiltshire when dairy waste becomes available to feed the pigs. Alternatively, the birth was arranged to happen six weeks before harvest, so that the pigs can go into the field to eat crop waste left in the fields after harvest.

2.2.3.2. Weaning Age

There are no historical British sources which refer to the weaning age of pigs. In modern practice, pigs can suckle as long as nine weeks (Bussemas and Weissmann 2008). Therefore, the suckling period of pigs is much shorter than cattle and sheep.

2.3. Evidence of Livestock Feed

This section will review the historical and archaeological evidence relating to the food fed to cattle, sheep/goats, and pigs. This information becomes crucial later when animal diet will be discussed from the data acquired for this study.

2.3.1. Cattle

Cattle are herbivores, so their food naturally derives from plants (unless humans deliberately include non-plant food to their fodder). Examples of food consumed by cattle are: woodland vegetation including twigs and leaves; grassland vegetation including hay and salt-marsh grass; crops, stubble, and weeds of arable land (Halstead 1981, 2006, Lepine et al. 2006, Miller 1890; I 1:28–9, Oschinsky 1971: 102, Rackham 1984: 89, Rowley-Conwy 1981).

However, there is a limited number of Roman and Anglo-Saxon documents where cattle feed is mentioned. In *De agricultura*, Cato refers to feeding rape and turnips to cattle, which was common in Britain only after the Agricultural Revolution in the eighteenth century (Shiel 2012). Cattle also consumed legumes, leafy boughs, hay and acorns (Shiel 2012). Other documents testify that it was common to feed leaf fodder to livestock not only when grass is less available in winter and dry summers but also while the livestock were kept in stalls in continental Europe as north as Norway and as south as the Mediterranean region (Halstead and Tierney 1998, Kelly 1997, Lucas 1989, Rasmussen 1990, Troels-Smith 1960). For example, leaves of deciduous trees, mainly oak, were still fed to livestock in winter in north-western Greece in the late 20th century (Halstead and Tierney 1998). Direct evidence of leaf

foddering comes from middle Neolithic sites in Switzerland, where remains of twigs and leaves from trees such as *Corylus* sp. (hazel), *Alnus* sp. (alder), *Betula* sp. (birch), *Salix* sp. (willow), *Fraxinus* sp. (ash) and *Tilia* sp. (lime) were identified from livestock dung levels (Akeret et al. 1999, Rasmussen 1989, 1990, 1993,). The habitats of these tree species are open forests, thus dense forests were not necessary for leaf foddering.

The practice of feeding leaves and young tree wood to livestock was also common in Britain. Tree species such as elm, lime, ash, and hazel were used to feed livestock during dry summers up to the 20th century (Rackham 1984: 89). Since these tree species are deciduous trees, their leaves are less available in winter. However, there is a reference of woodland resources fed to cattle in the pre-Conquest period by pollarding trees and lopping the new growth on the trunk (Rackham 1986: 66, Fig 5.1), suggesting that not only leaves but also barks and young branches of trees were fed. Thus, even in cases where the trees were deciduous trees, cattle could still consume other parts of the trees when leaves were less available during the winter. Equally, evergreen trees such as holly, ivy, and mistletoe were used to feed livestock (Dimbleby 1967: 534, 538, Field 1972: 106), and in Ireland in winter as well (Kelly 1997: 46).

In addition, other historical documents refer to the practice of feeding hay to cattle in Britain. The Venerable Bede referred to Ireland as ‘no-one there mows hay or builds stalls for his cattle as a provision against the cold of winter’ (Miller 1890: I 1 28–9). This suggests that hay was fed to cattle in the eighth century AD in Northumbria. Likewise, in Ælfric’s *Colloquy*, ‘to fill the mangers of the oxen with hay, to water them, and muck them out’ were mentioned

as some of the duties of the ploughman, suggesting that hay was fed to cattle (Garmonsway 1978:21).

In the Upper Thames Valley, there is evidence of hay. For example, archaeobotanical evidence indicated that there were wet meadows at Middle Iron Age Farmoor, Oxfordshire (Lambrick and Robinson 1979: Robinson 1981). Also, a large number of dung beetles and remains of cut hay in early Romano-British wells suggest that animals were grazing on hay at Farmoor (Lambrick and Robinson 1979, Lambrick and Robinson 1988, Robinson 1981). In addition, a small scythe was found at Romano-British Farmoor, presumably a miniature copy of one used for cutting hay (Lambrick and Robinson 1979). Another Romano-British site at Claydon Pike, Lechlade, Gloucestershire, yielded insect remains and archaeobotanical evidence which indicate that pastureland and hay meadow were present throughout the Romano-British period (Robinson 2007). At Yarnton, the earliest evidence of hay meadow was dated to cal AD 650–850 (95% probability; OxA–3643) in the Middle Saxon period (Hey 2004: 47, 266).

2.3.2. Sheep and Goats

Like cattle, sheep/goats are herbivores. Sheep are more adapted to grazing on pasture except for fresh-water marshes since they become affected by diseases such as foot rot and liver fluke (Mulville and Levitan 2004, Wilson 1993), while goats are more adapted to browsing on scrubs and woodland resources (Hagen 2006: 85, Zeuner 1963: 151). Basically however, the types of food they consume are similar to those of cattle described in the previous section.

There are few Roman and Anglo-Saxon documents where sheep and goat feed is mentioned. Varro in *De agricultura* recommends putting sheep in fields after harvest, because they drop dung and trample the straw into the soil as manure (Hooper and Ash 1989: 159–529). A similar custom was practiced in the medieval period (Dyer 1997). These sheep consumed immature cereals and stubble and consequently produced manure (Bogaard 2012:34). In addition, ethnoarchaeological evidence from small scale farming communities in Greece and southern Europe shows that sheep (and sometimes goats) grazed overgrown cereal crops in manured fields to prevent lodging (growing too tall and falling over) and promote tillering (Halstead 2006), although the reason sheep were used may be simply because they were the main livestock in these regions. In medieval Britain, sheep were fed hay, straw, and pea-haulms while kept sheltered from Martinmas (11 November) to Easter (Seebohm 1952: 128). Also, as with cattle, woodland resources were fed to sheep. According to Elwes (1983: 7), 'Black Welsh sheep will gnaw the bark of ash, elm, and beech branches cut and laid down for them as readily as deer will do…'.

2.3.3. Pigs

Pigs can consume a much wider variety of food compared to the herbivores mentioned above (Grigson 1982, Schley and Roper 2003). They can consume various vegetation resources such as fruits, seeds, nuts, acorns, roots, tubers, fungi, crop processing wastes, cereal grains, brewery waste, legumes, and pasture (Albarella 2006; 79, Albarella et al. 2007, Hamilton et al. 2009, Trow-Smith 1957; 53, 81). In addition, they can consume animal resources such as invertebrates like slugs and worms, insects, reptiles, eggs, carrion, and dairy waste (Albarella 2006; 79, Hamilton et al. 2009, Kelly 1997, Zeuner 1963: 263). Moreover, they can be fed

leftovers of human food, kitchen waste, and even excreta (Hamilton et al. 2009, Hamilton and Thomas 2012, Trow-Smith 1957; 53, 81).

Again, there is a limited number of Roman and Anglo-Saxon documents where pig feed is mentioned. A Roman reference to pigs in urban sites mentions that pigs eat the waste chaff produced from mills (Plaut. Capt. 4.2). Other Roman authors mention that pigs are primarily herbivorous, consuming grains, legumes, vegetables, fruits, and wastes from wine production (Col. Agri. 7.9.8–9, Ori. Med. Comp. 1.49, Varro Agri. 2.4, Verg. Geor. 2.520), and also foraging in woodlands (Col. Agri. 7.9.6). In addition, according to Irish laws from the seventh and eighth centuries AD, pigs were fed cereal or milk (Kelly 1997: 82–3). Documents from the medieval period also mention that cereal grains were fed to the pigs. For example, in Hampshire, pigs kept at a manor of the abbey of Bec at Combe in 1306–7 were fed Beremancorn (a maslin of wheat, barley and rye) and brotcorn (a maslin of oats and peas and/or vetches) (Trow-Smith 1957; 117). However, since cereal grains were costly because they were also consumed by humans (Wiseman 2000:41), it was difficult to make a profit from pigs fattened by feeding them cereal grains (Wiseman 2000: 125, 127).

Notably, the pannage system — paying woodland owners in return for managing pigs in their forests where they consumed beech mast, acorns, rhizomes and roots — was practiced up until the medieval period in Britain (Hamilton and Thomas 2012). However, beech mast and acorns are not available all year round. In Anglo-Saxon Britain, the pannage season started on 29 August and lasted until 31 December (Seebohm 1952: 129, Wiseman 2000: 33). In addition, pigs ate grass in spring, summer and early autumn in Anglo-Saxon England (Wiseman 2000: 31). Access to pasture was restricted to pigs which were ringed or yoked to

prevent them from foraging and grubbing in order to decrease the damage to pastures (Wiseman 2000: 31).

2.4. Summary

In this chapter, various types of evidence were discussed in order to reveal different aspects of livestock management in the past. In addition, evidence at Horcott where available was compared with that in Roman and Anglo-Saxon Britain in order to assess how typical the animal husbandry at Horcott was. In conclusion, faunal evidence revealed that livestock was reared for various products with no signs of import or export, suggesting that Horcott was a self-sufficient rural site regarding animal husbandry. However, the preferred livestock species changed from sheep/goats to cattle, which may have been affected by cultural change.

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Chapter 3. Human Diet in the Romano-British and the Anglo-Saxon Periods

This chapter will discuss what is known about food consumed by humans in Roman and Anglo-Saxon Britain. The first section covers the human diet in the Romano-British period, whereas the second covers the Anglo-Saxon period. There is extensive discussion of how the food was cooked in the literature (e.g. Cool 2006, Hagen 2006), but since the information on cooking methods is not relevant in answering the research questions of this thesis, it will not be reviewed here.

3.1. The Romano-British Period

This section discusses the influence of Roman culture to human diet in Roman Britain. Firstly, the evidence of locally available food consumed in Roman Britain will be investigated. Next, food stuffs which reflect the influence of Roman style diet will be investigated. Finally, the difference in access to food by social status and settlement types will be investigated. Although the variety of food mentioned in written documents is larger than that of food which were recovered from archaeological sites (c.f. Cool 2006), the main focus of this subsection is on archaeological evidence, since it gives direct evidence of when and where the food was consumed.

3.1.1. Locally Available Food in Roman Britain

The types of local food in Roman Britain discussed here are: cereals, vegetables and other plant derived food, animal products, and fish.

3.1.1.1. Cereals

The cereal types found at Romano-British sites are wheat, barley, rye, and oats (Cool 2006). The types of wheat from the Romano-British period were identified as: glume wheat such as emmer wheat (*Triticum dicoccum*) and spelt wheat (*Triticum spelta*); free threshing wheat such as bread wheat (*Triticum aestivum*) (Cool 2006: 69). The most commonly found wheat type in Roman Britain is spelt wheat (Murphy 1997, Pelling and Robinson 2000). However, since all of these wheat types are found in earlier periods (Greig 1991, Murphy 1997, Robinson 1995), none of them were introduced to Britain by the Romans. Following wheat, barley was the second most common cereal in the Romano-British period (Murphy 1985, Greig 1991). Other cereals, rye and oats, were minor crops in the Romano-British period. Rye have been found in Britain since the Bronze Age (Chambers and Jones 1984) but became slightly more common in the Romano-British period (Behre 1992). However, due to their low frequency, whether rye and oats were grown as crops in the Romano-British period rather than being weeds of other cereal crops is yet to be determined (Cool 2006: 71).

In the Upper Thames Valley, spelt wheat and six-row hulled barley were the main cereals found, as in other regions of Roman Britain (Booth et al. 2007: 281, 293). Other cereals, namely emmer wheat, bread wheat, rye, and oats were generally found in smaller amounts (Booth et al. 2007: 281), probably reflecting their lower importance as crops.

Unfortunately at Romano-British Horcott, there were hardly any cereal remains found. Those which were identifiable as cereal types were: one glume base of glume wheat (emmer or spelt wheat) (Hayden et al. forthcoming: Table 11.10); some charred remains of glume wheat (emmer or spelt wheat) and barley (Hayden et al. forthcoming: Tables 11.11, 11.12). It is not clear whether these cereals were cultivated at Horcott or brought from elsewhere.

3.1.1.2. Vegetables and Other Plant Derived Food

Vegetables are one of the least recovered food stuffs from archaeological sites since soft plant tissues are not preserved except in certain conditions such as when they are charred, waterlogged, desiccated, or replaced by mineral or metal oxides (Moffett 2011). Therefore, the limited amount of plant derived food recovered from archaeological sites is not surprising.

Still, there is a large number of examples from Romano-British sites. For instance, legumes such as Celtic beans and peas are commonly identified (Cool 2006: 126–7). In addition, charred remains of possibly *Lathyrus* species (e.g. vetchlings) were found at Fishbourne, West Sussex (Greig 1971: 376). There are also a few examples of parsnip seeds in waterlogged deposits (Bastow 1999: Tables 8, 10 and 14) and seeds of the *Brassica* family (e.g. cauliflower, Brussels sprouts, kale, broccoli and cabbage) (Cool 2006: 128). At Vindolanda, Northumberland, a cabbage stalk was found in a well dated to the late fourth century AD (Birley 1977: 89). Intriguingly, seeds of stinging nettles (*Urtica dioica*) and small nettles (*Urtica urens*) were found in a cesspit at Stonea, Cambridgeshire, suggesting that they were consumed by humans (van der Veen 1996: Table 65).

In addition to vegetables, remains of various fruits and nuts have been found. Apple and pear seeds have been more frequently found in kitchen waste than in cesspits, probably because the core of the fruits was not eaten (Willcox 1977:278). In contrast, sloe stones are found in cesspits, suggesting that despite the modern perception that they are too bitter to eat raw, they were in fact eaten whole. In addition, hazelnuts are a native species of Britain and have been frequently found at British sites regardless of period (Tomlinson and Hall 1996).

In the Upper Thames Valley, field or Celtic bean (*Vicia faba v.minor*) was identified at Yarnton (Hey et al. 2011), while a large amount of peas was identified at late Roman Mansfield Road, Oxford (Pelling 2000). At Claydon Pike, cabbages (*Brassica* sp.) and pears

(cf. *Pyrus pyraster*) were identified from contexts dated to the second century AD (Robinson 2007: 361), while strawberry (*Fragaria vesca*) was identified from the late Romano-British context (Robinson 2007). In addition, apples (*Malus* sp.) were identified at Farmoor (Lambrick and Robinson 1979).

At Horcott, charred remains from two Romano-British cremation burials were identified as *Vicia/Lathyrus* (vetch/pea) and *Vicia/Lathyrus/Pisum* (vetch/pea/garden pea), which may not necessarily have been cultivated crops since they can grow naturally in Britain (Lodwick and Challinor in Hayden et al. forthcoming). Yet, pollen of *Vicia/Lathyrus* (vetch/pea) identified from a fill of a waterhole dated to the Romano-British Phase 1 or 2 suggests that vetches or peas may have been grown as a crop, but since they can be consumed by livestock as well as by humans, it remains inconclusive whether they were grown for human consumption (Rutherford in Hayden et al. forthcoming).

3.1.1.3. Animal Products

Animal bone assemblages recovered at Romano-British sites indicate that cattle, sheep, goats, pigs, ducks, geese, domestic fowl, wild animals, and wild birds were consumed in Roman Britain (Cool 2006: Chapters 9, 11, and 13, Hesse 2011). In Roman Britain, an increase in cattle and pig remains suggests that more beef and pork was consumed than in previous periods (King 1999). Although written evidence indicates that pork was the most popular meat in the Roman diet (Brothwell 1988), King (1999) argues that there was a regional difference in the importance of pork in the Roman Empire. Preference in species also seems to have changed depending on the extent of Romanisation of the site, because pig remains as

well as domesticated fowl remains were more commonly found in prominent Romano-British towns (Albarella et al. 2008, Gerrard 2007, Grant 2004, Maltby 1997). Additionally, although a minor component, the variety and the amount of wild species consumed such as birds and deer increased in Roman Britain compared to the Iron Age (Grant 2004, Locker 2007).

As previously mentioned (in section 2.1.1.1), interspecies ratio of animal bone assemblages indicates that the predominant livestock reared in the Upper Thames Valley was cattle or sheep/goats, while pigs were lower in proportion. Wild animals and birds were found as well, although their variety and amount were greater in towns such as Cirencester (Maltby 1998), and in later phases in the Romano-British period as at Longdoles Field, Claydon Pike, probably reflecting a Romanisation in the exploitation of wild animals and birds (Sykes 2007b).

At Horcott, the predominant livestock was sheep/goats followed by pigs and cattle, while there were no remains of domestic birds, wild animals or wild birds (Hayden et al. forthcoming: Table 11.1). The absence of birds and wild animals suggest that the inhabitants at Horcott did not have access to a fully Romanised diet as seen in urban sites. This suggests that the lifestyle at Horcott was partially Romanised, possibly because it was a rural site (see Chapter 5 for other evidence).

In addition to meat, dairy products are an important source of protein in human diet. Pliny´s list of animals whose milk can be consumed are: cow, goat, ass, mare, roebuck, hare, and rabbit (NH 11.96). Fresh milk does not last long, but Columella mentions that milk was consumed and sold at markets (Col. Agri. 7.8). It was also a key ingredient in the food for the sick (Ori. Med. Comp. 4.7). Various kinds of cheese were made from milk in the Roman world (Pliny NH 11.117), and minor dairy products such as *oxygalum* (a soured-milk

product) (Col. Agri. 12.8). It has been argued that butter was not common due to preservation issues (André 1981, Dosi and Schnell 1992). It was also regarded as a food for 'barbarians' (Pliny NH 11.96, 28.35), possibly because it was an alternative to olive oil where the climate was not suitable for olive trees (Gal. Prop. Food. 3.14 K 684).

Varro (RR 2.11.1) ranks the milk depending on the animal as 'first sheep's milk, and then goat's milk'. Cow's milk is listed only for medicinal purposes, and it is still ranked lower than other milk for its medicinal benefits (Varro RR 2.11.1). Similarly, Columella (RR 7.2.1–2) states that 'it is the sheep which not only satisfies the hunger of the country folk with cheese and milk in abundance, but also embellishes the tables of people of taste with a variety of agreeable dishes' but he did not refer to cow's milk. This further supports the preference of sheep's milk over other milk in Roman Italy. Likewise, the utilisation of cow's milk is not strongly supported by animal bone evidence in Roman Britain (see section 2.1.2.1). Nevertheless, artefactual evidence proves that cheese making took place in Roman Britain. A ceramic vessel with a perforated base which resembles a cheese strainer recovered at Poundbury, Dorchester, had residues from milk (Evans and Card 1987). Other Early Romano-British finds identified as strainers and presses are mainly found in kilns associated with military sites such as at Longthorpe, Chester, and York (Dannell 1987: 151–3, Grimes 1930: 168 nos. 206–9, Monaghan 1997: 1022 nos. 4116, 4119, 4120). Strainers and presses found later in the Romano-British period were not necessarily associated to military sites, but the number of finds are small. Still, there is a possibility that perishable materials such as cloth and wood were used for cheese making instead of pottery (Cool 2006: 96, 97). Similarly, the lack of equipment related to butter making from archaeological sites may also be due to using perishable materials (Cool 2006: 94). An example from the Upper Thames Valley is from Wilcote, a roadside settlement to the north of the valley where five cheese-

presses were found from deposits dated to the second century AD or later (Hands 1998: 230–1).

3.1.1.4. Fish

Locally caught fish were probably consumed in Roman Britain, but due to their small size, fish bones tend to be overlooked in excavations especially when the soil is not sieved. Nevertheless, there are freshwater fish bones found and identified as eel (catadromous), roach, salmon (anadromous), and trout (Cool 2006: 105). Likewise, there are marine fish bones identified as: herring, flat fish including plaice and flounder, sea bream, grey mullet, and cod (Cool 2006: 205). Naturally, marine fish was most commonly found from coastal sites, but it was also found from inland sites such as Leicester which yielded herring or mackerel bones (Nicholson 1999: Table 74).

In the Upper Thames Valley, freshwater fish bones of pike (*Esex lucius*), eel (*Anguilla anguilla*), bleak (*Aburnus alburnus*), perch (*Perca fluviatilis*) and cyprinid (*Cyprinus* sp.) were found at Barton Court Farm (Wheeler 1984: fiche 8: C8–10). At late Romano-British Claydon Pike, only eel bones were found (Sykes 2007b), but a rectangular tank dug out below the water table seems to have been used for keeping live freshwater fish (Robinson 2007). The only fish bone found in Cirencester was identified as salmon from St. Michael's Field Site (Levitan 1990), but the scarcity of fish bones in Cirencester is probably due to the lack of extensive sieving (Maltby 1998). At Horcott, fish bones were not recovered, but since soil sieving was not carried out thoroughly except for organic rich sediments, it is possible that fish were consumed to some extent but their remains were overlooked during the excavation.

3.1.2. Non-Local Food in Roman Britain

There is ample evidence of new food introduced to Roman Britain. For example, plant remains identified as sour cherries, peaches, mulberries, dates, plums, walnuts, almonds, pine nuts, and coriander were found in various Romano-British sites, which are the earliest examples of these food stuffs found in Britain (Giorgi 2000: 66, Murphy 1984: 40, Murphy 2003: 209, Tomlinson and Hall 1996, van der Veen et al. 2008, Willcox 1977: 278–9). In addition, olive stones are only found from the Romano-British period and not from later periods, even in the post-medieval period (Tomlinson and Hall 1996). Moreover, various archaeological evidence from Hengistbury Head and Poundbury camp in Dorset shows that wine and other non-local food stuffs such as figs, chamomile, *garum* (fish sauce) and possibly olive oil were imported (Darvill 1995, Gale 2003, Sparey Green 1987: 143). Similarly, the earliest examples of millet found in Britain is broomcorn millet (*Panicum miliaceum*) from Romano-British London as well as at a few Romano-British military sites, but the amount recovered is too scarce that they are regarded as imports from outside of Britain (Hinton 1988, Sauer 2005, van der Veen et al. 2008, Willcox 1977). Another example is marine resources. Compared to previous periods, the amount and variation of the remains of marine fish and molluscs increased in the Romano-British period, even at sites far from the coast such as Leicester, Silchester, Hampshire, and Castle Copse, Wiltshire (Grant 2000, Locker 2007, Nicholson 1999: Table 74). Examples of non-local fish in Roman Britain are: bones of red mullet and Nile catfish (Dobney 2001: 38); unidentifiable salted fish products from amphorae fragments from Spain (Curtis 1991: 82, Martin-Kilcher 2003); and Spanish mackerel (Murphy et al. 2000).

Examples of non-local or non-indigenous foods found in the Upper Thames Valley are: coriander (*Coriandrum sativum*), celery (*Apium graveolens*) and common millet (*Panicum miliaceum*) from early Romano-British Alchester (Robinson 2000); coriander, celery, dill (*Anethum graveolens*), plum (*Prunus domestica*), cherry (*Prunus avium*), and summer savoury (*Satureja hortensis*) from the second century AD contexts at Claydon Pike (Robinson 2007: 361). Amphorae found at second century AD Claydon Pike probably contained olive oil and fish sauce (Miles et al. 2007: 166), and those from Barton Court Farm were identified as containers of olive oil and wine (Peacock 1984).

Robinson (1992: 58) argues that by the third century AD, the Upper Thames Valley sites show a clear evidence of the consumption of spicy and oily foods, or a more Romanised diet, even at low status rural sites such as Farmoor. In the Late Romano-British period, fennel (*Foeniculum vulgare*) was identified at Claydon Pike (Robinson 2007), in addition to various plums at Farmoor (Lambrick and Robinson 1979), and at Appleford (Robinson 1980: 94).

At Horcott, a charred nutshell of stone pine (*Pinus pinea*) was found in a Romano-British cremation burial (Lodwick and Challinor in Hayden et al. forthcoming). This species, originally from the Mediterranean region, was mainly used for fuel and its nuts for food, and was introduced to Britain in the Romano-British period (Tomlinson and Hall 1996). In addition, a single amphora rim was identified as a container for olive oil (Booth in Hayden et al. forthcoming).

3.1.3. Difference in Food Availability by Settlement Type and Social Status

As discussed above, an increase in the variety of food available can be observed in the Romano-British period. However, whether everyone in Britain had the same level of access

to a Romanised diet is debatable. It has been argued that the level of Romanisation itself was not homogenous throughout Britain, and was more evident in the south of England, especially in towns and military camps as well as among people with higher social status (see Chapter 1). In contrast, the rural settlements and individuals of lower social status apparently did not experience the same level of Roman influence (Millett 1992). Therefore, one can expect a Roman style diet to have been more common among people of higher social status or living in towns, but less common among people living in rural settlements. For example, King (1999) argues that pork was probably more common among people of high status in highly Romanised sites in the Roman Empire. In Roman Britain, the diet with high proportion of pig and cattle is most frequently detected among legionary and military sites followed by urban sites, which led King (1999) to conclude that the diet abundant in pork and beef was preferred by the Roman troops and townspeople. In addition, it has been argued that marine resources were a sign of luxury in Roman culture (Alcock 2002, Bekker-Nielsen 2002, Corcoran 1963, Curtis 1991, Frayn 1993, Purcell 1995), as seen in a writing tablet from Vindolanda referring to a gift of fifty oysters (Bowman and Thomas 1994: 272, no. 299). Apart from coastal sites, oyster shells have been more commonly found at urban sites in Roman Britain (Locker 2007), but less common among inland rural sites, apart from Roman villas with strong signs of a Romanised lifestyle (Locker 1990: 212, Locker 2007). British oysters were mentioned in contemporaneous written documents as a delicacy in the Roman Empire, although whether they were exported from Britain is yet to be confirmed (Dalby 2000: 284 footnote 59). Still, in coastal areas, marine resources were probably less praised because they were a daily food (Cool 2006: 109–110, Ørsted 1998: 26).

In the Upper Thames Valley, oyster shells were found at urban sites such as Cirencester (Holbrook 1998), the roadside town of Asthall (Powell et al. 1997), the Roman villa site of Barton Court Farm (Wilson 1984: Table I), Claydon Pike (Miles et al. 2007: 104), the rural

site at Cotswold Community (Powell and Nicholson 2010), the extramural site of Alchester (Winder 2001), and at Horcott from Romano-British features dated to Phase 2 (150–250 AD) and Phase 3 (250–350 AD) (author's observation while sampling animal bones).

In addition, domesticated birds tend to be found more frequently from urban sites, while less frequently found from military sites and villas, and rarely found in rural sites (Maltby 1997). The distribution of evidence of eggs also follow the same pattern as bird bones (Cool 2006: 102). This pattern seems to correspond with the extent of Romanisation of the inhabitants' lifestyle (Cool 2006: 99). Furthermore, the presence of bird bones seem to correlate with the social status of the consumer. A tablet from the Roman fort at Vindolanda, Northumberland, recorded a large number of chickens and some geese which seem to have been consumed in the *praetorium* in AD 102–4 (Bowman and Thomas 2003:23 no. 581). At Caerleon, Wales, the debris from a well dated AD 85–100 was interpreted as kitchen waste from meals of a senior officer, which included chicken, duck, and goose bones (Hamilton-Dyer 1993: Table 2).

In the Upper Thames Valley, the majority of bird bones were identified as domestic species, which are more frequently found in the late Romano-British period than earlier, and most commonly found at urban sites such as Cirencester (Booth et al. 2007: 295). Birds found in Cirencester are domestic fowl, duck/mallard, and greylag/goose (Maltby 1998). Similarly, at Barton Court Farm, bird bones from the third to the fifth centuries AD were identified as domestic fowl, geese, ducks, and doves (Bramwell et al. 1984). Additionally, at Longdoles Field, Claydon Pike, the proportions of domestic birds slightly increased in later phases, which may reflect a Romanisation in the exploitation of domestic birds (Sykes 2007b).

At Romano-British Horcott, no bird bones were recovered. However, since soil sieving was not carried out thoroughly except for organic rich sediments, it is possible that birds were consumed to some extent but their remains were overlooked during the excavation. Still, given that Horcott is a rural site, the amount of consumption of poultry was probably lower than that at urban sites.

Furthermore, lentils which are not native to Britain were found mostly from towns and military sites (Cool 2006: 127). For example, an account dated AD 97–102/3 from Vindolanda, Northumberland, refer to lentils (Bowman and Thomas 1994: 175 no. 204). Equally, figs are not native to Britain, but can be found from the early Romano-British period (but possibly slightly earlier) at Gorhambury, Hertfordshire (Cool 2006: 121). Yet, its presence is more common in towns and military sites (Bastow 1999: Tables 8–10, Goodwin and Huntley 1991: Fascicule 1/59: fig. 50B, Huntley and Hillam 2000: 356 Table 32, Kenward et al. 1986: 255 Table 255, Willcox 1977: 278–9). Similarly, grapes, date stones, and olive stones are more frequently found from urban and military sites (Bastow 1999: Table 15, 22, Caseldine and Busby 1993: 137, Cool 2006: 123, Goodwin and Huntley 1991: Fascicule 1/60, Huntley and Hillam 2000: 356 Table 32, Willcox 1977: 279).

3.2. The Anglo-Saxon Period

It has been argued that various changes took place after the end of the Roman rule in Britain around AD 410 (see Chapter 1). In terms of diet, the imported food available in the Romano-British period became scarce in the early Anglo-Saxon period. This is probably due to the collapse of the trade network which connected various regions of the Roman Empire at the end of the Roman rule in Britain. As a result, most food available in the early Anglo-Saxon period was locally produced food. What type of locally produced food was consumed will be investigated here.

3.2.1. Locally Available Food in Anglo-Saxon Britain

As done with evidence for the previous period, the types of local food in Anglo-Saxon Britain which are discussed here are: cereals, vegetables and other plant derived food, animal products, and fish.

3.2.1.1. Cereals

Archaeobotanical evidence shows that cereals consumed in the Anglo-Saxon period were the same as in the Romano-British period but the predominant wheat type changed. Instead of spelt wheat, bread wheat became more frequently found in the Anglo-Saxon period, and eventually the predominant wheat type was replaced by bread wheat in the mid Anglo-Saxon period (Robinson 2002). Yet, there is a disagreement over when this replacement occurred. On the one hand, the common argument is that spelt wheat was replaced by free-threshing wheat with Saxon colonization at the start of the Anglo-Saxon period (Pelling and Robinson

2000, Robinson 2002). On the other hand, there seems to have been a regional variation in when this shift occurred. Murphy (1997) argues that the trend of crops in East Anglia shows continuity from the Romano-British period until the fourth/fifth century AD, and discontinuity in the seventh century AD, despite the assumption of archaeologists that the Roman style agriculture declined in the earlier stages of the Anglo-Saxon period. Following Murphy (1997)'s argument, the replacement of spelt wheat with free-threshing wheat was not concurrent with the beginning of the Saxon migration, but occurred broadly two centuries after their arrival in East Anglia, although artefactual evidence in East Anglia shows a strong Anglo-Saxon cultural influence from the beginning of the Anglo-Saxon period. Equally, spelt wheat is found outside of East Anglia: early Anglo-Saxon Canterbury, Buckden Down, Huntingdonshire, probably at *Hamwic*, Middle Saxon Fladbury, Worcestershire, and the eighth and ninth centuries AD Gloucester (Green 1979, Monk 1977: 291, 302, 308, 294). Therefore, spelt wheat continued to be grown in some regions in Anglo-Saxon Britain.

Furthermore, the presence of emmer wheat in the Anglo-Saxon period has also been related to the migration of the Germanic tribes. Pelling and Robinson (2000) attribute the emmer wheat at two middle Saxon Thames Valley sites to the Saxon colonists: at Yarnton (Greig et al 2004: 351); and at Lake End Road, Dorney, Buckinghamshire (Pelling 2002). In addition, chaffs identified as emmer wheat was recovered from early Saxon Canterbury, and impressions of emmer grain were left in pottery and bricks at Buckden down, Huntingdonshire (Monk 1977: 291). Also, emmer wheat was possibly present at middle Saxon *Hamwic* and pollen identified as emmer wheat was found from the surface layer dated to AD 850–950 at Durham castle, County Durham (Monk 1977: 308, 312, 294).

However, all of these wheat types discussed above are native to Britain (Greig 1991, Murphy 1997, Robinson 1995), and none of them was commonly found in contemporaneous sites in north-western continental Europe, the alleged homeland of the Anglo-Saxons (Sakai 2008: 63–73). Barley was the most commonly found crop in north-western continental Europe, so the Anglo-Saxons were not necessarily familiar with wheat cultivation until they arrived in post-Roman Britain (Sakai 2008: 63–73). Therefore, it is not convincing to attribute the change in cultivation of any wheat type in Anglo-Saxon Britain to the introduction of the Anglo-Saxon agricultural practice.

Among cereals besides wheat, barley continued to be the common crop in East Anglia where spelt wheat declined and eventually disappeared in the course of the Anglo-Saxon period (Murphy 1994). However, in other regions where the soil condition was suitable for wheat cultivation, wheat was the most common cereal crop, as was spelt wheat in Gloucester (Green 1979: 189). Similarly, Green (1981: 139) argues that archaeobotanical evidence shows that barley was grown in smaller quantities than wheat in late Saxon Wessex.

Notably, rye apparently started to become more common in the Anglo-Saxon period and even more so in the Middle Ages (Behre 1992), showing a similar trend to bread wheat. However, there is less interest among researchers for attributing the increase in rye to the Anglo-Saxon migrants than for bread wheat. Indeed, rye was the common crop in continental north-western Europe because of its ability to grow in more severe soil and climate conditions (Monk 1977: 343). Ballantyne (2006) and Murphy (1985) argue that rye apparently became a more important crop by early medieval times. Nevertheless, it is not usually found in abundance

apart from some sites such as the granaries at Lydford, Devon (Green 1979: 186), Stafford (Moffett 1994), Staunch Meadow (Murphy 1994), and Wolvesey, Winchester (Green 1994).

Regarding oats, there are both cultivated and wild types, but it is difficult to distinguish cultivated types from wild ones unless the floret base of the chaff is present (Green 1981). Since chaffs are fragile and rarely survive (Moffett 2011), it often remains inconclusive in many archaeological specimens whether they are cultivated species or not. Still, there are Anglo-Saxon sites which yielded cultivated oats: sixth century AD Portdown, Portsmouth; Hawkshill, Leatherhead; early/mid Saxon Walton, Buckinghamshire; *Hamwic*; and Lloyds Bank site at Anglo-Danish York (Monk 1977: 291, 293, 300, 308,316, 325).

In the Upper Thames Valley, although all the cereal types grown in the Romano-British period except for rye were found, barley was the most common cereal (Booth et al. 2007: 319). However, free-threshing wheat was the most common cereal at Barrow Hills, Radley (McAdam 2007).

At Horcott, charred plant remains from Anglo-Saxon SFBs and a corn drier were dominated by barley (W. Smith in Hayden et al. forthcoming). There were also remains of glume wheat (spelt or emmer wheat), but its amount found was limited and the preservation condition was poor, making it difficult to identify them securely. Thus, this evidence is not strong enough to support the argument by Pelling and Robinson (2000) that emmer wheat was cultivated in the Upper and Middle Thames Valley in the Anglo-Saxon period. This leaves the possibility that glume wheat from Anglo-Saxon Horcott was a residual crop from the previous period, since an emmer wheat glume base was found from a Romano-British cremation burial (Smith, W.

forthcoming: Table 11.12). Also, there was a single free-threshing wheat rachis node found from a SFB, suggesting that free-threshing wheat was present at Anglo-Saxon Horcott.

3.2.1.2. Vegetables and Other Plant Derived Food

Urban sites in the middle Anglo-Saxon period and later have a wider variety of plant remains found including possibly non-local species such as walnuts, figs, and grapes at Anglo-Danish Coppergate, York (Kenward and Hall 1995) probably due to intensive and extended human activity. Similarly, at Beverley, East Yorkshire, remains of walnut, hazelnut, plum, strawberry, raspberry (*Rubus idaeus* L.), elderberry (*Sambucus nigra* L.), and bilberry (*Vaccineum myrtillus* L.) were found (Hall and Huntley 2007). Yet, some Anglo-Saxon rural sites also have good preservation of various plant derived food. For example, at Abbots Worthy, Hampshire, remains of apples, blackberries, elderberries, sloe, hazelnuts, peas, beans, carrots, celery, and cabbage were found (Carruthers 1991: 74). In addition, remains from pottery at West Cotton, Raunds, Northamptonshire, were identified as epicuticular leaf waxes from plants belonging to the *Brassica* family (e.g. cauliflower, brussels sprouts, kale, broccoli and cabbage), suggesting that vegetables of this family were boiled in the vessels (Charters et al. 1993, Charters et al. 1997, Evershed et al. 1991, Evershed et al. 1994). Furthermore, at a barrow burial dated to the late seventh century AD at Ford, Wiltshire, two bulbs of probably onions as well as four crab apples were found (Musty 1969: 109–10). Also, hazelnuts, a native species of Britain, are naturally found in abundance. For example, they were found in *Hamwic*, Yeavering, York, Feversham, Kent, and Broadstairs, Kent (Ellis Davidson et al. 1967, Holdsworth 1980: 129, Hope-Taylor 1977: 333, Radley 1971: 46, Webster and Cherry 1975: 223).

In the Upper Thames Valley, the amount of charred Celtic/field bean (*Vicia faba*) and peas (*Pisum sativum*) discovered increased compared to that in the Romano-British period (Booth et al. 2007: P319). At Yarnton, remains of lentils were found (Greig et al. 2004). However, no fruit remains were found from Anglo-Saxon sites in the Upper Thames Valley (Booth et al. 2007: 319).

At Horcott, the amount of charred plant remains found was scarce. Apart from weed seeds, charred plant remains which were possibly consumed by humans were as follows: a hazel nut fragment, a *Pisum/Vicia* fragment, a possible black mustard (*Brassica* cf. *nigra* L.), and a small mericarp of *Apiaceae* family (e.g. carrot, celery, parsley, dill, fennel), all found from SFBs and corn driers (W. Smith in Hayden et al. forthcoming: Table 11.9).

3.2.1.3. Animal Products

Animal bone assemblages indicate that animals consumed by Anglo-Saxon inhabitants were mainly domesticated animals such as cattle, sheep, goats, pigs, and fowl, and a limited amount of wild animals such as boars, birds, and deer (Arnold 1988, Crabtree 1991, Hagen 2006, O'Connor 2011). Among them, cattle seem to have been an important livestock, and based largely on written evidence, it has also been argued that pigs were also an important source of animal protein in the Anglo-Saxon period as well (Banham 2004, Hagen 2006). Faunal evidence does confirm the importance of cattle in the Anglo-Saxon period since cattle tend to be the most common animal recovered from Anglo-Saxon sites, but not the importance of pigs, whose proportion among animal bones tend to be lower than cattle and sheep/goats (see Chapter 2).

As already mentioned (in Chapter 2 section 2.1.1), interspecies ratio of animal bone assemblages indicate that the predominant livestock reared in the Upper Thames Valley tended to be cattle followed by sheep/goats, with pigs in lower proportion. At Barton Court Farm, faunal evidence suggests that the importance of mutton, pork, poultry and fish increased at the expense of beef, although cattle were killed at a younger age (presumably for meat) compared to in the Romano-British period (Booth et al. 2007: 321). Wild animals and wild birds were found in various sites as well, although their variety and amount was greater at later high status sites such as Eynsham, which became a monastic site in the late Anglo-Saxon period (Mulville 2003).

At Horcott, the predominant livestock was cattle followed by sheep/goats and pigs, with smaller amount of birds such as domestic fowl and geese, wild animals such as red deer and hare, and wild birds such as passerine (Hayden et al. forthcoming: Table 11.1).

Another animal product besides meat consumed by the Anglo-Saxons is dairy products. There is historical evidence of utilisation of dairy products in the Anglo-Saxon period. One example is the 11th century AD document *Rectitudines Singularum Personarum* which states that cattle herdsmen, shepherds, and goatherds were all entitled to receive the milk of the livestock they looked after (Leibermann 1898: 450–1). This suggests that milk of sheep and goats as well as cattle were utilised before the Norman Conquest.

Other historical records show that dairy farms existed by the mid-Anglo-Saxon period, and the animals kept were not limited to cattle (Finberg 1972: 105, Loyn 1970: 367, Robertson 1939: 171, Whitelock 1955: 489). Thus milk and dairy products of cattle, sheep, and goats were all utilised by humans, although sheep only produce one-tenth of the amount of milk produced by cattle, and goats produce one-fourth of cattle (Seebohm 1952: 126–8).

The utilisation of sheep and goat milk despite the limited amount available may indicate that cheese was commonly made from sheep and goat milk. This is because sheep's milk is more suitable for making cheese than cow's milk due to its richness in milk solids and also because its fat is not easily separated (Banham and Faith 2014: 111). Indeed, Ælfric's *Colloquy* dating from the tenth century AD supports this, since it mentions that a shepherd will milk his sheep twice daily and make the milk into cheese and butter (Garmonsway 1978: 22). Although having less protein and fat than sheep's milk (Thear 1988: 24), cow's milk is better for making butter because its fat globules are large and easy to separate (Mackenzie 1970). Consequently, the amount of cheese made from the same amount of milk is larger in sheep's milk compared to cow's milk (Thear 2002: 190). Goat's milk has a lower fat content compared to sheep's milk (Ryder 1983: 721), but is otherwise similar to sheep's milk, so it is also suitable for making cheese (Banham and Faith 2014: 112).

3.2.1.4. Fish

Not surprisingly, coastal sites such as the mid fifth to early sixth century AD Bishopstone, East Sussex, and mid Saxon *Hamwic*, early to late Saxon Portchester Castle, late Saxon Pool, Dorset, and Great Yarmouth produced remains of various marine fish and molluscs (Bell 1977, Holdsworth 1980, Cunliffe 1976: 62ff, Horsey and Winder in Good et al. 1991: 102–4, Wheeler and Jones 1974: 211ff.). Although not located on the coast, urban sites such as late Anglo-Saxon Exeter, mid to late Saxon Flaxengate, Lincoln, and mid Saxon Ipswich also yielded remains of marine fish and molluscs (Maltby 1979, O'Connor 1982, West 1963:

243,). Additionally, fish seems to have been consumed in monastic communities and societies of higher status (Taylor 1988: 465). However, evidence of marine fish consumption among the rest of the Anglo-Saxon population in inland rural sites is limited. The types of fish identified from the fifth to the seventh centuries AD site at West Stow were fresh water fish, namely perch and pike (West 1985).

In the Upper Thames Valley, at early Anglo-Saxon Barton Court Farm, freshwater fish bones identified as eel (*Anguilla anguilla*), pike (*Esox lucius*), perch (*Perca fluviatilis*), roach (*Rutilus rutilus*), and rudd (*Scardinius erythrophthalmus*) were found (Wheeler 1984). Intriguingly, the quantity of fish bones found from early Anglo-Saxon contexts was larger than that from the Romano-British contexts at Barton Court Farm, possibly indicating the rise in the importance of freshwater fish (Booth et al. 2007: 321). However, in contrast to Romano-British sites, there is no marine fish found from early Anglo-Saxon sites (Booth et al. 2007: 321). Exceptional amount and variety of fish were found at Eynsham. Fish bones from a pit dated from the mid/late seventh to the mid/late eighth centuries AD were from freshwater fish such as eel, pike, and perch, as well as marine fish such as ray and bullrout/freshwater stonefish (Mulville 2003). In addition, oyster shells were found from the mid eighth century AD and later (Light 2003). Eynsham became a monastic site in the late Anglo-Saxon period, but the presence of non-local fish precedes the foundation of the minster, suggesting that it could have been a high status site earlier (Mulville 2003).

At Horcott, fish bones were found in one sunken feature building (SFB 5255) (Hayden et al. forthcoming), but the species could not be identified. Still, since soil sieving was not carried out thoroughly except for organic rich sediments, it is possible that there were more fish

bones but their remains were overlooked during the excavation. In contrast to the Romano-British contexts, no oyster shells were found from Anglo-Saxon contexts.

3.2.2. Difference in Food Availability by Settlement Type and Social Status

It is possible that food choice was affected by the social status of the consumer in the Anglo-Saxon period (Härke 1990), although it is under debate whether pork was regarded as a high status meat in the Anglo-Saxon period (Albarella 2006, Arnold 1988: 19, Crabtree 1991). Despite Hagen (2006)'s argument that the difference in food choice is mainly about quality rather than availability, faunal evidence of monastic sites and high status sites such as Eynsham, Oxfordshire tend to have a wider variety of wild game animals and birds compared to rural sites (Mulville 2003).

In addition, apart from coastal sites, evidence of marine fish consumption is more frequently found from urban sites from the middle Anglo-Saxon period and later, as mentioned in the previous section. Likewise, fish seems to have been consumed more in monastic communities and societies of higher status (Taylor 1988: 465) such as at Eynsham (see previous section). Therefore, it is possible that the availability of marine fish depended on the type of the settlement.

However in the early Anglo-Saxon period when no towns, high status sites, or monastic sites had emerged, most sites were rural and self-sufficient. Thus, this difference in food choice depending on one's status or settlement type was probably less evident in the early Anglo-Saxon period.

3.3. Summary

In this chapter, botanical, faunal, and archaeological evidence were discussed in order to reveal the human diet in Roman and Anglo-Saxon Britain. In addition, evidence at Horcott where available was compared with that in Roman and Anglo-Saxon Britain in order to assess how typical the human diet at Horcott was.

An apparent change in human diet between the Romano-British period and the Anglo-Saxon period at Horcott concerns the presence or absence of non-local food. Oyster shells, a stone pine nut shell, and a rim of an amphora for olive oil were found from Romano-British contexts but no comparable evidence came from Anglo-Saxon contexts. The evidence of imported non-local food at Romano-British Horcott suggests that the inhabitants were familiar with Roman style eating habits, but compared to more elaborate villas and urban sites, the quantity and variety of non-local food were scarce, suggesting that the diet at Horcott was only partially Romanised. This also suggests that Horcott was not fully incorporated into the market economy to have a wider variety of non-local food in the Romano-British period. In the Anglo-Saxon period, the foodstuffs at Horcott were limited to locally available sources, which seems to correspond with the lack of market economy in early Anglo-Saxon Britain.

Chapter 4. Stable Isotope Evidence of Animal Husbandry and Human Diet

This chapter outlines the principles of stable isotope ecology, concentrating on their relevance for domestic fauna and human dietary ecology. Both carbon and nitrogen stable isotopes from bone collagen and tooth dentine, and carbon and oxygen stable isotopes in tooth enamel carbonate will be discussed. The later sections review published stable isotope data of collagen and enamel carbonate respectively that are relevant to the topic of this thesis.

4.1. Principles of Carbon and Nitrogen Stable Isotopes in Bone Collagen and Tooth Dentine

The ratios of the stable isotopes of carbon ($^{13}C/^{12}C$), and nitrogen ($^{15}N/^{14}N$) in animal tissues largely reflect the isotopic composition of dietary sources, which is passed to the body tissues of the consumer with some further fractionation depending on factors such as gut physiology (DeNiro and Epstein 1976, 1978). The ratios are so small that they are usually described using delta (δ) units in per thousand, or per mil (‰) (McKinney et al. 1950, Sharp 2007: 17–8) in comparison to the standard values of Vienna Pee Dee Belemnite (VPDB) carbonate for carbon stable isotope ($\delta^{13}C$) values and atmospheric nitrogen (AIR) for nitrogen stable isotope ($\delta^{15}N$) values (Hoefs 1997).

Bone tissues are continuously resorbed and redeposited, and in humans they are normally quoted as reflecting the last decade or so before death (Sealy et al. 1995), although this is an oversimplification as bone turns over more slowly in adulthood (Hedges et al. 2007). This is

not the case for dentine collagen, which is an incremental tissue laid down over the limited period of the tooth's growth (Hillson 2005). Collagen is a complex polypeptide; its nitrogen source comes entirely from protein in the diet, while the collagen carbon preferentially reflects protein-rich food sources in the diet (Ambrose and Norr 1993, Tieszen and Fagre 1993). Thus, $\delta^{13}C$ and $\delta^{15}N$ values in collagen largely reflect dietary protein sources (Lee-Thorp et al. 1989).

However, differences in the amount of protein in the diet can lead to isotopic variability in $\delta^{13}C$ values because in protein-poor diets, more non-essential amino acids form from non-protein sources, resulting in larger difference between collagen $\delta^{13}C$ values and dietary protein $\delta^{13}C$ values, while in protein-rich diets, more non-essential amino acids directly contribute to the formation of collagen without fractionation (Jim et al. 2006).

The $\delta^{15}N$ values of body tissues are generally 3–5 ‰ higher compared to the dietary sources (DeNiro and Epstein 1981, Minagawa and Wada 1984, Schoeninger and DeNiro 1984, Sealy et al. 1987), while $\delta^{13}C$ values are ^{13}C-enriched by up to 1.2 ‰ for each trophic step (Bocherens and Drucker 2003). As a result, $\delta^{15}N$ values increase more than $\delta^{13}C$ values in a food chain.

In addition, $\delta^{13}C$ and $\delta^{15}N$ values differ between marine (or freshwater) and terrestrial ecosystems. In the ocean this is because the ultimate sources of nitrogen and carbon are nitrates and dissolved inorganic carbon (HCO^{3-} and/or CO_2) (Farquhar et al. 1989, Raven et al. 2002), which are higher than sources available in terrestrial systems, and furthermore, the food chain is much longer. As a result, the $\delta^{15}N$ values of marine fish and animals are higher than terrestrial animals (Minagawa and Wada 1984, Shoeninger and DeNiro 1984). Freshwater systems do not have the same distinctive carbon and nitrogen sources as in the

ocean but the food chains are nevertheless longer than in the surrounding terrestrial ecosystems. These resources may have highly variable $\delta^{13}C$ composition depending on surrounding vegetation, but elevated $\delta^{15}N$ values compared to terrestrial food sources (Dufour et al. 1999). Consequently, consumption of aquatic resources mainly elevate $\delta^{15}N$ values.

4.2. Influences on Carbon Stable Isotope Composition in Terrestrial Ecosystems

Photosynthesis is the major influence on $\delta^{13}C$ variability and variation in terrestrial ecosystems. Overall, there is a variation in carbon stable isotope values, or $\delta^{13}C$ values, in plants depending on their photosynthetic pathways, C_3 and C_4, due to the different ways of discriminating $\delta^{13}C$ during CO_2 fixation (Smith and Epstein 1971, O'Leary 1981, Farquhar et al. 1989). On the one hand, plants following the C_3 photosynthetic pathway have lower $\delta^{13}C$ values because of a strong discrimination against ^{13}C during CO_2 fixation by ribulose biphosphate carboxylase/oxygenase (RUBISCO) (Lee-Thorp 2008). On the other hand, regarding plants with the C_4 photosynthetic pathway, discrimination against ^{13}C does not occur because CO_2 is concentrated in bundle-sheath cells before it is released into the RUBISCO cycle (Lee-Thorp 2008). Consequently, C_4 plants have higher $\delta^{13}C$ values than C_3 plants (DeNiro and Epstein 1978). The modal $\delta^{13}C$ value of modern C_3 plants is about -27 ‰ (O'Leary 1981, 1988) and the global mean of $\delta^{13}C$ value of modern C_4 plants is about -12.5 ‰ (Smith and Epstein 1971). Hence, $\delta^{13}C$ values can be used to differentiate diets based

on C_4 plants which are more adapted to hot, arid environments including maize, millet, sorghum, and cane sugar, from those based on C_3 plants which most plants from temperate climate belong to (Lee-Thorp 2008). In Europe, millet is the only C_4 plant cultivated in the past, but it was mostly confined to warmer regions and C_4 plants are rare in north-western Europe even today (Pyankov et al. 2010).

Furthermore, the $\delta^{13}C$ values of C_3 plants are affected by several environmental factors. C_3 plants must balance intake against water loss during photosynthesis, thus the amplitude of fractionation is influenced by water balance and temperature (O'Leary 1995, Schleser 1995, Stewart et al. 1995). As a result, in cooler, moister regions, plant values are more ^{13}C depleted compared to warmer, drier regions (Van Klinken et al. 1994). In addition, difference in soil type, especially the drainage level as well as topography, are reported to affect the $\delta^{13}C$ values by about 0.3–0.7‰ for oak trees in England and other places in Europe (Hill et al. 1996, Robertson et al. 1997a, 1997b).

Other environmental factors that also influence the C_3 plant $\delta^{13}C$ values are light (O'Leary 1995, Yakir and Israeli 1995), nutrients (Hill et al. 1996, Sparks and Ehleringer 1997), and atmospheric CO_2 concentration (Farquhar et al. 1989, Heaton 1999). For example, the $\delta^{13}C$ values of trees and plants in dense forests are 2–5‰ lower compared to those growing singly or in an open landscape (Shleser and Jayasekera 1985, van der Merwe and Medina 1989, 1991, Tieszen 1991, Broadmeadow and Griffiths 1993, France 1996). The main factors influencing these lower $\delta^{13}C$ values are limited amount of light and the presence of large amounts of respired CO_2 (van der Merwe and Medina 1989, 1991). Due to this so-called woodland canopy effect, leaves have different $\delta^{13}C$ values depending on where they grow in

the same tree (Vogel 1978, Medina and Minchen 1980, Schleser and Jayasekera 1985, van der Merwe and Medina 1989, Broadmeadow and Griffiths 1993). For example, the $\delta^{13}C$ values of leaves decrease from the tree top to the ground level by a gradient of about 0.15–0.2 ‰ per metre in trees about 20m high (Heaton 1999).

Furthermore, different type of C_3 plants growing in the same condition can have different $\delta^{13}C$ values. Woody plants tend to have elevated $\delta^{13}C$ values compared to herbaceous ones (Heaton 1999). For example, bulk tissues of tree leaves from the highest and driest part of Port Meadow, Oxford in June 2000 analysed by Dungait et al. (2008) have mean $\delta^{13}C$ values (-27.8 ±0.8‰) more elevated than those of grass leaves (-29.4 ±1.4‰), herb leaves (-29.4 ±1.2‰), and shrub leaves (-29.5 ±0.3‰).

Additionally, intra-species difference in C_3 plants can be about ±0.8 to ±1.5 ‰ (Heaton 1999). Compared to leaves, non-photosynthetic plant tissues including twigs have higher $\delta^{13}C$ values by 1 to 3 ‰ (Gebauer and Shulze 1991, Cernusak et al. 2009). This is because different biochemical components such as carbohydrates, protein, and lipids have difference in $\delta^{13}C$ values for up to several per mil (O'Leary 1981, Tieszen 1991).

There are also seasonal differences in plant $\delta^{13}C$ values which should be taken into consideration. Dungait et al. (2010) analysed the seasonal variation in plants from Manor Farm, North Somerset, and the mean $\delta^{13}C$ values of leaves of grasses collected in October was 1.5 ‰ lower than the leaves collected in May and July. Similar decreases in $\delta^{13}C$ values in autumn have been reported in various plant species in a temperate climate (Lowdon and

Dyck 1974, Garten and Taylor 1992, Flanagan et al. 1997, Lockheart et al. 1997, Neilson et al. 1998). Therefore, the $\delta^{13}C$ values of plant become elevated in summer and depleted in winter. The difference between mid-winter and mid-summer may be larger than the difference observed between October and July. In addition, parts of plants which form seasonally such as fruits, seeds, and nuts fix the carbon from the seasons they formed, making their $\delta^{13}C$ values different from other parts of plants by 1–2 ‰ (Deines 1980, Leavitt and Long 1986, O'Leary 1995).

4.3. Factors Which Influence the Nitrogen Stable Isotopes

Soil and plant $\delta^{15}N$ values become enriched by about 1–4 ‰ compared to air nitrogen, which is defined as 0 ‰ (Shearer et al. 1978, Handley and Raven 1992). The $\delta^{15}N$ values of soil can be influenced by various factors such as aridity (Schwarcz et al. 1999), salinity (Hicks et al. 2005), mean annual temperature, and mean annual precipitation (Amundson et al. 2003). Following the predictive equations of Amundson et al. (2003) and UK climate summarised by Perry and Hollis (2005), the $\delta^{15}N$ values of soil in Lowland England can vary by 1–2‰ (Millard et al. 2013).

In contrast to $\delta^{13}C$ values aforementioned in the previous section, the relation between $\delta^{15}N$ values of plants and abundance of water is still not clear. Different studies have shown contradicting results, some showing a positive and others showing a negative correlation (Amundson et al. 2003, Lopes and Araus 2006, Yousfi et al. 2010). Some results have shown that warmer and drier climates tend to increase the $\delta^{15}N$ values of plants compared to cooler and wetter climates (e.g. Amundson et al. 2003 Aranibar et al. 2004, Handley et al. 1999 a,

1999 b, Heaton 1987). Conversely, the results by Fraser et al. (2011) showed a positive correlation between $\delta^{15}N$ values and amount of rainfall in intensively manured (35t/ha of cattle manure) plots, while an increase in un-manured cereal $\delta^{15}N$ values did not occur when the amount of rainfall decreased. Thus, Fraser et al. (2011) reject the assumption of high $\delta^{15}N$ values of crops as evidence of aridity, and suggest taking other possible factors into consideration for high $\delta^{15}N$ values of crops.

Many studies have investigated the effect of soil management to soil $\delta^{15}N$ values. For example, by adding animal manure, a common practice in many agricultural communities to increase the fertility of cultivated soil (Bol et al. 2008, Choi et al. 2006, Senbayram et al. 2008), the soil becomes more enriched in ^{15}N compared to ^{14}N, which tends to be lost during the bio-degradation (Heaton 1986, Kendall et al. 2007, Kreitler and Jones 1975). As a result, manured soil has higher $\delta^{15}N$ values than soil without manure. Furthermore, it has been argued that management of agricultural land may have an effect on $\delta^{15}N$ values of plants (Aranibar et al. 2008, Broadbent et al. 1980, Kriszan et al. 2009), and the influence of manuring to the $\delta^{15}N$ value of crops were investigated by comparing crops harvested from manured and un-manured plots in various locations in Europe and the Near East (e.g. Bogaard et al. 2007, Fraser et al. 2011). Results by Fraser et al. (2011) show that the effect of manuring varied depending on crop type i.e. cereals or pulses, and cereal grains constantly had higher $\delta^{15}N$ values than cereal rachis, although both responded to manuring in the same magnitude. Fraser et al. (2011) suggest that if humans ate cereal grains while animal fodder consisted of other part of crops, the difference in $\delta^{15}N$ values depending on crop plant parts may contribute to the difference in the $\delta^{15}N$ values of the consumer.

As already mentioned in section 4.1, $\delta^{15}N$ values of body tissues are 3–5 ‰ higher compared to the diet. Therefore, herbivores have 3–5 ‰ higher $\delta^{15}N$ values then the plants they consume, and carnivores will have 3–5 ‰ higher $\delta^{15}N$ values than the animals they consume. Consequently, difference in $\delta^{15}N$ values makes it possible to distinguish individuals of different trophic levels. Indeed, $\delta^{15}N$ values have been used to identify the suckling period of children. This is possible because suckling infants of mammals living solely on their mothers' milk will be one stage above the trophic level of their mothers (Fuller et al. 2006). Infants have $\delta^{15}N$ values 2–3 ‰ higher than their mother until they are weaned (Fogel et al. 1989, Wright and Schwarcz 1998).

For omnivores like humans, $\delta^{15}N$ values have been used to assess the proportion of animal protein and plant protein in the diet (O'Connell and Hedges 1999), as they are the sources of nitrogen. Although the amount of protein in plants is much lower than in animal foods, the exception is leguminous plants. Leguminous plants can fix nitrogen from the atmosphere so they tend to have low $\delta^{15}N$ values similar to the atmosphere, which is 0‰ by definition (Sharp 2007), in contrast to non-nitrogen fixers which take up nitrogen salts from the soil. Therefore the leguminous plants have lower $\delta^{15}N$ values than other plants, let alone animal protein. Thus an individual who has a diet with abundant amount of legumes will have lower $\delta^{15}N$ values compared to one who has a diet with limited amount of legumes.

4.4 Principles of Carbon and Oxygen Stable Isotopes from Tooth Enamel Carbonate

Ratios of the stable isotopes of carbon ($^{13}C/^{12}C$), and oxygen ($^{18}O/^{16}O$) can be measured from tooth enamel carbonate. They are usually described using delta (δ) units in per thousand, or per mil (‰) (Sharp 2007: 17–8) relative to the standard values of Vienna Pee Dee Belemnite (VPDB) carbonate for carbon stable isotope ($\delta^{13}C$) values and Vienna Standard Mean Ocean Water (VSMOW) for oxygen stable isotope ($\delta^{18}O$) values (Hoefs 1997).

Unlike bones, tooth enamel does not turnover after it is formed and is more resistant against diagenesis (Hillson 2005). Thus, every part of a tooth enamel reflects the stable isotopes when it formed. In addition, each species has fixed timings of tooth formation. By sequential enamel sampling of several teeth of an individual, the change in $\delta^{13}C$ and $\delta^{18}O$ values in the course of tooth enamel formation can be investigated.

4.4.1 Carbon Isotopes

In contrast to bone collagen, the $\delta^{13}C$ values of tooth enamel carbonate reflects the whole diet including lipid and carbohydrates (Ambrose and Norr 1993, Tiezsen and Fagre 1993, Jim et al. 2004). This is because the carbon in the tooth enamel derives from bicarbonate dissolved in the blood (Sullivan and Krueger 1981).

The $\delta^{13}C$ values of enamel carbonate become elevated compared to the diet by about 12 ‰ but the extent of enrichment can vary depending on body mass and dietary physiology

(Krueger and Sullivan 1984, Lee-Thorp et al. 1989). This means that even when the food is the same, the $\delta^{13}C$ values of enamel carbonate can vary depending on different digestive systems and gut physiology of different animals. For example, regarding large ungulates including cattle, the enrichment can be around 14 ‰ (Cerling and Harris 1999, Passey et al. 2005).

4.4.2. Oxygen Isotopes

The $\delta^{18}O$ values of bioapatite in tooth enamel reflect the $\delta^{18}O$ values of body water which went through fractionation and species-dependent physiological and metabolic process (Longinelli 1984, Luz et al. 1984, Kohn 1996, Kohn et al. 1996, Iacumin and Longinelli 2002). Body water of animals derives from rainwater since ingested water is from rivers and plants (Land et al. 1980, Longinelli 1984, Luz et al. 1984, Kohn et al. 1996, D'Angela and Longinelli 1990, Delgado Huertas et al. 1995). The $\delta^{18}O$ values of rainwater reflect the climate and geographic features, such as temperature in high and middle latitudes, altitude, and distance from the sea (Dansgaard 1964, Gat 1980, Longinelli 1984, White et al. 1998). In principle, the $\delta^{18}O$ value of rainwater varies depending on the season in high and middle latitudes; it becomes elevated in warmer seasons, whereas it becomes depleted in colder seasons (although other factors can affect its $\delta^{18}O$ values as well) (McCrea 1950, Dansgaard 1964, Gat 1980, Kohn and Welker 2005).

During tooth mineralisation, the $\delta^{18}O$ value of bioapatite becomes fixed (Fricke and O'Neil 1996, Sharp and Cerling 1998). Depending on the species, each tooth will grow in certain years of one's lifespan. Consequently, every tooth of an individual will have different $\delta^{18}O$ values (Bryant et al. 1996a, 1996b, Fricke and O'Neil 1996). Moreover, for teeth which grow through several seasons such as the hypsodont teeth of herbivores, there is intra-tooth variation in $\delta^{18}O$ values depending on the timing of tooth mineralisation (Koch et al. 1989, 1995, Fricke and O'Neil 1996, Stuart-Williams and Schwarcz 1997, Kohn et al. 1998, Sharp and Cerling 1998, Sharma et al. 2004, Nelson 2005, Bernard et al.2009, van Dam and Reichart 2009). Consequently, the $\delta^{18}O$ values of animals in mid and high latitudes will show a sinusoidal curve with peaks corresponding to summer and bottoms corresponding to winter (Fricke et al. 1998). Animals born in the same season show similar sequences of $\delta^{18}O$ values in the similar part of the tooth, but animals born in different seasons have their sequences of $\delta^{18}O$ values shifted (Balasse et al. 2003, Fricke and O' Neil 1996).

The $\delta^{18}O$ values from animal tooth enamel have been used to investigate animal management, especially the seasonality of birth by sequential sampling tooth enamel of various teeth from an individual (e.g. Balasse et al. 2003, Nelson 2005, Balasse and Tresset 2007, Britton et al. 2009, Henton et al. 2010). However, there are factors which limit the precision of birth seasonality deduced from tooth enamel sequences. Firstly, the tooth enamel formation process is far from simple. Suga (1982) identified two phases in enamel mineralisation. The first phase is the deposition of matrix, a framework which becomes lightly mineralised as it is deposited from the cusp to the cervix (Hillson 2005: 155). The second phase is the maturation of matrix when most of the mineralisation takes place (Robinson et al. 1995). Suga (1982) categorised the spatially and temporary complex maturation process into three stages. The

first stage is the initial mineralisation from the surface to the innermost layer, the second stage is the secondary mineralisation of the same layers but in the opposite direction, and the third stage is the mineralisation of a thin subsurface layer. This process in cattle molar enamel will take minimum six to seven months at any point of the crown (Balasse 2002, Zazzo et al. 2005, Montgomery et al. 2010). Due to this long and complicated mineralisation process, the enamel carbonate $\delta^{18}O$ values reflect the averaged value of several different seasons. This also results in the dampening and the temporal shift of the enamel carbonate $\delta^{18}O$ values compared to the original $\delta^{18}O$ values of drinking water (Passey and Cerling 2002, Kohn 2004).

Balasse et al. (2012 b) concluded from their $\delta^{18}O$ value sequences of modern sheep with known life history that the time required for tooth maturation results in a 5–6 month shift in the seasonality recorded in the tooth enamel. For example, when a sheep is born at around the end of April or the beginning of May, its second permanent molar (M2) crowns start forming a month later, from the end of May to the beginning of June. However, when the $\delta^{18}O$ values of its M2 crown is analysed, the top of the crown (where crown formation starts) gives $\delta^{18}O$ values corresponding to late September and late October. This delay is allegedly due to the time it takes for the tooth to become fully mineralised, as well as the turnover time of carbon and oxygen in body fluids (Ayliffe et al., 2004; Podlesak et al., 2008; Zazzo et al., 2010). Therefore, it is not possible to directly deduce the season when the individual was born from the $\delta^{18}O$ value sequence itself.

In addition, Balasse et al. (2012 b) indicates that there is another major issue to be taken into consideration. This is the tooth size, which affects the variation in recording the seasonal

cycle at an individual level. For solving this issue of individual difference in tooth size, Blaise and Balasse (2011) proposed that normalising the distances between the sampled locations and the enamel-root junction by using the mean transverse diameter of modern sheep will enable a direct comparison of $\delta^{18}O$ value sequences from different individuals. This method works when fully grown molars with no wear is available, which is not always the case for archaeological specimens. In addition, this method does not totally eliminate the individual difference in the rate of tooth growth. As an alternative method, Balasse et al. (2012 b) proposed identifying the periodic cycle of $\delta^{18}O$ values which represents an annual sequence, and reducing the difference in tooth growth rate by modelling the annual sequence. This enables to compare the time difference among different individuals without the influence of tooth size difference and tooth growth rate difference. In this modelling method, worn teeth or teeth which are not fully grown can also be used as long as they cover the maximum and minimum $\delta^{18}O$ values.

Still, there is individual difference in the timing of tooth formation which influences the $\delta^{18}O$ value sequence. Apparently, this is larger among third permanent molars (M3) than second permanent molars (M2) (Blaise and Balasse 2011, Tornero et al. 2013). Therefore, M2 is preferred when applying this method rather than M3.

In addition, in order to examine the birth season of past herds, modern tooth enamel data with known birth dates are crucial as a reference. There is no reference data for cattle yet, while reference data of modern sheep was acquired from south-east France analysed by Blaise and Balasse (2011) and from the Orkney Islands, Scotland by Balasse et al. (2012 b).

Furthermore, this method cannot be applied to individuals which died before their M2s formed. Thus, calves died prematurely cannot be included, which may result in a bias in the birth season to those born during the ideal season, while in reality there may have been calves which were born outside of the main season and could not survive until their M2 formed (Brown et al. 1960).

Equally, there is another method of deducing birth seasonality that uses a different tooth; Towers et al. (2013) uses the change in $\delta^{13}C$ values observed in first permanent molars (M1) of ruminants. This method can be applied to calves that died too young to be analysed by Balasse et al. (2012 b)'s method. The $\delta^{13}C$ values of the enamel tend to rise from lower values closer to the cusp to higher values towards the cervix (Towers et al. 2013). Since the M1 crown of a cow starts mineralising before birth and finishes mineralising at the age of two to three months, they argue that this change in $\delta^{13}C$ values reflect the change in digestion mechanisms of ruminants. As aforementioned, higher $\delta^{13}C$ enrichment in ruminants compared to non-ruminants with a similar diet occurs because of the elevated $\delta^{13}C$ value of carbon dioxide produced by fermentation of food in the rumen. This higher $\delta^{13}C$ enrichment in ruminants corresponds to the higher $\delta^{13}C$ values closer to the cervix of M1 of ruminants.

In contrast, while a calf is suckling, its rumen is not fully developed and the way the calves digest the milk is similar to how a non-ruminant digests its food (Towers et al. 2013). As a result, a suckling calf has $\delta^{13}C$ values which are more depleted compared to a weaned calf (Towers et al. 2013). The depleted $\delta^{13}C$ values during suckling correspond to the lower $\delta^{13}C$ values closer to the cusp of M1 of ruminants.

Assuming that all calves are weaned at the same age, the timing when the gradient of $\delta^{13}C$ value sequence changes in the M1is free from individual differences. By comparing the corresponding $\delta^{18}O$ values when the gradient of $\delta^{13}C$ values changes, the difference in birth season can be deduced.

However, as aforementioned in the previous chapter, calves can be weaned at different ages depending on the purpose of rearing cattle. For example, if the mothers were milk cattle, their calves are weaned earlier than those born from beef cattle in order to keep milk for human consumption. Therefore, the difference in birth season deduced from this method may reflect the difference in the purpose of livestock rearing rather than the range of birth seasons.

4.5. Published Stable Isotope Data for Bone Collagen and Tooth Dentine

Next, the range of diet deduced from the collagen $\delta^{13}C$ and $\delta^{15}N$ data of domestic fauna and humans in Roman and Anglo-Saxon Britain will be explored. The discussion focuses on the Upper Thames Valley, the targeted area of this study.

4.5.1. Fauna

The minor difference among herbivores in a C_3 plant terrestrial environment derives partly from their plant foods (which may differ according to where they grow, species, and plant parts as described in sections 4.2 and 4.3) and partly from their digestive physiology. In a few cases, these difference in collagen stable isotope data reveal how the herbivores were managed. For example, collagen stable isotope data of cattle and sheep/goats from the Severn estuary, England was able to show that the practice of herbivores grazing on coastal salt marshes, a common practice in medieval England (Oschinsky 1971), dates back as early as the Bronze Age, because the Bronze Age herbivores had elevated $\delta^{15}N$ values probably due to grazing plants elevated in $\delta^{15}N$ values on salt marshes on the coast (Britton et al. 2008). In general however, the herbivore stable isotope data in the Romano-British and Anglo-Saxon periods are homogenous. Herbivores analysed in the Upper Thames Valley from the Romano-British and Anglo-Saxon period did not show a sharp change in stable isotope values. In addition, there was no difference in $\delta^{13}C$ and $\delta^{15}N$ values detected between cattle and sheep/goats, as seen at Romano-British Yarnton (Lightfoot et al. 2009).

In contrast, stable isotope data of pigs are more diverse. This is because pigs are omnivores consuming a wider variety of foods than herbivores (see Chapter 2). Their $\delta^{15}N$ values in particular are expected to become elevated with greater amount of high protein foods, and their distribution lies between the herbivores (such as cattle and sheep/goats) and the carnivores (such as dogs). In Roman Britain for example, the only pig at the rural site at Alinton Avenue, Dorset has a $\delta^{15}N$ value (9.9 ‰) higher than human Group 2, a group of humans with lower $\delta^{15}N$ values (7.9–9.5 ‰), although lower than the human Group 1, a group of humans with higher $\delta^{15}N$ values (10.0–11.4 ‰) (Redfern et al. 2010). Data of herbivores were not collected from the same site, but a cow, a sheep and a dog were collected from another adjacent rural Romano-British site at Maiden Castle Road, Dorset, and the pig had the highest $\delta^{15}N$ value among them followed by the dog (8.3‰), cow (6.2‰) and sheep (4.9‰).The difference of $\delta^{15}N$ value between pig and cow was 3.7‰, and between pig and sheep was 5 ‰, both corresponding to the difference of one trophic level which is +3–5 ‰ (see section 4.1). Therefore, the pig from Romano-British Alinton Avenue, Dorset probably had a highly omnivorous diet. Similarly, at the Eton College Rowing Course, Dorney, on the bank of River Thames in Buckinghamshire, all four Romano-British adult pigs analysed had $\delta^{15}N$ values higher than 8 ‰ including two which had $\delta^{15}N$ values higher than 9 ‰, and all of them were more enriched than the $\delta^{15}N$ values of cattle, suggesting that these pigs had an omnivorous diet as well (Stevens et al. 2012).

Yet, there are pigs in Roman Britain which seem to have a herbivorous diet, such as the only pig analysed from Gloucester, whose $\delta^{15}N$ value of 5.5 ‰ is lower than those of cattle (Chenery et al. 2010). In addition, there are sites with pigs which have a wide range of $\delta^{15}N$ values, possibly reflecting their different levels of omnivorous diet, such as at the military site of Catterick, where the lowest pig $\delta^{15}N$ value of 5.6 ‰ overlap with the $\delta^{15}N$ value of

herbivores, whereas the highest $\delta^{15}N$ value of 10.4 ‰ is higher than those of dogs (Chenery et al. 2011).

However, as already mentioned (in section 4.3), it is acknowledged that $\delta^{15}N$ values become elevated during the suckling period. Since the pigs with high $\delta^{15}N$ values discussed above were not aged apart from the four adult pigs at Eton College Rowing Course, Dorney, the possibility that suckling pigs were analysed with adult pigs which had lower $\delta^{15}N$ values cannot be excluded. The weaning period of modern pigs is nine weeks, which is much shorter than herbivores (detail in Chapter 2). In addition, bones of young individuals are not robust compared to adults, so there is less chance for bones of suckling pigs to be preserved. Nevertheless, suckling pigs were regarded as a delicacy in the Roman period (see Chapter 3), so if there were more young individuals consumed, their bones may have had a higher chance to survive at Romano-British sites compared to sites from other periods. If the pigs with high $\delta^{15}N$ values discussed above (apart from the adult pigs at Eton College Rowing Course) were actually suckling pigs, then these cases would have proved that the consumption of suckling pigs was common at some Romano-British sites. It is unfortunate that only a few pigs were analysed from each site, mostly without being aged.

In the Upper Thames Valley, the diet of pigs varied. For example, the pigs in Cirencester had a broad range of $\delta^{15}N$ values (Cummings 2008: 148). On the one hand, two out of eight pigs analysed had $\delta^{15}N$ values higher than 9 ‰ (9.1 and 11.0 ‰). Their $\delta^{15}N$ values overlap with those of humans and dogs, and thus it is possible that these pigs had an omnivorous diet, but since the age of the pigs are unknown, they could also be suckling pigs. On the other hand, the remaining six pigs analysed had $\delta^{15}N$ values overlapping with herbivores, probably

reflecting a herbivorous diet. The herbivorous pigs lowered the mean $\delta^{15}N$ value of pigs and consequently it was lower than the mean dog $\delta^{15}N$ value but higher than the mean cattle $\delta^{15}N$ value. Still, the difference between $\delta^{13}C$ and $\delta^{15}N$ values of pigs and herbivores were statistically significant, suggesting that pigs had a different diet from the herbivores (Cummings 2008: 148).

The only pig at the extramural site of Alchester and the two pigs at the roadside settlement of Asthall had $\delta^{13}C$ and $\delta^{15}N$ values higher than those of cattle but lower than those of humans (Cummings 2008: 147–9). These pigs may have had an omnivorous diet to some extent, but there is also a possibility that they were suckling piglets.

Additionally, at Yarnton, the mean $\delta^{13}C$ value of pigs was similar to those of cattle and sheep/goats, but the mean $\delta^{15}N$ value of pigs was higher than those of cattle and sheep/goats, and the difference was statistically significant (Lightfoot et al. 2009). Lightfoot et al. (2009) argue that this is a result of pigs being more omnivorous than ruminants, but the $\delta^{13}C$ values should also become elevated by about up to 1.2 ‰ as a result of an increase in trophic level by having an omnivorous diet or by suckling (see section 4.1), which was not the case at Yarnton. In addition, since the age of the pigs are unknown, the possibility that the high pig $\delta^{15}N$ values were due to the suckling effect cannot be excluded. Thus, it could be other factors besides being omnivorous or suckling which elevated the pig $\delta^{15}N$ values. Indeed, when the Romano-British animals were compared with Iron Age animals at Yarnton, although there was no significant difference in the mean $\delta^{13}C$ values of all animal species between the two periods, the mean $\delta^{15}N$ values of animals apart from cattle increased from the Iron Age to the Romano-British period (Lightfoot et al. 2009). Lightfoot et al. (2009) argue that this elevation in $\delta^{15}N$ values may have caused by an increase in manuring or a change in soil type from gravel terrace to floodplain where animals were kept.

In contrast to the Romano-British pigs, the majority of Anglo-Saxon pigs analysed by Hull (2008) from Shavard's Farm, Hampshire, Abbot's Worthy, Hampshire, Spong Hill, Norfolk, West Stow, Suffolk, had $\delta^{15}N$ values similar to cattle and sheep from the same site, which suggests that most pigs had a herbivorous diet. Similarly, pig $\delta^{15}N$ values at Bloodmoor Hill, Suffolk overlap with those of herbivores, suggesting that they had a herbivorous diet (O'Connell and Lawler 2009). Still, there were three exceptional adult pigs out of a total of 65 from West Stow which had $\delta^{15}N$ values higher than 9 ‰, suggesting that a minority had an omnivorous diet. Unfortunately, there are no Anglo-Saxon pigs analysed in the Upper Thames Valley, except for a single pig at Berinsfield (Privat et al. 2002). This pig has similar $\delta^{13}C$ and $\delta^{15}N$ values to those of herbivores at Berinsfield, suggesting that this pig had a herbivorous diet.

4.5.2. Humans

Stevens et al. (2012) compared data of collagen $\delta^{13}C$ and $\delta^{15}N$ values across Britain from the Neolithic to the Romano-British period and concluded that human diet in Britain throughout these periods is characterised as C_3 plant terrestrial food with a limited amount of marine resources. Unlike $\delta^{15}N$ values, they did not find a strong correlation between human and animal $\delta^{13}C$ values. Since the $\delta^{13}C$ values did not show a co-variation between animals and humans, they concluded that the variation in human $\delta^{13}C$ values between sites possibly reflects the contribution of plants to the diet.

Exceptionally, there are some individuals buried in Roman Britain with high $\delta^{13}C$ values but intermediate $\delta^{15}N$ values which clearly indicate a C_4 plant terrestrial diet, such as two individuals in York (Müldner et al. 2011), and one individual in Kent (Pollard et al. 2011). Since C_4 plants are scarce in England, it is possible that these individuals originally came from outside Britain (Müldner et al. 2011).

Yet, there are minor differences within the C_3 plant terrestrial food diet between urban and rural sites in Roman Britain. Cheung et al. (2012) compared the human diet in Gloucester, with that of the rural sites at Cotswold Community and Horcott Quarry, Gloucestershire. Although all individuals had their stable isotope values within the range of a C_3 plant terrestrial food diet, they detected subtle differences between urban and rural sites. In particular, the townspeople in Gloucester had slightly higher $\delta^{13}C$ and $\delta^{15}N$ values compared to the rural site individuals. They argued that these relatively elevated values in Gloucester was because a slightly higher proportion of marine and/or freshwater resources was consumed by the townspeople. Moreover, the individuals in Gloucester showed more variation among various categories of burials, which may suggest that the diet varied more in urban sites depending on one's social background.

However, the human diet difference between urban and rural sites is not always evident. Regarding the human diet of several rural sites adjacent to Dorchester, Dorset as well as some areas within the town, the variation in stable isotope values of individuals at urban sites was not much different from those at rural sites (Redfern et al. 2010). Additionally, Redfern et al. (2010) argue that the extent of Romanisation in diet of rural sites did not necessarily correlate with the distance from the Romano-British town of Dorchester.

Bone collagen data from several Upper Thames Valley sites are available from Romano-British urban sites: Asthall (Cummings 2008) and Cirencester (Cummings 2008); and Romano-British rural sites: Yarnton (Lightfoot et al. 2009), Tubney (Nehlich et al. 2011), Queenford Farm (Fuller et al. 2006), Stanton Harcourt (Cummings 2008), the extramural site of Alchester (Cummings 2008), and Cotswold Community (Cheung 2009) (Fig. 4.1). A limited number of Romano-British humans at Horcott, the site targeted in this study were analysed by Cheung (2009) and are included below and will also be analysed together with the results obtained for this study in Chapters 6 and 7.

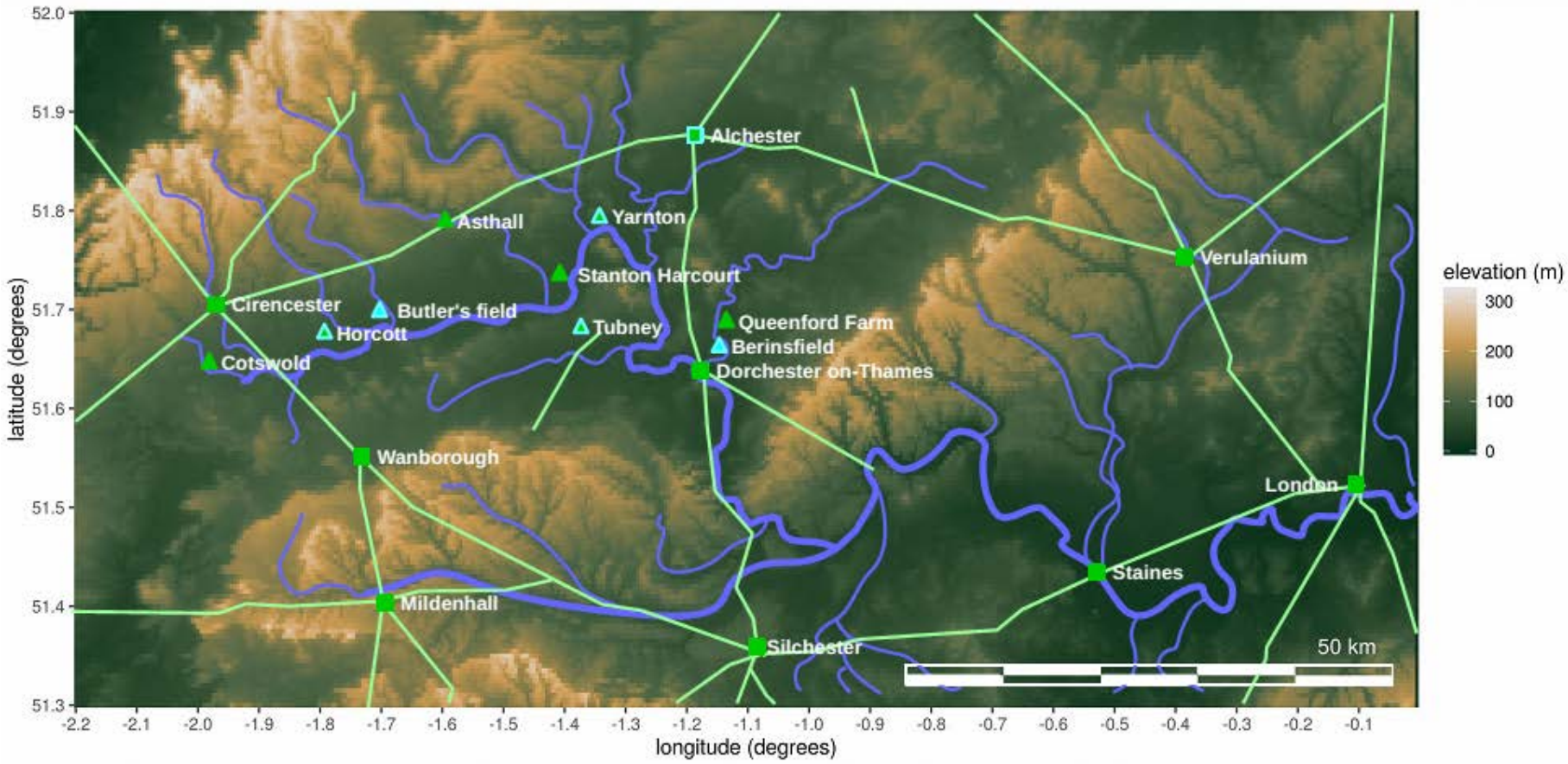


Fig. 4.1 Location of Upper Thames Valley sites with stable isotope data

Like other Romano-British sites discussed above, humans in the Upper Thames Valley rural sites have a narrower range of $\delta^{13}C$ values compared to those at urban sites (Figs. 4.2). Cummings (2008: 219) argues that the humans in Cirencester show a higher possibility of freshwater fish incorporated into the diet, while the humans at rural sites seem to have had a diet more restricted to terrestrial sources including animals and a limited amount of freshwater fish and marine resources. At Horcott, although showing some characteristics of a villa site (see Chapter 5), the ranges of $\delta^{13}C$ and $\delta^{15}N$ values are narrower than those in Cirencester, suggesting that the human diet at Horcott was less variable than that in Cirencester and more similar to other rural sites in the region.

Yet, careful examination shows that there is site-dependent difference in human diet among Romano-British rural sites in the Upper Thames Valley (Fig. 4.2). Although a rural site, the humans at Yarnton characteristically had high $\delta^{15}N$ values compared to any other Romano-British site in the Upper Thames Valley (Lightfoot et al. 2009). However, since the herbivore $\delta^{15}N$ values are elevated in the Iron Age as well as in the Romano-British period, there may be an alternative and more plausible explanation of elevated $\delta^{15}N$ values at Yarnton concerning the environment.

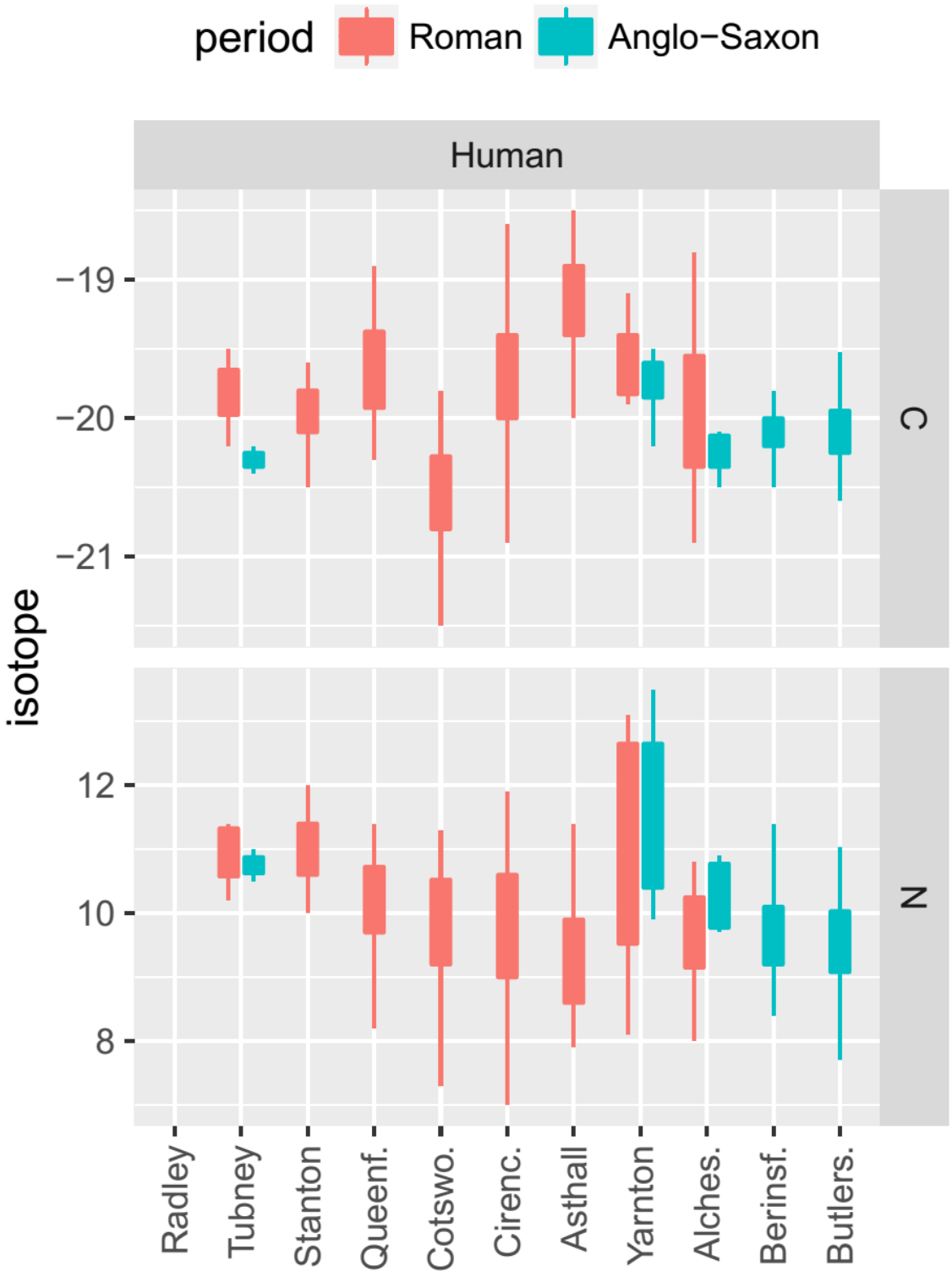


Fig.4.2 Box-plots of collagen data of human from Upper Thames Valley sites. The box represents 50% percentile around the median and the whisker represents the 90% percentile of the distribution, x-axis: sites, y-axis: stable isotope values; upper row: $\delta^{13}C$ values (‰), bottom row: $\delta^{15}N$ values (‰), red: the Romano-British period, blue: the Anglo-Saxon period. Data from Cummings 2008, Fuller et al. 2006, Lightfoot et al. 2009, Nehlich et al. 2011, and Privat et al. 2002.

In addition, there is site-dependent difference in correlation between stable isotope data and physical and burial characteristics. Regarding physical characteristics, there are not many cases which showed a strong correlation between stable isotope data with sex, age, and pathology. With respect to sex for example, males at Alchester had in average higher $\delta^{15}N$ values compared to females, and the difference was statistically significant (Cummings 2008: 153). Similarly, male adults from Queenford Farm had a higher mean $\delta^{15}N$ value than female adults which was statistically significant, and Fuller et al (2006) suggested that females may have consumed less amount of animal and/or fish protein than males.

Regarding age, female individuals at Alchester had a negative correlation between $\delta^{13}C$ values and age; the older the age, the lower the $\delta^{13}C$ values (Cummings 2008: 153). Conversely, at Stanton Harcourt, although the $\delta^{13}C$ value range is less than 1 ‰, female individuals had a positive correlation between their $\delta^{13}C$ value and age; the older the age, the higher the $\delta^{13}C$ values, (Cummings 2008: 154).

In respect of pathology, the only site with individuals that showed a correlation was Cirencester. Humans whose bones show signs of gout, a disease related to a high protein diet and common among wealthy people, had $\delta^{13}C$ and $\delta^{15}N$ values close to the higher end of the stable isotope value ranges (Cummings 2008: 164). This suggests that they had a larger amount of protein derived from animals and/or marine resources in their diet. Notably, this is one of the few cases which showed that diet varies depending on one's economic status.

In addition to physical characteristics, correlations between stable isotope values and various burial rites have been investigated at some sites. Although there was no statistically significant correlation between $\delta^{13}C$ and $\delta^{15}N$ values and burial orientation, grave goods, or

body position at any site, there were correlations with presence of coffins and decapitation at some sites.

For example, in Cirencester, there was a correlation with presence of coffins: individuals buried in elaborate coffins had similar $\delta^{13}C$ and $\delta^{15}N$ values, suggesting that one's diet correlated with one's social status in Cirencester (Cummings 2008: 164). Similarly, individuals buried in limestone coffins in Cirencester have $\delta^{13}C$ and $\delta^{15}N$ values near the higher ends of the stable isotope value ranges, suggesting that their diet was also different from the rest (Cummings 2008: 173). Similarly, although not from the Upper Thames Valley, individuals buried in the mausolea or in lead coffins at the Late Romano-British (fourth century AD) Poundbury Camp near Dorchester, Dorset, presumably of high status, had higher $\delta^{13}C$ and $\delta^{15}N$ values, reflecting a larger amount of marine resources in their diet compared to others buried in wood coffins as well as individuals from the Iron Age (Richards et al. 1998). This suggests that the amount of marine resources in the diet of the late Romano-British humans at Poundbury Camp varied depending on their social background.

In addition, in Cirencester, the decapitated individuals had in average lower $\delta^{13}C$ and higher $\delta^{15}N$ values compared to the rest who were not decapitated, and the difference in both $\delta^{13}C$ and $\delta^{15}N$ values was statistically significant (Cummings 2008: 176). Interestingly, decapitated individuals from other sites show slightly different trends. At Alchester, the only decapitated individual analysed had the lowest $\delta^{13}C$ value of all the analysed individuals and a $\delta^{15}N$ value which was lower than average (Cummings 2008: 179). In contrast, at Stanton Harcourt, the decapitated individuals had both of their stable isotope values elevated compared to the rest, but due to the small sample size, statistical significance could not be examined (Cummings 2008: 177). At Horcott, decapitated individuals had $\delta^{13}C$ values which were more elevated than those who were not decapitated (Cheung 2009: 119).

Unlike other Romano-British sites discussed above, intra-site statistically significant difference in $\delta^{13}C$ and $\delta^{15}N$ values was detected at Horcott which correlated with various burial rites (Table 4.1). Firstly, correlation between $\delta^{13}C$ values and the number of individuals buried in the same burial was observed. A multiple burial of three elder males all had depleted $\delta^{13}C$ values which formed a distinct group from the rest who were buried in single burials (Cheung 2009: 113). Secondly, there was a difference in $\delta^{13}C$ values corresponding to the orientation of the burials (Cheung 2009: 116). Individuals buried in a north-south orientation had enriched $\delta^{13}C$ values compared to those buried in a south-north orientation. Thirdly, there was a difference in $\delta^{15}N$ values correlating to body position. The individuals buried in prone position had more depleted $\delta^{15}N$ values compared to supine burials (Cheung 2009: 118). Although not from the Upper Thames Valley, there was also a statistically significant difference between prone burials and supine burials at Winchester, but unlike at Horcott, the difference was in $\delta^{13}C$ values; the prone burials at Winchester had more depleted $\delta^{13}C$ values than supine burials (Cummings 2008: 170–1). Cummings (2008: 171) argue that the individuals buried in a prone position did not have much meat or fish in their diet and their social status may have been low, but if this was the case there should also have been a difference in their $\delta^{15}N$ values.

	sex	no. of burials	orientation	position	decapitation	coffin	grave goods
Majority	male	single	N-S	supine	No	No	No
minority	female	multiple	S-N	prone	Yes	Yes	Yes
Cheung (2009)	no difference	lower $\delta^{13}C$	lower $\delta^{13}C$	lower $\delta^{15}N$	higher $\delta^{13}C$	no difference	no difference

Table 4.1 Majority and minority groups by various burial characteristics of Romano-British humans at Horcott and the statistical significances of the difference between each two groups by Cheung (2009).

As mentioned in Chapter 1, there is ample discussion regarding the change from the Romano-British to the Anglo-Saxon period, and stable isotope evidence has also been included in the discussion. Müldner and Richards (2007) argue that stable isotope data from Southern English sites suggests that there was a systematic difference in diet between the Late Romano-British and Anglo-Saxon periods, probably because while it was possible to source food from beyond the local area in the Romano-British period by taking advantage of the trade routes available in the Roman Empire, non-local food became far less available after the end of the Roman rule and the decline of the Roman trading network. Indeed, Müldner (2009) was able to compare between the late Romano-British and early Anglo-Saxon individuals at Wasperton Warwickshire. The difference in $\delta^{13}C$ values between the two later Romano-British individuals (radiocarbon date cal AD 250–420) and the seven early Anglo-Saxon individuals was marginal, suggesting that rural sites experienced little change in diet between the Romano-British and the Anglo-Saxon period. However, the sample size is too small for an argument of a change in diet, and there is also a possibility that any diet difference which did not affect the stable isotope values has been overlooked.

Still, some studies have argued that there is variation in human diet across Anglo-Saxon Britain. For example, variation by region was detected in human $\delta^{15}N$ values which ranged between 6 and 14 ‰ by Hull (2008) who analysed sites across Norfolk, Suffolk, and Hampshire. He points out the possibility that the variation of human $\delta^{15}N$ values were caused by regional difference in animal diet which were possibly affected by environmental differences such as geology, climate, rainfall, and vegetation. Since the pig $\delta^{15}N$ values were similar to other herbivores suggesting that the pigs had a herbivorous diet, he concludes that the high $\delta^{15}N$ values of some of the Anglo-Saxon human individuals cannot be explained by

high proportion of pig as their animal protein source. Instead, Hull (2008) argues the alternative possibility of fish in the human diet.

In contrast, Mays and Beavan (2012) analysed 76 adult humans from 18 different cemeteries in England dated between the fifth and seventh century AD, and tried to attribute the difference to the geographical location of the site: inland, riverine and coastal. They argue that there was a minor difference regarding $\delta^{13}C$ values between coastal sites and other two site groups, which could not be attributed to difference in the amount of marine resources in the diet since the $\delta^{15}N$ values at coastal sites were not as elevated as the $\delta^{13}C$ values. Another minor difference was detected in $\delta^{15}N$ values between riverine sites and inland sites, which was explained as a result of difference in the amount of freshwater resources in the diet. However, the sample size was rather small and no animals or other food sources were analysed to support their argument. Nevertheless, it seems that there was difference among sites in geographically similar locations, because individuals at Droxford and Shavard's Farm, the two sites on the opposite sides of the Meon River in Hampshire analysed by Hull (2008) showed a difference in $\delta^{13}C$ values suggesting that the river functioned as a boundary regarding diet.

In the Upper Thames Valley, Anglo-Saxon data are all from rural sites which are: the extramural site of Alchester (Cummings 2008), Berinsfield (Privat et al. 2002), Butler's Field (O'Connell and Wilson 2011), Tubney (Nehlich et al. 2011), and Yarnton (Lightfoot et al. 2009) (Fig. 4.1). Notably, the ranges of $\delta^{13}C$ and $\delta^{15}N$ values of Anglo-Saxon humans are more or less similar to those from Romano-British rural sites in the Upper Thames Valley (Figs 4.2). For example, at the extramural site of Alchester, although the post Romano-British

humans have a much narrower $\delta^{13}C$ value range compared to the Romano-British humans, the two groups were not statistically distinguishable with respect to mean $\delta^{13}C$ values (Cummings 2008: 166). Likewise, at Yarnton, the $\delta^{13}C$ and $\delta^{15}N$ ranges of Anglo-Saxon humans heavily overlap with those of the Romano-British individuals, suggesting that there was no isotopically detectable diet change between the Romano-British and Anglo-Saxon humans (Lightfoot et al. 2009).

Furthermore, in Anglo-Saxon Britain, there was difference in stable isotope values which correlate with physical characteristics such as sex and age, but not with height. However, Hull (2008) concluded that there was no consistent diet difference between the sexes across different regions in southern England, namely Hampshire, Norfolk, and Suffolk. In general, males had higher $\delta^{15}N$ values than females in Hampshire, but it was the opposite in Suffolk, while there was no clear sex difference detected in Norfolk and Oxfordshire.

Regarding age, Mays and Beavan (2012) argue that there was a correlation between age and $\delta^{15}N$ values of 38 male individuals from 18 sites in early Anglo-Saxon England. Those whose ages at death were between 30 to 49 years had higher $\delta^{15}N$ values than those who died between 18 and 29 years, suggesting a diet shift in the course of life only applicable to males. However, considering the turnover rate of collagen of adult cortical bone (see section 4.1), the diet shift of those over 30 years old possibly started during adolescence or early adult life instead of around the age of 30. An alternative explanation by Mays and Beavan (2012) is that individuals with higher $\delta^{15}N$ values had a better chance to have a longer life than others. Again, the sample size is small and the male individuals are from various sites, which affects the credibility of the significance.

Still, a difference between adult and children was observed among individuals analysed by Hull (2008). Many youths and juveniles had $\delta^{15}N$ values 1 ‰ lower than adults from the same sites, and the explanation adopted by Hull (2008) is that it may be due to metabolic differences. However, Waters-Rist and Katzenberg (2012) analysed sub-adults aged between seven and 19 and concluded that they did not show significantly different $\delta^{15}N$ values compared to adults. Therefore, the difference between adult and children detected by Hull (2008) could simply be due to diet difference.

In the Upper Thames Valley, the only significant correlation regarding physical characteristics was between age and $\delta^{15}N$ values. For example, at Berinsfield, since male individuals older than 30 years of age had higher $\delta^{15}N$ values than those younger than 30 years of age, Privat et al (2002) suggest that the isotopic diet difference between male individuals older than 30 years old and younger than 30 years old reflect the age distinction between individuals buried with weapons and without weapons, at the age of 30 argued by Härke (1995: 69). However, taking into account that human bone collagen reflects the average value of all the protein intake while the bone tissues take about ten years or more to fully turn over (see section 4.1), the diet difference shown between individuals who died before 30 years old and after 30 years old does not mean the diet shift occurred at the age of 30, but may have started earlier when they were younger. Thus, the age distinction of weapon burials does not necessarily agree with the age distinction of the change in diet.

Similarly, at Butler's Field, O'Connell and Wilson (2011) argue that the mean $\delta^{15}N$ value of male individuals aged 30–35 years was statistically significantly higher than that of the rest of the males. O'Connell and Wilson (2011) also note the similarity in the age of diet shift and

the peak age for weapon burials. However, for the same reason already mentioned in the case at Berinsfield, the age of diet shift does not necessarily agree with the peak age for weapon burials at Butler's Field.

Although Hull (2008) argues that the $\delta^{15}N$ values of Anglo-Saxon individuals vary regionally like the burial style does, regarding burial rites of inhumation burials in Hampshire, Norfolk, and Suffolk, the only trait which showed some correlation with stable isotope values was body position. For example, individuals in these regions who were buried in a prone position or were decapitated had stable isotope values which were different from the individuals buried around them, suggesting that these burial traits were applied to those with different diet during their lives (Hull 2008). In addition, a consistent correlation between $\delta^{13}C$ values and individuals buried crouched on their right side was detected (Hull 2008). There were a total of 22 individuals buried in a crouched position on their right side with almost identical $\delta^{13}C$ values of around -20.5 ‰ regardless of location among Norfolk, Suffolk, and Hampshire. Hull (2008) argues that their relatively low $\delta^{13}C$ values may be due to utilising forest resources, which have depleted $\delta^{13}C$ values as a result of the 'canopy' effect, including protein sources which were fed forest resources. Interestingly, Higham (1992) argue that crouched burials may represent a surviving 'British' population within an Anglo-Saxon population. Thus, Hull (2008) argues that the distinct group of crouched burials may have been indigenous Britons following their traditional diet, which was isotopically different from the diet of the Anglo-Saxons.

Unlike Romano-British burials, Anglo-Saxon burials tend to have a wide variety of grave goods, so correlation between $\delta^{13}C$ and $\delta^{15}N$ values and presence of grave goods has been investigated at various sites. Hull and O'Connell (2011) argue that the variations in $\delta^{15}N$ values which reflect the diversity in diet may also relate to the diversity in material culture of the Anglo-Saxons, but the data available so far do not support this. For example, at Berinsfield, individuals were classified into three groups, namely 'poor', 'intermediately wealthy', and 'wealthy' by the abundance of grave goods, and individuals from the 'poor' group had higher mean $\delta^{15}N$ values than those from the other two groups (Privat et al. 2002). Privat et al. (2002) explained the difference in $\delta^{15}N$ values as the difference in source of protein: 'poor' individuals ate aquatic resources and omnivores such as pigs which can higher $\delta^{15}N$ values than herbivores, more frequently than 'wealthy' and 'intermediately wealthy' individuals did.

However, there are several flaws in this argument. Firstly, the only pig analysed from Berinsfield did not have an elevated $\delta^{15}N$ value, and was rather similar to those of herbivores, suggesting that the pig had a herbivorous diet instead of an omnivorous diet. Therefore the argument that the elevation of $\delta^{15}N$ values was caused by eating omnivorous pigs does not hold for Berinsfield. Clearly, more animal data are needed to confirm whether pigs at Berinsfield had a herbivorous diet. Secondly, the statistical tests used to prove the significance of the difference were not appropriate. The statistical tests applied to verify the difference of mean $\delta^{15}N$ values of the three wealth groups was the two-sample t-test (Privat et al 2002), which can be problematic when there are more than two sample groups because applying two-sample t-test multiple times will increase the possibility of a Type I error — rejecting the null hypothesis when it is actually true (Kranzler and Moursund 1999: 86, 105). Therefore, the two-sample t-test is not the best choice in this case where there are three

groups. In addition, Shapiro-Wilk tests by the present author show that none of the $\delta^{15}N$ values of the three groups was normally distributed. Therefore, non-parametric tests should have been used. To statistically confirm the difference of the three groups, a Kruskall-Wallis test was applied here to the dataset, with the resulting p-value being larger than 0.05, indicating that the difference was not statistically significant. In conclusion, the argument by Privat et al. (2002) that the group with poor grave goods was different from the other two groups cannot be statistically confirmed.

Equally, O'Connell and Wilson (2011) categorised the individuals at Butler's Field into four groups — 'poor', 'intermediate', 'wealthier' and 'wealthy' — depending on their grave goods, especially weapons for males and brooches for females, but other objects as well which were listed in the wealth ranking of grave goods by Boyle et al. (1995). All groups have overlapping $\delta^{13}C$ and $\delta^{15}N$ value ranges, and unsurprisingly there was no statistically significant correlation between wealth and diet of the individuals. In addition, following Härke's (1995) argument that individuals buried with weapons in the Anglo-Saxon period belonged to a different population from the indigenous people, O'Connell and Wilson (2011) analysed the correlation of male burials between stable isotope values and the possession of weapons at Butler's Field. Although the individuals buried with weapons were isotopically different from those buried without weapons, the difference was not consistent throughout the phases and too slight to be statistically significant.

4.6. Published Stable Isotope Data of Tooth Enamel Carbonate in Fauna

This section will focus on discussing enamel sequential data of cattle and sheep/goats since they are the targeted animals for this study. Most of the published data in Britain and in continental Europe are from the Neolithic period. Since there are no data from the Roman and the Anglo-Saxon period, those from the earlier periods will be explored here in order to reveal seasonal dietary changes and birth seasonality.

Seasonal Dietary Change

Neolithic cattle teeth from Romania had $\delta^{13}C$ values which had a large amplitude and showed a strong covariation with the seasonal $\delta^{18}O$ value cycle (Gillis et al. 2013). Gillis et al. (2013) suggest that their high $\delta^{13}C$ values in summer was caused by consuming C_4 plants since the site is located in a riparian and marsh environment where wild C_4 plants such as *Chenopodiaceae* sp. and *Carex* sp. grow naturally. In addition, there was individual difference in $\delta^{13}C$ values corresponding to age difference. They argue that this was caused by different ratios of C_3 and C_4 plants consumed by cattle depending on their age.

Cattle and sheep teeth at a Neolithic site at Bercy, Paris, France showed low $\delta^{13}C$ values in winter (Balasse et al. 2012 a). Balasse et al. (2012 a) attributed the low $\delta^{13}C$ values to the so-called woodland canopy effect (see section 4.2). Although this explanation contradicts the bone collagen $\delta^{13}C$ values of domestic livestock which suggest that they were eating vegetation in open areas, it agrees with the bone collagen $\delta^{13}C$ values of wild herbivores

suggesting a closed canopy environment (Drucker et al. 2008) and also with the pollen remains suggesting that there was a dense oak forest (Leroyer 1998).

However, cattle teeth at two Bronze Age sites at Irthlingborough and Gayhurst, England gave varying results (Towers et al. 2011). On the one hand, some cattle showed a straightforward correlation between $\delta^{13}C$ and $\delta^{18}O$ value sequences, which can be explained as the enamel $\delta^{13}C$ values reflecting the seasonal variation in plant $\delta^{13}C$ values (Towers et al. 2011). On the other hand, some cattle showed an inverse correlation between $\delta^{13}C$ and $\delta^{18}O$ value sequences. Towers et al. (2011) argue that this may have been caused by the seasonal movement of cattle, for example to the shaded woodland from the open grassland in the summer. An alternative explanation by Towers et al. (2011) was that it could have been caused by seasonal variation in the plant species and plant parts available for them to consume. They argue that this may be a consequence of a managed diet of cattle by human herders.

More cattle tooth enamel from various British sites in different periods were analysed by Towers et al. (2013); cattle from Pool, Orkney dated to the Scandinavian Interface period (c. AD 800 – c. AD 950); cattle from Mine Howe, Orkney dated to the Iron Age (c.AD100 – c.AD 400); and cattle from Grimes Graves, Norfolk dated to the Middle Bronze Age (c.1100 BC). These $\delta^{13}C$ value sequences show individual difference depending on the time when tooth enamel formed. For example, the $\delta^{13}C$ value sequences of two out of five middle Bronze Age cattle at Grimes Graves (GG839 and GGT10) have higher $\delta^{13}C$ values in their M3s than in their M2s (Figs. 4.3 and 4.4). The $\delta^{13}C$ values of two other cattle (GG614 and GG120) show an increase in the latter half of their M2s but their M3s were not analysed (or not available) so it is uncertain whether the increase in $\delta^{13}C$ values continued while their M3s were formed (Figs. 4.5 and 4.6).

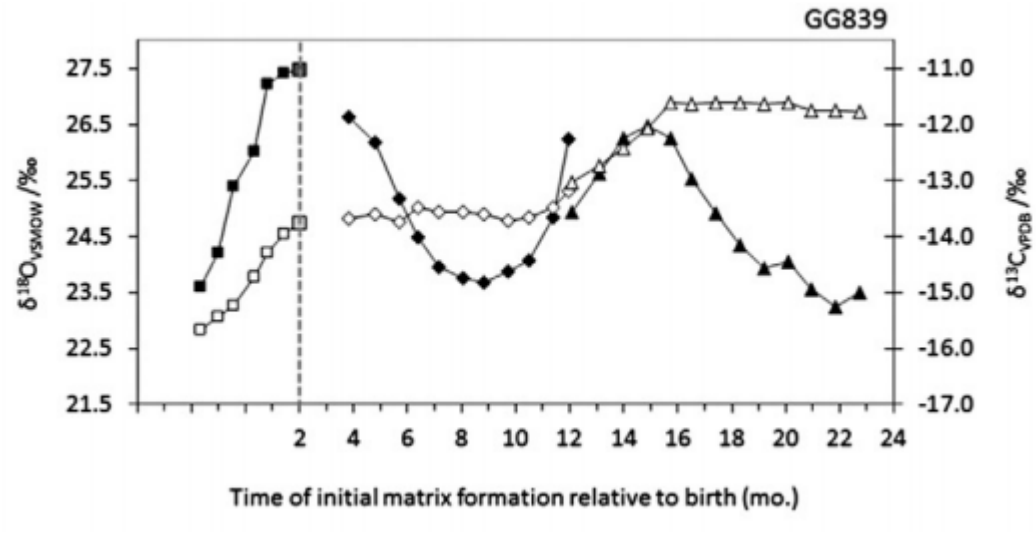


Fig. 4.3 Sequential enamel carbonate data of GG839 (Bronze Age cow at Grimes Graves) from Towers et al. (2013); x-axis: time relative to birth in months, y-axis: right: $\delta^{13}C$ values, left: $\delta^{18}O$ values, white markers: $\delta^{13}C$ values, black markers: $\delta^{18}O$ values, square: M1, diamond: M2, triangle: M3

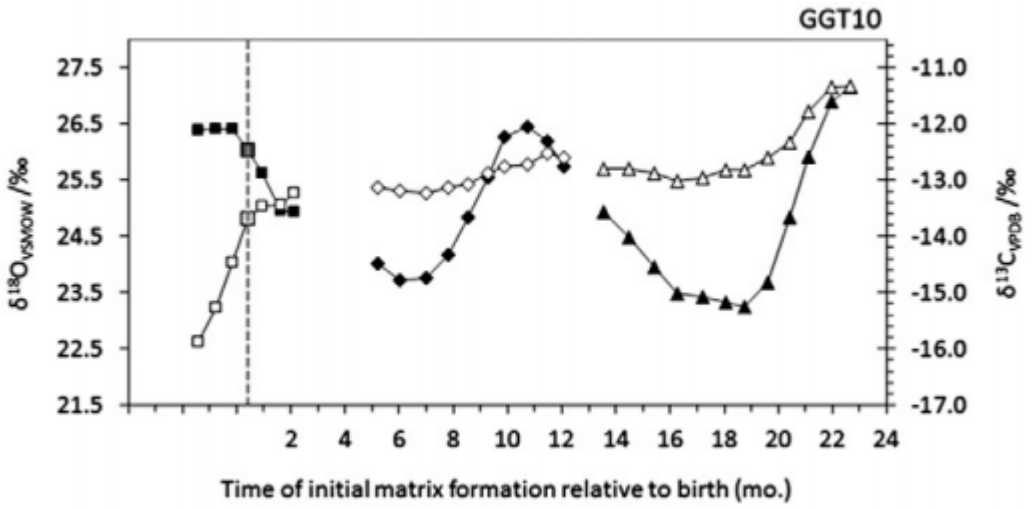


Fig. 4.4 Sequential enamel carbonate data of GGT10 (Bronze Age cow at Grimes Graves) from Towers et al. (2013); x-axis: time relative to birth in months, y-axis: right: $\delta^{13}C$ values, left: $\delta^{18}O$ values, white markers: $\delta^{13}C$ values, black markers: $\delta^{18}O$ values, square: M1, diamond: M2, triangle: M3

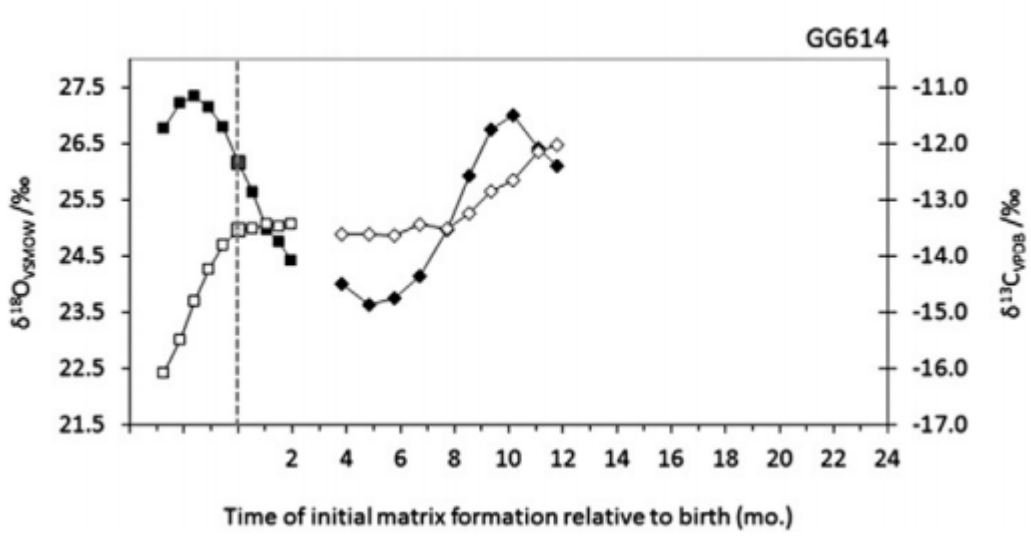


Fig. 4.5 Sequential enamel carbonate data of GG614 (Bronze Age cow at Grimes Graves) from Towers et al. (2013); x-axis: time relative to birth in months, y-axis: right: $\delta^{13}C$ values, left: $\delta^{18}O$ values, white markers: $\delta^{13}C$ values, black markers: $\delta^{18}O$ values, square: M1, diamond: M2, triangle: M3

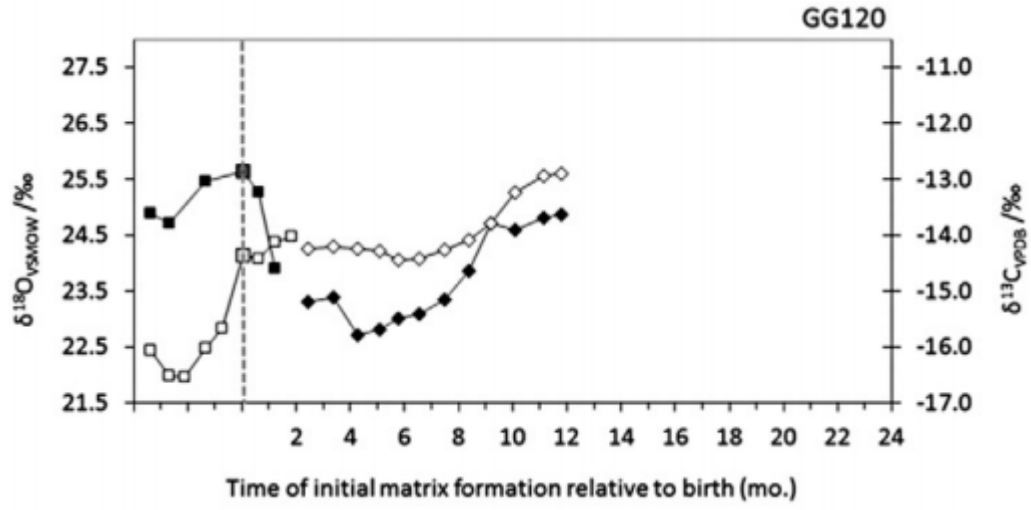


Fig. 4.6 Sequential enamel carbonate data of GG120 (Bronze Age cow at Grimes Graves) from Towers et al. (2013); x-axis: time relative to birth in months, y-axis: right: $\delta^{13}C$ values, left: $\delta^{18}O$ values, white markers: $\delta^{13}C$ values, black markers: $\delta^{18}O$ values, square: M1, diamond: M2, triangle: M3

Birth Seasonality of Cattle

The length of birth season of Neolithic cattle at Bercy, Paris France, deduced from nine M3 teeth, was six months (Balasse et al. 2012 a). This birth season is much longer than that of modern primitive breed cattle which were from May to July in Normandy and from May to June in Scotland, both spanning over two to three months (Lecomte and Le Neveu 1986, Reinhardt et al. 1986), This long birth season at Bercy which probably made cow milk available for a whole year, may have been enabled by food supplementation by humans to meet the nutritional demand of having an extended birth season. Moreover, cattle at two Bronze Age sites at Irthlingborough and Gayhurst, England showed a large range in birth seasons, which was concluded that calves were born throughout the year (Towers et al. 2011). However, since Towers et al. (2011) did not apply any sequence modelling methods, the birth season was not specified.

In contrast, the birth season deduced from five M3s of Neolithic cattle from Knap of Howar, the Orkney Islands, Scotland was two months, much shorter than that at Bercy (Balasse et al. 2012 a). Balasse et al. (2012 a) argue that the short birth season at Knap of Howar may be due to the severe climate resulting in restricting the suitable birth period, or resulting in early deaths of calves which were born outside of the ideal season before their M3 formed in their second year after birth (Brown et al. 1960).

Birth Seasonality of Sheep

At a Neolithic site at Bercy, Paris, France, the length of the birth season of sheep deduced from five M2 teeth was three to four months (Balasse et al. 2012 a), and their timing of birth season was similar to that of the modern Shetland cross breed sheep from the Orkney Islands, Scotland — between the end of April and the beginning of May (Balasse et al. 2012 b).

However, there are sites where the birth season of sheep was earlier. For example, the birth season of sheep deduced from M3 teeth from an Early Neolithic site at Măgură-Bodul lui Moş Ivănuş in southern Romania was late winter (Balasse et al. 2013). Similarly, at a Neolithic site at Collet-Redon, south-east France, four sheep had similar $\delta^{18}O$ value sequences as modern sheep born in January and February (Blaise and Balasse 2011). The sheep at Collet-Redon were born at about the same time as traditionally bred sheep in the modern day Mediterranean region (Blaise 2006, Halstead 2005, Helmer et al.2005), but earlier than wild caprines such as mouflons living in the same area today, whose birth seasons are from spring to early summer and mainly in April (Garel et al. 2005). This may suggest that the birth season of sheep shifted as a result of domestication (Lincoln et al. 1990, Thiéry et a. 2002). The shift in birth season of domestic sheep compared to wild species agrees with the argument that the timing of birth season between wild and domestic species as well as among different domestic breeds vary even at a similar latitude as a consequence of pressure due to selection and herding strategies in the course of domestication (Lincoln et al. 1990).

Exceptionally, one Eneolithic (Chalcolithic) sheep from Cheia, Romania showed a birth season in autumn, in contrast to the rest of the sheep which were born between late winter and early summer (Tornero et al. 2013). Autumn born sheep are not common due to the adverse condition in the following winter, and their survival highly depends on their nutrition level (see Chapter 2), suggesting that the sheep at Cheia were well fed.

Notably, compared to the birth season of modern free ranging unimproved Shetland sheep without breeding control observed in Normandy, France, which were from mid March to late April (Lecomte and Le Neveu 1986), the birth seasons of the Neolithic sheep are longer except for the early Neolithic sheep at Măgură-Bodul lui Moş Ivănuş in southern Romania. This may suggest that the birth season of Neolithic sheep was extended by human management. Extended birth season is beneficial for milk production (see Chapter 2), so it may possibly be the case that milk production was an important purpose for rearing sheep in the Neolithic period.

4.7. Summary

In this chapter, the principles of stable isotope analyses of collagen and enamel carbonate were explained, followed by a discussion of published data in order to later compare with the data acquired from Horcott.

Regarding collagen data in the Upper Thames Valley, herbivores from the Romano-British and Anglo-Saxon period did not show a sharp change in stable isotope values. Pigs showed both inter- and intra- site differences in the level of omnivorous diet in the Romano-British period, but the Anglo-Saxon pigs mostly had a herbivorous diet. Humans showed a wider variety in $\delta^{13}C$ values in urban sites which may reflect the higher amount of non-local imported food consumed by the townspeople. However, although more subtle, there were also site-dependent variations in human data among rural sites.

In addition, there was site-dependent difference in correlation between stable isotope data and physical and burial characteristics. At Horcott, intra-site difference in $\delta^{13}C$ and $\delta^{15}N$ values were detected which correlated with various burial rites such as the number of burials, the orientation of burials, body position, and decapitation.

Moreover, it has been argued that there was a systematic difference in diet between the Late Romano-British and Anglo-Saxon periods, due to the difference in the availability of non-local food, but the rural sites experienced little change in diet between the two periods. Correlation between diet and age and grave goods of individuals have been argued in some Anglo-Saxon sites, but most of them did not show a strong statistical significance.

Since tooth enamel carbonate data were not available from the Roman period and the Anglo-Saxon period, data from other periods were discussed. Seasonal change in diet were detected, but there were also inter-site and intra-site variations.

The birth seasons of cattle became longer than primitive species already in the Neolithic period, suggesting that humans were already consciously extending the birth season at an early stage after domestication probably in order to improve milk availability. Similarly, the birth season of Neolithic sheep was already different from wild species. Some were earlier than wild species, and others were longer than primitive species, suggesting that humans also managed the birth seasons of domestic sheep in order to maximise their benefits.

Chapter 5. Materials and Methods

In this chapter, the archaeological background of the site and the materials selected for this study will be explained first. Then, the sampling strategies and the overall characteristics of the sampled assemblage are explained. Finally, the methods used to produce the data are explained.

5.1. Selected Site: Horcott

The site at Horcott Quarry was chosen over two other contemporaneous sites which were initially also considered for analyses, Tubney and Shakenoak, because unlike the other two, there were animal remains as well as human remains from both Romano-British and Anglo-Saxon Horcott. In this section, the archaeological evidence at Horcott showing human activity in the late Romano-British and the Anglo-Saxon period will be explored.

Horcott is located about 1km south of Fairford, Gloucestershire, to the west of the river Coln (Fig. 5.1). The nearest Romano-British town is Cirencester, which is located about 14 km north-west of Horcott. Horcott is on the Second Gravel Terrace of the river which consists of sand and limestone gravels (Hayden et al. forthcoming). The excavation was carried out by Oxford Archaeology between April 2007 and April 2008. The archaeological features were excavated by hand. The excavation report is being prepared for publication and the information related to this study is extracted from the report and described below.

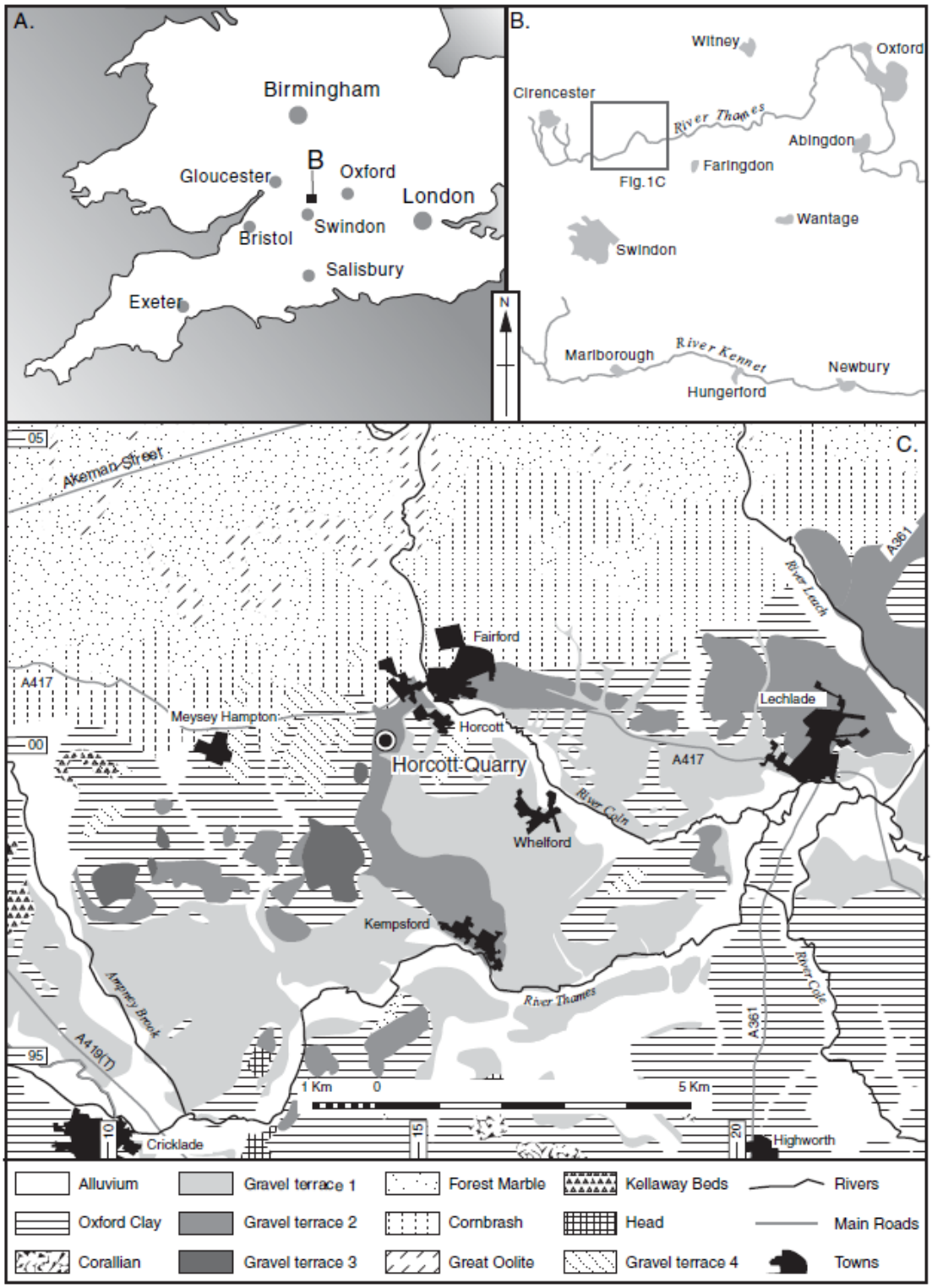


Fig. 5.1. Location of Horcott from Hayden et al. forthcoming.

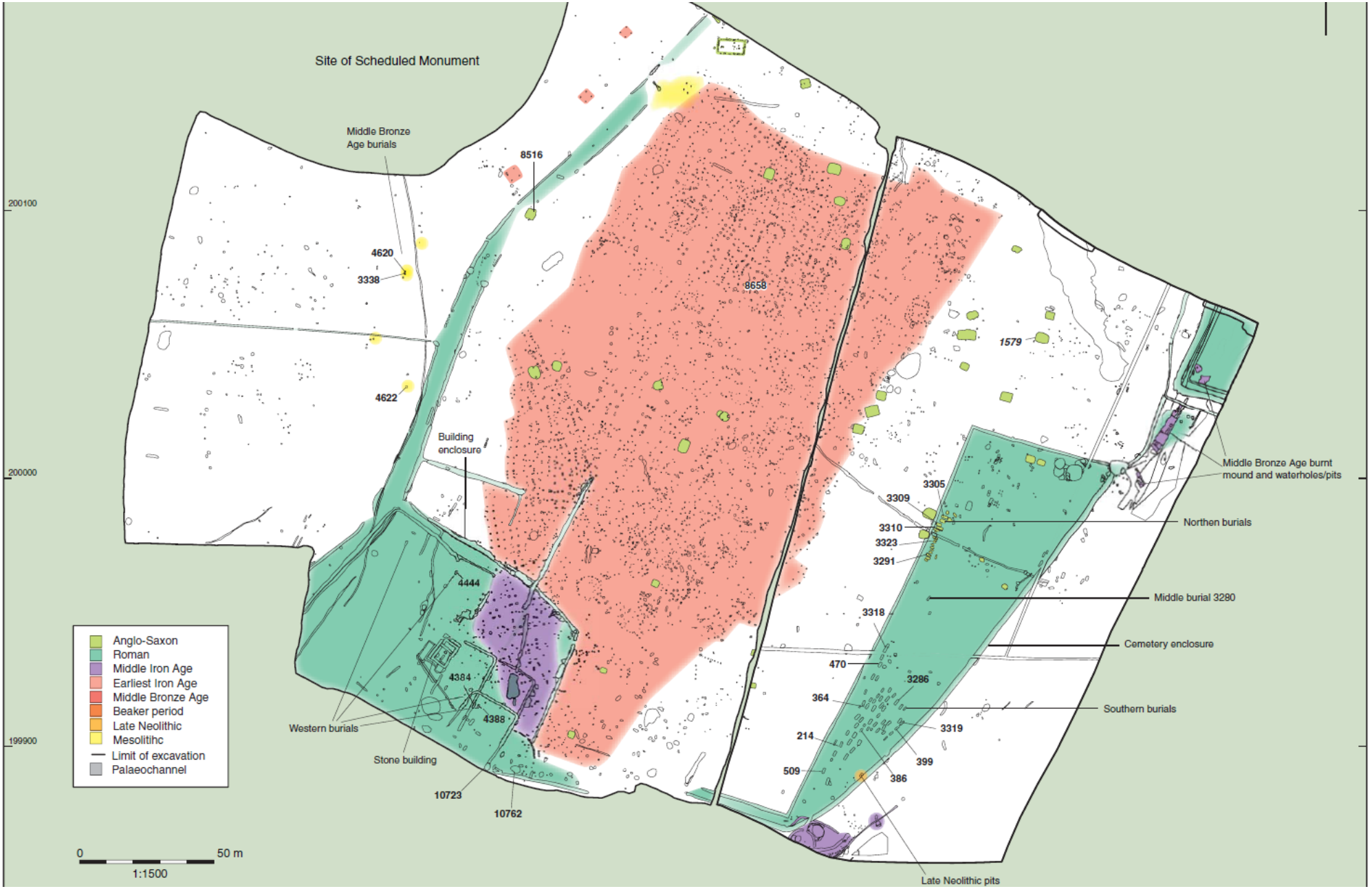


Fig. 5.2. Site plan of Horcott from Hayden et al. forthcoming.

5.1.1. Horcott: the Romano-British Period

5.1.1.1. The Settlement

There are four phases in the Romano-British period at Horcott (Hayden et al. forthcoming):

Phase 1: 100–150 AD

Phase 2: 150–250 AD

Phase 3: 250–350 AD

Phase 4: 350–400 AD

The only building dated to the Romano-British period is the Roman villa style part-masonry building (Fig. 5.3). Smith (in Hayden et al. forthcoming) argues that compared to the contemporaneous villa sites in the region, it was too modest to be classified as a villa. There were notable finds such as Samian ware, a fine table ware from southern Gaul, but Smith (in Hayden et al. forthcoming) argues that the number and types of archaeological finds were limited in general and concludes that it was not a permanent residential site, although it seems rather unusual to build a building with a stone base without the intention of living on a permanent basis. Nevertheless, the quantity of artefactual evidence suggests that the level of human activity was not high. The building is assigned to Phase 1 and 2.

Pollen and waterlogged remains from a waterhole associated to Romano-British Phase 1 or 2 indicate that the vegetation at Horcott was grassland and arable fields with some trees typical of open forests (W. Smith in Hayden et al. forthcoming) (see Chapter 7 for related discussion).

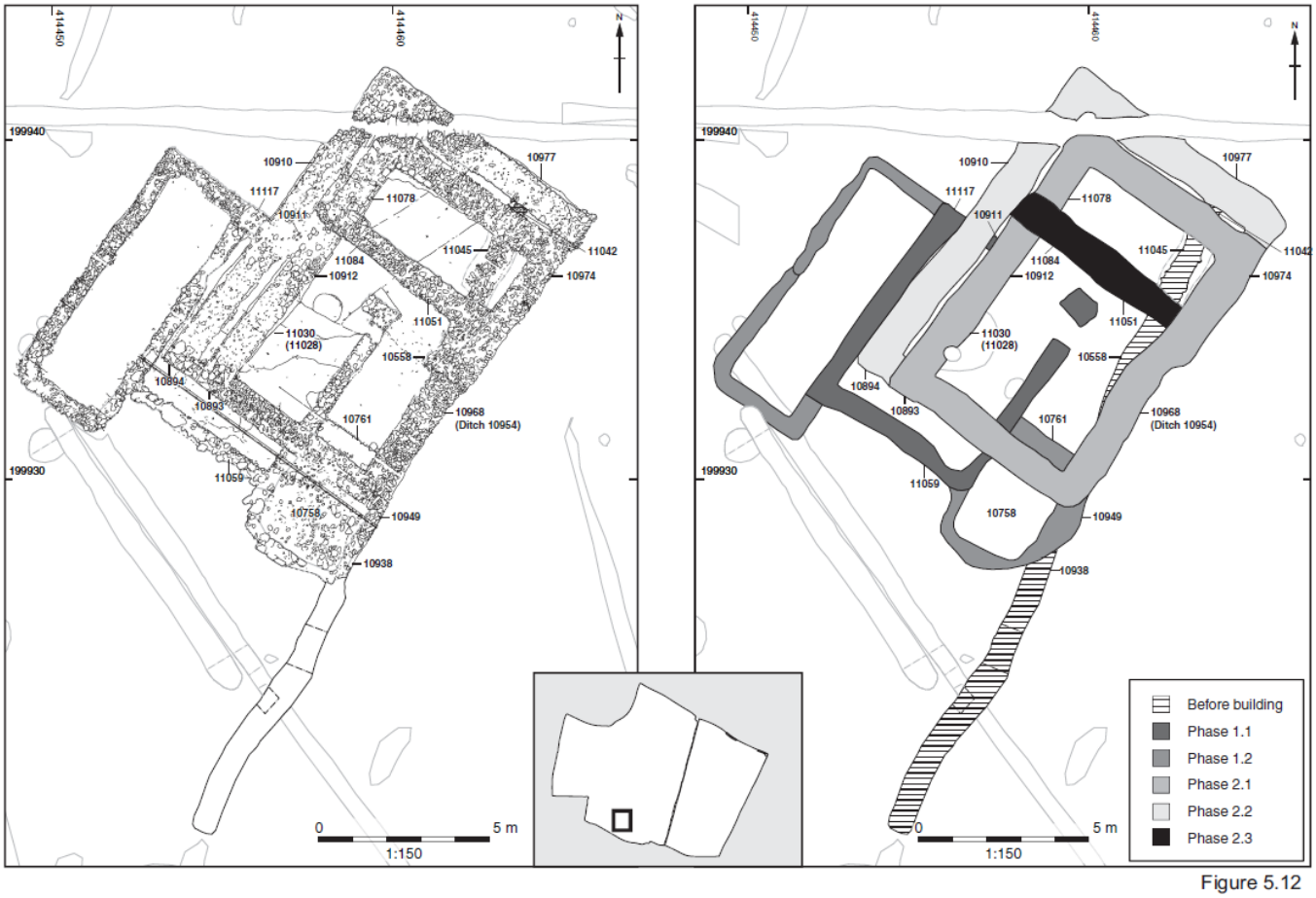


Fig. 5.3. Plan of Roman villa style part masonry building at Horcott from Hayden et al. forthcoming

Animal bones were more frequently found from pits than ditches (Hayden et al. forthcoming: Table 11.2). Among the bones identified to species, the most abundant species was horse (539 fragments), of which 528 fragments were from a semi-articulated horse skeleton. The second most abundant species was sheep/goat (23 fragments) followed by pig (17 fragments), cattle (13 fragments), dog (four fragments) and frog (one fragment) (Hayden et al. forthcoming: Table 11.1). As already mentioned in Chapter 3, there were no bird bones.

As described in detail in Chapter 2, the slaughter pattern deduced from the mortality profile by tooth eruption and wear of cattle was not reliable due to its small sample size. The

slaughter pattern of sheep/goats show that they were killed annually for various purposes, while that of pigs show that they were all killed for meat earlier than 2.5 years and more than 50% were killed by one year after birth. Since only the youngest pig had no wear on the first molar, eating suckling pigs was not common at Romano-British Horcott.

The semi-articulated horse skeleton was identified by Strid (in Hayden et al. forthcoming) as a 3–6 year old mare. There was no evidence of skinning or butchery. There were also a small amount of pottery and animal bone inside the pit. The pit had very steep sides and may have been dug specifically for the horse burial, although other explanations are possible. Strid (in Hayden et al. forthcoming) argues that it is possible that the horse burial had a ritual significance, but it could also be a mere disposal of livestock not regarded as being fit for consumption.

Among the limited number of animal bones, all livestock were overrepresented by bones from the head and feet, while the meat-rich body parts were underrepresented. Strid (in Hayden et al. forthcoming) argues that the animal assemblage found was possibly primary butchery waste discarded in waste pits, while the remains of meat-rich body parts after consumption may have been dumped on a midden or a dung heap and later scattered on the fields for fertilisation, but it seems odd if bone remains after meat consumption were used for fertilisation but other butchery waste was not. If the number of head and foot bones of cattle, sheep/goats and pigs was much larger, it may suggest that the Horcott was a butchery site and the inhabitants exported the meat-rich body parts. However, since this is not the case, it is more likely that the animals at Romano-British Horcott were kept for daily use and consumption. Beetles (Coleoptera) associated to animal dung were identified from Romano-British contexts (D.N.Smith in Hayden et al. forthcoming), indicating that the livestock grazed on site (see Chapter 7 for related discussion).

As discussed in Chapter 2, the animal bone assemblage does not indicate that livestock were exported or imported, suggesting that it was a self-sufficient rural site (Strid in Hayden et al. forthcoming). Thus, animal husbandry practices at Romano-British Horcott were not significantly affected by the demands of the Roman market economy and the occupants of Horcott were not involved in the trade of their livestock.

As mentioned in Chapter 3, oyster shells, a stone pine nut shell, and a rim of an amphora for olive oil were found from Romano-British contexts (Lodwick and Challinor in Hayden et al. forthcoming, Booth in Hayden et al. forthcoming). These pieces of evidence of imported non-local food at Romano-British Horcott suggest that the inhabitants were familiar with Roman style eating habits, but compared to urban sites and more elaborate villas, the quantity and variety of non-local food were scarce, suggesting that the diet at Horcott was only partially Romanised. This also suggests that Horcott was not fully incorporated into the market economy to have a wider variety of non-local food in the Romano-British period.

5.1.1.2. The Cemeteries

Two cemeteries are dated to the Romano-British period (Hayden et al. forthcoming). The western cemetery located close to the Roman villa is dated to Phase 2 and has seven burials (Fig. 5.4). The buried individuals were five female adults, one male adult, and one child. The graves are orientated north-south except for one female adult which was orientated east-west. Most individuals were laid in a supine position except for the male adult. There were no grave-goods except for hobnails presumably from foot wear such as boots.

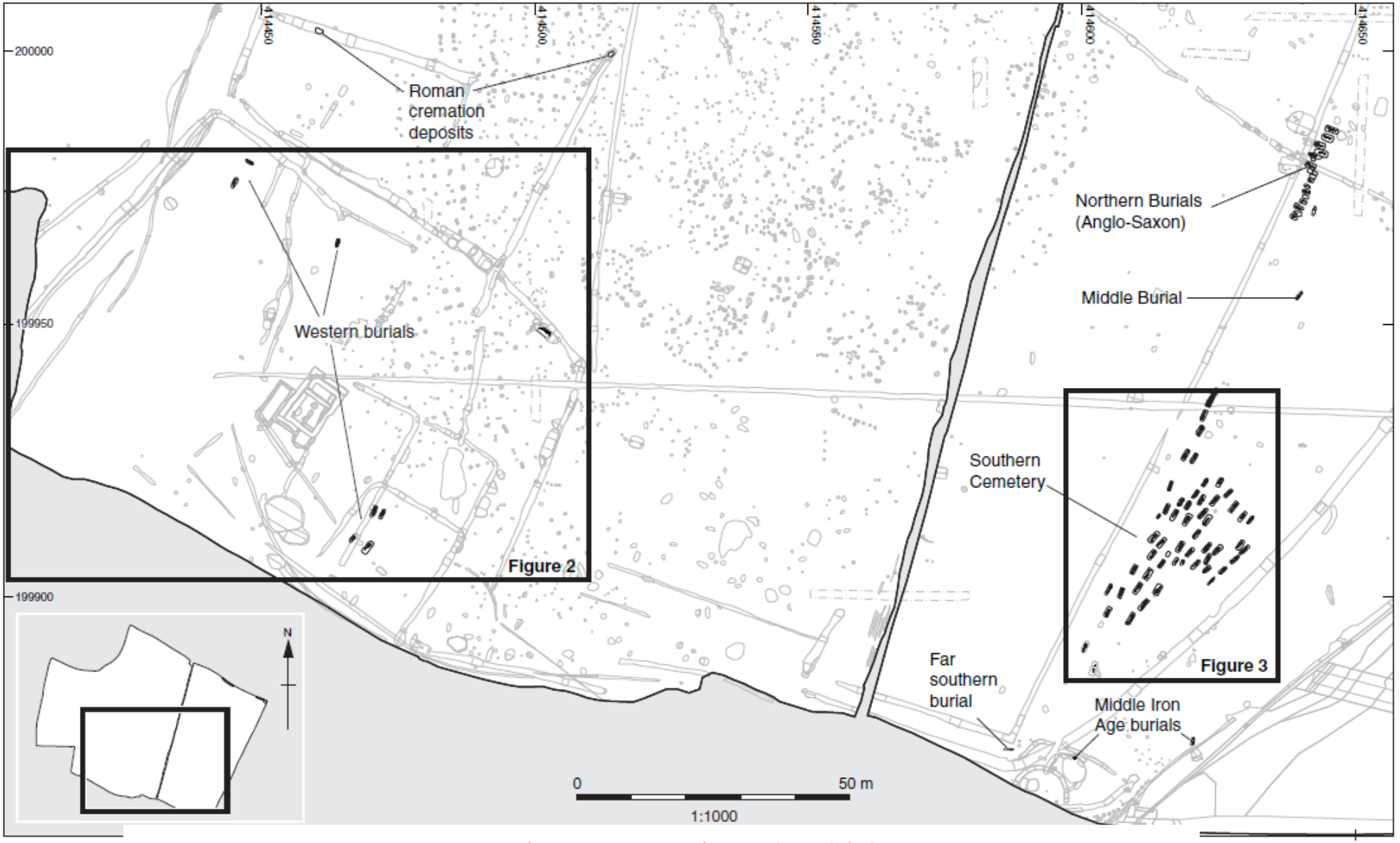


Fig. 5.4 Location of cemeteries at Horcott from Hayden et al. forthcoming.

The southern cemetery has burials of 52 adults, one adolescent, one child and two infants (Hayden et al. forthcoming). Individuals younger than adults, especially infants, are under-represented (Fig.5.5). Thirty individuals were identified as male and 22 as female, and most graves are orientated north-south (Fig. 5.6). They are all single burials except for one multiple burial of three male adults and three young female adults each buried with neonates. There are 13 prone burials while the rest were buried in a supine position, and seven individuals were decapitated with their skulls in various positions. Thirteen individuals were buried with nails and one individual was associated with a stain in the soil, both indicating the presence of coffins. Grave goods are scarce. The examples of grave goods are: charred plant remains, a knife, a copper alloy finger ring, copper alloy armlets, and hobnails found near the feet presumably from foot wear such as boots. The southern cemetery was assigned to Phase 3 based on radiocarbon dates from skeletons.

The western cemetery seems to be contemporaneous with the period when the building was in use in the second and third centuries AD (Smith in Hayden et al. forthcoming). However, the southern cemetery dated to the third and fourth centuries AD seems to have been in use even after the evidence of human activity at the settlement ceased by the end of the third century or possibly early in the fourth century AD.

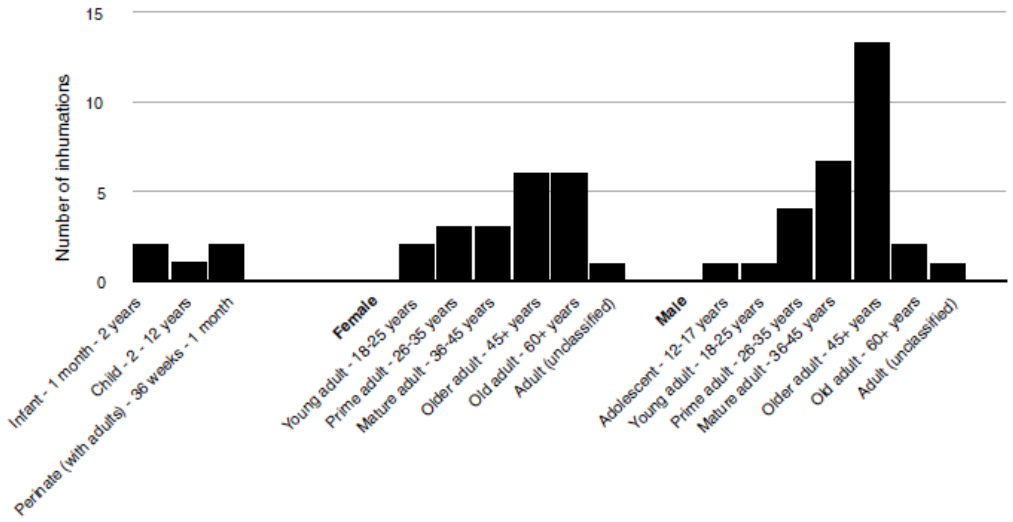


Fig.5.5 Age distribution of inhumations from the southern cemetery at Horcott from Hayden et al. forthcoming.

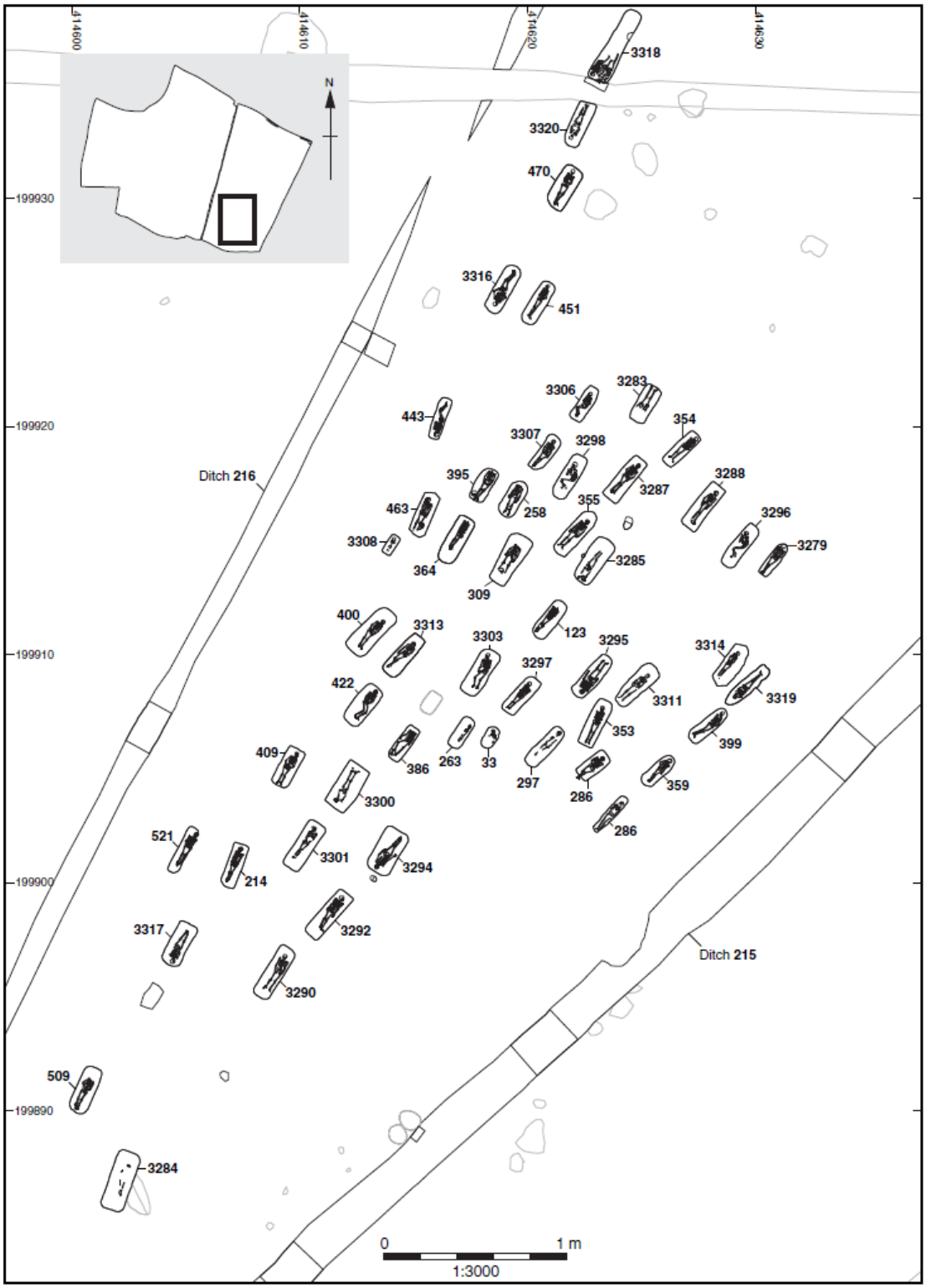


Figure 6.3: Overall plan of the southern burials

Fig. 5.6 Plan of the southern cemetery at Horcott from Hayden et al. forthcoming.

5.1.2. Horcott: the Anglo-Saxon Period

5.1.2.1. The Settlement

34 Sunken Feature Buildings (SFBs) and a rectangular timber hall were found, which are both characteristic buildings of the Anglo-Saxon period (Figs. 5.7 and 5.8) (Hayden et al. forthcoming). Most of the Anglo-Saxon pottery was recovered from SFBs, and was dated to a period between the fifth and the eighth century AD. However, the majority of pottery dates between the later fifth and seventh centuries (Hamerow pers.comm.). One SFB (5255) contained pottery sherds probably from the eighth to the 11th century AD, but they are likely to be intrusive, since SFBs dating to the eighth century or later have not been reported (Hamerow pers.comm.). Two crop-drying ovens associated with charcoal and charred grain were also dated to the Anglo-Saxon period because they were built across a Roman trackway (Hayden et al. forthcoming).

A waterhole associated to Romano-British Phase 4 or early Anglo-Saxon period yielded waterlogged plant remains and limited insect remains suggesting continuity of the environment, open grassland or pasture as well as arable fields and without trees (W. Smith, D.N. Smith in Hayden et al. forthcoming) (see Chapter 7 for related discussion).

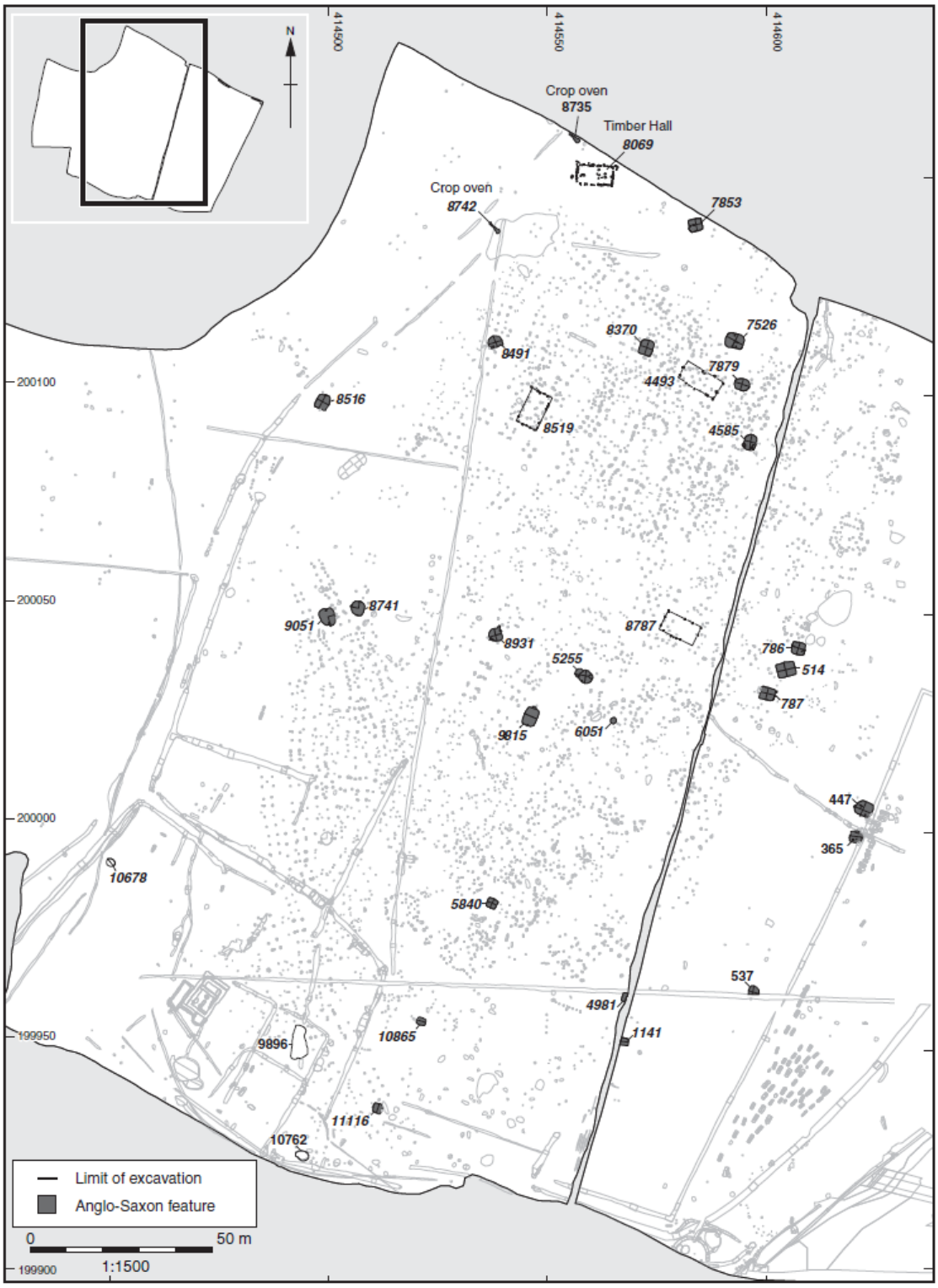


Figure 7.1a: Overall plan of Anglo-Saxon occupation

Fig. 5.7 Plan of Anglo-Saxon features in the western area at Horcott from Hayden et al. forthcoming.

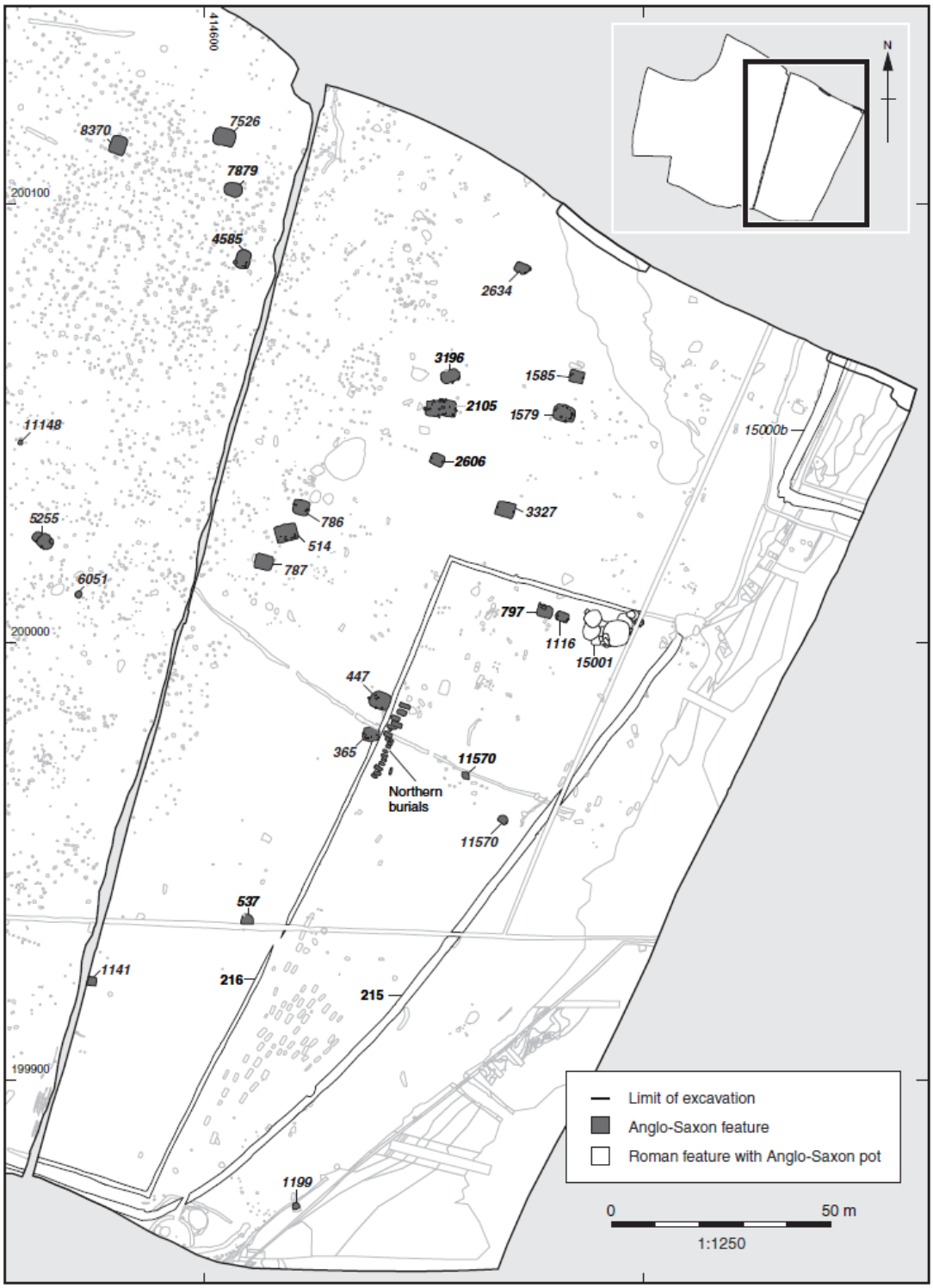


Figure 7.1b: Overall plan of Anglo-Saxon occupation

Fig. 5.8 Plan of Anglo-Saxon features in the eastern area at Horcott from Hayden et al. forthcoming.

Animal bones were all found from SFBs, probably deposited as waste after the structures were out of use (Hayden et al. forthcoming: Table 11.2). Bone from all body parts were present, suggesting that the bone recovery rate was not strongly biased by the slaughter and butchery process. Among the bones identified to species, the most abundant species was cattle (415 fragments) followed by horses (283 fragments), sheep/goats (176 fragments), pigs (74 fragments), cats (35 fragments), domestic fowl (35 fragments), red deer (12 fragments), rabbits (11 fragments), geese (10 fragments), dogs (seven fragments), passerines (two fragments), and hares (one fragment) (Hayden et al. forthcoming: Table 11.1). The red deer fragments were all antlers, possibly collected after shedding for craftwork. Strid (in Hayden et al. forthcoming) argues that the rabbit is probably intrusive, since they were not common in Britain until they were introduced by the Normans (Sykes 2007 d: 80–83). As described in detail in Chapter 2, the slaughter pattern show that cattle were killed annually with peaks at around 1.5 years and older than three years. This pattern is similar to that at early Anglo-Saxon West Stow, a self-sufficient or rural producer site. Sheep/goats were killed annually for various purposes as in the Romano-British period, with 40% of sheep/goats were killed in their first year, also a similar pattern to that of early Anglo-Saxon West Stow. The slaughter pattern of pigs were similar to that of Romano-British period, all being killed for meat before the age of 2.5 years.

Most horses were adults apart from three unfused horse bones, possibly from the same individual, of which one was aged as 1–1.5 years and the other two aged as younger 3.5 years respectively. The presence of young horses suggest that horses were bread on site.

Only a limited number of bones were sexed, and there were more females than males (Hayden et al. forthcoming: Table 11.5). Regarding the cattle and sheep/goat bones which were measurable, the size was within the size range from contemporaneous British sites in

the ABMAP database (University of Southampton 2003) (Hayden et al. forthcoming: Table 11.6).

Butchery marks were few, but those identified were similar to the patterns observed in other contemporaneous sites (O'Connor 1982: 16–8, 24–5, 34, Sykes 2007 d: 45–6, 88).

Pathological conditions of some cattle bones show symptoms caused by traction, while other cattle and sheep/goat bones show conditions of infection, such as exostoses, spavin, and osteophytes.

Cattle skulls were found at the base of two SFBs, which may have been deliberately placed. Strid (in Hayden et al. forthcoming) argues that the placement of skulls in foundation deposits before abandoning and deliberately backfilling may be a ritual act, although she notes that other plain explanations are also possible.

Overall, as in the Romano-British period, faunal evidence in the Anglo-Saxon period shows that Horcott was a self-sufficient rural site. Beetles (Coleoptera) identified at Horcott from Anglo-Saxon contexts indicate the livestock were grazing on site (D.N.Smith in Hayden et al. forthcoming) (see Chapter 7 for related discussion).

As discussed in Chapter 3, there was no evidence of non-local food from Anglo-Saxon contexts. Unlike the Romano-British period, the foodstuffs at Horcott were limited to locally available sources, which seems to correspond with the lack of market economy in early Anglo-Saxon Britain.

5.1.2.2. The Cemetery

There is a third cemetery to the north of the Romano-British southern cemetery. The radiocarbon dating of five individuals suggested that there were two phases in the Anglo-Saxon period (Hayden et al. forthcoming):

Phase 1: 400–550 AD

Phase 2: 600–700 AD

The northern cemetery burials were all aligned in a west-east direction except for one burial orientated in a north-south direction (Fig.5.9). In addition, Phase 2 burials had their positions slightly protruding towards the west compared to Phase 1 burials. Phase 1 burials consist of three female adults of old age, four children and five infants, while Phase 2 burials consist of two adolescents and one child (Fig.5.10). Some burials from Phase 1 have coffins and stone structures, whereas none from Phase 2 have them. In contrast, grave goods were found from Phase 2 burials but not from Phase 1 burials. As with the two Romano-British cemeteries, grave goods from the northern cemetery were relatively scarce (Hayden et al. forthcoming). The grave goods were Romano-British and Anglo-Saxon potsherds as well as metal objects such as iron knives and iron buckles, but there were no typical Anglo-Saxon grave goods such as weapons, brooches and accessories.

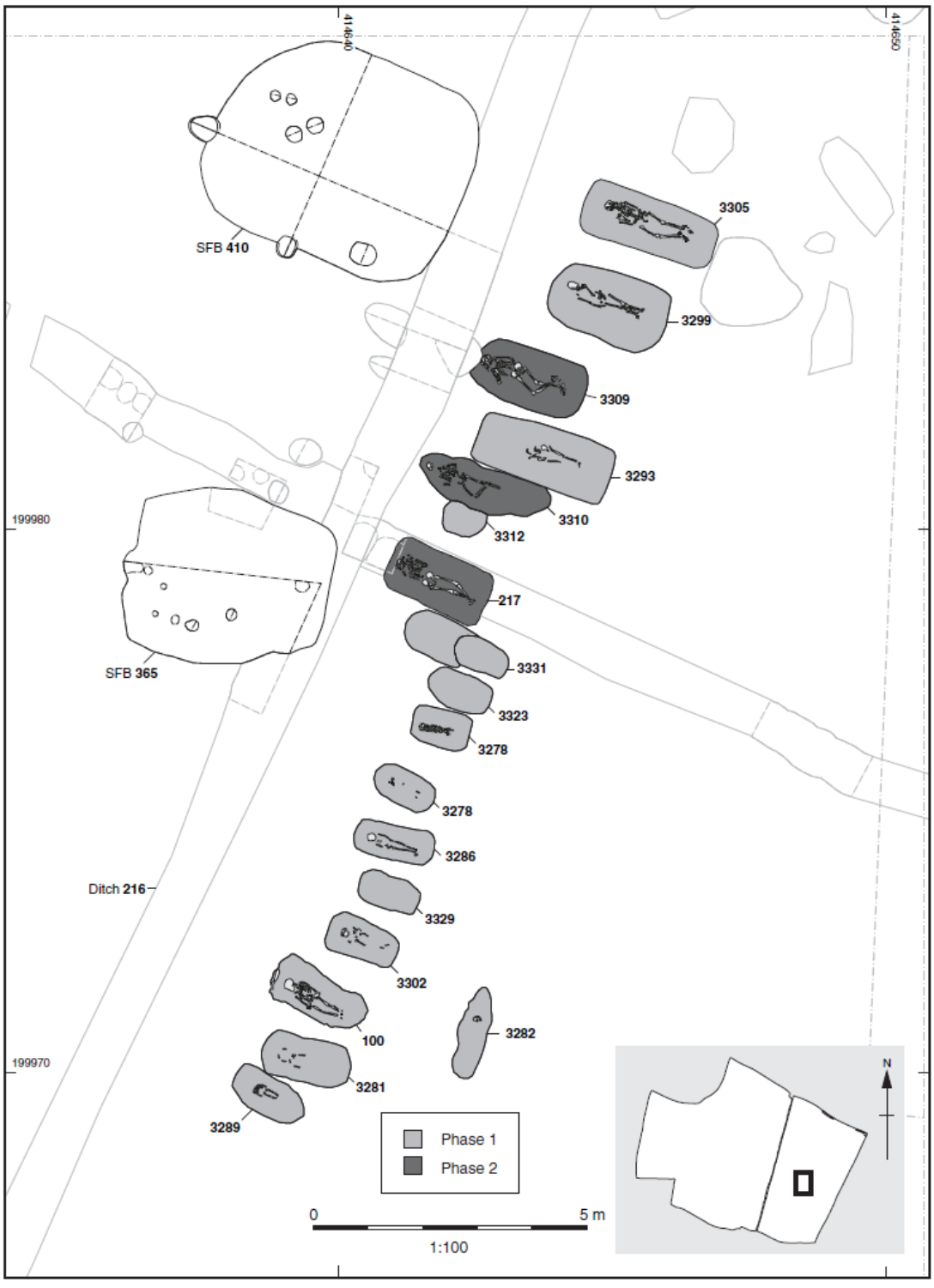


Fig. 5.9 Plan of the northern cemetery at Horcott from Hayden et al. forthcoming.

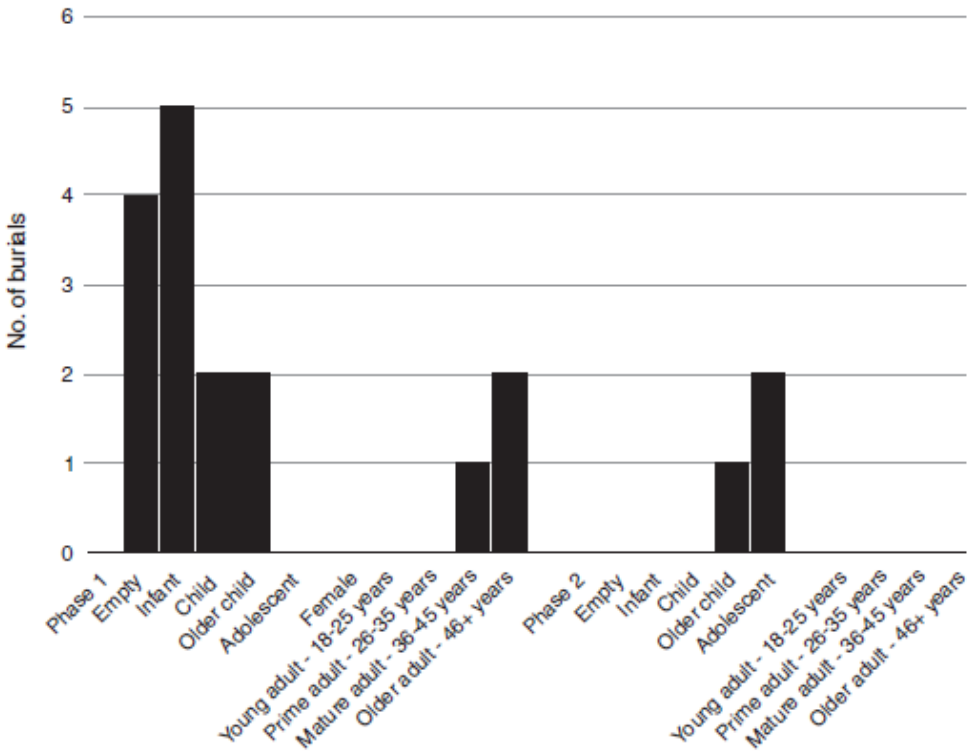


Fig. 5.10 Age distribution of inhumations from the northern cemetery at Horcott from Hayden et al. forthcoming.

5.1.3. Change or Continuity at Horcott?

At Romano-British Horcott, the architectural style of the part-masonry building show Roman cultural influence. However, animal husbandry practices did not suggest that animals were reared for market supply, so the inhabitants did not aim for livestock trading. Similarly, the limitation in the variety of imported non-local food compared to urban sites and more elaborate villas shows that Horcott did not have access to the full range of products available in the trading network. Therefore, although the inhabitants experienced the influence of Roman culture to some extent, Horcott was not fully incorporated in the market economy and was likely to have been a rural self-sufficient site.

At Anglo-Saxon Horcott, the burials from the northern cemetery burials did not obviously look different from Romano-British Phase 3 burials from the southern cemetery due to the scarcity of grave goods (Hamerow pers. comm.). It was only after the individuals from the northern cemetery were radiocarbon dated that it became apparent that the northern cemetery was used not in the late Romano-British period as presumed based on their burial custom, but later in the Anglo-Saxon period.

Similarly, waterlogged plant remains and limited insect remains suggest continuity of the environment consisting of open grassland or pasture and arable fields (W. Smith, D.N. Smith in Hayden et al. forthcoming)

In contrast, the architectural features such as the SFBs and the timber halls are different from the stone-base villa style building in the Romano-British period and clearly show the influence of Anglo-Saxon culture. Types of food available were even more confined to local resources probably due to the collapse of the Roman market economy (see Chapter 3).

In addition, cattle became the predominant species in the Anglo-Saxon period after the cessation of Romanised economy, suggesting a change in livestock preference from the Romano-British period (see Chapter 2). However, the slaughter patterns show similarity in at least sheep/goat and pig husbandry strategy (see Chapter 2).

Therefore, the burial custom and vegetation do not seem to show a change between the two periods, while human diet and livestock management practice changed to some extent, and the architecture showed a more obvious change. This may suggest that the inhabitants were partially under the influence of Roman and Anglo-Saxon material culture.

In conclusion, above, all, Horcott was a self-sufficient rural site in both periods. But there was some change as well as some continuity depending on the aspect of settlement life from the Romano-British to the Anglo-Saxon period at Horcott.

5.2. Sampled Materials from Horcott

Two types of materials were sampled. Firstly, bone collagen and tooth dentine of humans and animals were sampled for carbon and nitrogen stable isotope analyses (Table 5.1). Secondly, cattle and sheep/goat tooth enamel were sampled for carbon and oxygen stable isotope analyses. Bone and teeth from the same individuals were sampled where possible. Deciduous teeth and teeth forming during pre-weaning stage were not sampled because they are prone to suckling offsets (see Chapter 4). Cremated individuals were excluded since the heat of fire affects the composition of bones and tooth enamel.

	Early Iron Age	Romano-British (Phase 1–4)	Anglo-Saxon
Humans	n/a	11 (Phase 3)	9
Cattle	2	8 (Phase 3)	27
Sheep/goat	1	11 (Phase 2,3,4)	17
Pigs	1	8 (Phase 2,3)	9
Horses	n/a	1 (Phase n/a)	6
Dogs	n/a	4 (Phase 2,3)	2

Table 5.1 Sampled bone and dentine from Horcott for collagen analyses

5.2.1. Humans

Since humans from the southern cemetery analysed by Cheung (2009) were mainly mature and old adults, sub-adults and young adults were sampled to correct the bias of age distribution. From the northern cemetery, all individuals were sampled except for infants and

young children, because they are prone to suckling offsets and are therefore not comparable with the older individuals with respect to diet. Bone samples were taken from ribs or from femurs when ribs were not available (see Table S7 a in appendix).

5.2.2. Animals

5.2.2.1. Identification and Sampling of Animals

Bone samples of cattle, sheep/goat, pigs, horses and dogs were taken from mandibles or maxillae with teeth still attached, because the age at death could be estimated from the tooth eruption stage and tooth wear stage, and also because both bone and teeth from the same individual can be analysed. Species were identified by the author following Hillson (1992). Unfortunately no animal bone reference collection was available to the author at the time of identification. The tooth eruption stage of all animals was aged following Hillson (2005:229–242) and Schmid (1972). The tooth wear of cattle, sheep/goat and pigs were classified according to the tooth wear stage diagrams by Grant (1982, in Hillson 2005: Appendix A). The tooth wear stage diagrams were available only for mandibular teeth, thus maxillae were less precisely classified by tooth wear stage than the mandibles. Strid (in Hayden et al. forthcoming) analysed the animal bone assemblage and reported that there were 23 Romano-British sheep/goat bones but none of them were identifiable further as sheep or goats, while from the Anglo-Saxon period, 12 were identifiable as sheep and three as goats apart from 161 sheep/goat bones, although the type of bones identified were not reported (Hayden et al. forthcoming: Table 11.1). While sampling for mandibles and maxillae, the author found a few goat horn cores from the Anglo-Saxon assemblage, which what may have been identified as goats by Strid (in Hayden et al. forthcoming).

Furthermore, sheep/goat mandibles sampled for the study were differentiated between sheep and goats from their teeth by the author following Payne (1985), Halstead et al. (2002), and Balasse and Ambrose (2005). Most of the individuals showed sheep-like characteristics, apart from one Romano-British individual (ROM sg 8) and five Anglo-Saxon individuals (SAX sg 2, SAX sg 5, SAX sg 6, SAX sg 12, and SAX sg 13) identified as possibly goat from their third and fourth premolars following Halstead et al. (2002), and another Anglo-Saxon individual (SAX sg 16) identified as possibly goat from its deciduous fourth premolar following Payne (1985).

Early Iron Age individuals were also sampled to have a longer time perspective and to see if the Romano-British period individuals were any different from those from the earlier period. All Romano-British animals derived from pits and ditches including features dated to Phases 2, 3, and 4. All Anglo-Saxon animals were found from SFBs dated between the fifth and the eighth centuries AD, although the reliability of this dating from pot sherds has been discussed above. There were several contexts with animal bones dated as Roman-Saxon, but all of these equivocal contexts were excluded from sampling to avoid distorting the results.

5.2.2.2. Sampling of Animal Teeth

Tooth enamel samples were taken from permanent premolars and molars of cattle and sheep/goat. Mandibles with complete or nearly complete sets of molars were selected so that several teeth from the same individual can be compared. In addition, individuals with less worn teeth were preferred because they provide more sampling points for sequential sampling for detecting seasonal difference. In order to avoid selecting the same individual from the same context, age and size of mandibles and shapes, sizes and wear condition of teeth were

compared with one another when selecting individuals. In total, 495 enamel carbonate samples from cattle and sheep/goats were analysed.

5.3. Sample Preparation Methods

5.3.1. Bone Collagen

Collagen was extracted from bone samples following the collagen extraction protocol based on Longin (1971). Bones were broken into small pieces and their weights were measured. First, they were left in glass test tubes with 0.5M hydrochloric acid (HCl) until they were demineralised. Next, they were rinsed in distilled water and soaked into pH 3 distilled water and left at about 75 degrees Celsius until they dissolved. The solution was filtered using 8mm EZee filters and poured into pre-weighed plastic test tubes. Then, they were freeze-dried to be dehydrated. Finally, the weight of dry collagen was measured to calculate the mass % yield of collagen. Samples with collagen yield less than 1% were rejected.

Each collagen samples with weights between 1 to 2 mg were measured into two tin capsules. Standards of alanine, USGS40, and seal bone were also measured into tin capsules. The carbon and nitrogen stable isotope values of collagen samples were measured at the University of Oxford Research Lab of Archaeology and History of Art by a 20–22 Stable Isotope Ratio Mass Spectrometer attached to a Europa EA-GSL Sample Preparation System.

Finally, all measurements of $\delta^{13}C$ (VPDB) and $\delta^{15}N$ (AIR) values were calibrated using the measured and accepted values of standards: alanine, USGS40 and seal bone. Analytical precision was ± 0.07 ‰ for $\delta^{13}C$ (VPDB) and ± 0.07 ‰ for $\delta^{15}N$ (AIR) as estimated from the relative percent difference.

5.3.2. Tooth Enamel Carbonate

Enamel carbonate was extracted from tooth enamel samples following the extraction protocol based on Sponheimer (1999). The buccal side of the tooth were selected for sampling. For permanent first molars and permanent second molars, the anterior lobe was used, and for permanent third molars, the middle lobe was used.

The teeth surface was cleaned by sandblasting and drilling. Enamel powder were drilled off by a hand-held drill with a diamond-tipped burr in 2mm wide horizontal strips across the crown pillar every 4mm from the crown cusp (which forms first) to the enamel-root junction (which forms last).

About 5mg of each enamel powder sample was weighed out. The samples were treated in 1.5ml of sodium hypochlorite (NaOCl) solution (1%) for 30 minutes and agitated a few times to remove organic matter. After reaction ceased, samples were centrifuged for two minutes and rinsed with distilled water three times. After the distilled water was removed for the third time, the samples were treated in 1.5ml of 0.1M acetic acid (CH_3COOH) to remove exogenous carbonate. They were agitated and left for six minutes. Then they were centrifuged for two minutes and rinsed with distilled water three times. Then they were freeze-dried to be dehydrated. The samples were weighed into septa-capped vials.

The carbon and oxygen stable isotope values of enamel carbonate samples were measured at the University of Bradford using a Delta V Advantage Isotope Ratio Mass Spectrometer connected to Finnigan Gas Bench II, an automatic carbonate preparation device. Each sample was reacted with phosphoric acid (100%) at 70 degrees to release carbon dioxide. The carbon dioxide gas was analysed against the reference carbon dioxide gas.

All $\delta^{13}C$ (VPDB) and $\delta^{18}O$ (VSMOW) measurements were calibrated by the measurement errors deduced from the measured and accepted values of standards: MERCK, CO–1, BES, and NBS19. Analytical precision was ± 0.05 ‰ for $\delta^{13}C$ (VPDB) and ± 0.17 ‰ for $\delta^{18}O$ (VSMOW) as estimated from the relative standard deviation.

5.4. Statistical Methods

Various statistical tests were used to evaluate the significance of any observed difference. Non-parametric methods were opted for when data was not normally distributed, such as some of the bone collagen samples from Horcott. In addition, parametric methods were used for either normally distributed data or multivariate data where the effect of covariants had to be eliminated. This was the case for all bone collagen samples. Finally, cyclic statistics were used for data represented in circular (also called cyclic or periodic) dimensions. This was the case for birth seasonality deduction.

5.5. Programming Softwares Used

Figures were created by using either Microsoft's Excel, Mathwork's Matlab and R, depending on which one was most convenient for each situation.

Deduction of the birth seasonality was implemented in Matlab. While methods by Balasse et al. (2012 b) and Towers et al. (2013) have already been described in Chapter 4, an intensive search was developed as part of this research to cover potential inherent shortcomings of the two methods. A new estimation technique (thorough search with fine tuning) was developed, of which the only assumption is that the shape of $\delta^{18}O$ value sequence should be sinusoidal, which is a constant feature of $\delta^{18}O$ value sequence of enamel carbonate for all the samples used in this research. Regarding animals with several teeth from a tooth row, this technique approximates the $\delta^{18}O$ values in these teeth by a sinusoidal curve with average value M, amplitude A, wavelength X and phase x0. The technique searches what the values of these parameters (i.e., M, A, X and x0) are that best approximate the original $\delta^{18}O$ value sequence.

Among the parameters M, A, X and x0, the last one needs to have a different value for each teeth, as the $\delta^{18}O$ values of each teeth are expected to start from a different seasonality time, which corresponds to a different phase on the sinusoidal curve. For this reason, the search technique tries different values of x0 for each teeth – it tries all possible combinations.

However, there are no per-se restrictions on what values the other parameters (i.e. M, A, and X) may have across different teeth. They may share the same values for all teeth of the same animal (which will correspond to a model that assumes all teeth follow similar sinusoidal shape), or some animal species may have widely different values across teeth (e.g. M3 may have a larger amplitude than M1 and M2). An accuracy-complexity measurement estimates which of these set of parameters is most plausible, having into account not only how accurately each modelled sequence approximates the original data, but also how complex (i.e. how many parameters) the modelled sequence is. The method used in this research was the standard Akaike Information Criterion (AIC), which penalises the accuracy of each modelled sequence through the number of parameters that each modelled sequence uses.

5.6. Summary

The archaeological background of the selected site, Horcott shows that it was a self-sufficient rural site in the Romano-British and the Anglo-Saxon periods. However, it also seems that there was change in some aspects of settlement life between the two periods.

Materials selected for answering the research questions were introduced, and the sampling strategies and the overall characteristics of sampled assemblage were explained. Finally the methods used to produce stable isotope data were explained, followed by the statistical tests and software used to analyse the data.

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Chapter 6. Results

In this chapter, the results are presented in two sections, depending on the nature of the data — bone collagen (section 6.1) or enamel carbonate (section 6.2). Each section is further divided into different species. This chapter focuses on numerical and statistical results, leaving their interpretation for the next chapter.

6.1. Bone Collagen Results

The total number of collagen samples was 113–19 from humans and 94 from various animal species (results in Tables S1, S2, S3, S4, S5, and S7 in appendix). Three samples did not have collagen yield high enough to be measured. All the measured samples had their C/N ratios between 2.9 and 3.6, the range for good quality collagen (DeNiro 1985), except for four measurements, which were excluded. Analytical precision was ± 0.07 ‰ for $\delta^{13}C$ (VPDB) and ± 0.07 ‰ for $\delta^{15}N$ (AIR) as estimated from the relative percent difference (see Chapter 5).

The results will be presented for each animal species and humans, which will be analysed in special detail.

6.1.1. Fauna

6.1.1.1. Cattle

Samples from 36 out of 37 individuals produced enough collagen: two early Iron Age, seven Romano-British, and 27 Anglo-Saxon individuals (Table S1 in appendix). The mean $\delta^{13}C$

value is the same in both periods (Table 6.1), while the $\delta^{15}N$ values somewhat vary by period (Fig. 6.1). Almost all Romano-British cattle have $\delta^{15}N$ values higher than 5‰ and only Anglo-Saxon cattle have $\delta^{15}N$ values lower than 5 ‰. Although the $\delta^{15}N$ value ranges of the two groups overlap more substantially, the mean $\delta^{15}N$ value is 1.3 ‰ higher in the Romano-British period.

Cow	Rom $\delta^{13}C$(‰) (n=7)	Sax $\delta^{13}C$(‰) (n=27)	Rom $\delta^{15}N$(‰) (n=7)	Sax $\delta^{15}N$(‰) (n=27)
Mean	-21.8	-21.8	6.6	5.3
SD	0.2	0.3	1.0	1.1
Max	-21.4	-21.1	7.7	7.8
Min	-22.1	-22.4	5.1	2.9
Max-Min	0.7	1.3	2.5	4.9

Table 6.1 Values calculated from collagen data of cattle at Horcott.

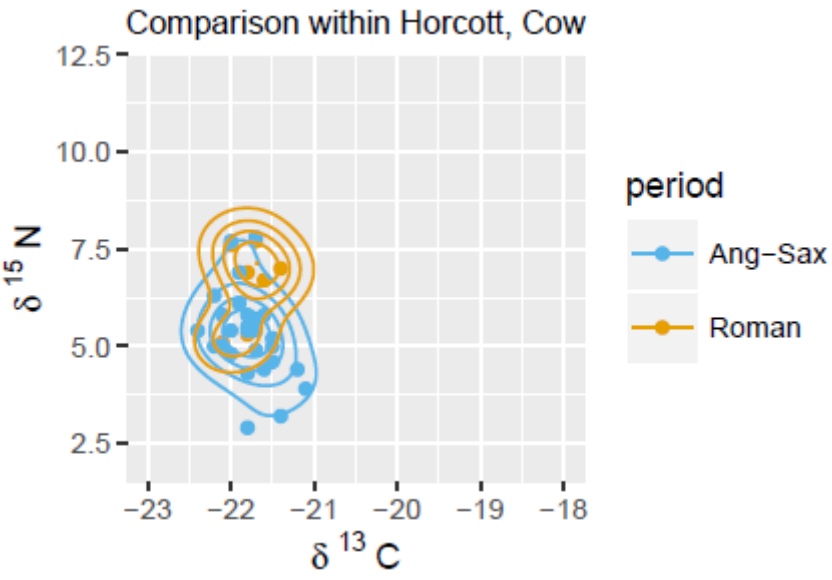


Fig.6.1 Comparison of distribution of cattle at Horcott by period, x-axis: $\delta^{13}C$ values (‰), y-axis: $\delta^{15}N$ values (‰), orange: Romano-British period, blue: Anglo-Saxon period. Data points are shown with level lines of probability density estimated by the Gaussian kernel function.

Statistical tests were applied to evaluate whether the mean and variance of $\delta^{13}C$ and $\delta^{15}N$ values were significantly different between the two periods. Because the data do not show a normal distribution, non-parametric tests as well as parametric tests were applied. In respect of $\delta^{13}C$ values, p-values of differences in both mean and variance by the generalised linear model (a standard parametric test) were all higher than 0.05, which indicate that the difference is not statistically significant (Fig. 6.2). In contrast, for $\delta^{15}N$ values, the difference in means between the two periods is statistically significant (p=0.0080). Equally, the Mann-Whitney U test (a non-parametric alternative) gave statistically significant results (p=0.021).

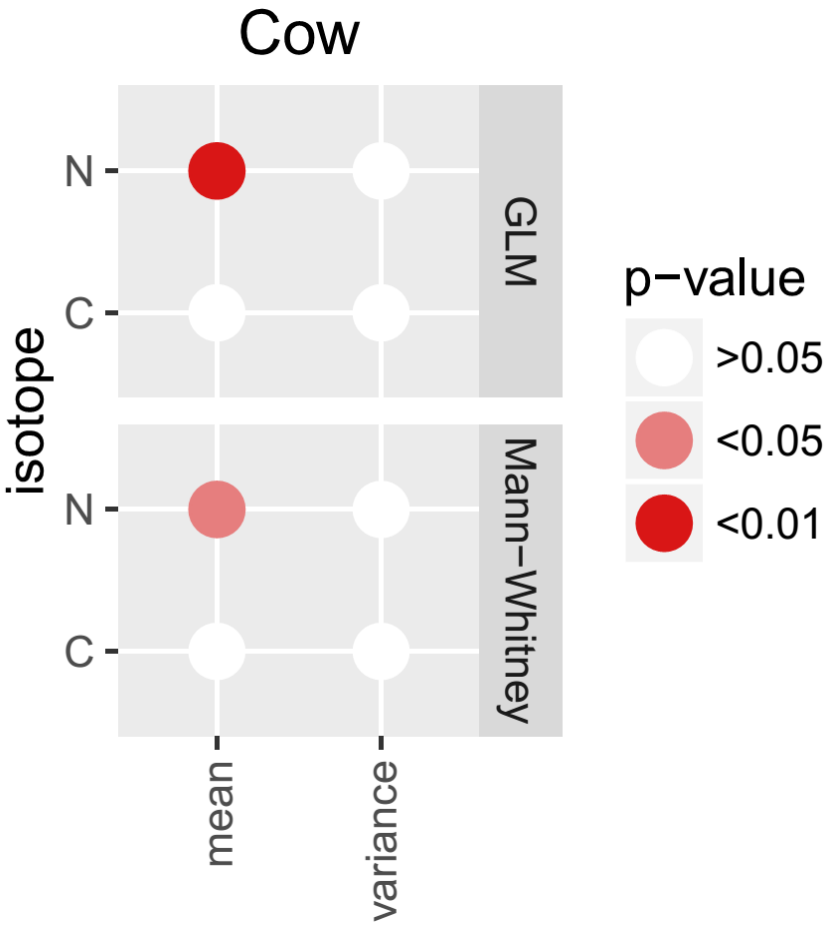


Fig. 6.2 Statistical significance of difference in mean and variance of cow stable isotope values between the two periods: x-axis: variables compared, y-axis: stable isotope values, upper rows: generalised linear model (GLM), bottom rows: Mann-Whitney U test.

Next, since the age at death (and age of formation regarding collagen from tooth dentine) of each individual had been estimated (see Chapter 2), the relationship between the age at death and $\delta^{13}C$ and $\delta^{15}N$ values were examined respectively (Fig. 6.3). Romano-British cattle had higher $\delta^{15}N$ values on average than Anglo-Saxon cattle, and this was still the case even after age difference was taken into account.

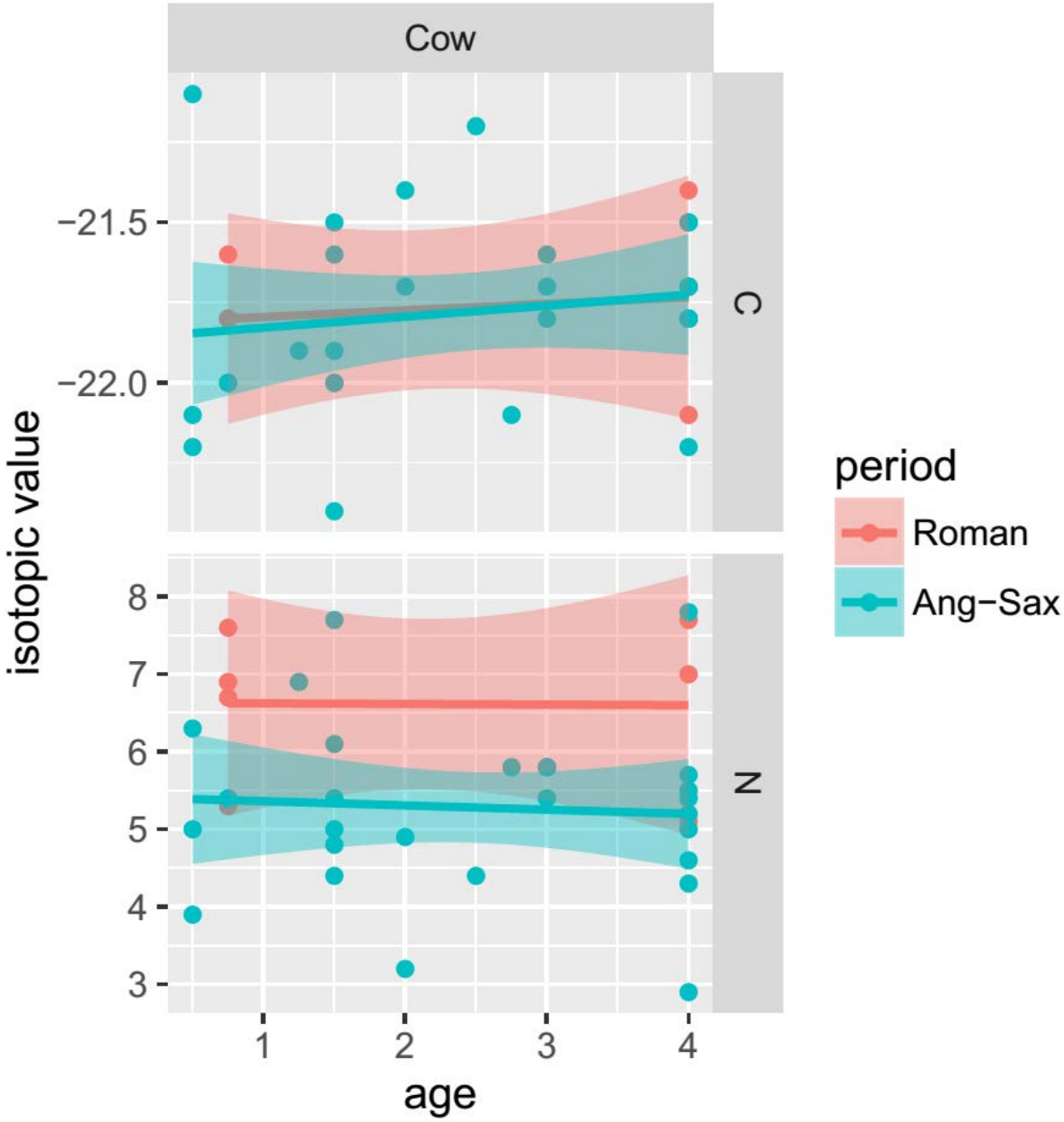


Fig. 6.3 Correlation between age and stable isotope values of cow, x-axis: age, y-axis: stable isotope values, upper row: $\delta^{13}C$ values (‰), bottom row: $\delta^{15}N$ values (‰), red: Romano-British period, blue: Anglo-Saxon period.

Correlation coefficients were calculated to check if any correlation between stable isotope values and age of individuals was statistically significant (Fig. 6.4). All the p-values were higher than 0.05, confirming that there was no significant correlation between stable isotope values and age in both periods.

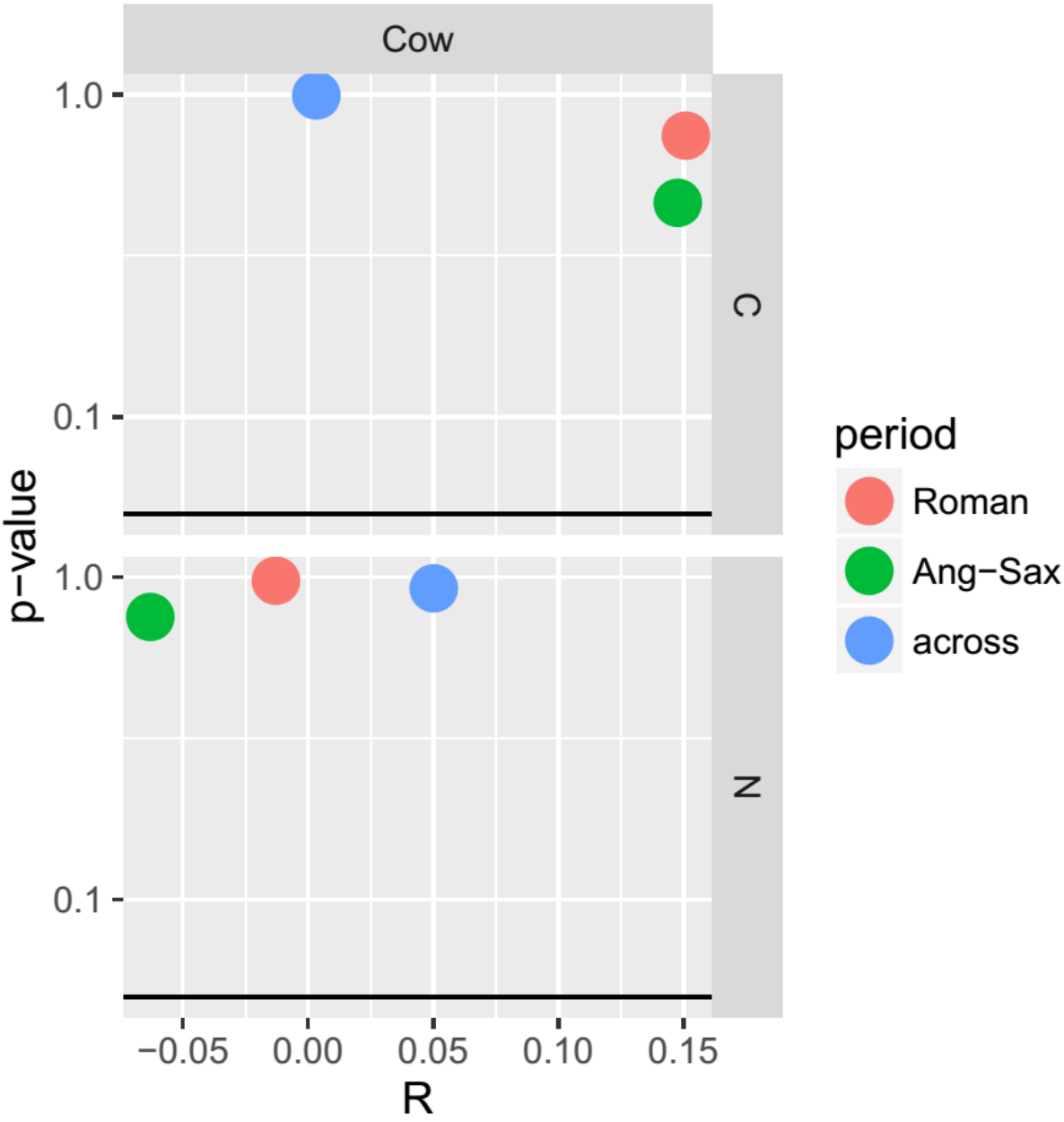


Fig. 6.4 Statistical significance of correlation between age and stable isotope values of cow, x-axis: correlation coefficient, y-axis: p-value indicating the level of probability of correlation, upper row: $\delta^{13}C$ values, bottom row: $\delta^{15}N$ values, red: Romano-British period, green: Anglo-Saxon period, blue: Comparison of the correlations between two periods. The black solid horizontal line shows p= 0.05

6.1.1.2. Sheep/Goats

All 29 individuals produced enough collagen: one early Iron Age, 11 Romano-British, and 17 Anglo-Saxon individuals (Table S2 in appendix). The mean $\delta^{13}C$ value is similar in both periods (Table 6.2), but the $\delta^{15}N$ values vary depending on period (Figs. 6.5). The early Iron Age sheep/goat had the highest $\delta^{15}N$ value and the Anglo-Saxon sheep/goats had the lowest $\delta^{15}N$ values, while the Romano-British sheep/goats had $\delta^{15}N$ values between the two groups with an overlap with the Anglo-Saxon sheep/goats at the lower half of their $\delta^{15}N$ value range. Still, the mean $\delta^{15}N$ value is 1.2 ‰ higher in the Romano-British period.

Among the one Romano-British and six Anglo-Saxon individuals which were identified as possibly goats from their teeth (see Chapter 5), only SAX sg 13 stood out by its highest $\delta^{13}C$ value of all the sheep/goat individuals, while the others had overlapping $\delta^{13}C$ values with the sheep. In addition, their $\delta^{15}N$ values were hugely overlapping with the sheep. Therefore, those identified as possibly goats were not necessarily different from the sheep in respect of collagen $\delta^{13}C$ and $\delta^{15}N$ values.

s/g	Rom $\delta^{13}C$(‰) (n=11)	Sax $\delta^{13}C$(‰) (n=17)	Rom $\delta^{15}N$(‰) (n=11)	Sax $\delta^{15}N$(‰) (n=17)
Mean	-21.6	-21.7	6.2	5.0
SD	0.5	0.4	0.8	1.0
Max	-20.8	-20.5	7.3	6.3
Min	-22.4	-22.2	4.9	2.3
Max-Min	1.5	1.8	2.4	3.9

Table 6.2 Values calculated from collagen data of sheep/goats at Horcott.

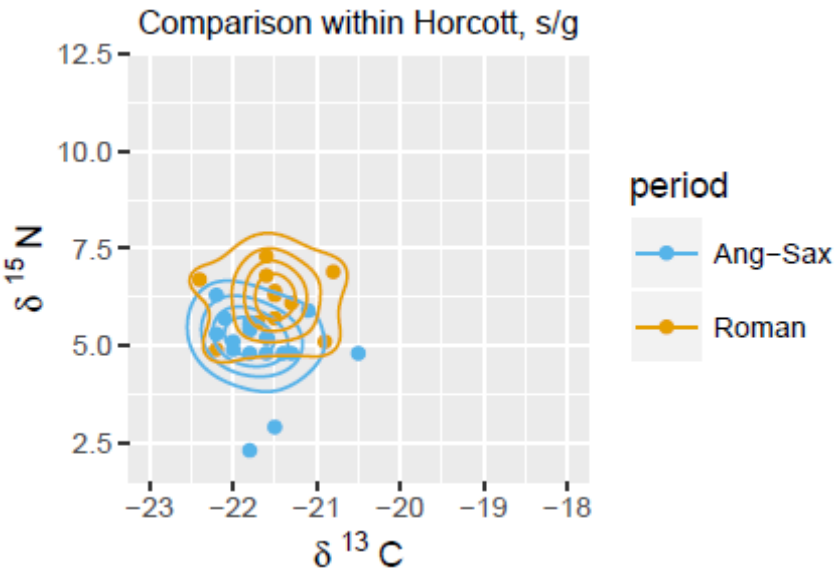


Fig. 6.5 Comparison of distribution of sheep/goats at Horcott by period, x-axis: $\delta^{13}C$ values (‰), y-axis: $\delta^{15}N$ values (‰), orange: Romano-British period, blue: Anglo-Saxon period. Data points are shown with level lines of probability density estimated by the Gaussian kernel function.

Statistical tests were applied to determine whether the mean and variance of $\delta^{13}C$ and $\delta^{15}N$ values were significantly different between the two periods. As with cattle, both parametric (GLM) and non-parametric (Mann-Whitney U) tests were applied, which showed similar results (Fig. 6.6). Although there was no significant difference for $\delta^{13}C$ values ($p>0.05$), there was a significant difference for $\delta^{15}N$ values regarding the mean (p-values= parametric: 0.0019, non-parametric: 0.0014). Therefore, the difference in mean $\delta^{15}N$ values between the two periods was verified.

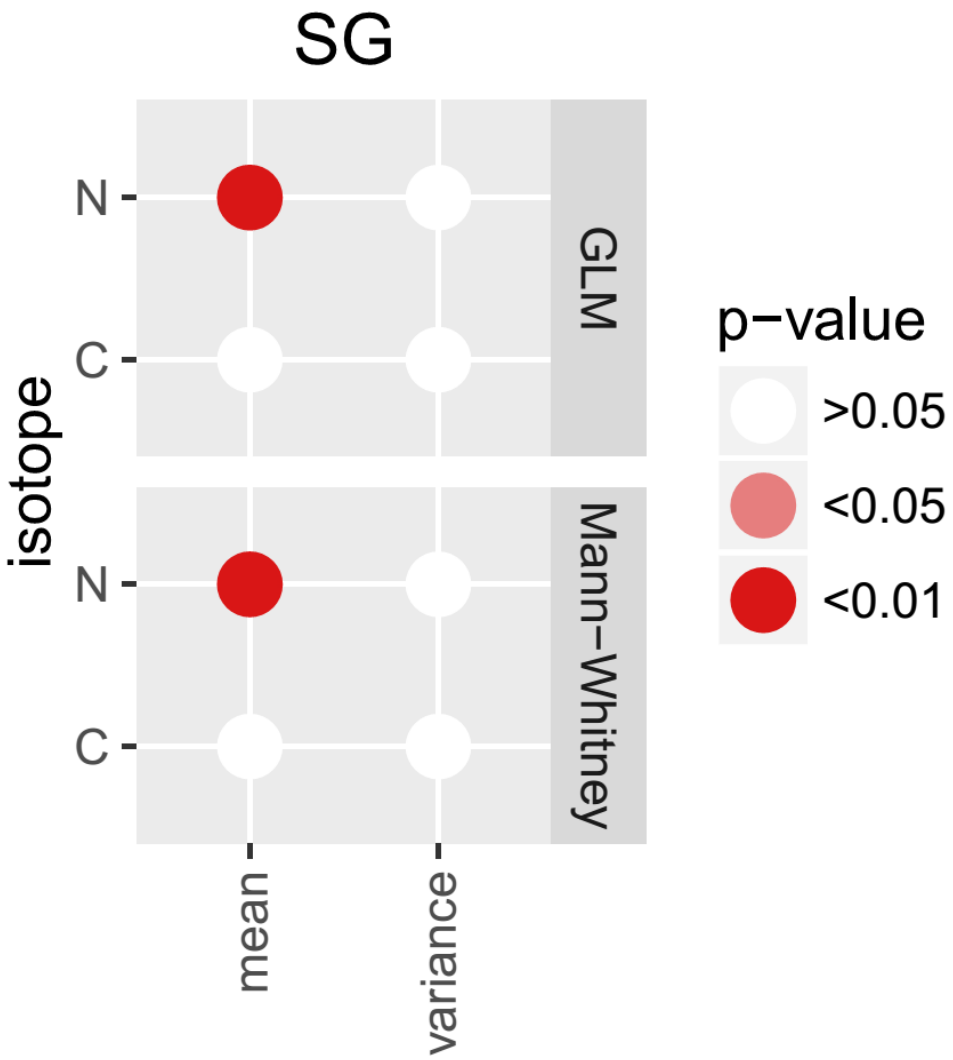


Fig. 6.6 Statistical significance of difference in mean and variance of sheep/goat stable isotope values between the two periods: x-axis: variables compared, y-axis: stable isotope values, upper rows: generalised linear model (GLM), bottom rows: Mann-Whitney U test.

Next, the relationship between the age at death (see Chapter 2) and $\delta^{13}C$ and $\delta^{15}N$ values were examined (Fig 6.7). Romano-British sheep/goats had higher $\delta^{15}N$ values than Anglo-Saxon sheep/goats (see above), and this was still the case even after age difference was taken into account.

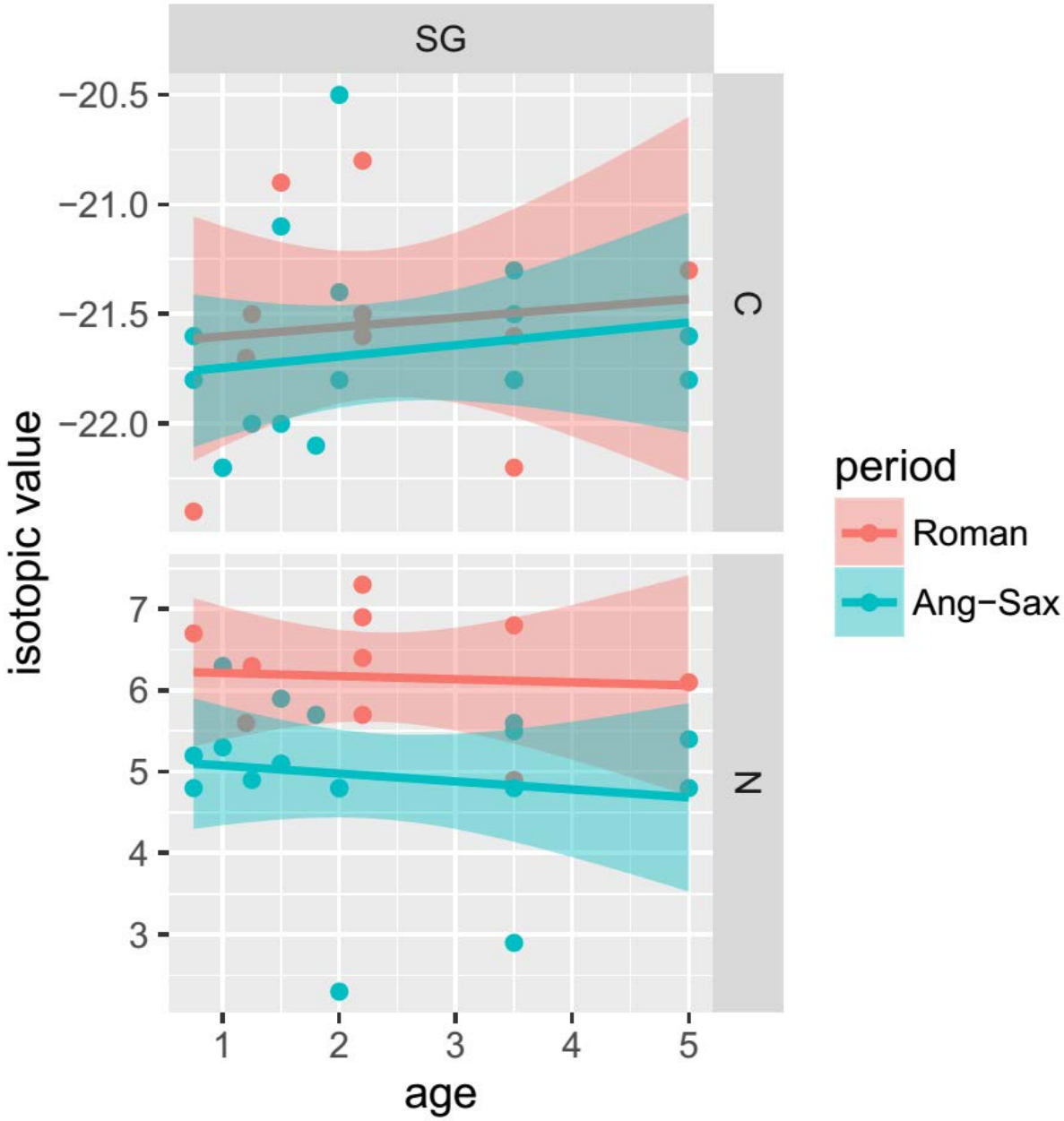


Fig. 6.7 Correlation between age and stable isotope values of sheep/goats, x-axis: age, y-axis: stable isotope values, upper row: $\delta^{13}C$ values (‰), bottom row: $\delta^{15}N$ values (‰), red: Romano-British period, blue: Anglo-Saxon period.

Correlation coefficient was calculated to test the significance of correlation between stable isotope values and the age of individuals (Fig. 6.8). All the p-values were higher than 0.05, confirming that there was no significant correlation between stable isotope values and age in both periods.

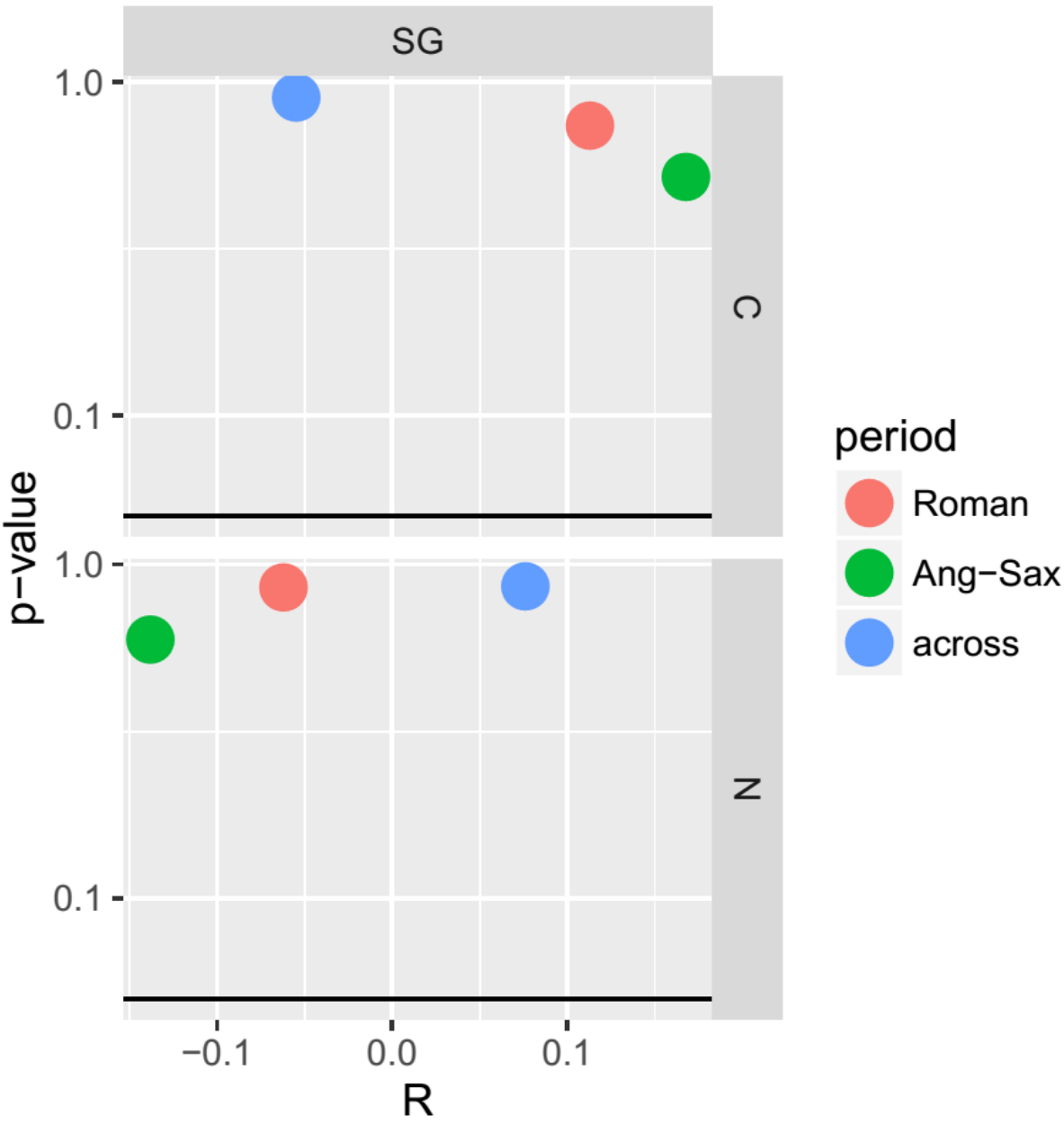


Fig. 6.8 Statistical significance of correlation between age and stable isotope values of sheep/goat, x-axis: correlation coefficient, y-axis: p-value indicating the level of probability of correlation, upper row: $\delta^{13}C$ values, bottom row: $\delta^{15}N$ values, red: Romano-British period, green: Anglo-Saxon period, blue: Comparison of the correlations between two periods. The black solid horizontal line shows p= 0.05

6.1.1.3. Pigs

Samples of 17 out of 18 individuals produced enough collagen: one early Iron Age, seven Romano-British, and nine Anglo-Saxon individuals (Table S3 in appendix). The difference of the mean $\delta^{13}C$ values between the two periods is negligible (Table 6.3).

pig	Rom $\delta^{13}C$(‰) (n=7)	Sax $\delta^{13}C$(‰) (n=9)	Rom $\delta^{15}N$(‰) (n=7)	Sax $\delta^{15}N$(‰) (n=9)
Mean	-21.2	-21.4	8.9	7.2
SD	0.3	0.3	1.1	1.1
Max	-20.7	-20.8	10.2	8.9
Min	-21.7	-22.0	7.1	5.6
Max-Min	1.0	1.1	3.2	3.3

Table 6.3 Values calculated from collagen data of pigs at Horcott.

In contrast, the $\delta^{15}N$ value ranges are higher in the Romano-British period compared to the Anglo-Saxon period, although the maxima remain similar. As with cattle, the $\delta^{15}N$ values of individuals somewhat vary depending on the period (Figs. 6.9); Romano-British pigs have the highest $\delta^{15}N$ values while the Anglo-Saxon pigs have the lowest $\delta^{15}N$ values, although the ranges overlap. Likewise, the mean $\delta^{15}N$ value is 1.7 ‰ higher in the Roman period.

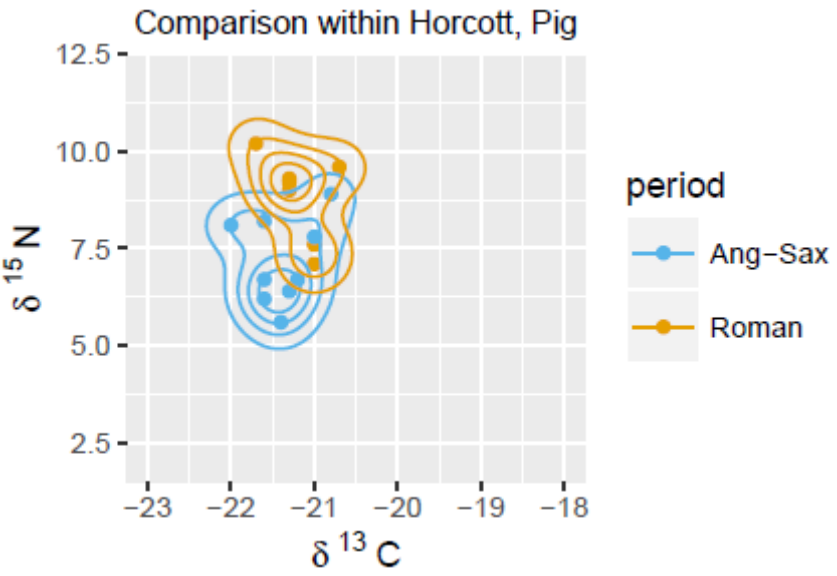


Fig. 6.9 Comparison of distribution of pigs at Horcott by period, x-axis: $\delta^{13}C$ values (‰), y-axis: $\delta^{15}N$ values (‰), orange: Romano-British period, blue: Anglo-Saxon period. Data points are shown with level lines of probability density estimated by the Gaussian kernel function.

When statistical tests were applied to verify the differences in the mean and variance of $\delta^{13}C$ and $\delta^{15}N$ values between the two periods, both parametric and non-parametric tests showed similar results (Fig. 6.10). The p-values for difference in mean and variance of $\delta^{13}C$ were all higher than 0.05, and thus not significant. In contrast, the p-values for difference in mean $\delta^{15}N$ were lower than 0.05 (p-values= parametric: 0.0093, non-parametric: 0.015). Thus, the difference in mean $\delta^{15}N$ is statistically significant between the two periods.

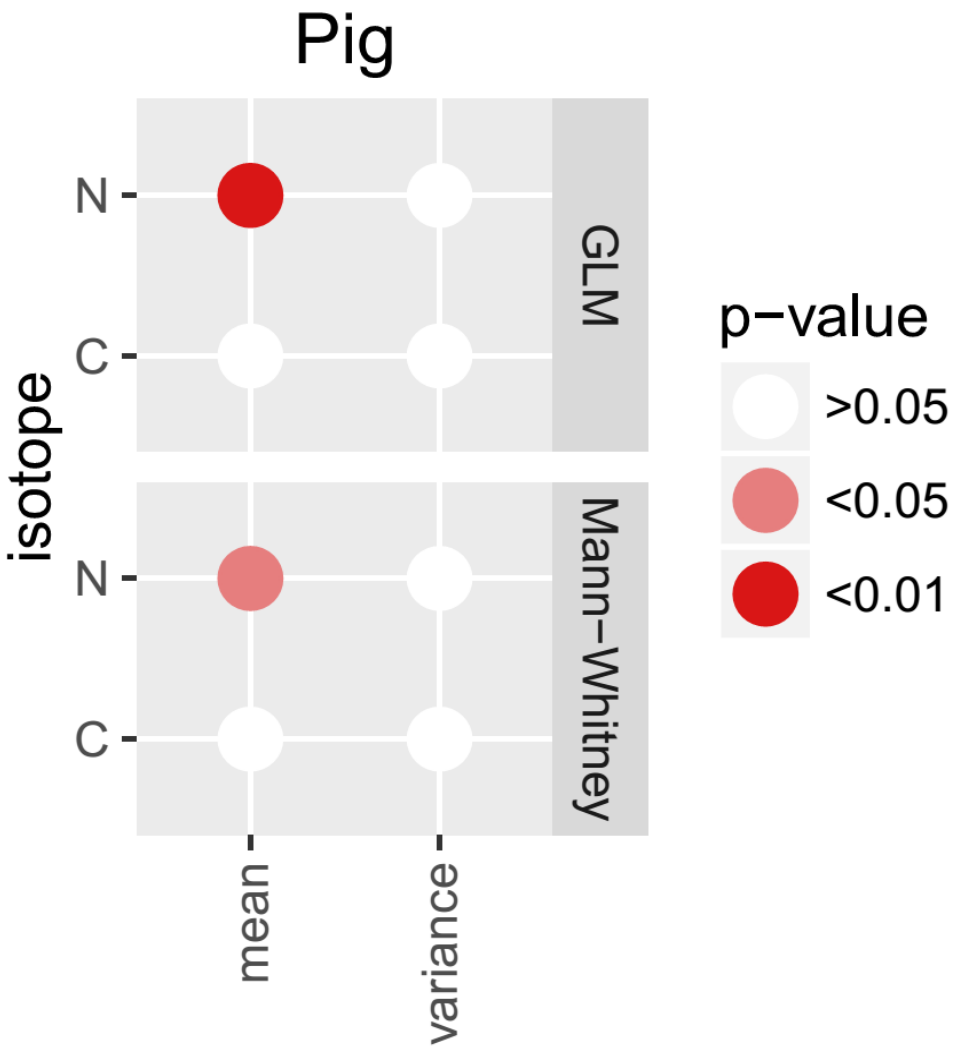


Fig. 6.10 Statistical significance of difference in mean and variance of pig stable isotope values between the two periods: x-axis: variables compared, y-axis: stable isotope values, upper rows: generalised linear model (GLM), bottom rows: Mann-Whitney U test.

Next, the relationship between the age at death (see Chapter 2) and $\delta^{13}C$ and $\delta^{15}N$ values were examined respectively (Fig 6.11). The $\delta^{13}C$ values of both Romano-British and Anglo-Saxon pigs follow a similar trend: higher $\delta^{13}C$ values when they are younger than one year old compared to older pigs. Thus $\delta^{13}C$ values of pigs tend to decrease by age regardless of periods.

Regarding $\delta^{15}N$ values, the two period groups show different trends. Pigs younger than one year old from both periods have similar $\delta^{15}N$ values, but the $\delta^{15}N$ values of Romano-British pigs increase by age, whereas the $\delta^{15}N$ values of Anglo-Saxon pigs decrease by age. Consequently, adult Romano-British pigs have higher $\delta^{15}N$ values than adult Anglo-Saxon pigs.

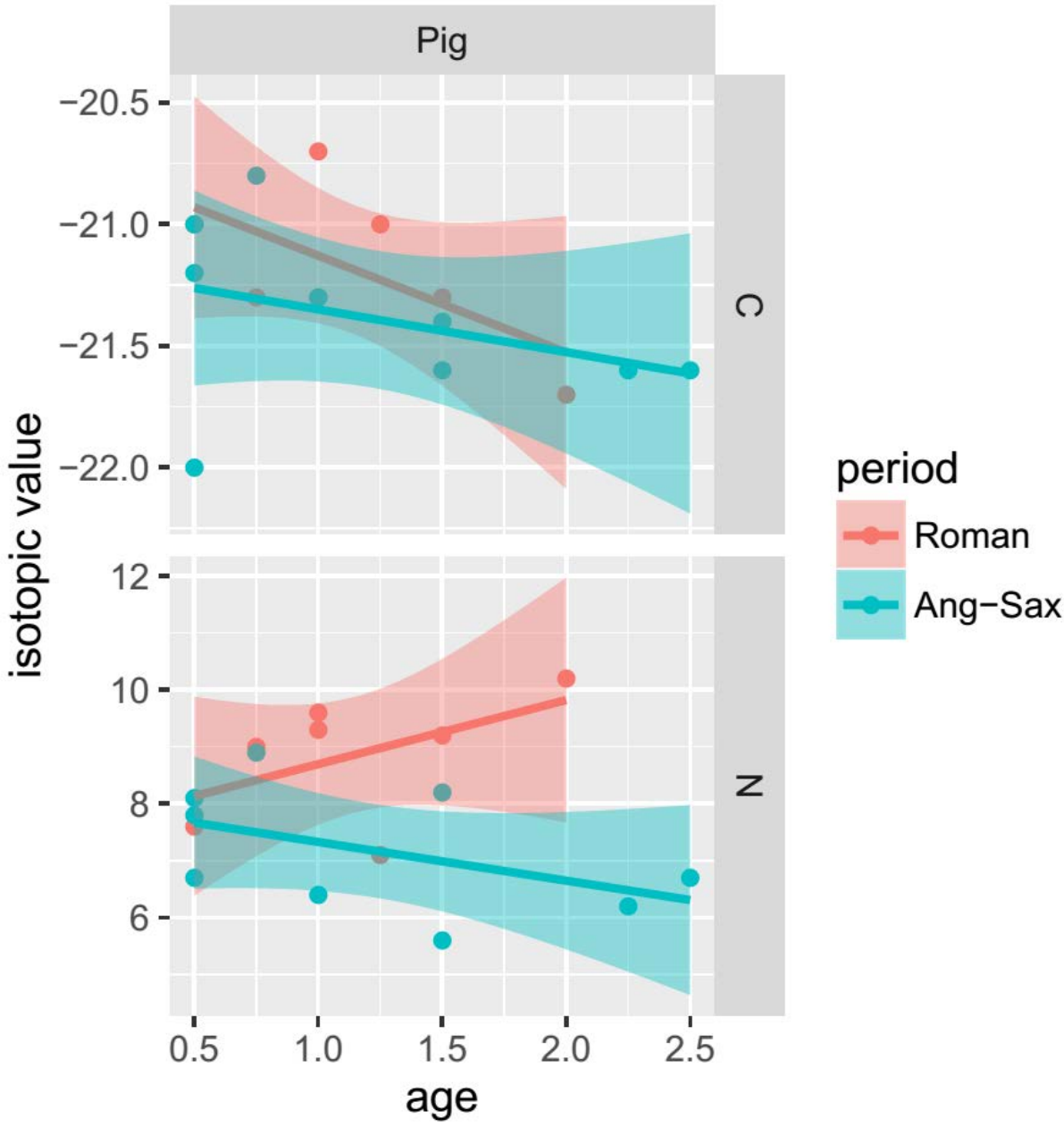


Fig. 6.11 Correlation between age and stable isotope values of pigs, x-axis: age, y-axis: stable isotope values, upper row: $\delta^{13}C$ values (‰), bottom row: $\delta^{15}N$ values (‰), red: Romano-British period, blue: Anglo-Saxon period.

Correlation coefficient was calculated to check the significance of correlation between stable isotope values and age of pigs by period (Fig. 6.12). All the p-values were higher than 0.05, indicating that none of the apparent correlation between stable isotope values and age was statistically significant. The lowest p-value was for the comparison of the correlation between the Romano-British period and the Anglo-Saxon period in $\delta^{15}N$ values by age, which was 0.1 (blue circle in Fig. 6.12). Still it failed to prove that the difference in correlation in $\delta^{15}N$ values by age depending on the period was significant. This may due to the small sample size of pigs.

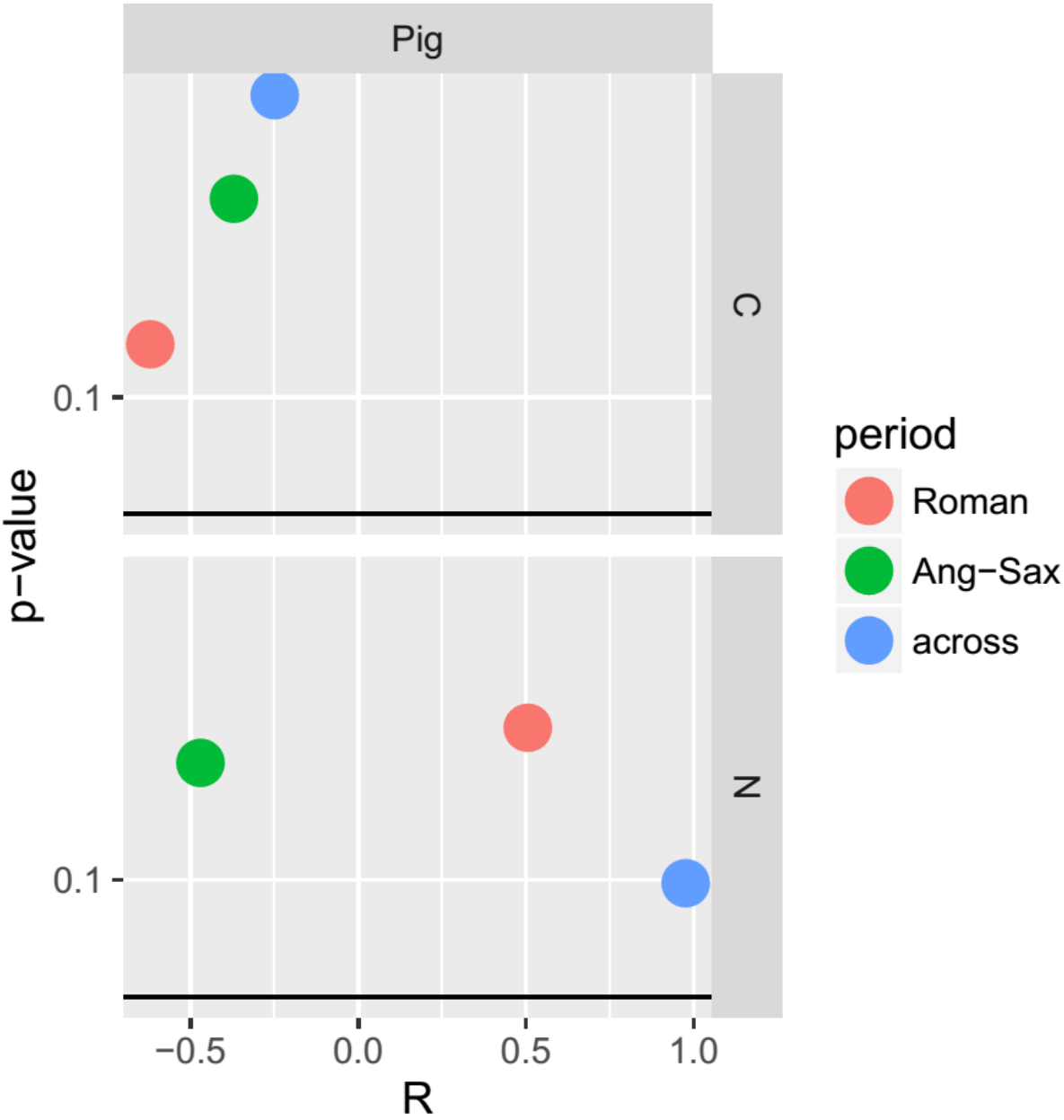


Fig. 6.12 Statistical significance of correlation between age and stable isotope values of pig, x-axis: correlation coefficient, y-axis: p-value indicating the level of probability of correlation, upper row: $\delta^{13}C$ values, bottom row: $\delta^{15}N$ values, red: Romano-British period, green: Anglo-Saxon period, blue: Comparison of the correlations between two periods. The black solid horizontal line shows p= 0.05

6.1.1.4. Inter-Specific Comparison

Next, all data of animals at Horcott are compared with one another. The sample size of horses and dogs are small, making it impossible to test for significance. Thus, they will only be discussed together in this section in comparison to other animals.

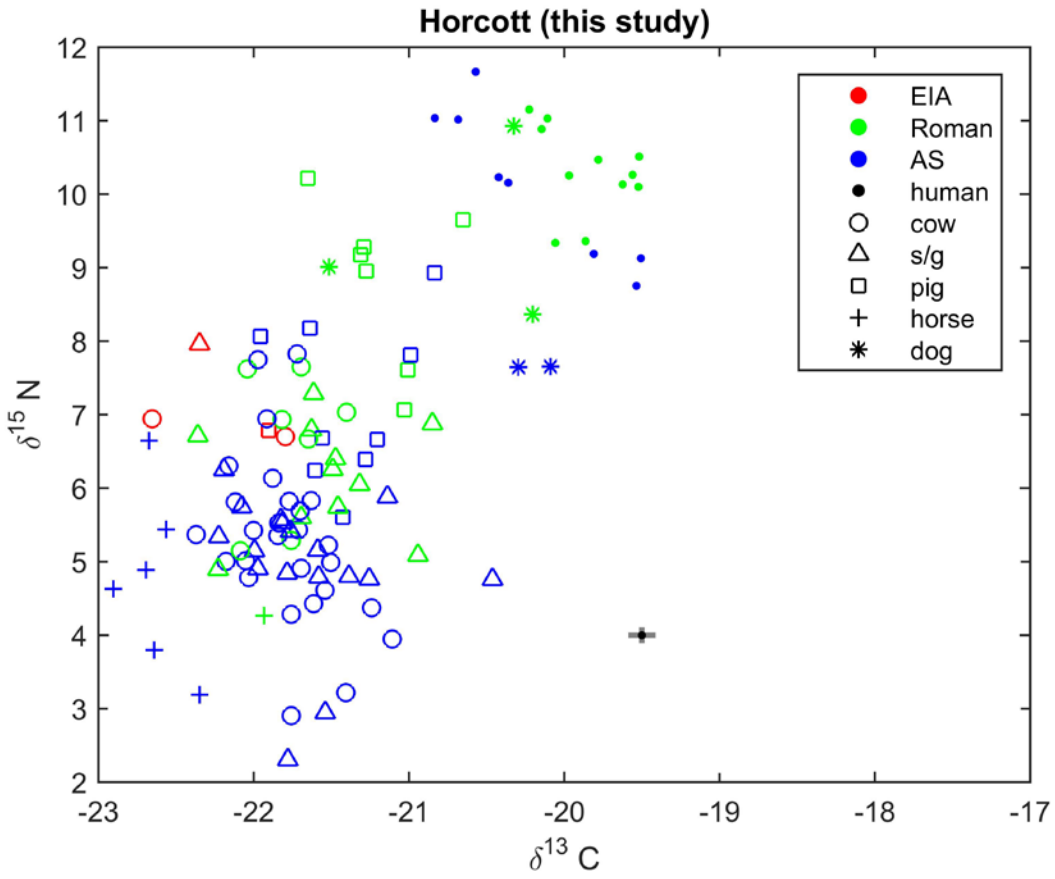


Fig.6.13 Collagen results from Horcott. EIA: Early Iron Age, AS: Anglo-Saxon, s/g: sheep/goats, x-axis: $\delta^{13}C$ values (‰), y-axis: $\delta^{15}N$ values (‰).

Among the herbivores, cattle and sheep/goats have overlapping $\delta^{13}C$ and $\delta^{15}N$ values (Fig. 6.13). Statistical tests gave p-values higher than 0.05 for the differences in $\delta^{13}C$ and $\delta^{15}N$ values between cattle and sheep/goats for both periods (Fig. 6.14). Thus there is no significant difference between cattle and sheep/goats.

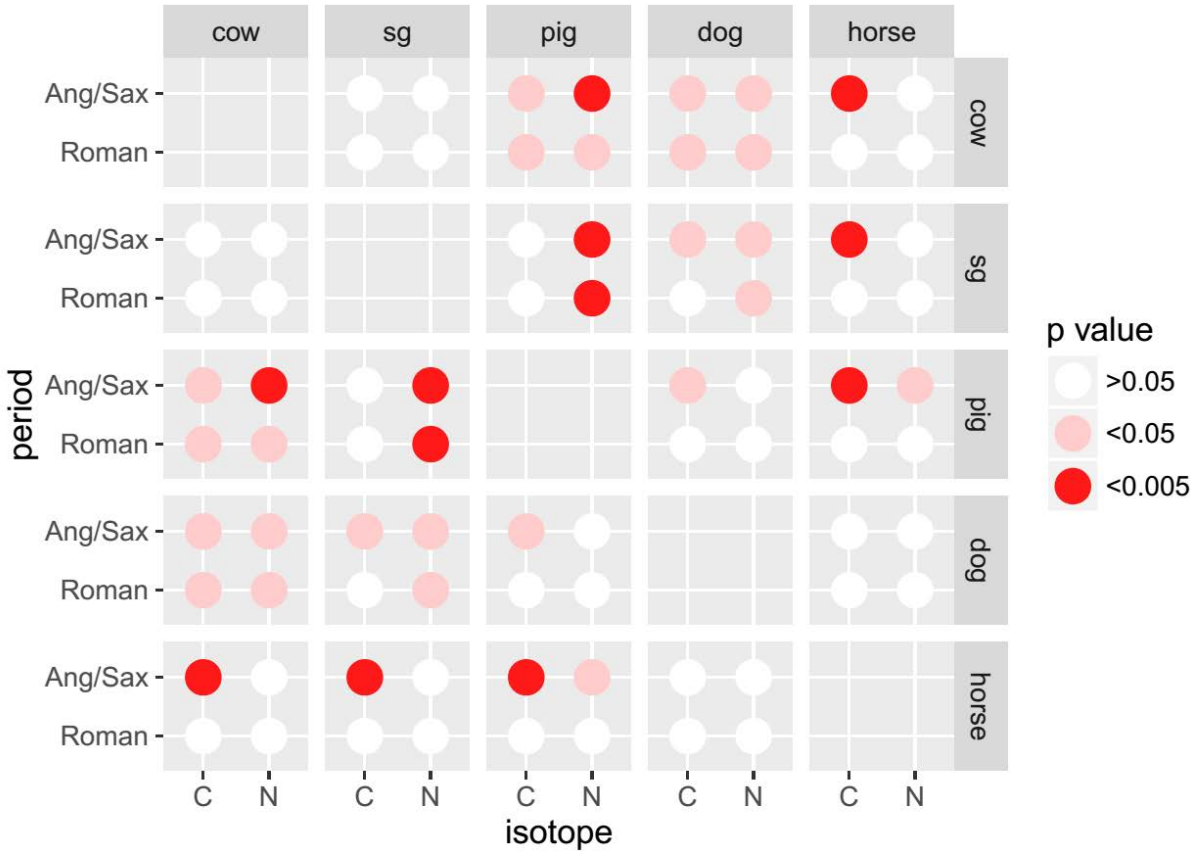


Fig. 6.14 Inter-specific comparison of animals at Horcott; rows: species by period, columns: stable isotope values by species.

Horses however, although they are also herbivores, have lower $\delta^{13}C$ values than other herbivores (cattle and sheep/goats) (Fig. 6.13). Due to the extremely small sample size of Romano-British horse, the difference in the Romano-British period could not be confirmed statistically. However, statistical test show that the differences in $\delta^{13}C$ values between horse and other herbivores in the Anglo-Saxon period were significant (Fig. 6.14). This difference between horses and ruminant herbivores is possibly due to the difference in the digestive system (Lee-Thorp pers.comm).

Other animals analysed are not herbivores. Pigs tend to have higher $\delta^{15}N$ values than those of cattle and sheep/goats (see Chapter 7 for further discussion). Indeed, statistical test show that

the difference in $\delta^{15}N$ values between pigs and herbivores (cattle, sheep/goats) was significant for both periods.

Interestingly, dogs show stable isotope values similar to pigs and are dispersed between herbivores and humans. Being carnivores, dogs should be somewhat higher in the trophic level than omnivorous pigs, if not a full trophic level. Thus, in theory their $\delta^{13}C$ and $\delta^{15}N$ values are higher than those of pigs. However, it is not necessarily the case in the Romano-British period, because only one out of three dogs have higher $\delta^{15}N$ values than pigs. The Anglo-Saxon dogs, having lower $\delta^{15}N$ values than in the Romano-British period, also have similar $\delta^{15}N$ values to the Anglo-Saxon pigs. The statistical tests show that only the difference between $\delta^{13}C$ values of pigs and dogs in the Anglo-Saxon period is significant.

6.1.2. Humans

All 19 individuals selected produced enough collagen: 11 Romano-British and eight Anglo-Saxon individuals (Table S7a in appendix). The 11 Romano-British individuals and the data of 19 Romano-British individuals previously analysed by Cheung (2009) (Table S7b in appendix) were tested using a robust linear model (Marazzi 1993), which is robust to outliers and deviation from normality, to see if the two data sets are significantly different. Although there was a significant difference in $\delta^{15}N$ values due to the age of the individual and the type of bone sampled, there was no significant difference depending on the analyses (Cheung or the present author). Therefore, in the results presented below, the Romano-British individuals analysed by Cheung and the author are treated as one group. Both intra-site and inter-site differences in the two periods were investigated.

6.1.2.1. Intra-Site Comparison by Period and Phase

First, the Romano-British individuals were compared with all Anglo-Saxon individuals. Both $\delta^{13}C$ value and $\delta^{15}N$ values of the two periods overlap (Fig. 6.15).

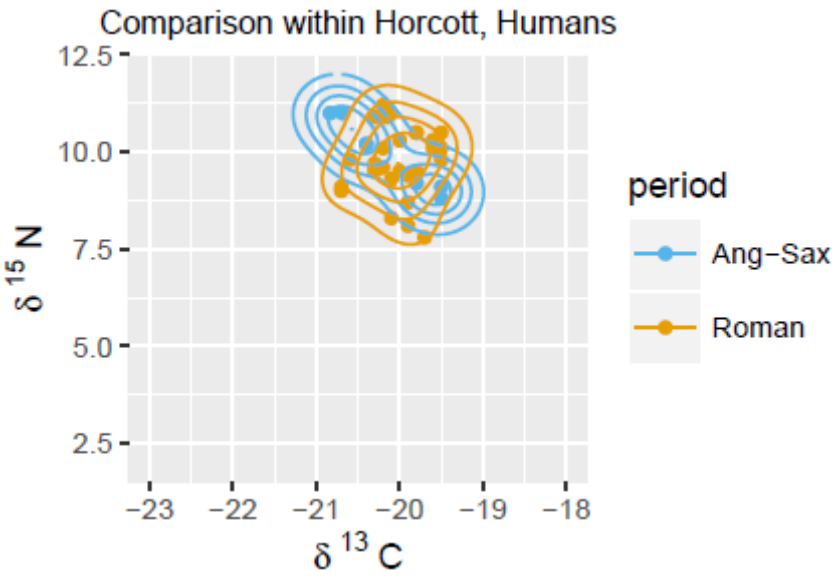


Fig. 6.15. Comparison of distribution of humans at Horcott by period, x-axis: $\delta^{13}C$ values (‰), y-axis: $\delta^{15}N$ values (‰), orange: Romano-British period, blue: Anglo-Saxon period. Data points are shown with level lines of probability density estimated by the Gaussian kernel function.

Statistical tests were applied to verify the difference in the mean and variance of $\delta^{13}C$ and $\delta^{15}N$ values depending on the period. As with the animals, both non-parametric and parametric tests were applied, which gave similar results (Fig. 6.16). Only the p-values for variance in $\delta^{13}C$ values were lower than 0.05 (p-value= parametric: 0.014, non-parametric: 0.017) indicating that only the difference in the variance in $\delta^{13}C$ values between the two periods is statistically significant.

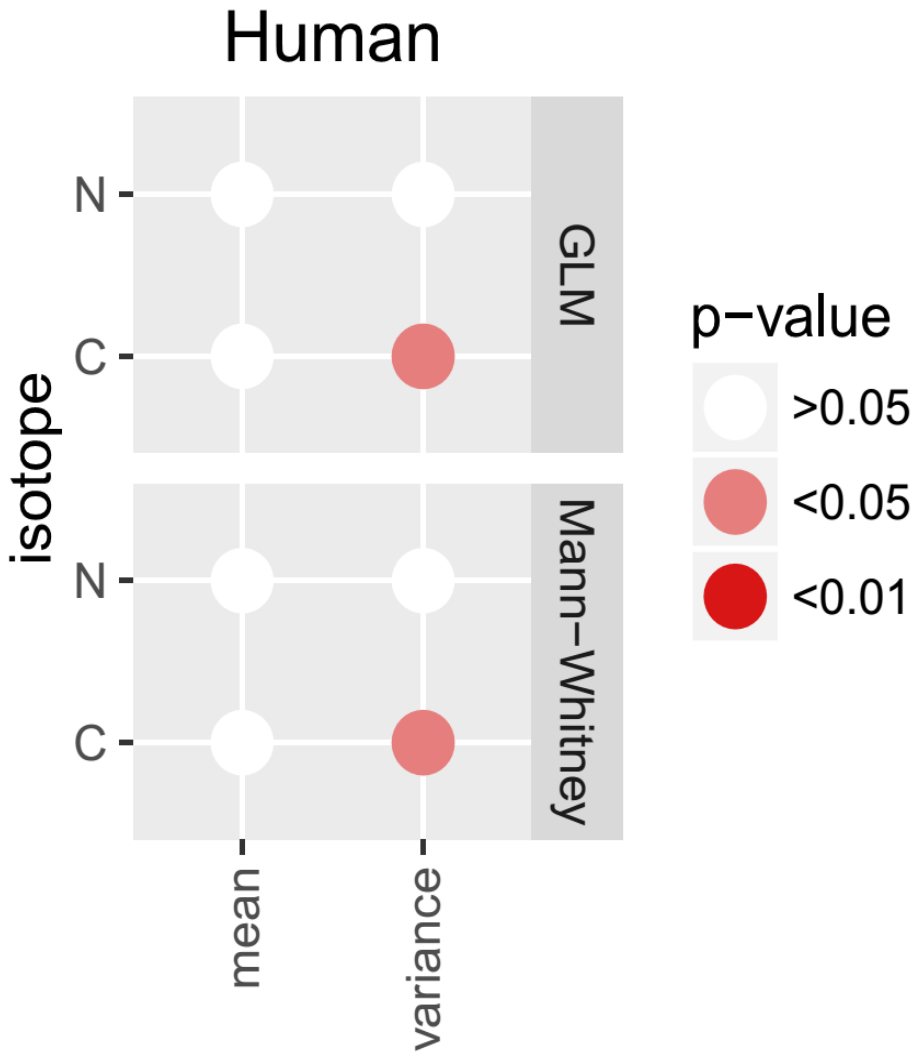


Fig. 6.16 Statistical significance of difference in mean and variance of human stable isotope values between the two periods: x-axis: variables compared, y-axis: stable isotope values, upper rows: generalised linear model (GLM), bottom rows: Mann-Whitney U test.

Next, the Romano-British individuals (hereafter RB) were compared with the Anglo-Saxon individuals divided by phase: Phase 1 (hereafter AS1) and Phase 2 (hereafter AS2) (Table 6.4).

human	RB $\delta^{13}C$(‰) (n=30)	AS1 $\delta^{13}C$(‰) (n=5)	AS2 $\delta^{13}C$(‰) (n=3)	RB $\delta^{15}N$(‰) (n=30)	AS1 $\delta^{15}N$(‰) (n=5)	AS2 $\delta^{15}N$(‰) (n=3)
Mean	-20.0	-20.6	-19.6	9.7	10.8	9.0
SD	0.3	0.2	0.2	0.8	0.6	0.2
Max	-19.5	-20.4	-19.5	11.2	11.7	9.2
Min	-20.7	-20.8	-19.8	7.8	10.2	8.8
Max-Min	1.2	0.5	0.3	3.4	1.5	0.4

Table 6.4 Values calculated from collagen data of humans at Horcott.

Statistical tests were applied to verify the difference in $\delta^{13}C$ and $\delta^{15}N$ values among the three groups of different period and phase (RB, AS1, and AS2). Since the sample size of the two Anglo-Saxon phase groups are small, only non-parametric tests were applied. Mann-Whitney U test gave p-values which were lower than 0.05 except for the difference in $\delta^{15}N$ values between the RB group and AS2 group (Fig. 6.17). Thus, the differences in the median of both $\delta^{13}C$ and $\delta^{15}N$ values were significant between RB and AS1, and between AS1 and AS2, but only the difference in the median of $\delta^{13}C$ values was significant between RB and AS2.

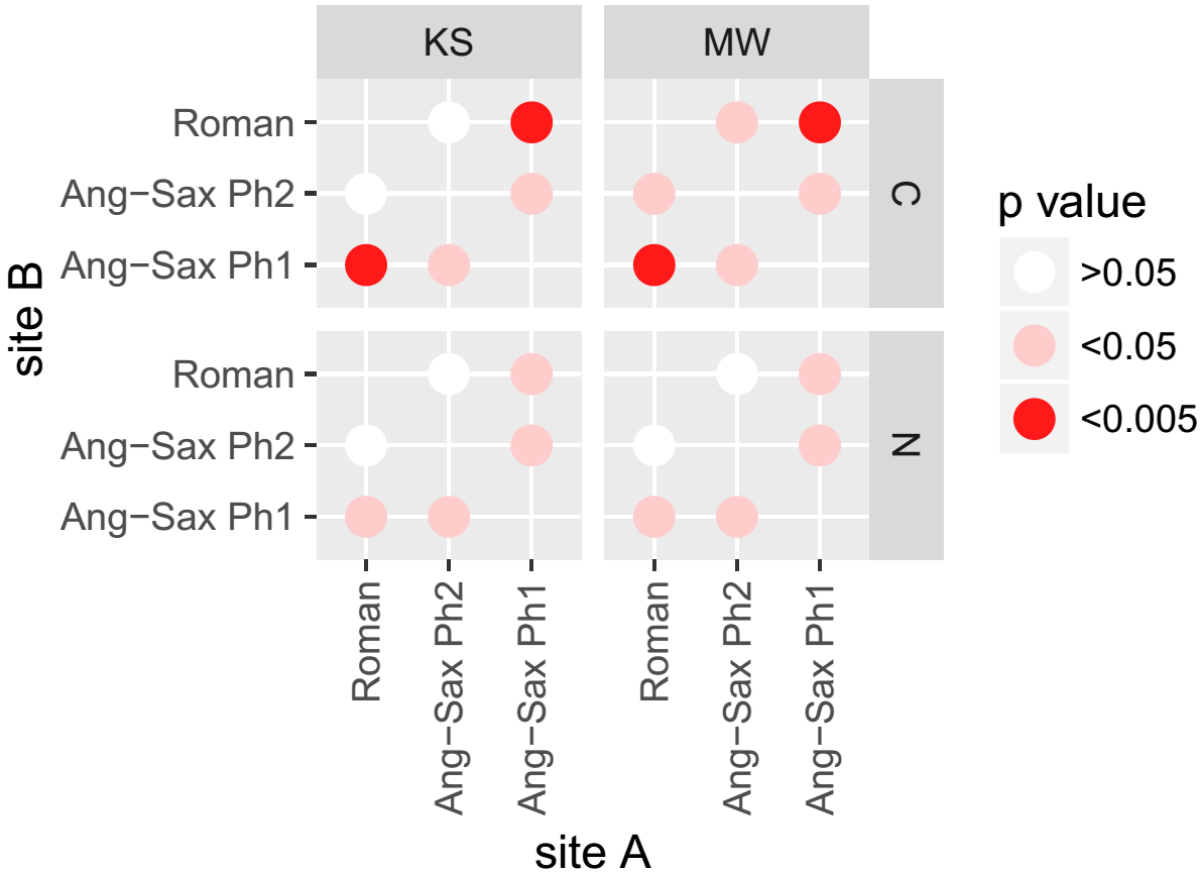


Fig. 6.17 Statistical significance of comparison by period and phase, upper rows: $\delta^{13}C$ values by period and phase, lower rows: $\delta^{15}N$ values by period and phase, left: Kolmogorov-Smirnov test by period and phase, right: Mann-Whitney U test by period and phase.

The p-values of a Kolmogorov-Smirnov test were lower than 0.05 except for the difference between the RB and AS2 group in both $\delta^{13}C$ and $\delta^{15}N$ values (Fig. 6.17). Thus, the differences in the distribution of $\delta^{13}C$ and $\delta^{15}N$ values were significant between RB and AS1, and between AS1 and AS2, but not between RB and AS2. In summary, the AS1 group was different from the other two groups, while the RB group and the AS2 group were more similar to each other.

6.1.2.2. Intra-Site Difference in the Romano-British Period

Since information on burial characteristics were available for each burial, they were compared with isotopic values (Fig. 6.18, Table 6.5). The characteristics examined are: sex, number of individuals per burial, grave orientation, body position, decapitation, presence of coffins, presence of grave-goods, pathology, and age. Statistically significant differences were found in the number of individuals per burial, grave orientation, body position, and decapitation.

	sex	**no. of burials**	**orientation**	**position**	**decapitation**	**coffin**	**grave goods**	**enamel hypoplasia**	**cribra orbitalia**
Majority (blue)	male	single	N-S	supine	No	No	No	Yes	No
minority (red)	female	multiple	S-N	prone	Yes	Yes	Yes	No	Yes
Cheung (2009)	no difference	lower $\delta^{13}C$	lower $\delta^{13}C$	lower $\delta^{15}N$	higher $\delta^{13}C$	no difference	no difference	not analysed	not analysed
this research	no difference	lower $\delta^{13}C$	lower $\delta^{13}C$	lower $\delta^{15}N$	higher $\delta^{13}C$	no difference	no difference	no difference	no difference

Table 6.5 Majority and minority groups by various burial characteristics of Romano-British humans at Horcott. The two lower rows are the statistical significances of the difference between each two groups by Cheung (2009) and this study.

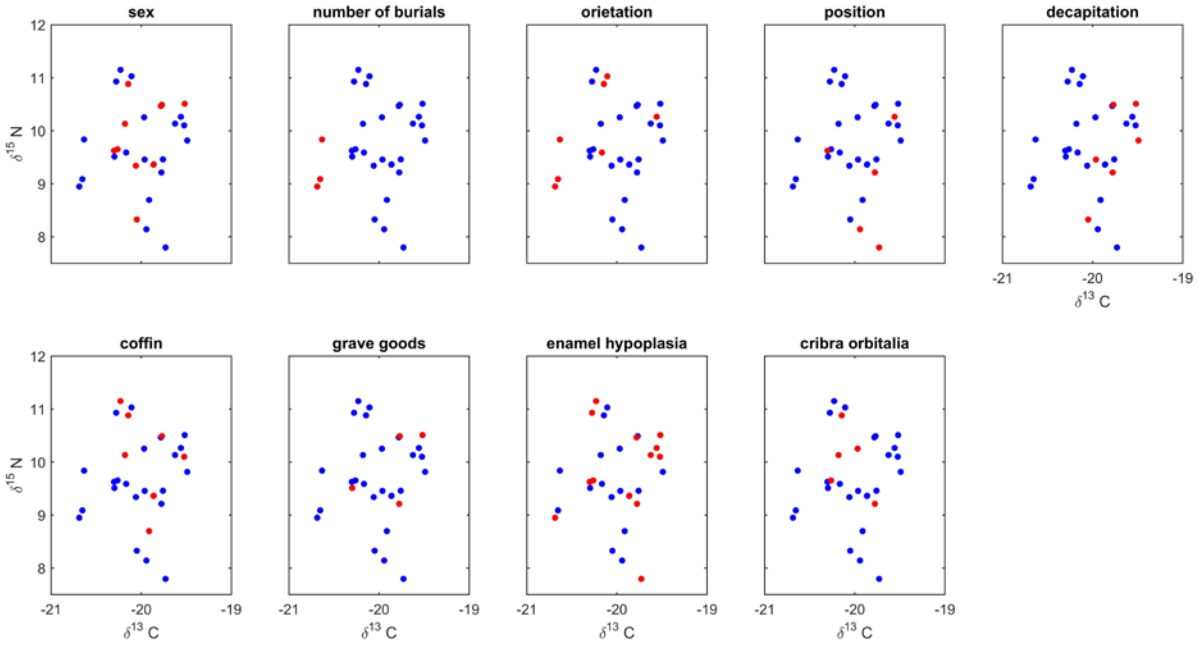


Fig. 6.18 Comparison of collagen data by various burial characteristics; x-axis: $\delta^{13}C$ values (‰), y-axis: $\delta^{15}N$ values (‰). See Table 6.5 for classifications of the majority groups (blue) and minority groups (red).

Regarding number of individuals per burial, three individuals — SK 467, SK519, and SK520 — were buried in the same multiple burial. Although their lower $\delta^{13}C$ values (-20.7, -20.7, and -20.6 ‰ respectively) measured by Cheung (2009) do not overlap with the rest buried in single burials, they are still not low enough to make them distinct outliers. Nevertheless, the GLM showed statistical significance in correlation between the number of burials and the $\delta^{13}C$ values at Horcott. In contrast to the $\delta^{13}C$ values, there was no statistical difference between the two groups regarding $\delta^{15}N$ values.

In respect of grave orientation, most of the Romano-British individuals analysed (23 individuals) were buried in a north-south orientation. Among the rest (seven individuals) buried in an opposite (south-north) orientation, all three individuals from the multiple burial have lower $\delta^{13}C$ values than the 23 individuals, but the other four individuals from single burials have $\delta^{13}C$ values overlapping with the 23 individuals. Therefore, it is not necessarily

the case that the two groups of different orientation have different $\delta^{13}C$ values. Still, the GLM showed that there was a statistically significant correlation between orientation and $\delta^{13}C$ values. The result was still marginally significant after the Bonferroni correction for multiple comparisons. These tests showed significance probably because the three individuals from the multiple burials were all in a south-north orientation, which is nearly half of the seven individuals buried in the same orientation. Unlike their $\delta^{13}C$ values, there was no statistically significant difference between the two groups regarding $\delta^{15}N$ values.

Regarding body position, there was no statistical difference between the two groups regarding $\delta^{13}C$ values. However, concerning $\delta^{15}N$ values, two out of five Romano-British individuals buried in a prone position had the lowest values, but the other three individuals had $\delta^{15}N$ values near the average $\delta^{15}N$ value of the Romano-British humans. Therefore it is not necessarily the case that the prone burial group always have lower $\delta^{15}N$ values than the supine burial group. Still, the GLM showed a marginal significance in correlation between the body position and $\delta^{15}N$ values.

Not only all six decapitated Romano-British individuals but also others who were not decapitated were in the higher range of $\delta^{13}C$ values. Thus, decapitated individuals do not form a different group from those who were not decapitated with respect to $\delta^{13}C$ values. Nevertheless, the GLM showed a marginal significance in correlation between the decapitation and $\delta^{13}C$ values. In contrast, there was no significant difference between the two groups with respect to $\delta^{15}N$ values.

6.1.2.3. Intra-Site Difference in the Anglo-Saxon Period

All eight Anglo-Saxon individuals yielded enough collagen. The characteristics of individuals examined are: phase, age, sex, and presence of coffins and stone linings. Since the sample size is small, non-parametric tests were applied to test the significance of differences observed.

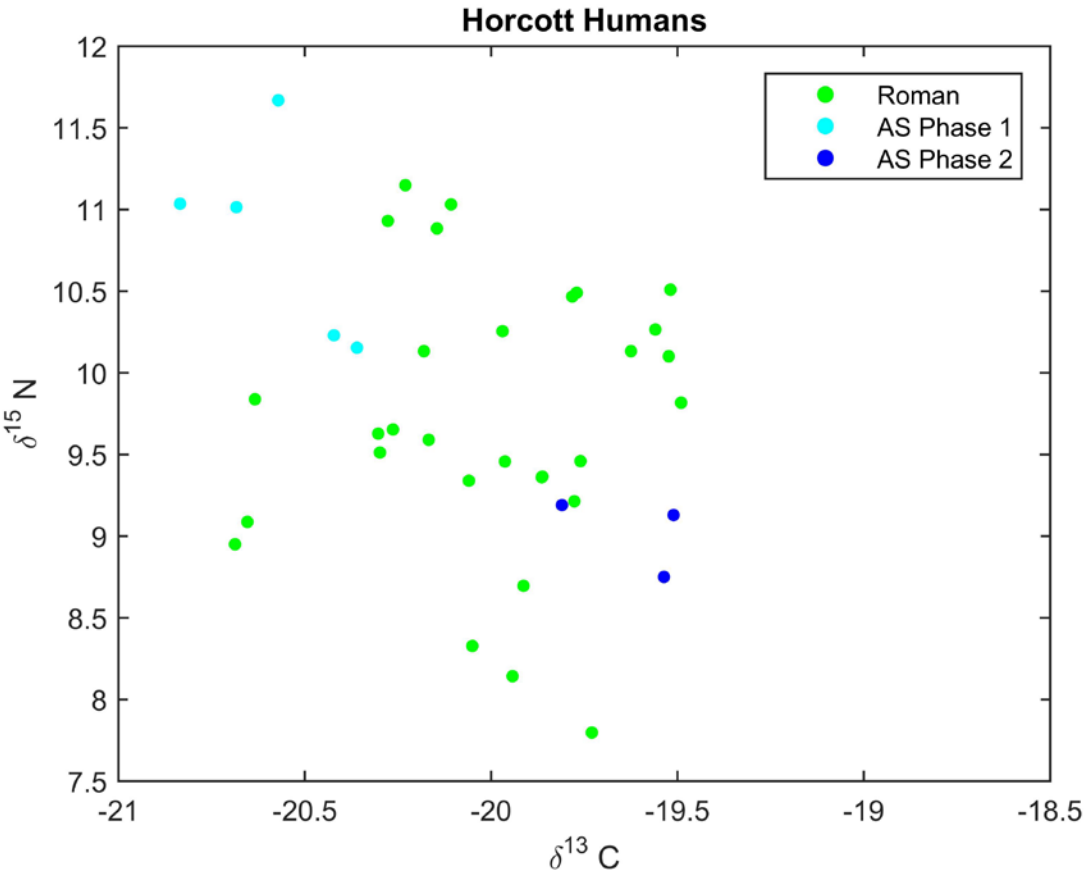


Fig. 6.19 Collagen results of humans at Horcott by period and phase; x-axis: $\delta^{13}C$ values (‰), y-axis: $\delta^{15}N$ values (‰). Data from Chueng (2009) and this study.

Firstly, five AS1 (Anglo-Saxon Phase 1) individuals were compared with the three AS2 (Anglo-Saxon Phase 2) individuals (Fig. 6.19). As already mentioned above (section 6.1.2.1), both Mann-Whitney U tests and Kolmogorov-Smirnov tests gave p-values lower than 0.05

for the difference in $\delta^{13}C$ values and $\delta^{15}N$ values between the AS1 and AS2 group. This shows that the difference between AS1 and AS2 is likely to be real, because the significance was confirmed despite the small sample size of the two groups.

Next, age of individuals and their $\delta^{13}C$ and $\delta^{15}N$ values were compared (Fig. 6.20). There seems to be a negative correlation between age and $\delta^{13}C$ values, while apparently a positive correlation exists between age and $\delta^{15}N$ values.

Although there is a possibility that the young children' $\delta^{15}N$ values may retain the suckling offset which makes their $\delta^{15}N$ values more enriched than adult $\delta^{15}N$ values (see Chapter 4), it is not necessarily the case for Anglo-Saxon humans at Horcott. The $\delta^{15}N$ values of the Anglo-Saxon children are not elevated enough to indicate a suckling offset, except for the youngest individual, SK87, from AS1. SK87 was aged six years and has the highest $\delta^{15}N$ value of all the humans from Horcott (Table S7a in appendix). Thus, only the $\delta^{15}N$ value of SK87 may be due to the suckling offset.

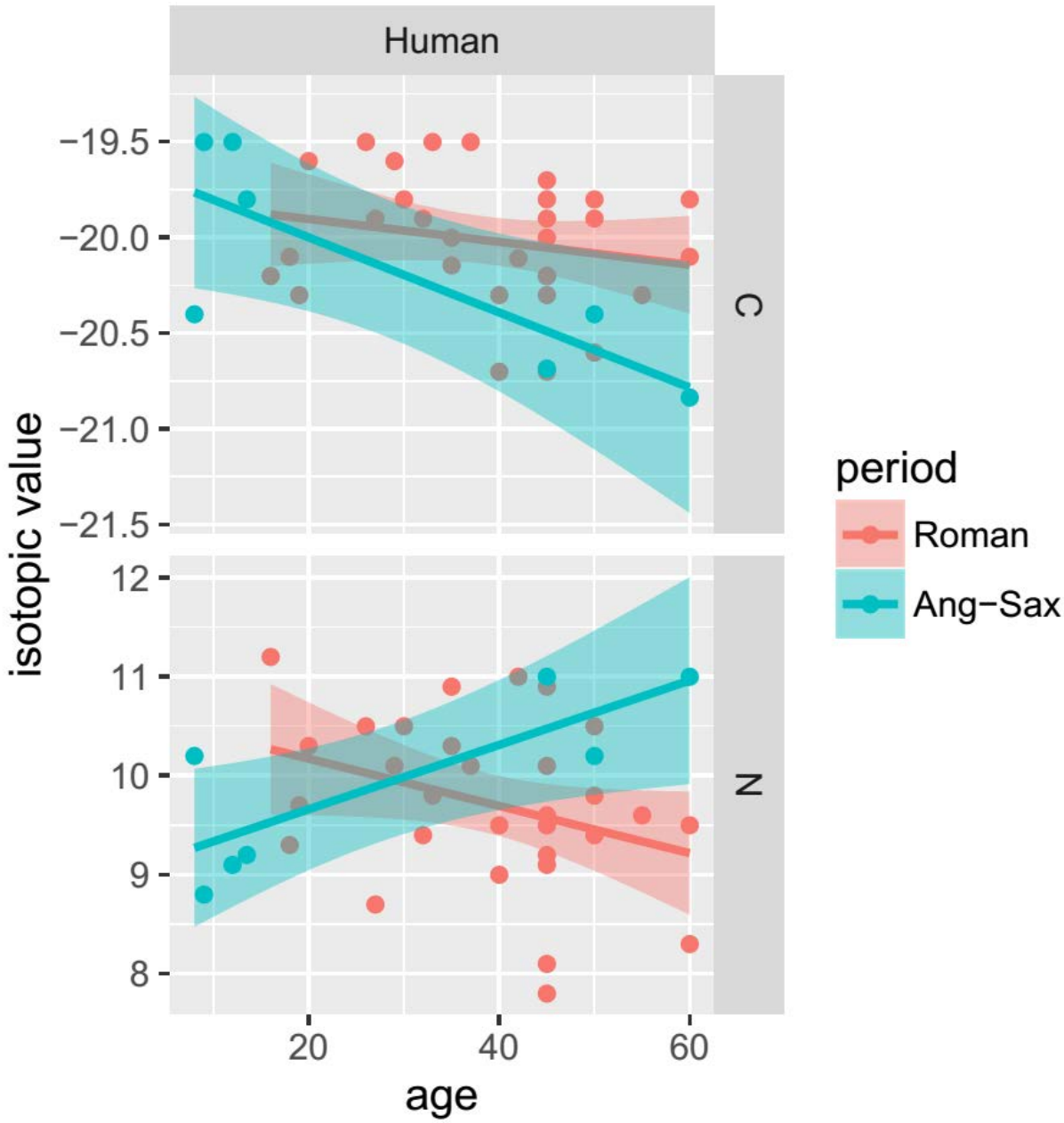


Fig. 6.20 Correlation between age and stable isotope values of humans, x-axis: age, y-axis: stable isotope values, upper row: $\delta^{13}C$ values (‰), bottom row: $\delta^{15}N$ values (‰), red: Romano-British period, blue: Anglo-Saxon period. The youngest Anglo-Saxon child (SK87) is excluded due to the possibility of suckling offset.

Moreover, Hull (2008) notes that the youth and juveniles had $\delta^{15}N$ values which were 1 ‰ lower than adults in Anglo-Saxon Norfolk, Suffolk, and Hampshire, and suggests that the lower $\delta^{15}N$ values could have been caused by high metabolism in rapidly growing sub-adults.

Indeed, at Anglo-Saxon Horcott, the children apart from the youngest child discussed above and the two adolescents all have lower $\delta^{15}N$ values than the rest who are all adults.

After excluding the youngest child (SK87) due to the possibility of a nursing offset, statistical tests were carried out to test the significance of the correlation between stable isotope values and age of individuals (Fig. 6.21). The p-values were lower than 0.05, indicating that the correlation with age was significant for both $\delta^{13}C$ and $\delta^{15}N$ values.

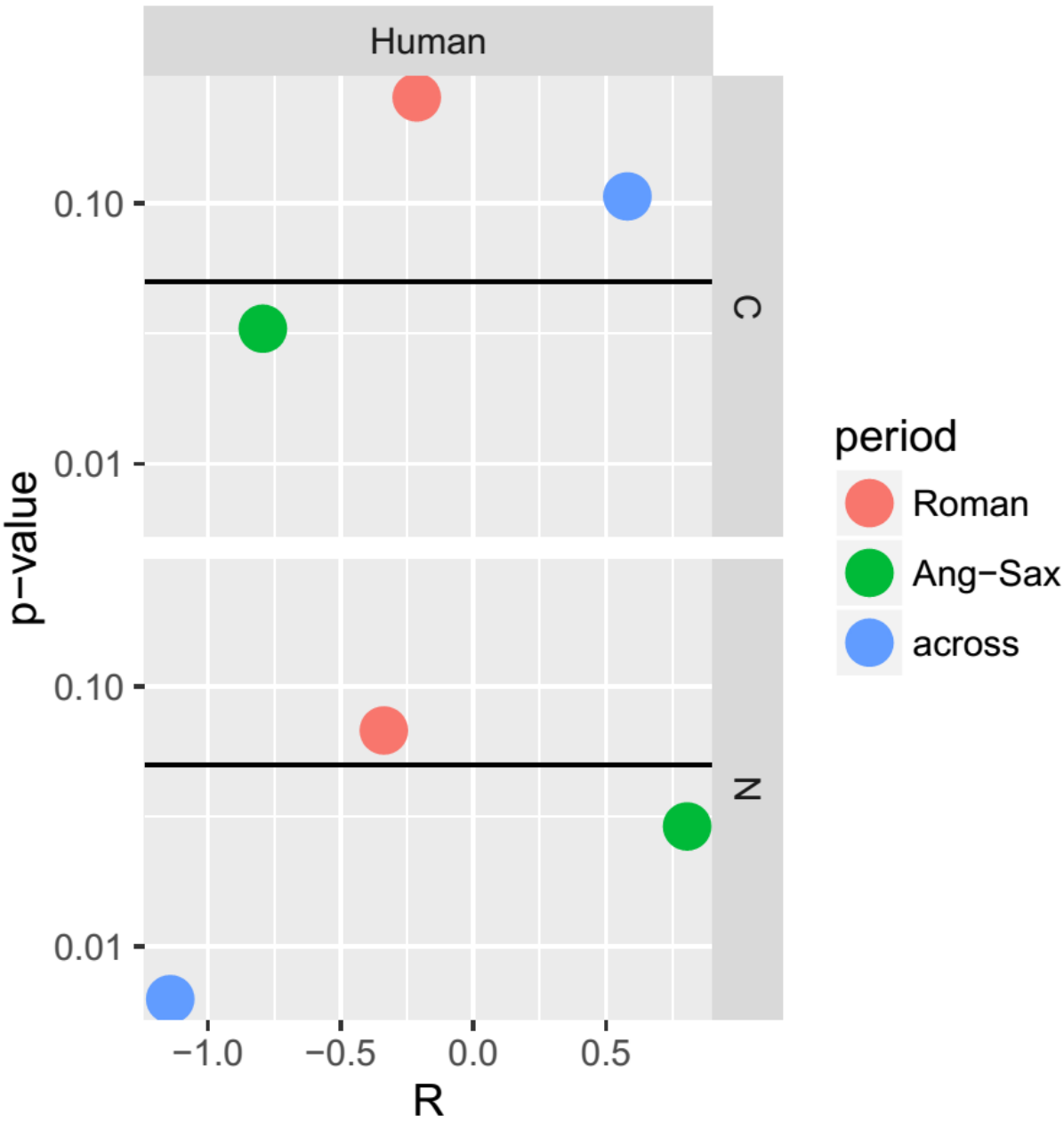


Fig. 6.21 Statistical significance of correlation between age and stable isotope values of human, x-axis: correlation coefficient, y-axis: p-value indicating the level of probability of correlation, upper row: $\delta^{13}C$ values, bottom row: $\delta^{15}N$ values, red: Romano-British period, green: Anglo-Saxon period, blue: Comparison of the correlations between two periods. The black solid horizontal line shows p= 0.05

However, as discussed above, there was a statistical significance in the difference in both $\delta^{13}C$ and $\delta^{15}N$ values between the two phases. Thus, the correlation between $\delta^{13}C$ and $\delta^{15}N$ values and age for each phase was investigated next.

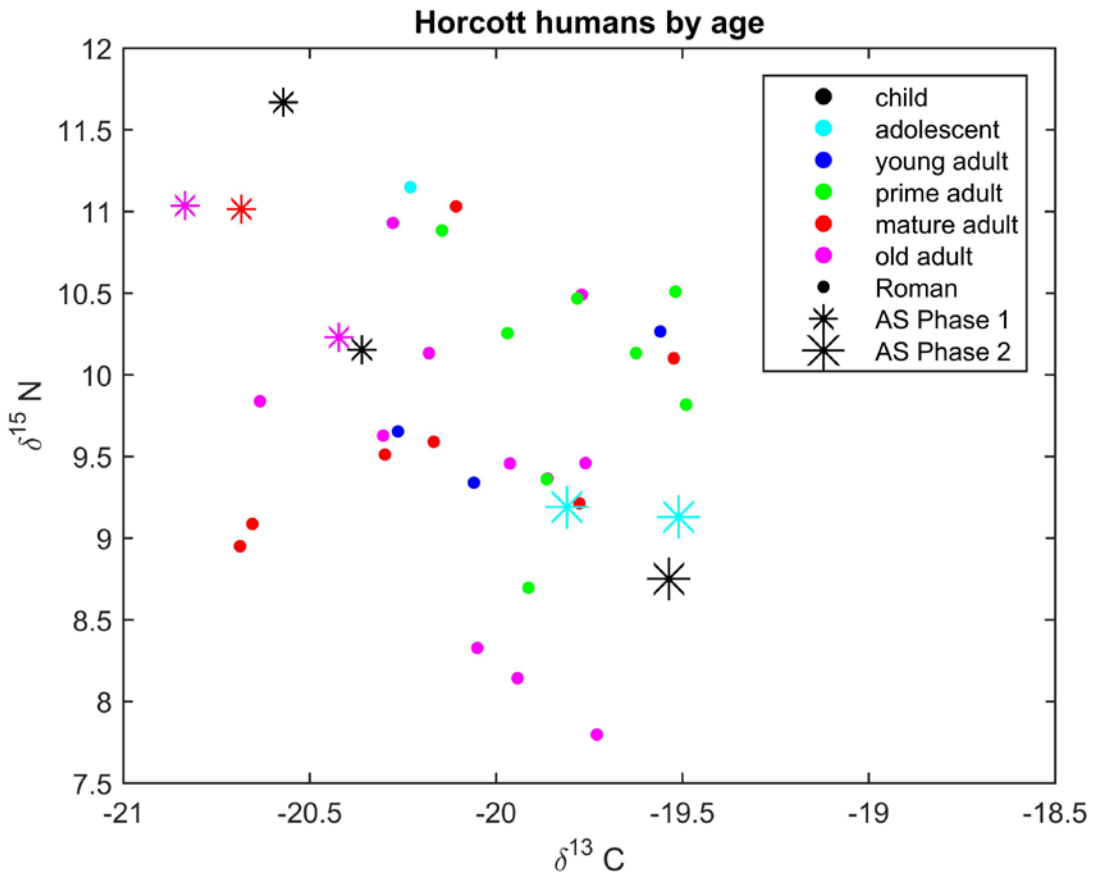


Fig. 6.22. Collagen data of humans at Horcott by age category; x-axis: $\delta^{13}C$ values (‰), y-axis: $\delta^{15}N$ values (‰). See age information in Tables S7a and S7b in appendix.

The three adults, all from AS1, have their $\delta^{13}C$ values in the lower half of the $\delta^{13}C$ value range and their $\delta^{15}N$ values in the higher half of the $\delta^{15}N$ value range of the whole Anglo-Saxon group (Fig. 6.22). In contrast, the two adolescents, both from AS2, have their $\delta^{13}C$ values in the higher half of the $\delta^{13}C$ value range and their $\delta^{15}N$ values in the lower half of the $\delta^{15}N$ value range of the Anglo-Saxon group as a whole. However, the low $\delta^{15}N$ values of AS2 individuals may have been the result of high metabolism in sub-adults (see discussion above).

The three children in contrast, are spread across almost the entire range of $\delta^{13}C$ and $\delta^{15}N$ values of the Anglo-Saxon group. As already mentioned, the stable isotope values of the youngest child may have a nursing offset. But even after this six-year-old child from AS1 is

excluded, individuals from AS1 have higher $\delta^{15}N$ values regardless of age compared to the AS2 group (Fig. 6.23).

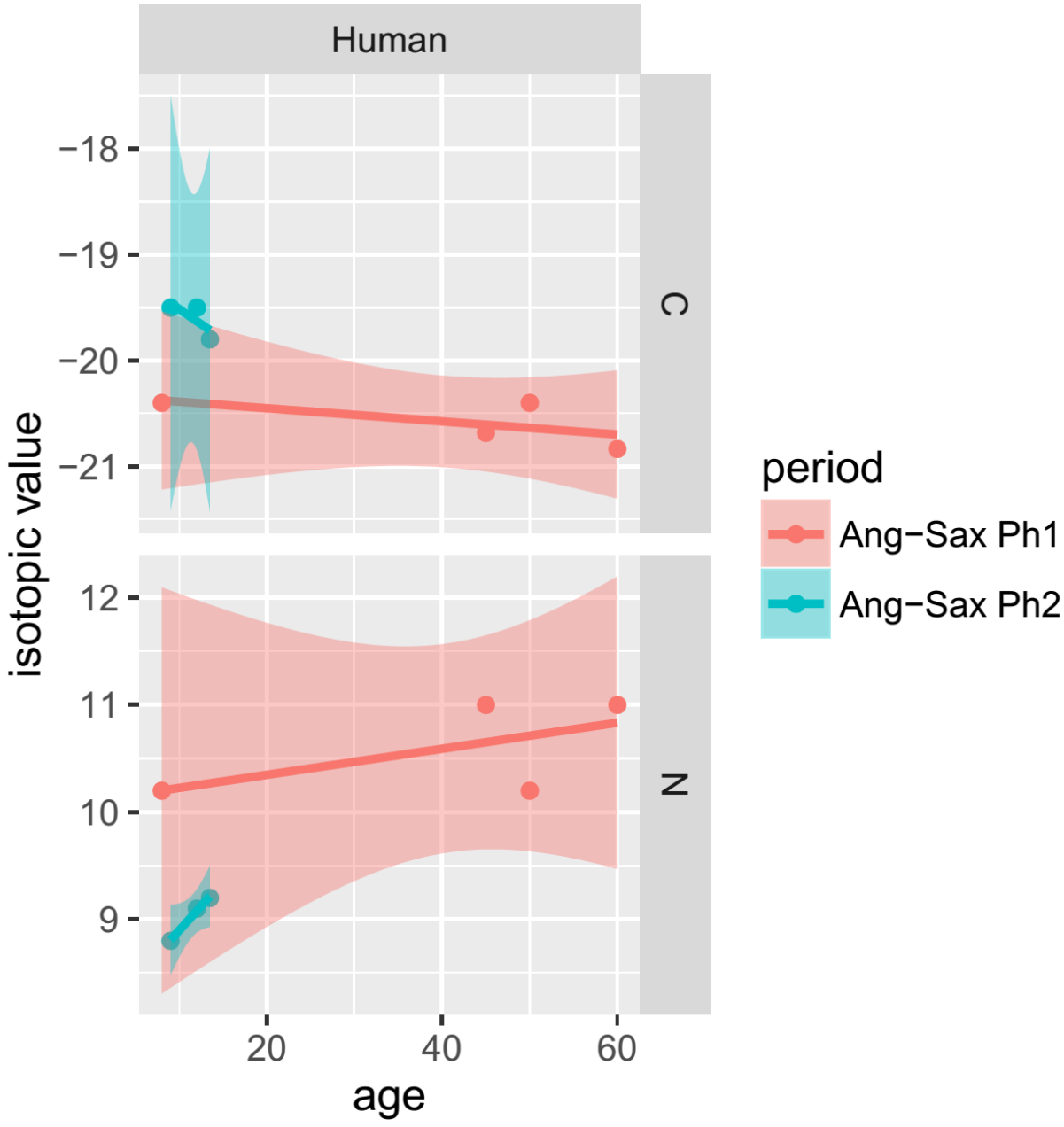


Fig. 6.23 Correlation between age and stable isotope values of Anglo-Saxon human by phase, x-axis: age, y-axis: stable isotope values, upper row: $\delta^{13}C$ values (‰), bottom row: $\delta^{15}N$ values (‰), red: Anglo-Saxon period Phase 1, blue: Anglo-Saxon period Phase 2. The youngest Anglo-Saxon child (SK87) is excluded due to the possibility of suckling offset.

Correlation coefficients were calculated to see whether the correlation between age and $\delta^{13}C$ and $\delta^{15}N$ values of each phase was significant (Fig. 6.24). None of the p-values was lower than 0.05, indicating that no correlation was significant, probably due to the small sample size of each phase group.

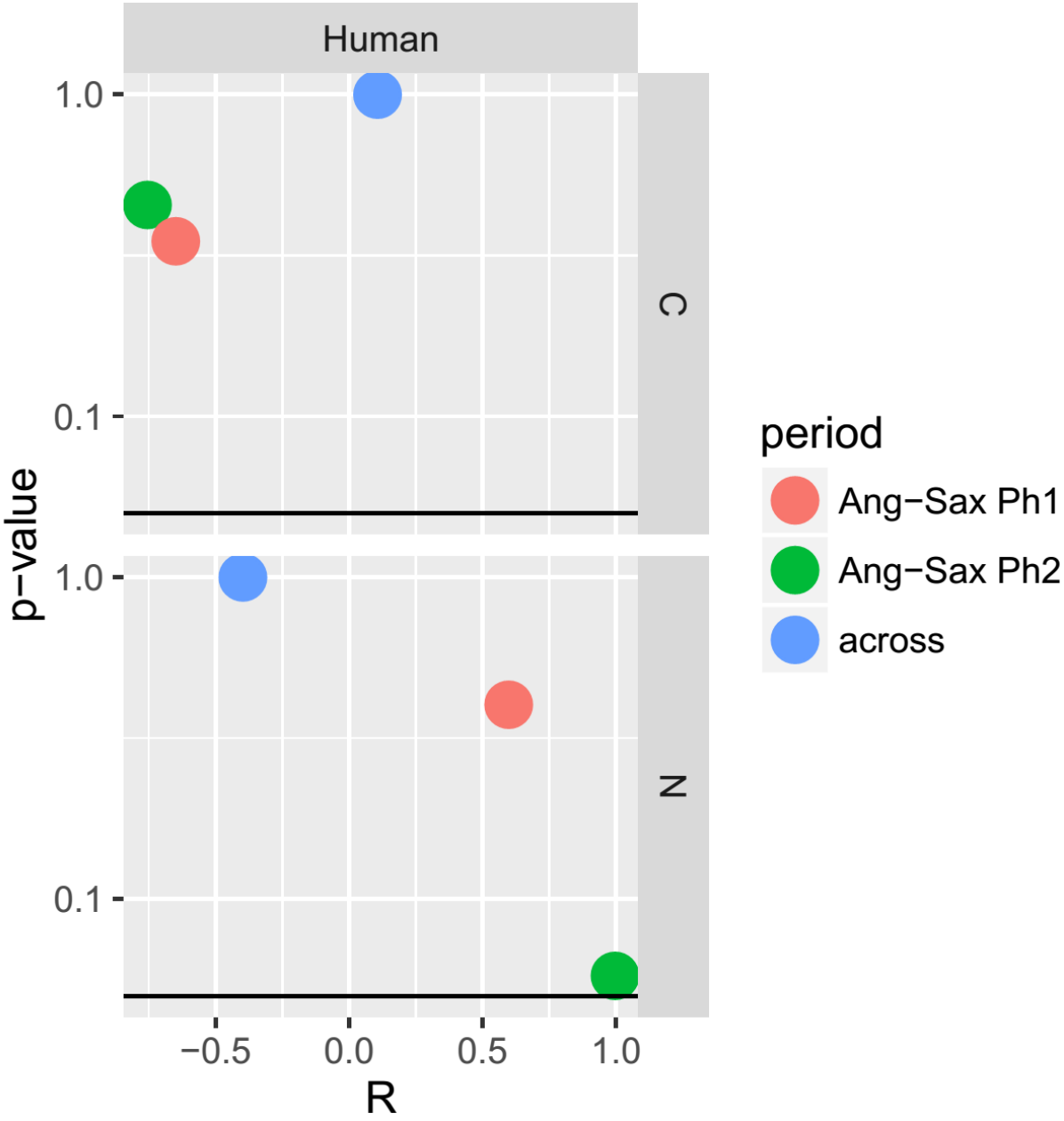


Fig. 6.24 Statistical significance of correlation between age and stable isotope values of Anglo-Saxon human by phase, x-axis: correlation coefficient, y-axis: p-value indicating the level of probability of correlation, upper row: $\delta^{13}C$ values, bottom row: $\delta^{15}N$ values, red: Anglo-Saxon period Phase 1, green: Anglo-Saxon period Phase 2, blue: Comparison of the correlations between two phases. The black solid horizontal line shows p= 0.05

Sex identification was possible for adults: one female mature adult and two female old adults. However, the sexes of adolescents and children are unknown, except for one adolescent from AS2 (SK219) sexed as possibly male. SK219 has a higher $\delta^{13}C$ value and a lower $\delta^{15}N$ value than the three females from AS1. Since the sample sizes are extremely small, unsurprisingly the correlation between sex and $\delta^{13}C$ and $\delta^{15}N$ values did not show any statistical significance.

Regarding burial characteristics, the differences are whether they had coffin nails and/or stone linings in their graves, or neither of the two. SK87, SK111, and SK229 had coffin nails. They are all from AS1 and therefore are towards the lower end of the $\delta^{13}C$ value range and the higher end of the $\delta^{15}N$ value range of Horcott humans. SK111, SK 119, SK180, and SK219 had stone linings. They are also from AS1 except for SK219, which is from AS2 and therefore has a higher $\delta^{13}C$ value and a lower $\delta^{15}N$ value than the rest. Again the sample sizes are extremely small, and the correlation between burial characteristics and $\delta^{13}C$ and $\delta^{15}N$ values did not show any statistical significance.

6.2. Sequential Enamel Carbonate Results

The results of tooth enamel carbonate are from a permanent fourth premolar (P4), permanent first molars (M1), permanent second molars (M2), permanent third molars (M3) of cattle and sheep/goat (Tables 6.6 and 6.8, and Table S6 in appendix). Only one permanent fourth premolar was analysed and since there are no other comparable data, the examination of the stable isotope values here are focused on molars. Analytical precision was ± 0.05 ‰ for $\delta^{13}C$ (VPDB) and ± 0.17 ‰ for $\delta^{18}O$ (VSMOW) as estimated from the relative standard deviation (see Chapter 5).

As already mentioned in Chapter 4, $\delta^{13}C$ values from enamel carbonate reflect the whole diet of an individual, and, sequential $\delta^{13}C$ values of enamel carbonate show change through time during tooth formation, which is useful for investigating seasonal diet change. $\delta^{18}O$ values reflect seasonal change and sequential $\delta^{18}O$ values of enamel carbonate have been used to deduce birth seasonality.

The following sections will describe the stable isotope data for each species. In addition, birth seasonality deduced by modelling the sequential $\delta^{18}O$ values (detailed description in previous chapter) for each species will be examined.

6.2.1. Cattle

In total, 15 out of 37 cattle selected for collagen analyses had their tooth enamel analysed: one early Iron Age individual, two Romano-British individuals, and 12 Anglo-Saxon individuals (Table 6.6). Firstly, whether there is change in $\delta^{13}C$ values during tooth formation will be examined. Next, the cattle $\delta^{13}C$ values are compared between the Romano-British and the Anglo-Saxon periods. Then, the difference in $\delta^{18}O$ values between the Romano-British and the Anglo-Saxon periods will be investigated.

Period	Species	ID	graph ID	M1	M2	M3
Start				1/3 at birth	birth	0.5 to 1yr
Finish				0.5yr	1yr	1.5 to 2yrs
EIA	cow	1	EC501	+		
ROM	cow	1	RC101	+	+	+
ROM	cow	2	RC102	+	+	+
SAX	cow	1	SC201	+		
SAX	cow	2	SC202	+	+	
SAX	cow	5	SC205	+		
SAX	cow	6	SC206	+		
SAX	cow	7	SC207	+		
SAX	cow	8	SC208	+	+	+
SAX	cow	9	SC209			+
SAX	cow	12	SC212	+	+	+
SAX	cow	14	SC214	+	+	
SAX	cow	a	SC a	+	+	+
SAX	cow	d	SC d	+	+	+
SAX	cow	h	SC h	+	+	+

Table 6.6 Sampled cattle teeth at Horcott for enamel carbonate analysis; start and end of growth period of permanent molars from Hillson (2005: Table 3.3.). EIA: Early Iron Age, ROM: Roman, SAX: Anglo-Saxon, sampled teeth indicated as '+'.

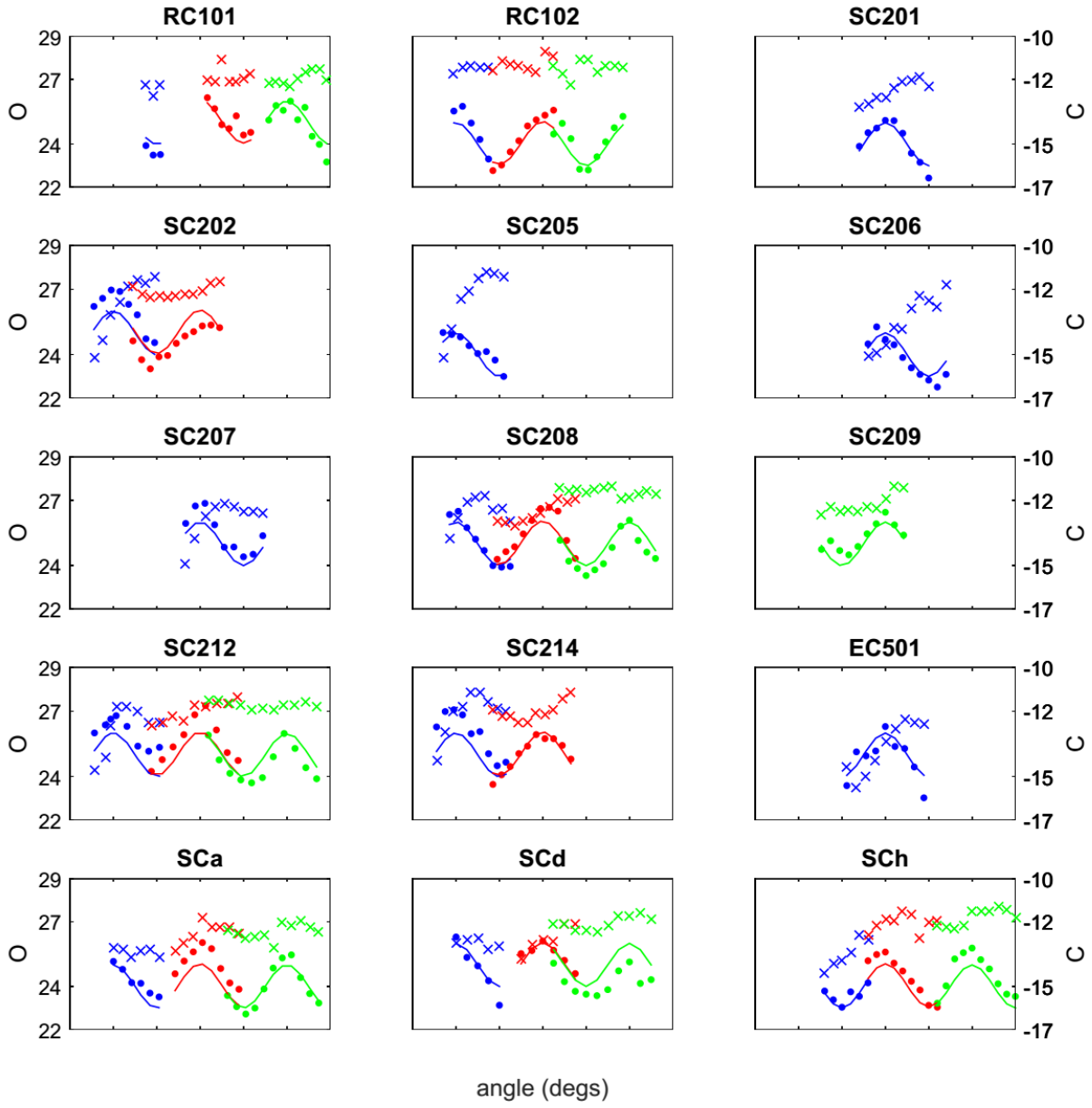


Fig. 6.25 Sequential enamel carbonate data of cattle at Horcott; x-axis: time difference of enamel formation deduced from distance from enamel root junction, y-axis: right: $\delta^{13}C$ values (cross), left: $\delta^{18}O$ values (dot), solid line: modelled $\delta^{18}O$ value curve, blue: M1, red: M2, green: M3. Individuals indicated by graph ID. See Table 6.6 for matching sample ID with graph ID

Change in $\delta^{13}C$ values while the tooth was forming were observed in some individuals. For example, M1 of the early Iron Age cow (EC501) and nine Anglo-Saxon cattle (SC201, SC202, SC205, SC206, SC207, SC208, SC212, SC214, and SC h) had lower $\delta^{13}C$ values in the samples closer to the occlusal surface (Fig. 6.25). M1s from the rest of the cattle whose

enamel were shorter (RC101, RC102, SC a, and SC d) did not show an increase in $\delta^{13}C$ values (Fig. 6.25).

Enamel near the occlusal surface are formed at the early stage of tooth formation. One-third of M1 is already formed by the time when a calf is born and the crown of M1 finishes forming at around 6 months after birth (Hillson 2005: Table 3.3.). Thus, the lower $\delta^{13}C$ values of samples closer to the occlusal surface reflect the diet when the calves were suckling. The reason of lower $\delta^{13}C$ values is possibly because milk has high percentage of lipids, which are depleted in $\delta^{13}C$ values (DeNiro and Epstein 1977, Melzer and Schmidt 1987, Rossmann et al. 1991, Gleixner and Schmidt 1997). Another reason argued by Towers et al. (2013) is that this change reflects the change in digestion process of calves from a non-ruminant while suckling milk to a ruminant when they start consuming grass besides milk. Thus the suckling calves may initially have low $\delta^{13}C$ values but the $\delta^{13}C$ values will increase as they start eating grass. In contrast, shorter enamel carbonate sequences of M1 from other cattle did not show an increase in $\delta^{13}C$ values (Fig. 6.25). This is probably because the part of enamel which had lower $\delta^{13}C$ values were already worn off and only the enamel formed after an increase in $\delta^{13}C$ values were remaining. The suckling period of calves can be as long as 12 months, but calves may be weaned earlier if they were reared for milk (see Chapter 2 section 2.1.2.1.). So there is also a possibility that the cattle with shorter M1 happened to have been weaned earlier.

Next, when cattle $\delta^{13}C$ values are compared between the Romano-British and the Anglo-Saxon periods, the range of $\delta^{13}C$ value of Romano-British cattle is smaller than that of Anglo-Saxon cattle (Fig. 6.25). This is mainly because the M1 of Romano-British cattle were too worn to show the expected low $\delta^{13}C$ values during the suckling period. In fact, after the $\delta^{13}C$ values of M1 which are affected by suckling were excluded, the averaged amplitudes

(difference between the maximum and minimum $\delta^{13}C$ values) were similar between the two periods: 1.4‰ in the Romano-British period and 1.5‰ in the Anglo-Saxon period. The relatively small amplitudes of $\delta^{13}C$ values of M2 and M3 show that the $\delta^{13}C$ values are relatively stable during the time of tooth enamel formation of M2 and M3 in both the Romano-British and the Anglo-Saxon periods. This indicates that the diets of cattle were isotopically relatively constant regardless of seasonality.

However, there is one exception. When plotting the $\delta^{13}C$ value sequence along with the $\delta^{18}O$ value sequence for each individual, M3 of ROM cow 2 show a partial correlation between $\delta^{13}C$ values and $\delta^{18}O$ values (RC 102 in Fig 6.25). Initially, the $\delta^{13}C$ values of three samples closest to the occlusal surface (and therefore formed the earliest) decrease as the $\delta^{18}O$ values decrease. Then, the $\delta^{13}C$ values of the next four samples form a convex curve opposed to the concave curve of the $\delta^{18}O$ values. Finally, the $\delta^{13}C$ values of the last three samples increase as the $\delta^{18}O$ values increase. None of the Anglo-Saxon cattle show a similar correlation between $\delta^{13}C$ values and $\delta^{18}O$ values. Although the $\delta^{13}C$ value sequences of SAX cow 8 and SAX cow d (SC208 and SC d in Fig. 6.25) have larger amplitudes than ROM cow 2, they reflect the difference between lower M2 values and higher M3 values rather than seasonal fluctuation. Thus, it seems that the food of Anglo-Saxon cattle was isotopically even less affected by seasonality than the food of the Romano-British cattle.

period	graph ID	Max $\delta^{13}C$	Min $\delta^{13}C$	Max-Min $\delta^{13}C$	mean $\delta^{13}C$	SD $\delta^{13}C$	Max $\delta^{18}O$	Min $\delta^{18}O$	Max-Min $\delta^{18}O$	mean $\delta^{18}O$	SD $\delta^{18}O$
EIA	EC501										
ROM	RC101	-11.06	-12.31	1.25	-11.91	0.32	26.2	23.2	3.0	25.0	0.8
ROM	RC102	-10.68	-12.23	1.55	-11.38	0.35	25.6	22.8	2.8	24.2	1.0
SAX	SC201										
SAX	SC202	-11.62	-12.38	0.76	-12.12	0.27	25.4	23.3	2.0	24.5	0.7
SAX	SC205										
SAX	SC206						25.3	22.5	2.8	23.8	0.9
SAX	SC207						26.9	24.4	2.5	25.5	0.9
SAX	SC208	-11.33	-13.15	1.82	-12.04	0.60	26.7	23.5	3.1	25.0	1.0
SAX	SC209	-11.34	-12.66	1.32	-12.18	0.47	26.5	24.5	2.0	25.3	0.6
SAX	SC212	-11.32	-12.65	1.33	-11.84	0.35	27.3	23.7	3.6	25.1	1.0
SAX	SC214	-11.10	-12.54	1.44	-12.01	0.44	25.9	23.6	2.3	25.0	0.8
SAX	SC a	-11.82	-13.33	1.51	-12.49	0.40	26.0	22.7	3.3	24.4	1.0
SAX	SC d	-11.58	-13.70	2.12	-12.33	0.56	26.1	23.6	2.5	24.7	0.8
SAX	SC h	-11.28	-12.77	1.49	-11.92	0.41	25.8	23.0	2.7	24.5	0.9

Table 6.7 Values calculated from enamel carbonate data of cattle at Horcott (Max and Min $\delta^{13}C$ values calculated only from M2 and M2). See Table 6.6 for sample ID corresponding to graph ID.

Regarding $\delta^{18}O$ values, the range, amplitude, and mean in the Romano-British period are less various than those in the Anglo-Saxon period (Table 6. 7). However, the smaller variation in the $\delta^{18}O$ values of Romano-British cattle may be affected by its small sample size, because the mean amplitudes are similar between the two periods: 2.9‰ in the Romano-British period and 2.7‰ in the Anglo-Saxon period.

6.2.2 Sheep/Goats

12 out of 29 sheep/goats selected for collagen analyses had their tooth enamel analysed: one early Iron Age individual, five Romano-British individuals, and six Anglo-Saxon individuals (Table 6.8). In addition, a set of molars from an Anglo-Saxon sheep/goat which was found without the mandible was also analysed (SAX sg A).

period	Species	ID	graph ID	M1	M2	M3
start				½ at birth	birth	1yr
finish				9months	1yr	2yr
EIA	sheep	1	ES601	+	+	+
ROM	sheep	1	RS301	+	+	
ROM	sheep	4	RS304	+	+	
ROM	sheep	6	RS306		+	+
ROM	goat?	8	RS308	+	+	+
ROM	sheep	10	RS310		+	+
SAX	sheep	1	SS401		+	+
SAX	goat?	2	SS402	+	+	+
SAX	sheep	4	SS404	+	+	
SAX	goat?	6	SS406	+	+	+
SAX	goat?	12	SS412	+	+	+
SAX	sheep	17	SS417	+	+	
SAX	sheep	A	SSA	+	+	+

Table 6.8 Sampled sheep/goat teeth at Horcott for enamel carbonate analysis: start and end of growth period of permanent molars from Hillson (2005: Table 3.3.). EIA: Early Iron Age, ROM: Roman, SAX: Anglo-Saxon, sampled teeth indicated as '+'.

Firstly, whether there is change in $\delta^{13}C$ values of sheep/goats at Horcott during their tooth formation will be examined. Next, the sheep/goat $\delta^{13}C$ values are compared between the Romano-British period and the Anglo-Saxon period and also with the cattle $\delta^{13}C$ values at Horcott. Then, the difference in sheep/goat $\delta^{18}O$ values between the Romano-British and the Anglo-Saxon periods will be investigated, and a comparison with those of cattle will be made.

Unlike cattle, most M1 analysed did not show the low $\delta^{13}C$ values closer to the occlusal surface, except for two individuals (RS304 and SS404 in Fig. 6.26). As already discussed with cattle, this may partly be because the part of enamel which had lower $\delta^{13}C$ values were already worn off and only the enamel formed after the increase in $\delta^{13}C$ values were remaining. Other possible reasons are related to the length of the suckling period and tooth formation time. Sheep are weaned when they are 16 to 18 weeks old, which is earlier than calves (see Chapter 2 section 2.1.2.2.). In addition, the crown of M1 of sheep is already half formed by the time of birth and completed by nine months (Hillson 2005: 229, 231). Since the suckling period of sheep/goats is shorter, the enamel formed during the suckling period will wear after birth more quickly. Alternatively, the suckling period of sheep may be too short to exhibit a change in $\delta^{13}C$ values.

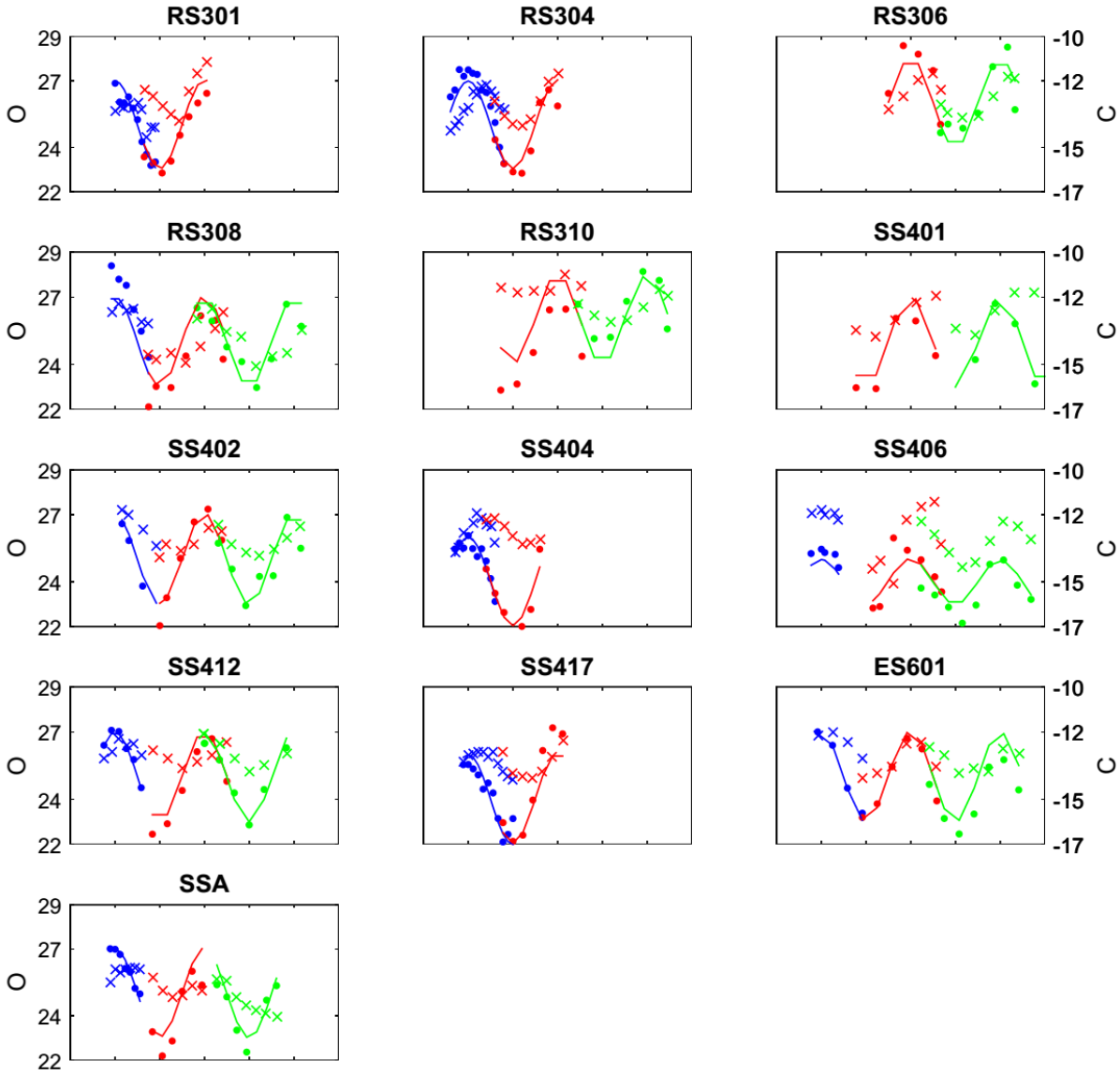


Fig. 6.26 Sequential enamel carbonate data of sheep/goats at Horcott; x-axis: time difference of enamel formation deduced from distance from enamel root junction, y-axis: right: $\delta^{13}C$ values (cross), left: $\delta^{18}O$ values (dot), solid line: modelled $\delta^{18}O$ value curve, blue: M1, red: M2, green: M3. Individuals indicated by graph ID. See Table 6.8 for matching sample ID with graph ID.

Moreover, in contrast to cattle, when plotting the $\delta^{13}C$ value sequence of sheep/goats along with the $\delta^{18}O$ value sequence for each individual, the $\delta^{13}C$ value sequence correspond more with the sinusoidal curve of $\delta^{18}O$ value (Fig. 6.26). Equally, most individuals have $\delta^{13}C$ value sequences with a smaller amplitude than the $\delta^{18}O$ values, except for SAX sg 6 (SS406 in Table 6.9). SAX sg 6 was identified as possibly goat (see Chapter 5), as well as three other

individuals whose teeth were analysed (ROM sg 8, SAX sg 2, and SAX sg 12). However, apart from SAX sg 6, the individuals identified as possibly goat do not show much difference in amplitude of $\delta^{13}C$ values from the rest identified as sheep. Among those identified as sheep, M2 of ROM sg 4 shows a very strong covariation between the $\delta^{13}C$ values and $\delta^{18}O$ values, although the amplitude of $\delta^{13}C$ values is smaller than that of $\delta^{18}O$ values (RS304 in Fig. 6.26). These patterns suggest that the fluctuation of sheep/goat $\delta^{13}C$ values covariate with the seasonal cycle. Yet, there is no consistent difference in $\delta^{13}C$ values between sheep and goats.

period	graph ID	Max $\delta^{13}C$	Min $\delta^{13}C$	Max-Min $\delta^{13}C$	mean $\delta^{13}C$	SD $\delta^{13}C$	Max $\delta^{18}O$	Min $\delta^{18}O$	Max-Min $\delta^{18}O$	mean $\delta^{18}O$	SD $\delta^{18}O$
EIA	ES601	-12.44	-14.03	1.59	-13.27	0.56	26.7	22.5	4.3	24.5	1.3
ROM	RS301	-11.14	-13.77	2.63	-12.59	0.89	26.4	22.9	3.6	24.4	1.4
ROM	RS304	-11.66	-14.03	2.37	-13.10	0.88	26.6	22.8	3.8	24.5	1.5
ROM	RS306	-11.67	-13.64	1.96	-12.68	0.72	28.6	24.7	3.9	26.5	1.5
ROM	RS308	-12.54	-15.07	2.53	-13.97	0.84	28.4	22.1	6.3	25.2	1.7
ROM	RS310	-10.95	-13.13	2.18	-12.04	0.66	26.5	22.9	3.6	24.6	1.6
SAX	SS401	-11.75	-13.79	2.04	-12.74	0.77					
SAX	SS402	-12.46	-13.93	1.47	-13.22	0.51	27.2	22.1	5.2	25.0	1.6
SAX	SS404	-12.16	-13.30	1.14	-12.79	0.49	26.1	22.0	4.1	24.4	1.4
SAX	SS406	-11.45	-15.08	3.64	-13.16	1.06	26.0	22.2	3.8	23.9	1.1
SAX	SS412	-12.09	-13.79	1.70	-12.93	0.53	26.7	22.5	4.3	24.8	1.5
SAX	SS417	-12.37	-14.06	1.68	-13.41	0.64	27.2	22.1	5.1	24.5	2.2
SAX	SSA	-13.31	-15.05	1.74	-14.09	0.59	27.0	22.0	5.1	24.8	1.6

Table 6.9 Values calculated from enamel carbonate data of sheep/goats at Horcott (Max and Min $\delta^{13}C$ values calculated only from M2 and M2). See Table 6.8 for sample ID corresponding to graph ID.

Next, the $\delta^{13}C$ data were compared between the two periods. The range of $\delta^{13}C$ value of Romano-British sheep/goat is slightly larger than that of Anglo-Saxon sheep/goat (Fig. 6.26), which is also apparent in the mean of amplitudes (difference between the maximum and minimum $\delta^{13}C$ values): 2.3‰ in the Romano-British period and 1.9‰ in the Anglo-Saxon period. However, the variance in the amplitude of $\delta^{13}C$ values is larger in the Anglo-Saxon

period; the individuals with the smallest and largest amplitudes of the $\delta^{13}C$ values are both from the Anglo-Saxon period (Table 6.9: SAX sg 4: 1.1 ‰, SAX sg 6: 3.6 ‰). Therefore the extent of seasonal difference in $\delta^{13}C$ values seems to vary more depending on the individual in Anglo-Saxon sheep/goats at Horcott.

In addition, some differences were detected between sheep/goat and cattle $\delta^{13}C$ values. Firstly, the $\delta^{13}C$ values of sheep/goats from M2 and M3 tend to be lower than those of cattle (Tables 6.7 and 6.9). Secondly, the amplitudes of sheep/goats are larger than that of cattle regardless of period. In other words, not only are the sheep/goat $\delta^{13}C$ values lower than cattle but they are also less constant than cattle. Therefore, the food of sheep/goat at Horcott were apparently more isotopically affected by seasonality.

When sheep/goat $\delta^{18}O$ values are compared between the two periods, the mean $\delta^{18}O$ values are similar, but the amplitudes are slightly larger in the Anglo-Saxon period (Table 6.9).This is possibly due to the annual difference in the temperature of summer and winter. Again, there was no consistent difference in $\delta^{18}O$ values between those identified as sheep and others identified as possibly goat.

Finally, the sheep/goat $\delta^{18}O$ values were compared with the cattle $\delta^{18}O$ values at Horcott. The mean $\delta^{18}O$ values are similar, but the ranges and amplitudes of sheep/goat $\delta^{18}O$ values are larger than those of cattle (Tables 6.7 and 6.9). This suggests that the $\delta^{18}O$ values of sheep/goats display a stronger fluctuation which reflects seasonal difference in rain water $\delta^{18}O$ values. In other words, the water the sheep/goats at Horcott drank was more influenced by seasonality than the water the cattle drank.

In addition, the noise of $\delta^{18}O$ value sequences in sheep/goats is larger than that of cattle (Figs. 6.25 and 6.26). The size of sheep/goat teeth is smaller and their enamel layer is thinner than those of cattle but the length of formation time is more or less the same as that of cattle. This means that in any point in time a smaller amount of enamel is formed in a smaller area compared to cattle teeth. This may have resulted in higher possibility of sampling enamel which formed in a range of periods and mixing them than when sampling from cattle teeth. Thus, modelling of the sinusoidal $\delta^{18}O$ value sequence developed by the author was effective for eliminating the noise.

6.2.3 Birth Seasonality from $\delta^{18}O$ Values

In this section, the birth seasonality deduced from the $\delta^{18}O$ values is examined comparing livestock species or period. Both methods developed by Balasse et al. (2012 b) and Towers et al. (2013) (see Chapter 4) were applied to the data, and the results for both were compared.

In order to incorporate the sequences that are not long enough to calculate the birth seasonality and that would be normally rejected, I developed a systematic model based on the sinusoidal $\delta^{18}O$ sequence (see Chapter 5). This model also enabled to concatenate sequences of different molars of the same individual, minimise the noise in the original sequences and produce smooth sinusoidal sequences in order to improve the accuracy of birth seasonality. The methods by Balasse et al. (2012 b) and Towers et al. (2013) were applied to the modelled $\delta^{18}O$ value sequences instead of the original $\delta^{18}O$ value sequence to deduce birth seasonality. The results for birth seasonality for cattle and sheep/goats are described below.

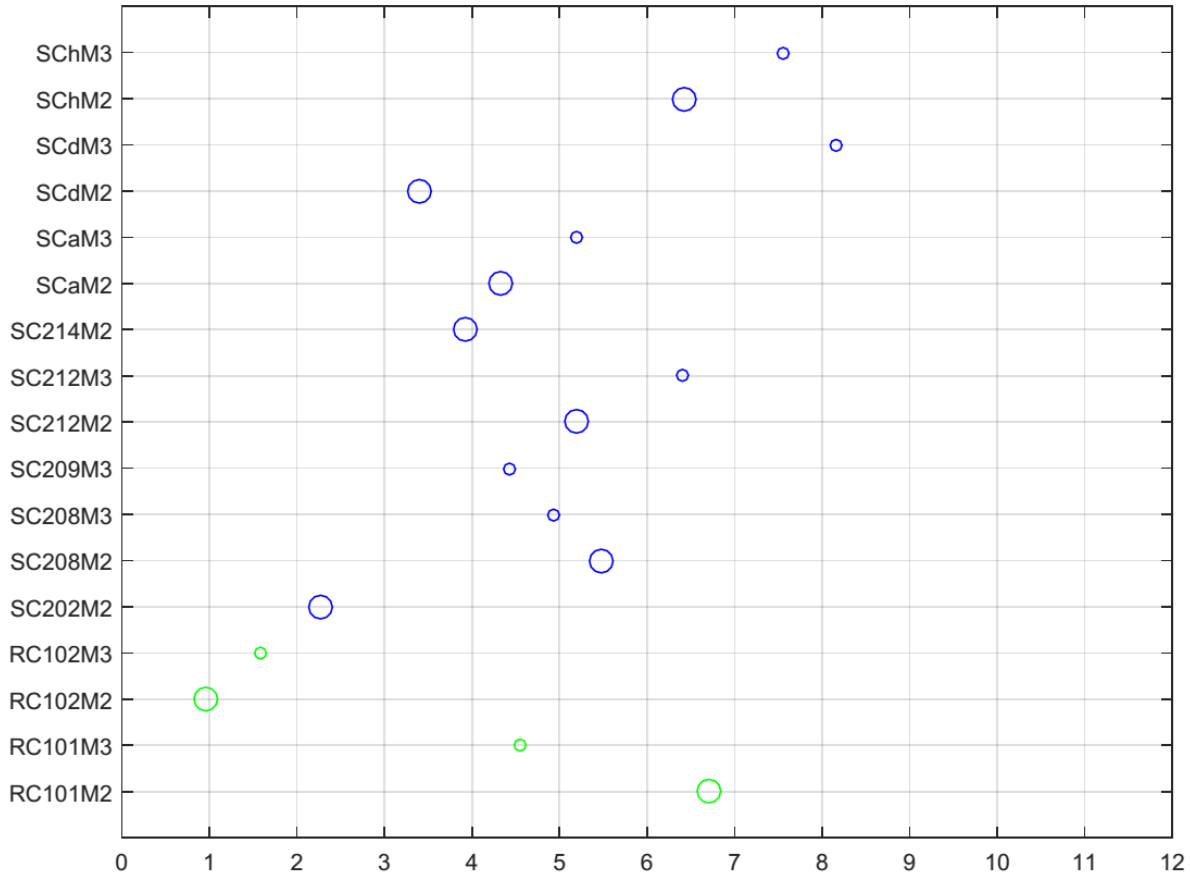


Fig. 6.27 Birth seasonality of cattle at Horcott from the method by Balasse et al. (2012 b); x-axis: months (not necessarily corresponding to calendar months), y-axis: graph ID of samples (See Table 6.6 for corresponding sample ID), green: Roman, blue: Anglo-Saxon, large circle: M2, small circle: M3.

6.2.3.1 Cattle

Birth seasonality deduced from the method by Balasse et al. (2012 b) using M2 and M3 show a slight difference between M2 and M3 of the same individual (Fig.6.27). The birth seasons of the two Romano-British cattle from M2 are six months apart while those from M3 are three months apart. Similarly, the birth seasons of Anglo-Saxon cattle from M2 of seven individuals are maximum four and a half months apart, while those from M3 of six Anglo-Saxon cattle are maximum four months apart. Thus, results from M2 show that the Romano-British cattle had a longer birth season despite being smaller in sample size compared to the

Anglo-Saxon cattle, while results from M3 show that the Anglo-Saxon cattle had a longer birth season. This difference between the length in birth season deduced from M2 and M3 may have been affected by the small sample size as well as the individual time difference in the formation of M3 which is larger than in M2 (see Chapter 4).

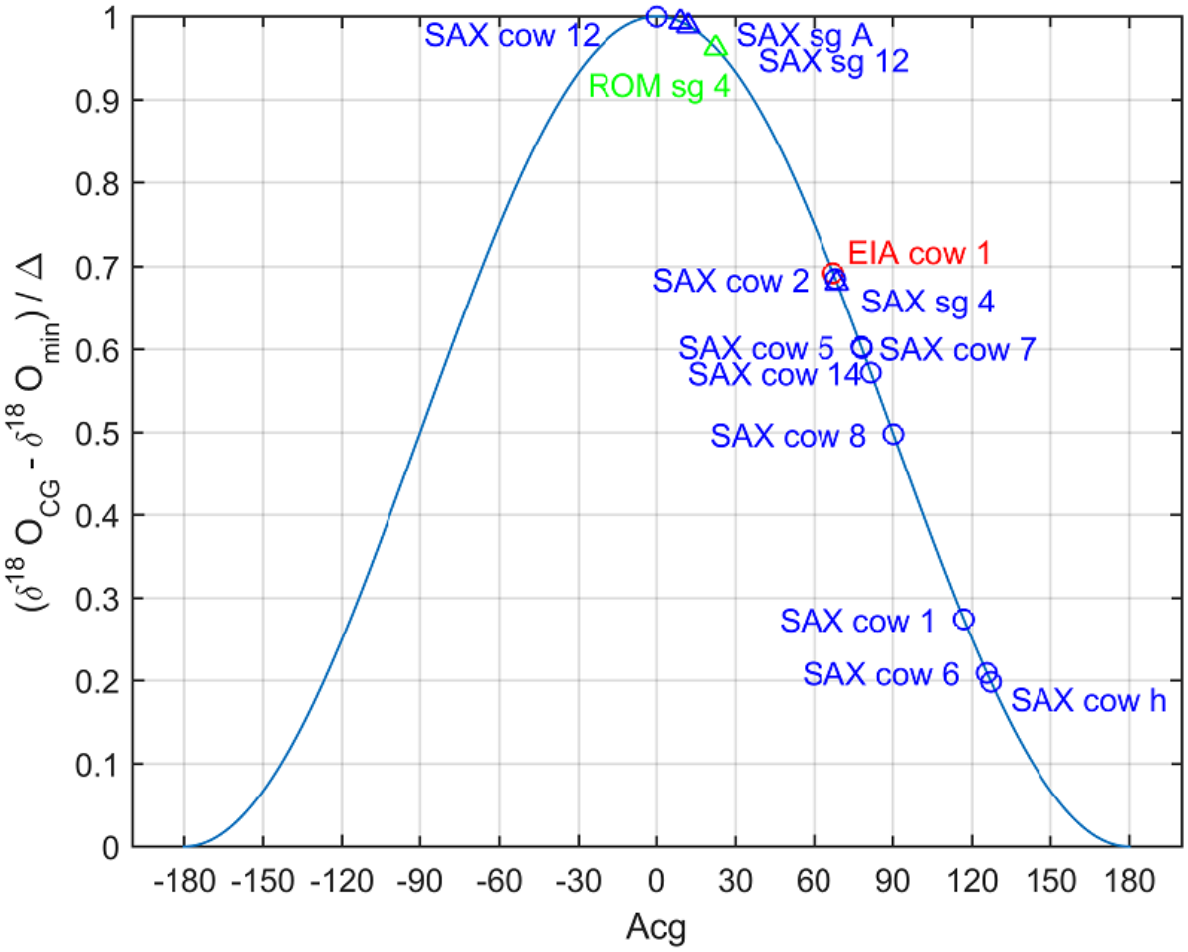


Fig. 6.28 Birth seasonality of cattle and sheep/goats at Horcott from the method by Towers et al. (2013); x-axis: Birth season from Acg (angle of $\delta^{18}O$ value curve when gradient change in $\delta^{13}C$ value sequence occurred) (30 degrees= 1 month), y-axis: difference between $\delta^{18}O$ value at the point of gradient change in $\delta^{13}C$ value sequence and minimum $\delta^{18}O$ value divided by amplitude of $\delta^{18}O$ value curve (Δ), red: EIA, green: Roman, blue: Anglo-Saxon, circle: cow, triangle: sheep/goat.

The method by Towers et al. (2013) using M1 could only be applied to nine out of 12 Anglo-Saxon cattle and an early Iron Age cow because M1 from two Romano-British and three

Anglo-Saxon cattle were too worn to show the full $\delta^{13}C$ shift, which is what the method relies on. The birth season of nine Anglo-Saxon cattle deduced by this method is maximum four and a half months, consistent with that deduced using the method by Balasse et al. (2012 b) (Fig. 6.28). Thus the difference in the result between the two methods for birth seasonality is negligible for Anglo-Saxon cattle at Horcott.

6.2.3.2 Sheep/Goats

The birth seasonality deduced from the method by Balasse et al. (2012 b) show a difference between M2 and M3 of the same individual, which is larger than that observed in the results of cattle (Fig. 6.29). The birth seasons of Romano-British sheep/goat from M2 of five individuals are maximum about five months apart, while those from M3 of three individuals are three months apart. Similarly, the birth seasons of Anglo-Saxon sheep/goat from M2 of seven individuals are maximum six and a half months apart, while those from M3 of five individuals are maximum five and a half months apart. As with cattle, this difference in the length of birth season probably reflects the individual time difference in the formation of M3 which is larger than in M2 (see Chapter 4). Still, results from both M2 and M3 show that the Romano-British sheep/goats had a slightly shorter birth season than Anglo-Saxon sheep/goats.

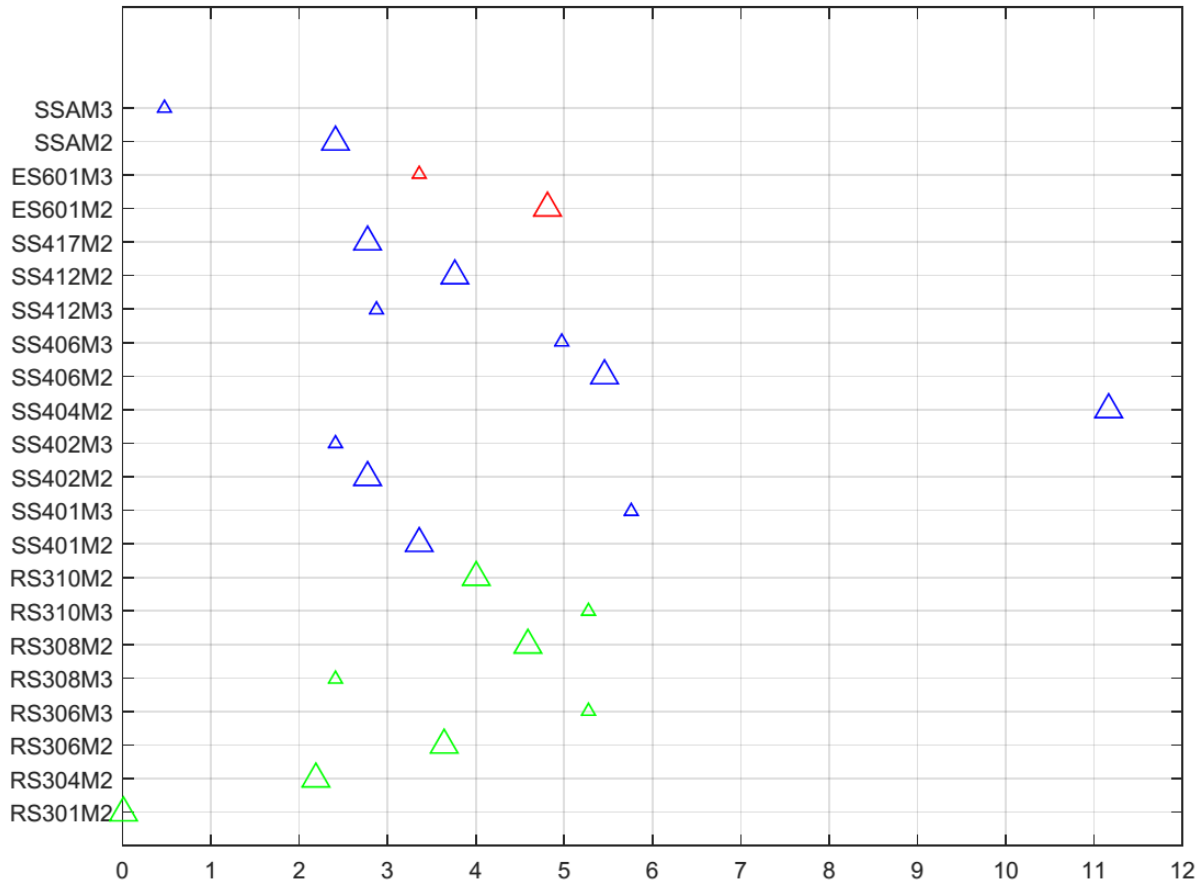


Fig. 6.29 Birth seasonality of sheep/goats at Horcott from the method by Balasse et al. (2012 b); x-axis: months, y-axis: graph ID of samples (See Table 6.8 for corresponding sample ID), green: Roman, blue: Anglo-Saxon, large triangle: M2, small triangle: M3

Notably, lambs/kids were not constantly born throughout the whole birth season. Most of the individuals were born within a period of three to four months, except for one Roman sheep/goat (ROM sg 1) and one Anglo-Saxon sheep/goat (SAX sg 4), which were born in a different season from the rest (Fig. 6.29). Thus, this may suggest that there was more than one birth season at Horcott; one major season and one minor season.

Among the 13 sheep/goat individuals whose tooth enamel sequences were produced, one Romano-British (RS 308 in Fig. 6.29) and three Anglo-Saxon (SS402, SS406, and SS412 in

Fig. 6.29) were identified as possibly goats from their teeth (see Chapter 5), but all of them were born in the major season. Therefore only the sheep had both a major and a minor birth season.

The method by Towers et al. (2013) could only be applied to one Romano-British sheep/goat and three out of six Anglo-Saxon sheep/goats. This is because two Romano-British and one Anglo-Saxon sheep/goat did not have M1, and the remaining one Early Iron Age, four Romano-British and three Anglo-Saxon sheep/goats either: a) did not have a sequence long enough, or b) had too short suckling periods to show the change from lower $\delta^{13}C$ value to higher $\delta^{13}C$ value (which is what the method relies on). The birth seasons of Anglo-Saxon sheep/goat deduced by this method is maximum two months apart (Fig. 6.29). This is much shorter than the birth season deduced from the method by Balasse et al. (2012 b), probably due to the small sample size. Thus, the method by Balasse et al. (2012 b) gave a more reliable birth seasonality than the method by Towers et al. (2013) for Anglo-Saxon sheep/goats at Horcott.

6.3. Summary

This chapter presented the results of collagen and enamel carbonate measurements. Collagen data of cattle, sheep/goats, and pigs showed a statistically significant difference between the Romano-British and Anglo-Saxon periods in respect of $\delta^{15}N$ values. Notably, pig $\delta^{15}N$ values were always elevated over those of cattle and sheep/goats. Moreover, there was a correlation between age and $\delta^{15}N$ values with respect to pigs, which was different between the two periods. In addition, collagen data of humans showed that both $\delta^{13}C$ and $\delta^{15}N$ values of Anglo-Saxon Phase 1 individuals were different from the Romano-British and the Anglo-Saxon Phase 2 individuals, but no significant difference was detected between Romano-British and Anglo-Saxon Phase 2 individuals. Enamel carbonate data showed that the amplitudes of cattle $\delta^{13}C$ values were smaller and thus less affected by seasonal change compared to those of sheep/goats. In addition, birth seasonality deduced from modelled $\delta^{18}O$ value sequences showed that the length of birth season varied depending on the period, species, and also the type of tooth analysed.

Chapter 7. Discussion

The results presented in the previous chapter will be discussed here in light of other archaeological and historical evidence. The aim of this chapter is to interpret the aforementioned results to address the research questions presented in Chapter 1.

7.1. Diet from Collagen Results

Interpretation of the collagen results is divided into two sections — animals (7.1.1) and humans (7.1.2). In all cases, no extreme $\delta^{13}C$ values or $\delta^{15}N$ values are found. All values fit within the range of a C_3 plant terrestrial diet, which is what is expected from this region in the Romano-British and Anglo-Saxon period (see Chapter 4).

7.1.1. Animals

7.1.1.1. Cattle and Sheep/Goats

As explained in Chapter 6, statistical tests indicated that the observed difference in $\delta^{15}N$ values of cattle between the two periods was significant. The direction of this effect is towards Romano-British cattle having higher $\delta^{15}N$ values, and this difference seems to be independent of age. Similar trends were observed in $\delta^{15}N$ values of sheep/goats. Following these results, the possible factors causing the difference between the two periods will be discussed, and inter-site difference will be investigated by comparing results at Horcott with those at other contemporaneous Upper Thames Valley sites with published collagen data.

Possible Factors Contributing to the Difference between the Two Periods

As already mentioned in Chapter 3, $\delta^{15}N$ values can be affected by various factors including suckling, and calves are weaned at nine to ten months after birth, or earlier when cattle are reared for milk production, while lambs are weaned at 16 to 18 weeks after birth (see Chapter 2 section 2.1.2.2). Consequently, collagen formed before weaning can have higher $\delta^{15}N$ values than that formed after weaning. If the Romano-British individuals were younger than the Anglo-Saxon individuals, the cause of higher $\delta^{15}N$ values could be due to retaining the suckling effect rather than difference in diet. Since this is not the case, the differences in $\delta^{15}N$ values between the Romano-British and Anglo-Saxon cattle as well as sheep/goats was not affected by age difference. It is therefore more likely to have been caused by difference in $\delta^{15}N$ values of food. There are various factors which may have produced these differences in $\delta^{15}N$ values between the Romano-British and Anglo-Saxon periods which are food intake, natural soil condition, and artificially altered soil condition.

The first factor as a potential source of difference in $\delta^{15}N$ values to be considered is food intake. Cattle and sheep/goats are herbivores, so normally the food consumed by them derive from plants (see Chapter 2). What types of food were consumed by them in the Romano-British and the Anglo-Saxon periods? There is some archaeobotanical evidence suggesting that there were wet meadows in the Upper Thames Valley at least by the Middle Iron Age (see Chapter 2) and insect remains suggesting that animal grazing was practiced earlier in the Neolithic period in the Middle Thames Valley (Robinson 2000 b, 2000 c). However, the difference in plant $\delta^{15}N$ values reflect the ^{15}N composition of the soil (see Chapter 4). Therefore, in order to discuss whether the plant $\delta^{15}N$ values varied, it is crucial to investigate the soil conditions where the plants grew.

The next potential factor to be considered that affects the $\delta^{15}N$ values is natural soil condition. Since natural cattle and sheep/goat food derives from plants, the isotopic difference between various food stuffs is a result of different growing conditions including aridity, sea spray, and manuring which will enrich ^{15}N in the soil and consequently the $\delta^{15}N$ values of plants grown in these conditions (see Chapter 4). However, among those natural conditions which elevate soil and plant $\delta^{15}N$ values, the conditions available at Horcott are few. Soil in Britain is more likely to be wet rather than dry as in the Mediterranean region, thus aridity is not a possible factor for elevation in $\delta^{15}N$ values of plants. Similarly, Horcott is not near the coast so sea spray is not a possible factor for elevation in $\delta^{15}N$ values of plants either.

The remaining possible factor for elevation in $\delta^{15}N$ values of plants is therefore artificially altered soil condition such as fertilisation including manuring. In the past, various types of manure were applied to the soil. Examples of types of manure are: faeces and urine of animals such as cattle, sheep/goats, horses, pigs, and humans, bird droppings, carcase waste, fish waste (Hall 1921: 237, 248), green manure such as leguminous plants, immature crops, weeds (Russell 1961), and ash (Shiel 2012: 16–18). Less common types of manure are: thatch, seaweed, shell sand (Finberg 1951: 89–91), and marl (Shiel 2012: 17, 18).

There is some archaeological evidence for the practice of fertilisation in Roman Britain. It has been argued that agricultural practice intensified in southern Britain in the Romano-British period as a result of Romanisation (see Chapter 1). To maintain the nutrient status of soils despite the intensification of land-use, manure and household rubbish seem to have been added to the soil in the Romano-British period (Dark 2000: 82). Lambrick (1992: 97) argues that in the Thames Valley, 'Roman manuring scatters are quite common and clearly suggest efforts to maintain or improve soil fertility'.

Smith (in Hayden et al. forthcoming) argues that kitchen waste including animal bones from meat-rich body parts may have been transported to the fields as a fertiliser at Romano-British Horcott. Applying kitchen waste including animal bones to fields will raise the ^{15}N content of the soil. This is because $\delta^{15}N$ values also become elevated when the trophic level increases and animals have elevated $\delta^{15}N$ values than plants because they are higher up the food chain (see Chapter 4).

Therefore, the factor which elevated the $\delta^{15}N$ values of plants at Horcott was probably manuring. Only kitchen waste is mentioned as possible manure (Smith in Hayden et al. forthcoming), which tends to be easier to detect because of unperishable pottery fragments mixed into it (Jones 2004). But that does not necessarily mean that animal dung and urine was not also used for manuring the fields (Jones 2009: 211). It is plausible that animal manure was used wherever livestock was present; it simply does not leave detectable traces (Jones 2012: 152). Instead, pottery fragments scattered in fields suggest that animals were kept close to where human activity took place. Ethnoarchaeological studies in Methana, Greece by Forbes (2012) records that human rubbish was thrown into the courtyard where animals were kept when they were not grazing, resulting in human rubbish being mixed with animal dung. Interestingly, when the number of livestock was too large to keep in restricted spaces near households, they were kept at the edge of the village or farther away (Forbes 2012: 170). This results in a larger amount of dung with a limited chance of being mixed with human rubbish compared to when the livestock were kept within households (Forbes 2012: 170).

One way of distributing animal dung and urine is by folding animals where the farmers want to apply manure (Shiel 2012: 19). Varro recommended putting sheep in fields after harvest,

because they will drop dung and trample the straw into the soil as manure (Hooper and Ash 1989: 159–529). Thus, livestock released in crop fields would produce manure while they consumed immature cereals and stubble (Bogaard 2012:34).

Another way recommended by Cato in *De agricultura* is spreading the bedding which absorbed animal excrement onto the fields (Hooper and Ash 1989: 1–157). Transporting heavy manure requires extra labour compared to folding animals. Ethnoarchaeological studies in Methana, Greece note that the farmers transported manure by loading it on donkeys and mules several times (Forbes 2012: 167, 168). Understandably, they strategically applied manure where it was most needed (Forbes 2012: 167). The lands they chose to apply manure to were: vegetable gardens adjacent to the village, small irrigated fields near the coast, terraces where they grew crop trees such as olives, almonds and figs with cereals and legumes sown underneath, and terraces with fertile soils where they grew wheat (Forbes 2012: 168).

From this point of view, it seems likely that the inhabitants of Romano-British Horcott chose to apply manure to fields where it would be cost effective and labour efficient. It is possible that crop fields close to the settlement were one of the most preferred fields for manuring. As Varro recommended, putting livestock in crop fields after harvest may have been the way the crop fields were manured. Since animal bone evidence suggests that the number of livestock kept at Romano-British Horcott was small (see Chapter 2), there were probably enough crop remains for them to eat.

Following the evidence discussed above, it is argued that the Romano-British cattle and sheep/goats at Horcott were consuming plants grown in manured fields, most likely to be

crop plants, resulting in elevated $\delta^{15}N$ values. Cereal grains were expensive and were also a human food, so it may have been difficult to make a profit by feeding cereal grains to livestock. However, the other parts of the crop which are the remains of harvesting and crop processing, were more reasonable sources as animal feed. Therefore, it is possible that the food which elevated the $\delta^{15}N$ values of Romano-British Horcott was leftover crop plants such as stubble and crop processing waste.

Of course cattle and sheep/goats were probably not only consuming crop processing waste. However, other plant materials, such as grass from pasture and hay are not likely to have elevated $\delta^{15}N$ values, unless grassland and hay meadows were heavily manured. Cattle and sheep/goats in hay meadows will naturally drop their dung while grazing there, so some nutrients were returned to hay meadows. But if animal dung was collected by the farmers and distributed on crop fields, soil and plant $\delta^{15}N$ values of grassland and hay meadows will not become as elevated as those of crop fields.

In fact, the $\delta^{15}N$ values of cattle and sheep/goats became depleted in the Anglo-Saxon period compared to the Romano-British period at Horcott. This possibly reflects the depletion in plant $\delta^{15}N$ values. Fraser et al. (2011) detected a gradual decline in $\delta^{15}N$ values of barley by 3.5 ‰ in the course of 70 years after manuring ceased at a long-term experimental site at Rothamsted, England. The differences in herbivore mean $\delta^{15}N$ values between the two periods at Horcott are smaller (cattle: -1.3 ‰, sheep/goats: -1.2 ‰), but this decline may also be due to the lack of sufficient soil fertilisation, resulting in lower $\delta^{15}N$ values of plants, possibly crop plants, and their consumers. Thus, it is possible that the nutrient level of the soil of crop fields was maintained by intense fertilisation including manuring during the Romano-British period, but afterwards the practice of fertilisation was not intense enough to stop the gradual decrease in soil and plant $\delta^{15}N$ values, as observed in the barley at Rothamsted.

Therefore, the decline in the intensity of fertilisation of crop fields may explain the depletion of $\delta^{15}N$ values of Anglo-Saxon cattle and sheep/goats compared to Romano-British individuals at Horcott.

Vetches were another type of food fed to livestock. Pollen of *Vicia/Lathyrus* (vetch or pea) was identified from a layer dated to the Romano-British Phase 1 or 2 which was from the fill of a waterhole at Horcott (Rutherford in Hayden et al. forthcoming). However, legumes in general have depleted $\delta^{15}N$ values. This is because the bacteria in root nodules fix nitrogen from air, which is depleted in $\delta^{15}N$ value compared to soil (see Chapter 4). Even when grown in manured fields, legume $\delta^{15}N$ values will still be depleted compared to other plants grown in the same condition (Fraser et al. 2011). Therefore, livestock eating legumes such as vetches will have depleted $\delta^{15}N$ values, which is not the case at Romano-British Horcott. Hence, the $\delta^{15}N$ values of cattle and sheep/goats do not suggest that the amount of legumes fed to them was enough to decrease their $\delta^{15}N$ values.

Inter-Site Difference of Cattle and Sheep/Goats

Cattle

First, cattle at Horcott were compared with those from other contemporaneous Upper Thames Valley sites to see if they were any different from other sites in the region (Fig. 7.1 and Table 7.1).

period	type	site	n	Max $\delta^{13}C$ (‰)	Min $\delta^{13}C$ (‰)	Max-Min $\delta^{13}C$ (‰)	Mean $\delta^{13}C$ (‰)	SD $\delta^{13}C$ (‰)	Max $\delta^{15}N$ (‰)	Min $\delta^{15}N$ (‰)	Max-Min $\delta^{15}N$ (‰)	Mean $\delta^{15}N$ (‰)	SD $\delta^{15}N$ (‰)
Roman	mix	Alchester	8	-21.1	-22.0	0.9	-21.5	0.3	6.8	5.7	1.1	6.3	0.4
Roman	urban	Asthall	8	-21.3	-22.1	0.8	-21.7	0.3	8.5	2.4	6.1	5.6	2.3
Roman	urban	Cirencester	9	-21.5	-22.4	0.9	-21.9	0.3	7.4	2.9	4.5	5.1	1.7
Roman	rural	Radley	4	-21.2	-22.4	1.2	-21.8	0.5	7.1	5.9	1.2	6.4	0.5
Roman	rural	Tubney	3	-21.0	-21.8	0.8	-21.4	0.4	9.4	5.8	3.6	7.9	1.9
Roman	rural	Yarnton	10	-21.0	-22.4	1.4	-21.5	0.4	10.4	3.8	6.6	6.7	2.1
Roman	rural	Horcott	7	-21.4	-22.1	0.7	-21.8	0.2	7.7	5.1	2.5	6.6	1.0
AS	rural	Horcott	27	-21.1	-22.4	1.3	-21.8	0.3	7.8	2.9	4.9	5.3	1.1
AS	rural	Berinsfield	4	-21.4	-21.8	0.4	-21.6	0.2	6.3	5.3	1.0	5.8	0.4

Table 7.1 Values calculated from collagen data of cattle from Upper Thames Valley sites. Data from Cummings 2008, Lightfoot et al. 2009, Nehlich et al. 2011, and Privat et al. 2002, and this study.

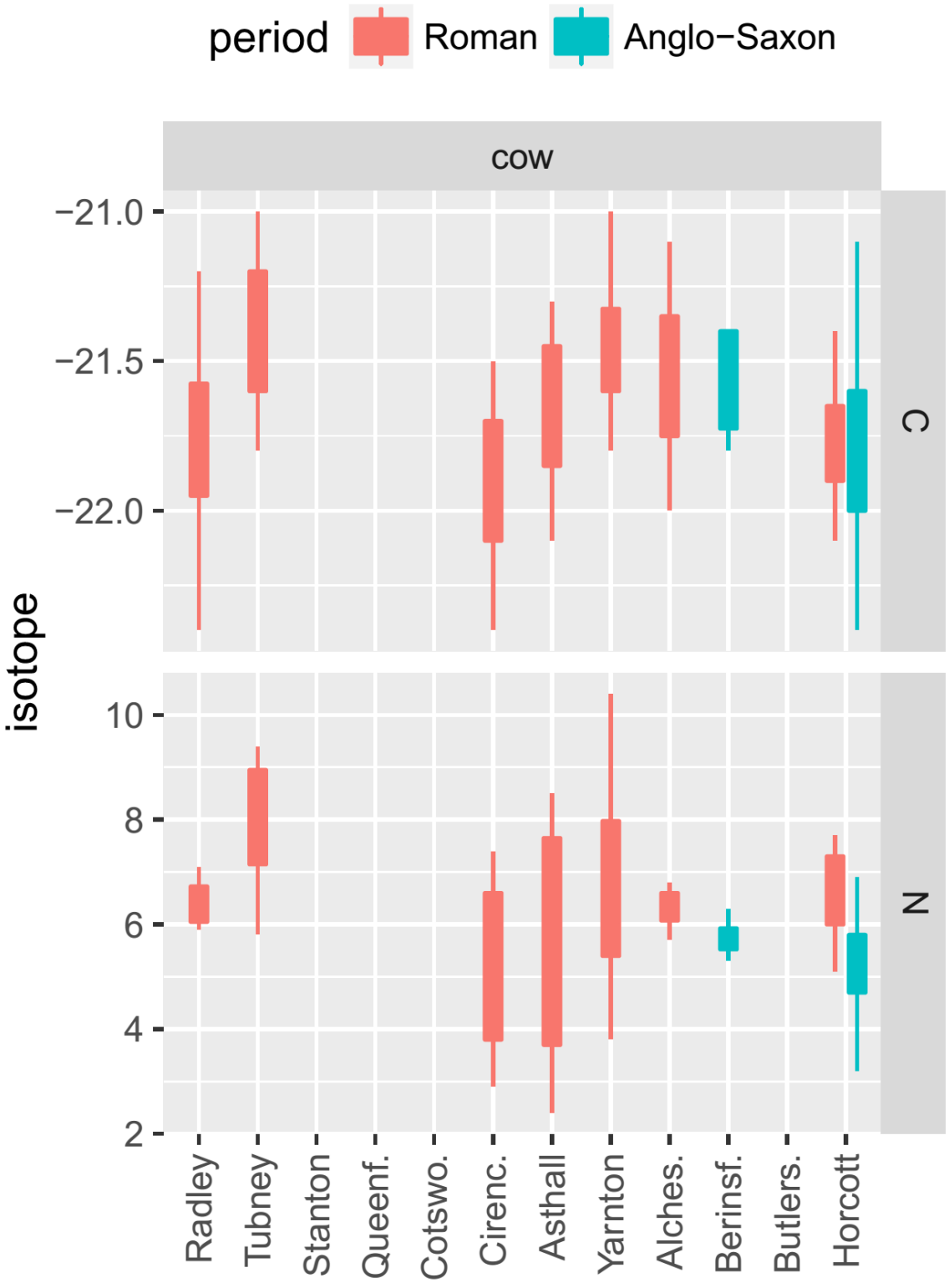


Fig.7.1 Box-plots of collagen data of cow from Horcott in comparison with other Upper Thames Valley sites. The box represents 50% percentile around the median and the whisker represents the 90% percentile of the distribution, x-axis: sites, y-axis: stable isotope values; upper row: $\delta^{13}C$ values (‰), bottom row: $\delta^{15}N$ values (‰), red: the Romano-British period, blue: the Anglo-Saxon period. Data from Chueng 2009, Cummings 2008, Fuller et al. 2006, Lightfoot et al. 2009, Nehlich et al. 2011, Privat et al. 2002, and this study.

Mann-Whitney U test was applied to evaluate the differences in the mean and variance of $\delta^{13}C$ and $\delta^{15}N$ values between Horcott and other sites. When the $\delta^{13}C$ values between Romano-British Horcott and other Romano-British sites (Radley, Tubney, Yarnton, Alchester, Asthall, and Cirencester) and between Anglo-Saxon Horcott and Anglo-Saxon Berinsfield were compared, the p-values were all higher than 0.05 (Fig. 7.2). It was the same case for $\delta^{15}N$ values: all p-values were higher than 0.05. These results therefore indicate that none of the differences in $\delta^{13}C$ and $\delta^{15}N$ values between Horcott and other sites is statistically significant for both periods. Therefore, although there was a significant difference in $\delta^{15}N$ values between Romano-British and Anglo-Saxon cattle at Horcott, when compared with cattle at other contemporaneous sites, cattle at Horcott had a diet which was isotopically not uncommon in the Upper Thames Valley. However, the reason of no significant difference may be due to the small sample sizes of cattle data of most sites.

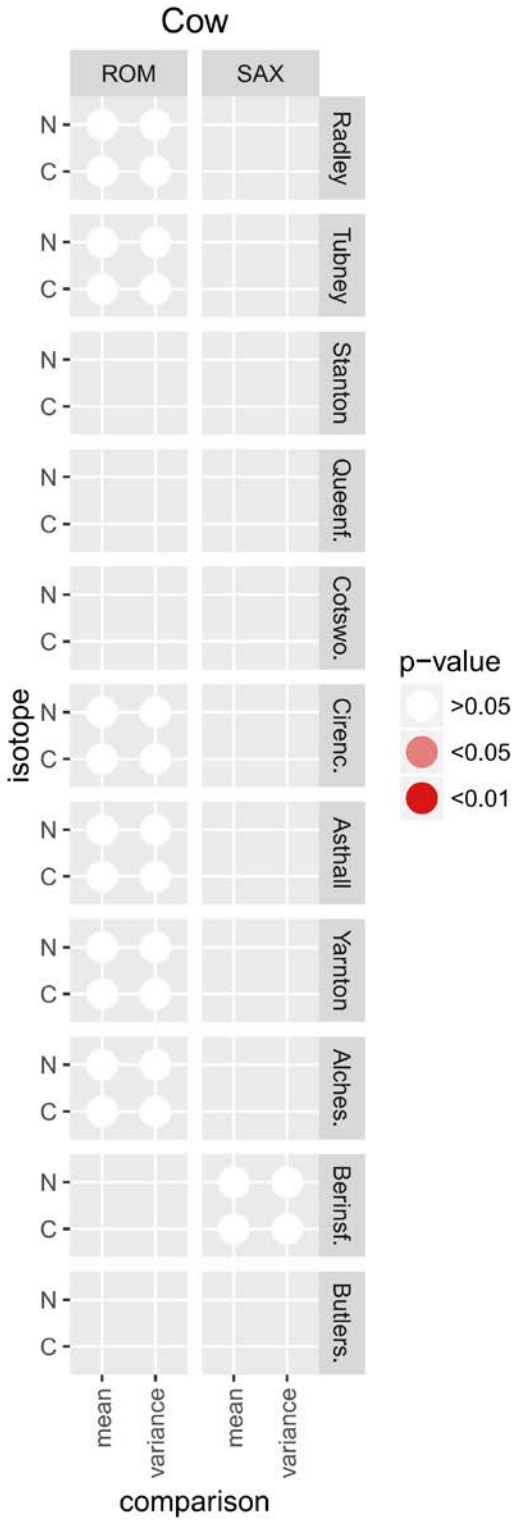


Fig.7.2: Statistical significance of difference in mean and variance of stable isotope values of cow between Horcott and other Upper Thames Valley sites, rows: stable isotope values by site, columns: values compared for each period.

Sheep/Goats

Next, sheep/goats at Horcott were compared with those from other Upper Thames Valley sites (Fig. 7.3 and Table 7.2).

period	type	site	n	Max $\delta^{13}C$ (‰)	Min $\delta^{13}C$ (‰)	Max-Min $\delta^{13}C$ (‰)	Mean $\delta^{13}C$ (‰)	SD $\delta^{13}C$ (‰)	Max $\delta^{15}N$ (‰)	Min $\delta^{15}N$ (‰)	Max-Min $\delta^{15}N$ (‰)	Mean $\delta^{15}N$ (‰)	SD $\delta^{15}N$ (‰)
Roman	rural	Alchester	5	-21.0	-22.4	1.4	-21.7	0.5	10.5	5.6	4.9	7.3	2.2
Roman	urban	Asthall	7	-19.9	-21.3	1.4	-21.0	0.5	8.3	5.5	2.8	7.1	1.0
Roman	urban	Cirencester	11	-20.7	-22.8	2.1	-21.5	0.6	8.0	2.6	5.4	5.5	1.5
Roman	rural	Radley	2	-21.3	-21.8	0.5	-21.6	0.4	6.4	6.2	0.2	6.3	0.1
Roman	rural	Tubney	1	-21.1	-21.1	0.0	-21.1	n/a	4.6	4.6	0.0	4.6	n/a
Roman	rural	Yarnton	9	-20.9	-21.9	1.0	-21.4	0.3	10.0	4.9	5.1	7.6	1.9
Roman	rural	Horcott	11	-20.8	-22.4	1.5	-21.6	0.5	7.3	4.9	2.4	6.2	0.8
AS	rural	Horcott	17	-20.5	-22.2	1.8	-21.7	0.4	6.3	2.3	3.9	5.0	1.0
AS	rural	Berinsfield	2	-21.2	-21.4	0.2	-21.3	0.1	6.4	5.8	0.6	6.1	0.4

Table 7.2 Values calculated from collagen data of sheep/goats from Upper Thames Valley sites. Data from Cummings 2008, Lightfoot et al. 2009, Nehlich et al. 2011, and Privat et al. 2002, and this study.

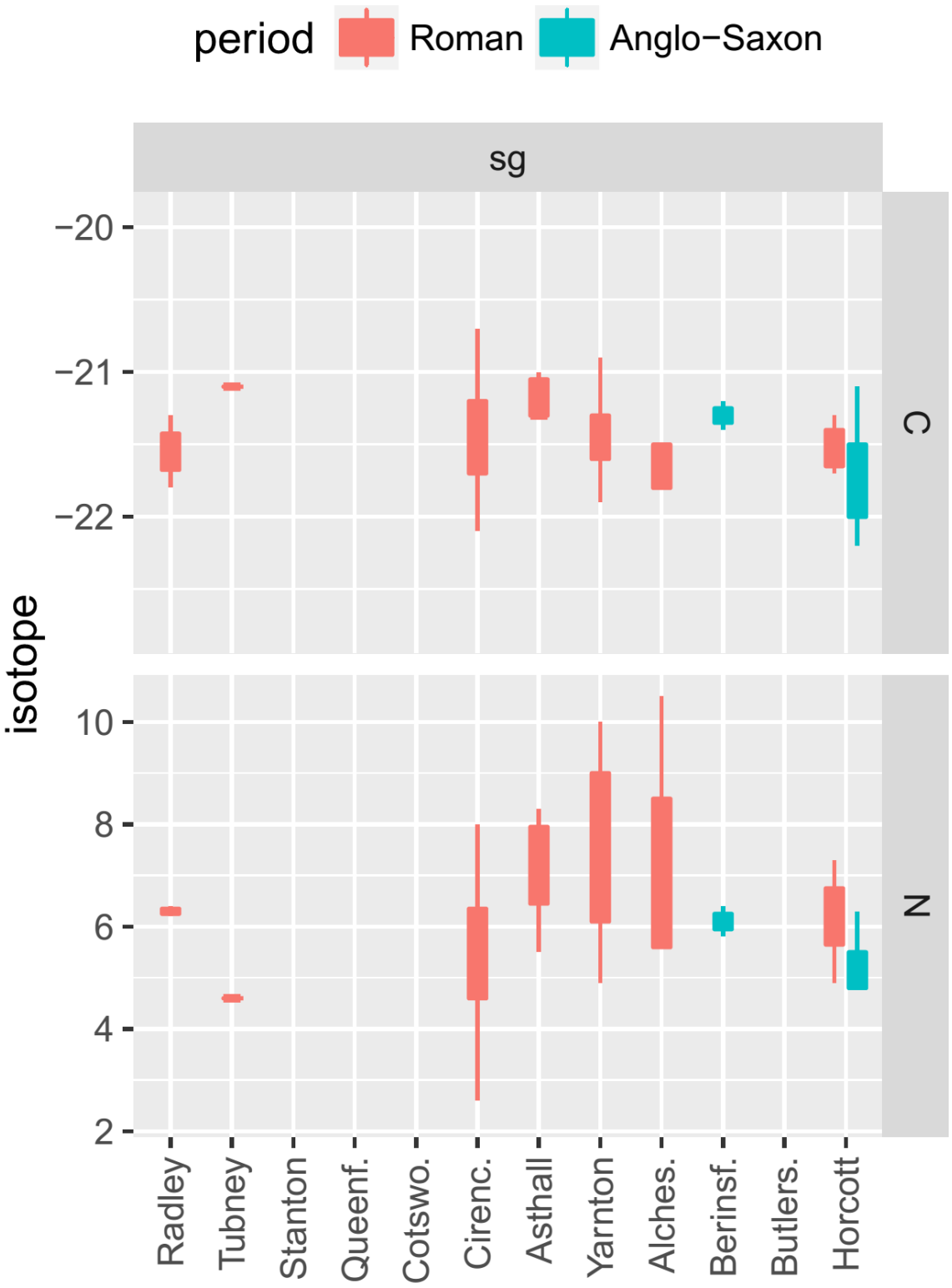


Fig.7.3 Box-plots of collagen data of sheep/goat from Horcott in comparison with other Upper Thames Valley sites. The box represents 50% percentile around the median and the whisker represents the 90% percentile of the distribution, x-axis: sites, y-axis: stable isotope values; upper row: $\delta^{13}C$ values (‰), bottom row: $\delta^{15}N$ values (‰), red: the Romano-British period, blue: the Anglo-Saxon period. Data from Chueng 2009, Cummings 2008, Fuller et al. 2006, Lightfoot et al. 2009, Nehlich et al. 2011, Privat et al. 2002, and this study.

As with cattle, Mann-Whitney U test was applied to verify the difference in the mean and variance of $\delta^{13}C$ and $\delta^{15}N$ values between Horcott and other contemporaneous local sites (Fig. 7.4). All p-values were higher than 0.05, except for the mean $\delta^{13}C$ values between Horcott and Asthall and the variance in $\delta^{15}N$ values between Horcott and Yarnton, and Horcott and Alchester, in the Romano-British period. Thus, only these three comparison in the Romano-British period were statistically significant for sheep/goats.

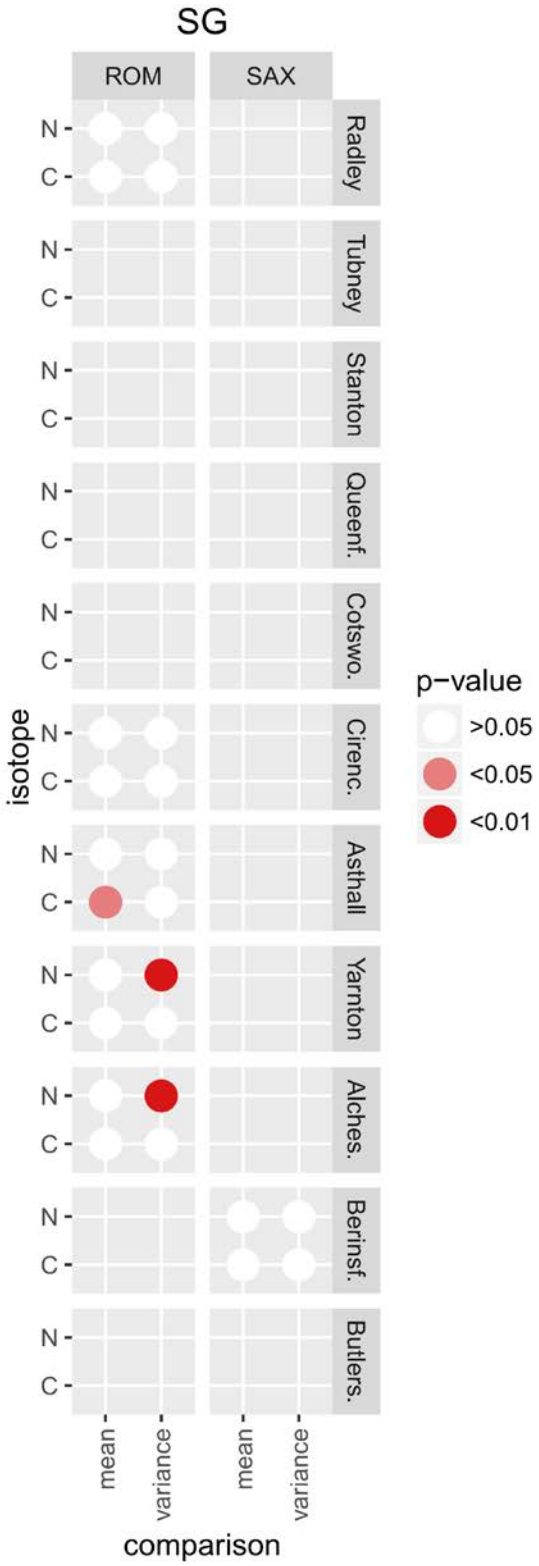


Fig.7.4 Statistical significance of difference in mean and variance of stable isotope values of sheep/goat between Horcott and other Upper Thames Valley sites, rows: stable isotope values by site, columns: values compared for each period.

7.1.1.2. Pigs

Statistical tests mentioned in Chapter 6 indicated that the observed difference in $\delta^{15}N$ values of pigs between the two periods was significant. Not only were the $\delta^{15}N$ values of the Romano-British pigs higher than those in the other periods but also high enough to overlap with the human $\delta^{15}N$ value range.

Possible Factors Contributing to the Difference between the Two Periods

Pigs are omnivores which can eat a wide variety of food (see Chapter 2) and stable isotope values of collagen will change according to their protein intake (see Chapter 4). To investigate how omnivorous the pigs at Horcott were, the difference of mean $\delta^{15}N$ values between pigs and herbivores (cattle and sheep/goat) was compared to that between pigs and dogs. In the Romano-British period, the difference of mean $\delta^{15}N$ values was 2.2 ‰ between pigs and cattle and 2.7‰ between pigs and sheep/goats. These differences are slightly smaller than the difference commonly accepted for arguing an increase in trophic level, which is +3–5‰ (see Chapter 4). In contrast, the difference of mean $\delta^{15}N$ values between Romano-British pigs and Romano-British dogs was 0.6 ‰. Therefore pigs were omnivorous enough to have elevated $\delta^{15}N$ values similar to the dogs in the Romano-British period. On the other hand, in the Anglo-Saxon period, the differences of mean $\delta^{15}N$ values were slightly smaller than those in the Romano-British period respectively; 1.9 ‰ between the pigs and the cattle and 2.2 ‰ between pigs and sheep/goat. However, the difference of mean $\delta^{15}N$ values between Anglo-Saxon pigs and Anglo-Saxon dogs was 0.5 ‰, which is similar to that observed in the Romano-British period. This is probably because the Anglo-Saxon dogs had rather low $\delta^{15}N$

values (7.6 and 7.7 ‰) for carnivores. Therefore, Anglo-Saxon pigs were slightly less omnivorous compared to their Romano-British counterparts.

Unlike the cattle and sheep/goats, there is a correlation between the age at death and the $\delta^{15}N$ value to some extent. However, the correlation varies between the two periods. Pigs younger than one year old from both periods have similar $\delta^{15}N$ values, but the $\delta^{15}N$ values of Romano-British pigs increase by age, whereas the $\delta^{15}N$ values of Anglo-Saxon pigs decrease by age (Fig. 6.11 in Chapter 6). Suckling effect may be the reason for the elevated $\delta^{15}N$ values in young Anglo-Saxon pigs (see Chapter 4). But since pigs wean by nine weeks (see Chapter 2) and the older the pigs become the less pronounced the suckling effect will be, the elevated $\delta^{15}N$ values of the older Roman pigs were probably not due to the suckling effect. This suggests that the older pigs were fed isotopically different food in the Romano-British period from the Anglo-Saxon period.

In contrast, the relation between the age at death and $\delta^{13}C$ value is different from that of $\delta^{15}N$ values. Both Romano-British and Anglo-Saxon pigs follow a similar trend; slightly higher $\delta^{13}C$ values when they are up to one year old compared to older pigs (Fig.6.11 in Chapter6). These slightly elevated $\delta^{13}C$ values in younger individuals can be due to the suckling effect, since the difference in $\delta^{13}C$ values between the younger and older pigs is about 1‰, which is comparable to a one trophic level shift (see Chapter 4). Therefore, the food fed to fatten the Romano-British pigs had similar $\delta^{13}C$ values but more elevated $\delta^{15}N$ values compared to that fed to the Anglo-Saxon pigs.

The foods consumed by pigs (see Chapter 2) vary isotopically. The food stuffs with more elevated $\delta^{15}N$ values are animal resources, as a result of being higher up the food chain (see Chapter 4). Similarly, waste of human food (especially animal protein) and excreta will also have elevated $\delta^{15}N$ values.

In addition, regardless of the proportion of animal protein in the diet, pig $\delta^{15}N$ values could become elevated as a result of manuring. However, manuring could affect all livestock consuming crops grown in manured fields. Indeed, as discussed in previous sections, the elevation in the $\delta^{15}N$ values of herbivores at Romano-British Horcott compared to that of Anglo-Saxon Horcott was attributed to intensive manuring in the Romano-British period. Therefore, just manuring will not make the pig $\delta^{15}N$ values higher than the herbivore $\delta^{15}N$ values. Interestingly, the elevation in the $\delta^{15}N$ values of pigs at Romano-British Horcott compared to that of Anglo-Saxon Horcott is larger than that of herbivores; the mean $\delta^{15}N$ value of Romano-British pigs is 1.7 ‰ higher than that of Anglo-Saxon pigs, while the difference in mean between the Romano-British and Anglo-Saxon periods is 1.3 ‰ in cattle and 1.2 ‰ in sheep/goat. The larger difference in pigs suggests that the elevation of Romano-British pig $\delta^{15}N$ values was not just the result of manuring, but also the result of a higher proportion of animal resources in their diet.

Pigs raised free-range (see Chapter 2) — feeding pigs in the woodland with mast (beech nuts and acorns) — will have stable isotope values closer to an herbivorous diet. This is not the case at Horcott because pig $\delta^{15}N$ values reflect an omnivorous diet. Therefore the pig $\delta^{15}N$ values do not suggest that pannage was the main source of pig food at Romano-British and Anglo-Saxon Horcott.

Following the discussion above, it is possible that Romano-British pigs at Horcott were fed animal resources such as waste from dairy production, waste of human food and excreta, in addition to plant materials. The Anglo-Saxon pigs at Horcott were less omnivorous, so the amount of animal resources in their diet was probably lower than that of Romano-British pigs. The decrease in animal resources in pig diet may correspond to the decrease in human activity in the Anglo-Saxon period resulting in less waste.

Inter-Site Difference

Next, $\delta^{13}C$ and $\delta^{15}N$ values at Horcott were compared with those at other contemporaneous Upper Thames Valley sites to see if they were any different from other sites in the region (Fig.7.5 and Table 7.3).

period	type	site	n	Max $\delta^{13}C$ (‰)	Min $\delta^{13}C$ (‰)	Max-Min $\delta^{13}C$ (‰)	Mean $\delta^{13}C$ (‰)	SD $\delta^{13}C$ (‰)	Max $\delta^{15}N$ (‰)	Min $\delta^{15}N$ (‰)	Max-Min $\delta^{15}N$ (‰)	Mean $\delta^{15}N$ (‰)	SD $\delta^{15}N$ (‰)
Roman	rural	Alchester	1	-20.3	-20.3	0.0	-20.3	n/a	7.5	7.5	0.0	7.5	n/a
Roman	urban	Asthall	2	-20.3	-20.6	0.3	-20.5	0.2	5.9	5.2	0.7	5.6	0.5
Roman	urban	Cirencester	8	-20.1	-21.6	1.5	-21.1	0.5	11.0	4.8	6.2	7.2	2.0
Roman	rural	Yarnton	8	-20.8	-22.1	1.3	-21.6	0.5	10.0	6.4	3.6	8.8	1.2
Roman	rural	Horcott	7	-20.7	-21.7	1.0	-21.2	0.3	10.2	7.1	3.2	8.9	1.1
AS	rural	Horcott	9	-20.8	-22.0	1.1	-21.4	0.3	8.9	5.6	3.3	7.2	1.1
AS	rural	Berinsfield	1	-20.9	-20.9	0.0	-20.9	n/a	6.0	6.0	0.0	6.0	n/a

Table 7.3 Values calculated from collagen data of pigs from Upper Thames Valley sites. Data from Cummings 2008, Lightfoot et al. 2009, Nehlich et al. 2011, and Privat et al. 2002, and this study.

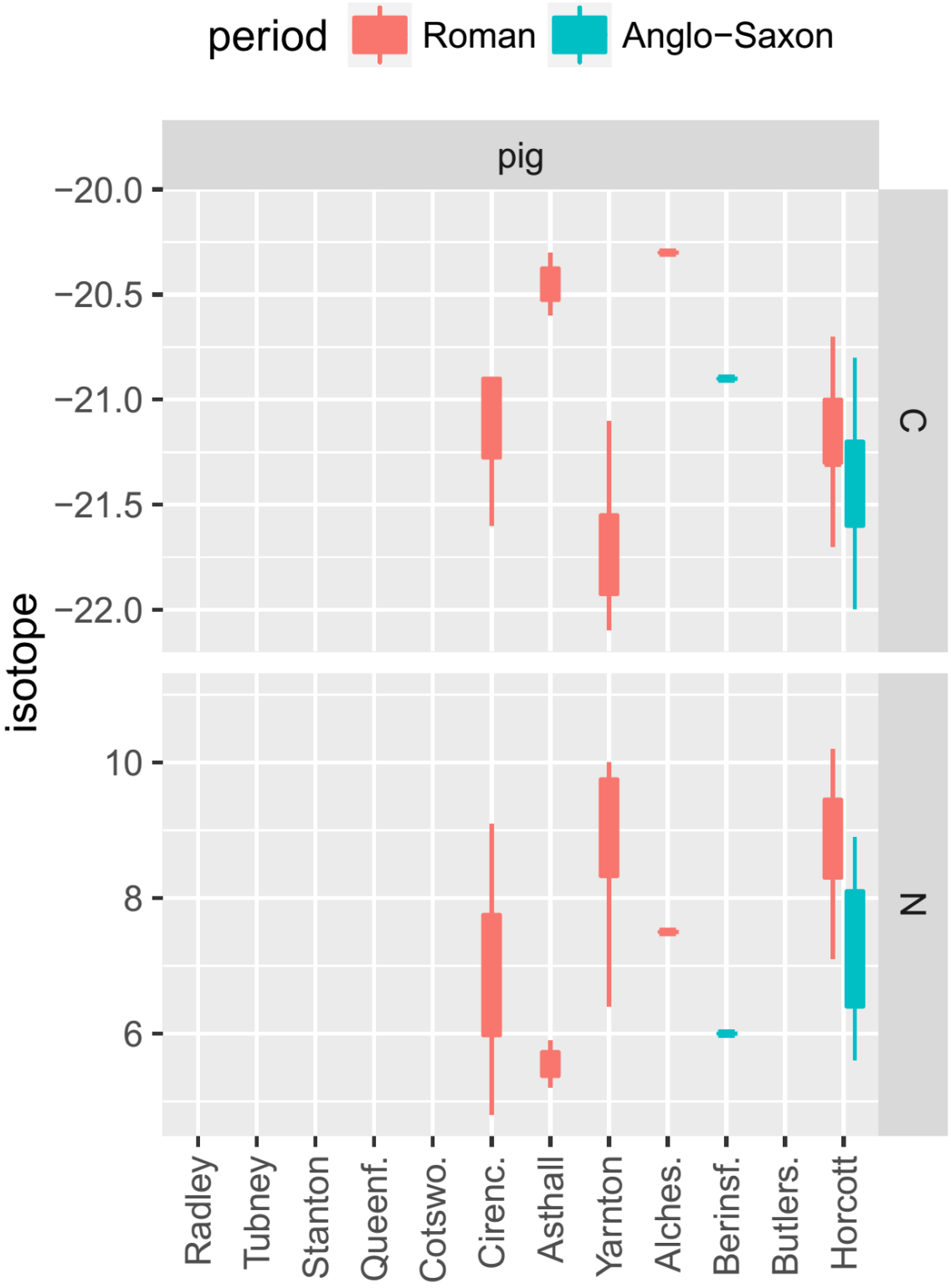


Fig.7.5 Box-plots of collagen data of pig from Horcott in comparison with other Upper Thames Valley sites. The box represents 50% percentile around the median and the whisker represents the 90% percentile of the distribution, x-axis: sites, y-axis: stable isotope values; upper row: $\delta^{13}C$ values (‰), bottom row: $\delta^{15}N$ values (‰), red: the Romano-British period, blue: the Anglo-Saxon period. Data from Chueng 2009, Cummings 2008, Fuller et al. 2006, Lightfoot et al. 2009, Nehlich et al. 2011, Privat et al. 2002, and this study.

Mann-Whitney U test was applied to evaluate the differences in the mean and variance of $\delta^{13}C$ and $\delta^{15}N$ values between Horcott and other sites (Fig. 7.6). None of the p-values were lower than 0.05, indicating that the observed differences above are not statistically significant. Therefore, although there was a significant difference in $\delta^{15}N$ values between Romano-British and Anglo-Saxon pigs at Horcott, when compared with pigs at other contemporaneous sites, those at Horcott had a diet which was isotopically common in the Upper Thames Valley. However, since the sample sizes of all sites are small, this may have affected the test results.

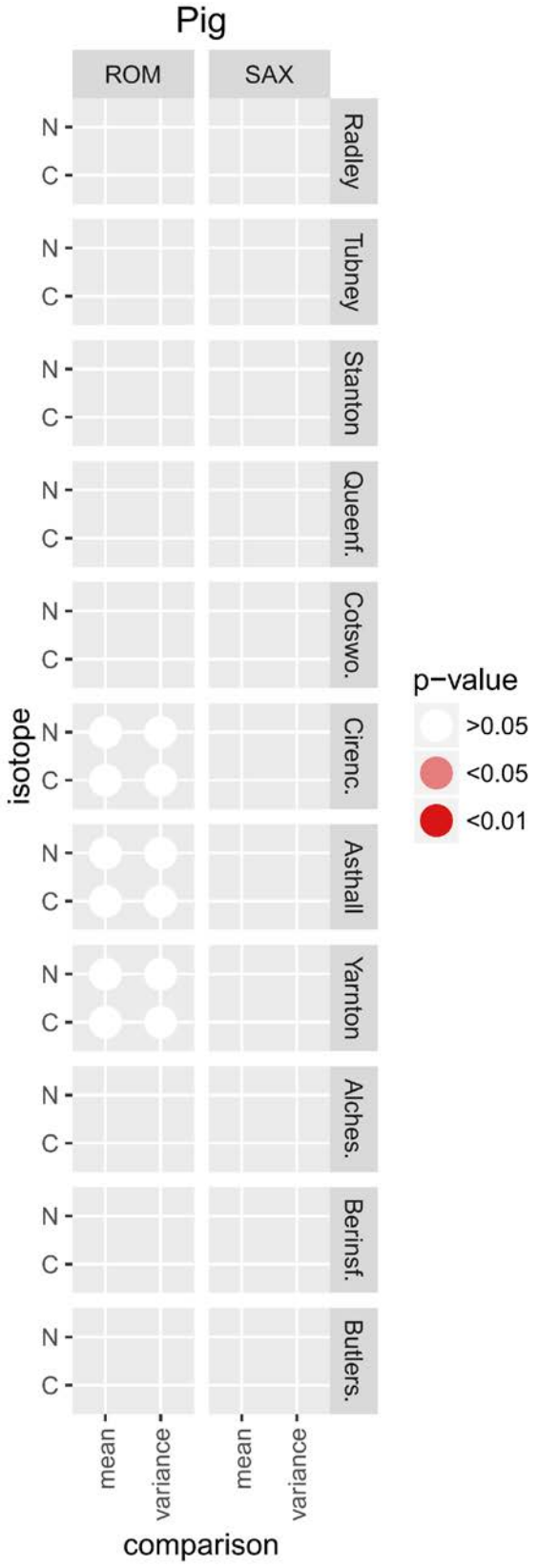


Fig. 7.6 Statistical significance of difference in mean and variance of stable isotope values of pig between Horcott and other Upper Thames Valley sites, rows: stable isotope values by site, columns: values compared for each period.

7.1.1.3. Summary of Animal Diet from Collagen Results

There are no statistically significant differences in $\delta^{13}C$ values of cattle, sheep/goats and pigs between the Romano-British and Anglo-Saxon periods. However, their $\delta^{15}N$ values are elevated in the Romano-British period and the differences between the two periods are statistically significant in all three livestock species. The most likely explanation of this result is intensive fertilisation of the soil including manuring in the Romano-British period which probably raised the $\delta^{15}N$ values of soil and plants, possibly crop plants. Feeding crop plants grown in manured fields such as stubble and crop processing waste to livestock possibly contributed in the elevation of animal $\delta^{15}N$ values.

In addition, pigs from both periods had $\delta^{15}N$ values higher than cattle and sheep/goats. They probably had animal derived food in their diet in order to have elevated $\delta^{15}N$ values compared to the herbivores (cattle and sheep/goat).

In conclusion, the Romano-British cattle, sheep/goats and pigs consumed food stuffs which were isotopically different from their counterparts from the Anglo-Saxon period at Horcott. The difference is likely to derive from different levels of manuring between the two periods applied to the crop plants, whose waste was fed to the animals. The food stuffs consumed by the animals itself probably did not change but the change in intensity of fertilisation of the soil including manuring contributed to the isotopic difference of the livestock's diet. In addition, pigs had a different diet from that of the herbivores in both periods, suggesting that pigs at Horcott had an omnivorous diet.

When animals were compared with other Upper Thames Valley sites, the mean $\delta^{13}C$ values and the variance of $\delta^{15}N$ values of sheep/goats were the only factors which showed significant difference between Horcott and other sites among the main livestock, cattle,

sheep/goats, and pigs. However, this result may have been affected by the small sample sizes of animal data from other sites.

7.1.2. Humans

Next, human collagen results will be discussed in light of archaeological and historical evidence. The first subsection will discuss about the diet difference by period and phase at Horcott. The second subsection covers the intra-site difference within the Romano-British humans at Horcott. And the third subsection argues about the intra-site difference within the Anglo-Saxon humans at Horcott. Then, in the fourth subsection, the human collagen data at Horcott are compared with results of human collagen from other contemporaneous sites in the Upper Thames Valley in order to examine inter-site differences.

7.1.2.1. Diet Difference by Period and Phase

Statistical tests indicated that the differences in human $\delta^{13}C$ and $\delta^{15}N$ values between the Romano-British and the Anglo-Saxon period are not statistically significant except for the variance in $\delta^{13}C$ values (see Chapter 6). However, when the Anglo-Saxon individuals were divided by phase, there was significant difference between AS1 (Anglo-Saxon Phase 1) and AS2 (Anglo-Saxon Phase 2) as well as between AS1 and RB (Romano-British) individuals. Only the difference between RB and AS2 was not significant. Indeed, compared to the AS1 group, the AS2 group looks more similar to the Romano-British humans. For example, as in the Romano-British period, the difference between the mean human $\delta^{15}N$ value and the mean cattle $\delta^{15}N$ value (3.7 ‰) as well as between the human and sheep/goat (4.1‰) were within the difference of one trophic level respectively. However, the difference between the mean human $\delta^{15}N$ value and the mean pig $\delta^{15}N$ value (1.8 ‰) was not. The similar pattern may suggest that the diet composition of the AS2 group was comparable to that of the Romano-British individuals.

Yet, it is possible that not all changes in diet are reflected in collagen data for several reasons. Firstly, the $\delta^{13}C$ and $\delta^{15}N$ values from collagen show an averaged value of the protein consumed. Therefore, any food with low protein content will not affect the collagen stable isotope values as much as food with high protein content (see Chapter 4). Secondly, humans have an omnivorous diet, so the collagen will show an averaged value of all the protein consumed. Eating a combination of proteins with high stable isotope values as well as proteins with low stable isotope values will result in an averaged value which would appear the same as eating protein with intermediate values. Thus, similarity in $\delta^{13}C$ and $\delta^{15}N$ values between the RB and the AS2 group does not necessarily mean that their diet was identical.

Since the Roman market economy collapsed in the course of the fifth century AD, it is unlikely that the Anglo-Saxons had access to the same range of imported food stuffs found in Roman Britain. Thus, it may be the case that there was also a diet difference between Romano-British and AS2 group but it did not result in an isotopic difference in collagen at Horcott.

In conclusion, the Phase 1 Anglo-Saxon humans had an isotopically different diet from most of the Romano-British individuals and the Phase 2 Anglo-Saxons. This may suggest that imported non-local food available in the Romano-British period ceased to be consumed after the collapse of the Roman economy and trade network. However, by Phase 2 in the Anglo-Saxon period the diet becomes isotopically more similar to the Romano-British period to a certain extent, even though it is unlikely that the Anglo-Saxons ever had access to the same variety of food available in the Romano-British period. Therefore, there is still a possibility that there is a diet difference between the Romano-British group and Anglo-Saxon Phase 2 group which did not affect the collagen stable isotope values.

7.1.2.2. Diet at Romano-British Horcott

Historical and archaeological evidence show that the local diets of Romano-British inhabitants were influenced by the Roman cuisine introduced after the Britain was incorporated into the Roman Empire (see Chapter 1). However, whether everyone in the Romano-British period had the same level of access to a Romanised diet is debatable. The level of Romanisation itself was not homogenous throughout Britain (see Chapter 1). One can expect a Roman style diet to have been more common among people of a higher social status or living in Romano-British towns, but less common among people living in rural settlements.

A variety of animal protein was consumed in Roman Britain according to historical and archaeological evidence (see Chapter 3). Among the animals consumed, pig remains as well as domesticated bird remains became more commonly found in prominent Romano-British towns (see Chapter 3). At Romano-British Horcott, the difference between the mean of human $\delta^{15}N$ values and the mean of cattle $\delta^{15}N$ values (3.1 ‰) as well as between the human and sheep/goat $\delta^{15}N$ values (3.6‰) were within the difference of one trophic level respectively, which is 3–5 ‰ (see Chapter 4). However, the difference between the mean of human $\delta^{15}N$ values and the mean of pig $\delta^{15}N$ values was only 0.9 ‰. Being pork consumers, humans are one trophic level higher than pigs, so the human $\delta^{15}N$ values should also be 3–5 ‰ higher than pig $\delta^{15}N$ values. Since this is not the case, it suggests that pork, a popular component of a Romanised diet (see Chapter 3), was not consumed enough to elevate the $\delta^{15}N$ values of humans at Horcott. As with the limited evidence of imported food at Romano-British Horcott (see Chapter 3), this further supports the previous discussion that the human diet at Horcott was only partially Romanised in the Romano-British period.

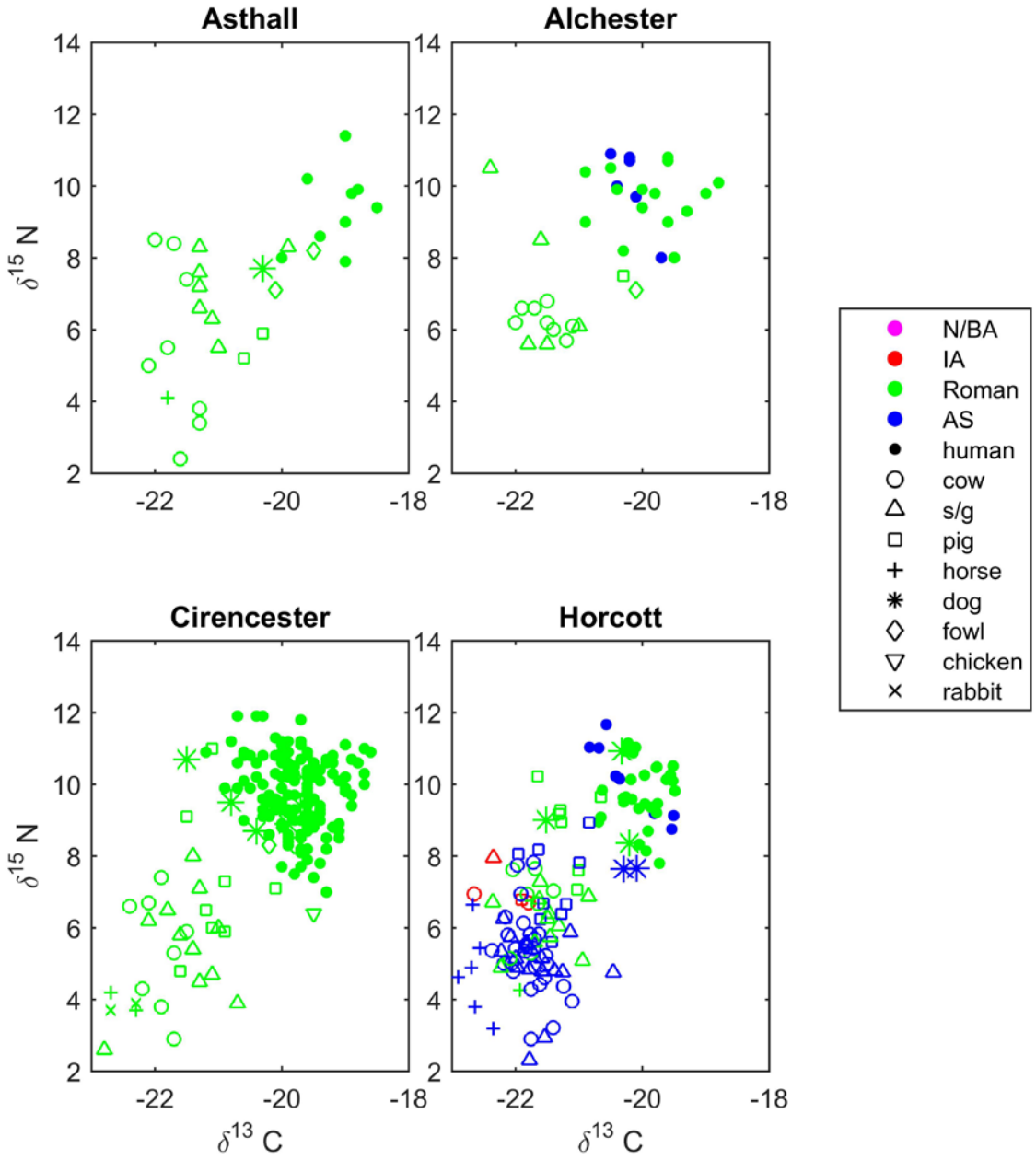


Fig 7.7 Collagen results from Horcott in comparison with other Upper Thames Valley sites. N/BA: Neolithic/Bronze Age, IA: Iron Age, AS: Anglo-Saxon, s/g: sheep/goats; x-axis: $\delta^{13}C$ values (‰), y-axis: $\delta^{15}N$ values (‰). Data from Chueng 2009, Cummings 2008, and this study.

Domesticated birds tend to have relatively high $\delta^{13}C$ and $\delta^{15}N$ values compared to herbivores, as in contemporaneous results at Asthall and Cirencester (Fig. 7.7). The reason of high $\delta^{13}C$

and $\delta^{15}N$ values may be because they consumed insects and possibly kitchen waste which may have included cereal crops from manured fields. Moreover, birds were commonly fattened before being slaughtered in Roman times (Col. Agri. 8.7.1., 8.10, Cato Agri.89, Pliny NH 10.25, Varro Agri. 3.6, 3.9.19–21), and one of the foodstuffs fed to them was bread soaked in milk (Cato Agri, 89, Varro Agri. 3.9.19–21), of which the milk can cause elevation in $\delta^{13}C$ and $\delta^{15}N$ values of birds. Unfortunately, no bird bones were recovered from Romano-British Horcott. However, since soil sieving was not carried out thoroughly except for organic rich sediments, it is possible that birds were consumed to some extent but their remains were overlooked during the excavation. Still, given that Horcott is a rural site, the amount of consumption of poultry was probably lower than in Cirencester.

Also, there is a possibility that the humans were consuming other food stuffs with depleted $\delta^{15}N$ values, which will counteract the elevated stable $\delta^{15}N$ values of pork. Legumes would be one such example (see Chapter 4). They are also a common ingredient in the Mediterranean diet (Garnsey 1999) and archaeobotanical evidence proves the diversity and abundance of legumes in the Mediterranean region (College et al. 2005). In fact, human $\delta^{15}N$ values at some sites in the eastern Mediterranean and south-east Europe are relatively low (Triantaphyllou 2001: 135–6, Tables 7.10–11). This may be reflecting the abundance of pulses in their diet. However, the amount of legumes found at Romano-British Horcott was limited (see Chapter 3). Pollen of *Vicia/Lathyrus* (vetch/pea) was identified from Romano-British layers, suggesting that vetches may have been grown as a crop, but they can be consumed by livestock as well as humans (Rutherford in Hayden et al. forthcoming). Banham and Faith (2014: 125) argue that vetch seeds are toxic to humans and therefore it must have been consumed by livestock. Thus, it remains inconclusive whether the humans were eating enough legumes to counteract the elevated stable $\delta^{15}N$ values caused by eating pork.

In addition to site-dependent differences, there is also a possibility of diet difference among individuals within the same site. In order to detect any intra-site diet difference at Romano-British Horcott, statistical significances of difference in $\delta^{13}C$ and $\delta^{15}N$ values among the Romano-British humans and various burial traits were tested in Chapter 6. The results indicated that there were no significant differences depending on sex, the presence of coffins, grave goods, or pathologies reflecting nutrition deficiency (Table 6.5 in Chapter 6). However, there were statistical differences depending on the number of burials, orientation, body position, and decapitation. Among them, the difference in $\delta^{13}C$ values between the two groups classified by the number of burials is noteworthy, because unlike the other three categories (number of burials, orientation, and body position) which also had statistically significant differences, the multiple burial individuals do not overlap with the majority (single burial individuals) at all (Fig. 6.18 in Chapter 6). This strongly shows that the three individuals from the multiple burial had an isotopically different diet from all the rest who were buried in single burials.

The multiple-burial individuals had lower $\delta^{13}C$ values than the majority, which could be caused by the lack of food with higher $\delta^{13}C$ values in the diet. One example of such food is C_4 plants (including maize and millet). However, among the C_4 plants, there is no possibility of maize consumption in Roman Britain since maize was limited to the American continent until the arrival of Christopher Columbus in AD 1492. In addition, the amount of millet found in Roman Britain is so scarce that it is regarded as being imported from outside of Britain (see Chapter 3). Therefore, consumption of C_4 plants is questionable for most rural inhabitants in Roman Britain. In other words, the lack of C_4 plants is not relevant as an explanation for lower $\delta^{13}C$ values of the multiple-burial group.

Another example of food with higher $\delta^{13}C$ value is marine resources. As already mentioned in Chapter 2, the consumption of fish was more common in Romanised communities, especially towns, military camps and villas. Since marine fish have elevated $\delta^{13}C$ as well as $\delta^{15}N$ values compared to other foods in the C_3 terrestrial environment (see Chapter 4), individuals who did not eat them could have lower $\delta^{13}C$ and $\delta^{15}N$ values than those who ate them.

At Horcott, oyster shells are found from Romano-British contexts so the inhabitants did have access to marine resources. Fish bones were not recovered, but since soil sieving was not carried out thoroughly except for organic rich sediments, it is possible that fish were consumed to some extent but that their remains were overlooked during the excavation. Nonetheless, no Romano-British humans show high stable isotope values which reflect the consumption of marine fish and shellfish. Therefore, it is possible that the amount of marine resources such as oysters consumed was not large enough to affect the stable isotope values of not just the three individuals from the multiple burial with low $\delta^{13}C$ values, but any Romano-British human at Horcott. Therefore, difference in the amount of marine resource in the diet is not a convincing explanation for the low $\delta^{13}C$ values of the multiple burial individuals.

Interestingly, even though faunal evidence indicates that the amount of marine resources consumed in the Romano-British period increased than in the Iron Age especially in towns, military camps and villas, the amount is still not comparable to that in the medieval period (Cool 2006: 105). Fish was regularly consumed in the medieval period during fast days in the Christian calendar (Cool 2006: 105) when meat was forbidden which sum up to almost half of the year (Kurlansky 1998:24). Indeed, Müldner and Richards (2005) analysed the human diet of Later Middle Ages (13th to early 16th century AD) in northern England and explained

their high $\delta^{13}C$ and $\delta^{15}N$ values as a result of the rise in the amount of aquatic resources consumed. This was further confirmed by an analysis of human diet at York spanning from the late second to the early 19th century AD, where a similar rise in $\delta^{13}C$ and $\delta^{15}N$ values was observed in the medieval period (Müldner and Richards 2007). Thus, it is likely that compared to the medieval period, fish was consumed less regularly in the Romano-British period. Therefore, it may not be really surprising after all that the stable isotope values of the Romano-British humans do not necessarily suggest a diet with a high proportion of marine resource.

Also, the amount of animal protein in a diet can affect the $\delta^{13}C$ and $\delta^{15}N$ values of the consumer: the larger the amount consumed, the higher the values will be. Both $\delta^{13}C$ and $\delta^{15}N$ values should be depleted in order to argue for a limited amount of animal protein in the diet, but the $\delta^{15}N$ values of the multiple-burial group are not the lowest among the Romano-British Horcott humans. Therefore, lack of animal protein is not a relevant explanation for the low $\delta^{13}C$ values of the multiple burial individuals either.

Is there a better explanation for the lower $\delta^{13}C$ values of the multiple-burial group? Stevens et al. (2012) argue that the observed difference in $\delta^{13}C$ values in humans in Britain from the Neolithic to the Romano-British periods can be explained as reflecting the difference in an overall C_3 terrestrial food diet with limited amounts of marine resources (see Chapter 4). Furthermore, the reason there was no co-variation between animals and human $\delta^{13}C$ values was argued that the variation in human $\delta^{13}C$ values between sites was reflecting the contribution of plants to the diet (Stevens et al. 2012). Likewise, the difference in $\delta^{13}C$ values between the multiple-burial group and the single-burial group at Romano-British Horcott

could also be reflecting the difference in diet composition of plants, although it is not clear which plants are causing the difference.

Alternatively, their low $\delta^{13}C$ values may suggest that they consumed limited amount of non-local food. As a result of the introduction of Roman cuisine, non-local food which was not available in Britain before the Roman conquest was increasingly consumed post-conquest (see Chapter 3). Archaeological evidence for the consumption of non-local food at Horcott is limited to a charred nutshell of *Pinus pinea* (stone pine) found in a Romano-British cremation burial, oysters shells, and possibly olive oil (see Chapter 3). Nevertheless, there may have been different accessibility to non-local food depending on one's social status (see Chapter 3). Therefore, the multiple burial individuals could be of a lower social status and possibly did not have access to imported food unlike the others.

Cheung (2009) identified the three individuals from the multiple burial as 'immigrants' from their low $\delta^{13}C$ values and their unique burial style. Although they have the lowest $\delta^{13}C$ values among the Romans at Horcott, they are still within the range of $\delta^{13}C$ values observed in the Upper Thames Valley in the Romano-British period. There are individuals with even lower $\delta^{13}C$ values from contemporaneous sites in the Upper Thames Valley: seven individuals from Cotswold Community as well as some individuals from urban settlements such as Cirencester, Asthall, and Alchester have lower $\delta^{13}C$ values than the multiple-burial individuals from Horcott (Cheung 2009, Cummings 2008). Thus, the multiple group could have come from outside Horcott, but not necessarily far from Horcott.

The differences in the other burial categories — orientation, body position, and decapitation — are less prominent since the majority and the minority group overlap (Fig. 6.18 in Chapter

6). This suggests that there was isotopic variation in diet correlating with these burial traits but the variation was not meaningful. In addition, there was no strong correlation between human $\delta^{13}C$ and $\delta^{15}N$ values and age, suggesting that diet did not isotopically change depending on age at Horcott.

In conclusion, the only intra-site difference within the Romano-British humans at Horcott that was outstanding was the three Romano-British individuals from the multiple burial. They were isotopically different from the rest of the Romano-British population buried in single burials. Their low $\delta^{13}C$ values could be reflecting the difference in diet composition of plants, although what plants affected their $\delta^{13}C$ values is not clear. An alternative explanation of their low $\delta^{13}C$ values is the lack of access to imported food due to their low social background.

7.1.2.3. Diet at Anglo-Saxon Horcott

As presented in Chapter 6, despite the small sample size, the difference between the two phases was statistically significant: the AS 1 (Anglo-Saxon Phase 1) group had low $\delta^{13}C$ and high $\delta^{15}N$ values, while the AS 2 (Anglo-Saxon Phase 2) group had high $\delta^{13}C$ and low $\delta^{15}N$ values. However, difference in any burial and physical characteristics did not correlate with stable isotope values, probably due to the small sample size. Still, the difference by phase suggests that there was an isotopic change in diet between AS1 and AS2.

What kind of diet change resulted in the difference in stable isotope values of the two Anglo-Saxon phase groups? The low $\delta^{13}C$ values of AS1 group were comparable to those from the multiple-burial individuals in the Romano-British period. As argued for the multiple-burial group at Romano-British Horcott in the previous section, the lower $\delta^{13}C$ values of the AS1 group may suggest that they had isotopically different diet composition from the AS2 group, possibly reflecting the difference in diet composition of plants. An alternative possible factor for low $\delta^{13}C$ values regarding the Romano-British multiple burial group was the presence or lack of non-local food in their diet, which may have been the case for the AS1 group as well.

In addition, as is the case with the Romano-British individuals at Horcott, the high $\delta^{15}N$ values of the AS1 group are not elevated enough to indicate abundant consumption of marine resources. Consumption of marine resources will result in elevated $\delta^{13}C$ values as well as $\delta^{15}N$ values, but the AS1 group have the lowest $\delta^{13}C$ values from Horcott, thus confirming that the consumption of marine resources is not the reason for their elevated $\delta^{15}N$ values.

Alternatively, if both $\delta^{13}C$ and $\delta^{15}N$ values were depleted, it is possible to argue that there was a low amount of animal protein in the diet of the AS1 group. Although the $\delta^{13}C$ values of AS1 group are low, the difference in mean $\delta^{13}C$ values between humans and cattle (1.2 ‰), humans and sheep/goats (1.1 ‰), and humans and pigs (0.8 ‰) are within one trophic level (see Chapter 4), suggesting that these livestock resources were consumed by the AS1 group. Regarding $\delta^{15}N$ values, the difference between the mean human $\delta^{15}N$ value and the mean pig $\delta^{15}N$ value (3.6 ‰) was within the difference of one trophic level (3—5 ‰) for AS1, suggesting that pork was part of the diet for the AS1 group. However, the difference between human and cattle (5.5 ‰) and human and sheep/goats (5.9 ‰) were larger than the difference of one trophic level, which suggests that the $\delta^{15}N$ values of AS1 group cannot be explained

only by the consumption of these livestock. It is possible that there were other food sources with higher $\delta^{15}N$ values which contributed to the elevation of $\delta^{15}N$ values of the AS1 group.

Other protein sources available in Anglo-Saxon Britain are domesticated birds and riverine resources. On the one hand, domesticated birds tend to have even higher $\delta^{13}C$ and $\delta^{15}N$ values than those of domesticated mammals, as observed at Anglo-Saxon sites such as Abbot's Worthy, Hampshire, West Stow, Suffolk, and Carlton Colville (Hull 2008, O'Connell and Lawler 2009). Indeed, bird bones were found from several sunken feature buildings at Horcott which were identified as domestic fowl, goose and medium-sized passerine (Strid in Hayden et al. forthcoming), suggesting that domesticated birds were likely to have been consumed in the Anglo-Saxon period. However, although the consumption of protein from domesticated birds may account for the higher $\delta^{15}N$ values of the AS1 group, it does not explain their lower $\delta^{13}C$ values. Therefore, there may be other sources of protein, possibly riverine resources, which affected the low $\delta^{13}C$ and high $\delta^{15}N$ values of the AS1 group.

Therefore, it is likely that marine resources was limited, while terrestrial animals was common in the Anglo-Saxon AS1 diet. The low $\delta^{13}C$ values of the Anglo-Saxon AS1 group may be the result of difference in diet composition of plants, consuming limited amount of non-local food, or possibly consuming riverine sources. Limited amount of non-local food could be due to the collapse of the Roman trading network, which would have diminished the population's access to imported food in the early Anglo-Saxon period.

7.1.2.4. Inter-Site Differences

In this section, data from Horcott are compared with other contemporaneous sites in the Upper Thames Valley (Fig. 7.8 and Table 7.4).

period	type	site	n	Max $\delta^{13}C$ (‰)	Min $\delta^{13}C$ (‰)	Max-Min $\delta^{13}C$ (‰)	Mean $\delta^{13}C$ (‰)	SD $\delta^{13}C$ (‰)	Max $\delta^{15}N$ (‰)	Min $\delta^{15}N$ (‰)	Max-Min $\delta^{15}N$ (‰)	Mean $\delta^{15}N$ (‰)	SD $\delta^{15}N$ (‰)
Roman	mix	Alchester	15	-18.8	-20.9	2.1	-19.9	0.6	10.8	8	2.8	9.7	0.8
Roman	urban	Asthall	9	-18.5	-20	1.5	-19.1	0.5	11.4	7.9	3.5	9.4	1.1
Roman	urban	Cirencester	145	-18.6	-21.2	2.6	-19.7	0.5	11.9	7	4.9	9.8	1.0
Roman	rural	Cotswold	24	-19.8	-21.5	1.7	-20.6	0.4	11.3	7.3	4	9.8	1.0
Roman	rural	Queenford	36	-18.9	-20.3	1.4	-19.7	0.4	11.4	8.2	3.2	10.2	0.8
Roman	rural	Stanton	27	-19.3	-20.6	1.3	-20.0	0.3	12	9.1	2.9	10.9	0.7
Roman	rural	Tubney	4	-19.5	-20.2	0.7	-19.8	0.3	11.4	10.2	1.2	10.9	0.6
Roman	rural	Yarnton	4	-19.1	-19.9	0.8	-19.6	0.4	13.1	8.1	5	10.9	2.3
Roman	rural	Horcott	30	-19.5	-20.7	1.2	-20.0	0.3	11.2	7.8	3.4	9.7	0.8
AS1	rural	Horcott	5	-20.4	-20.8	0.5	-20.6	0.2	11.7	10.2	1.5	10.8	0.6
AS2	rural	Horcott	3	-19.5	-19.8	0.3	-19.6	0.2	9.2	8.8	0.4	9.0	0.2
AS	rural	Alchester	6	-19.7	-20.5	0.8	-20.2	0.3	10.9	8	2.9	10.0	1.1
AS	rural	Berinsfield	70	-19.7	-20.7	1	-20.1	0.2	11.6	8.4	3.2	9.7	0.7
AS	rural	Butler'sfield	127	-19.5	-20.6	1.1	-20.1	0.2	11.0	7.5	3.5	9.5	0.7
AS	rural	Tubney	2	-20.2	-20.4	0.2	-20.3	0.1	11	10.5	0.5	10.8	0.4
AS	rural	Yarnton	7	-19.5	-20.2	0.7	-19.8	0.2	13.5	9.9	3.6	11.7	1.4

Table 7.4 Values calculated from collagen data of humans from Upper Thames Valley sites. Data from Cheung (2009), Cummings (2008), Fuller et al. (2006), Lightfoot et al. (2009), Nehlich et al. (2011), O'Connell and Wilson (2011), and Privat et al. (2002), and this study.



Fig.7.8 Box-plots of collagen data of human from Horcott in comparison with other Upper Thames Valley sites. The box represents 50% percentile around the median and the whisker represents the 90% percentile of the distribution, x-axis: sites, y-axis: stable isotope values; upper row: $\delta^{13}C$ values (‰), bottom row: $\delta^{15}N$ values (‰), red: the Romano-British period, blue: the Anglo-Saxon period. Data from Chueng 2009, Cummings 2008, Fuller et al. 2006, Lightfoot et al. 2009, Nehlich et al. 2011, Privat et al. 2002, and this study.

First, all Romano-British data from Upper Thames Valley sites including Horcott were compared with one another to see if there was a consistent difference between urban and rural sites. Mann-Whitney U test was applied to all data.

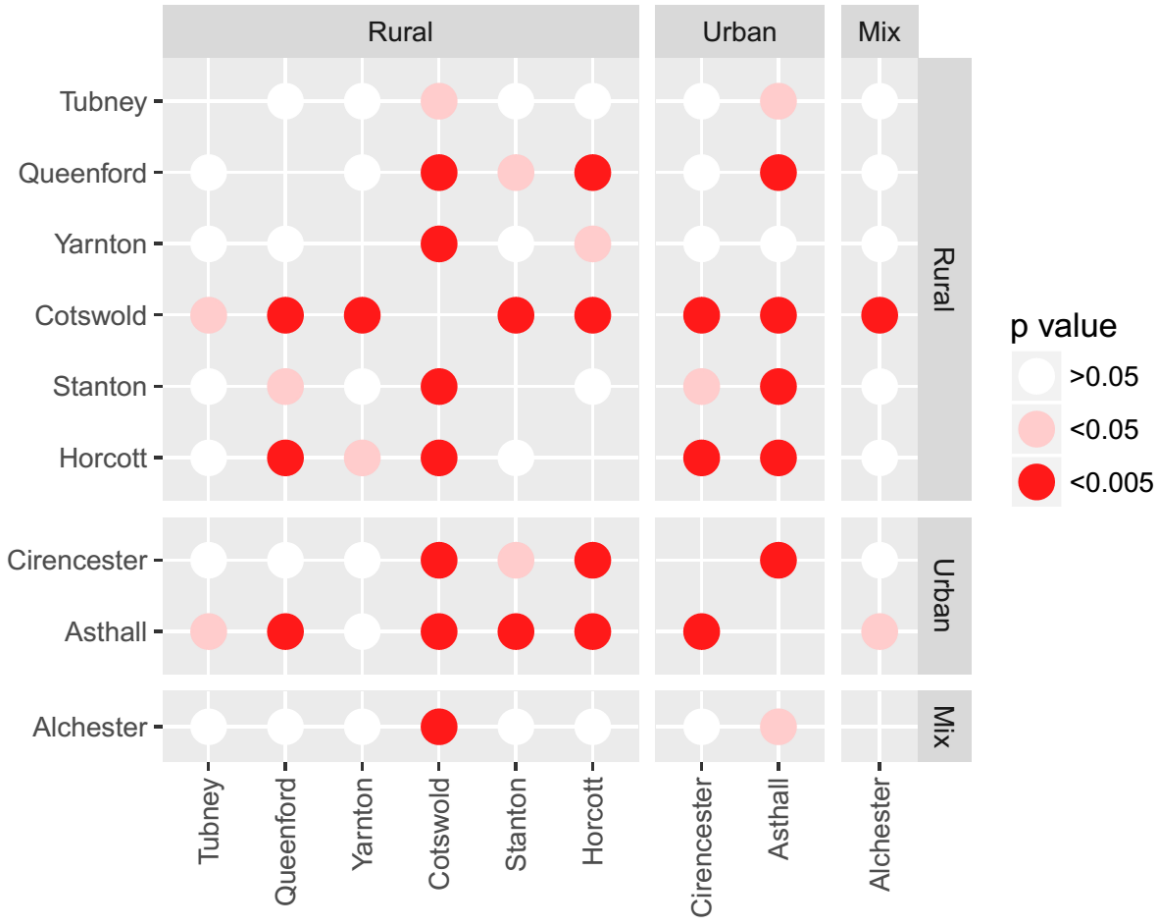


Fig.7.9 Statistical significance of difference in human $\delta^{13}C$ values among Romano-British Upper Thames Valley sites.

There was significant inter-site difference among Romano-British data more frequently in $\delta^{13}C$ values. The two urban sites, Cirencester and Asthall, were significantly different from each other, while they were not different from some of the rural sites (Fig. 7.9). Alchester, a town site although the samples were from the extramural area, shows similarity to both rural and urban sites. Thus, the difference between urban sites and rural sites was not always significant for $\delta^{13}C$ values. Rural sites also showed inter-site difference. Horcott showed

significant difference when compared with the two urban sites as well as some of the rural sites. Cotswold Community was significantly different from all the other rural sites and the urban sites (Fig. 7.9).

The results of $\delta^{15}N$ values are somewhat different. The two urban sites and Alchester were similar to one another as well as some rural sites (Fig. 7.10). Thus, the urban sites show similarity in $\delta^{15}N$ values, but also show similarity with the $\delta^{15}N$ values of some rural sites as well. The rural sites showed some difference as well. Horcott was significantly different from Stanton Harcourt, Queenford farm, and Tubney, while Stanton Harcourt was significantly different from other rural and urban sites except for Yarnton and Tubney (Fig. 7.10).

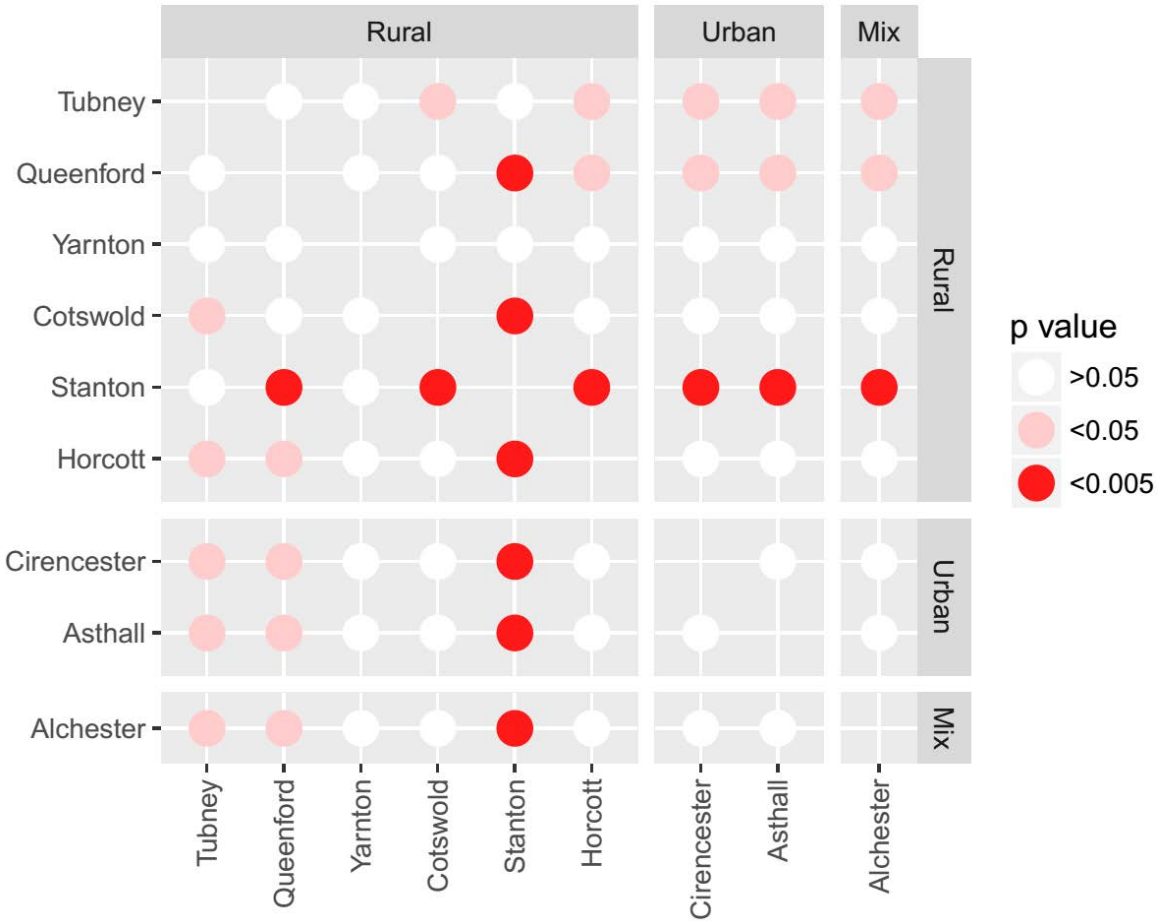


Fig.7.10 Statistical significance of difference in human $\delta^{15}N$ values among Romano-British Upper Thames Valley sites.

Therefore, statistical tests showed that both $\delta^{13}C$ and $\delta^{15}N$ values of Romano-British Horcott were significantly different from some of the other Romano-British sites. However, there was no clear consistent isotopic difference between human diet at urban and rural sites. The results also suggest that in the Romano-British period there was site-specific isotopic difference in human diet to some extent, which affected the $\delta^{13}C$ values more. As already discussed in this Chapter, the difference in $\delta^{13}C$ values may reflect the difference in diet composition of plants, although what plants affected the Romano-British human $\delta^{13}C$ values at Upper Thames Valley sites remains inconclusive. Alternatively, also already mentioned, it may reflect the difference in the amount of non-local food in their diet, although again which food affected the human $\delta^{13}C$ values in the Romano-British Upper Thames Valley is not clear.

Equally, all Anglo-Saxon data from Upper Thames Valley sites including Horcott were compared with one another. All data are from rural sites, so inter-site difference among rural sites were investigated by applying the Mann-Whitney U test.

When Anglo-Saxon Horcott was compared as a whole with other Anglo-Saxon sites, none of the differences were significant (Fig. 7.11). Regarding the Kolmogorov-Smirnov test, only the difference in $\delta^{13}C$ values between Horcott and Butler'sfield was significant. However, when the humans at Horcott were divided by phase (AS1 and AS2), there were more differences which are significant. For example, Horcott AS1 was significantly different in both $\delta^{13}C$ and $\delta^{15}N$ values from Berinsfield and Butler's field. Horcott AS1 did not show significant difference when compared with Tubney in all tests and with Alchester in most tests, but it may be due to the small sample size of these sites. Similarly, Horcott AS2 showed significant difference in $\delta^{13}C$ values when compared with Berinsfield and Butler's field, while the $\delta^{15}N$ values were significantly different from Yarnton by both tests and Berinsfield

by Mann-Whitney U test. Comparison between Berinsfield and Butler's field did not show any significant difference in either $\delta^{13}C$ or $\delta^{15}N$ values, but other comparisons showed significant difference from one site to another. Tubney showed the least number of significant difference, although this may have been affected by its small sample size.

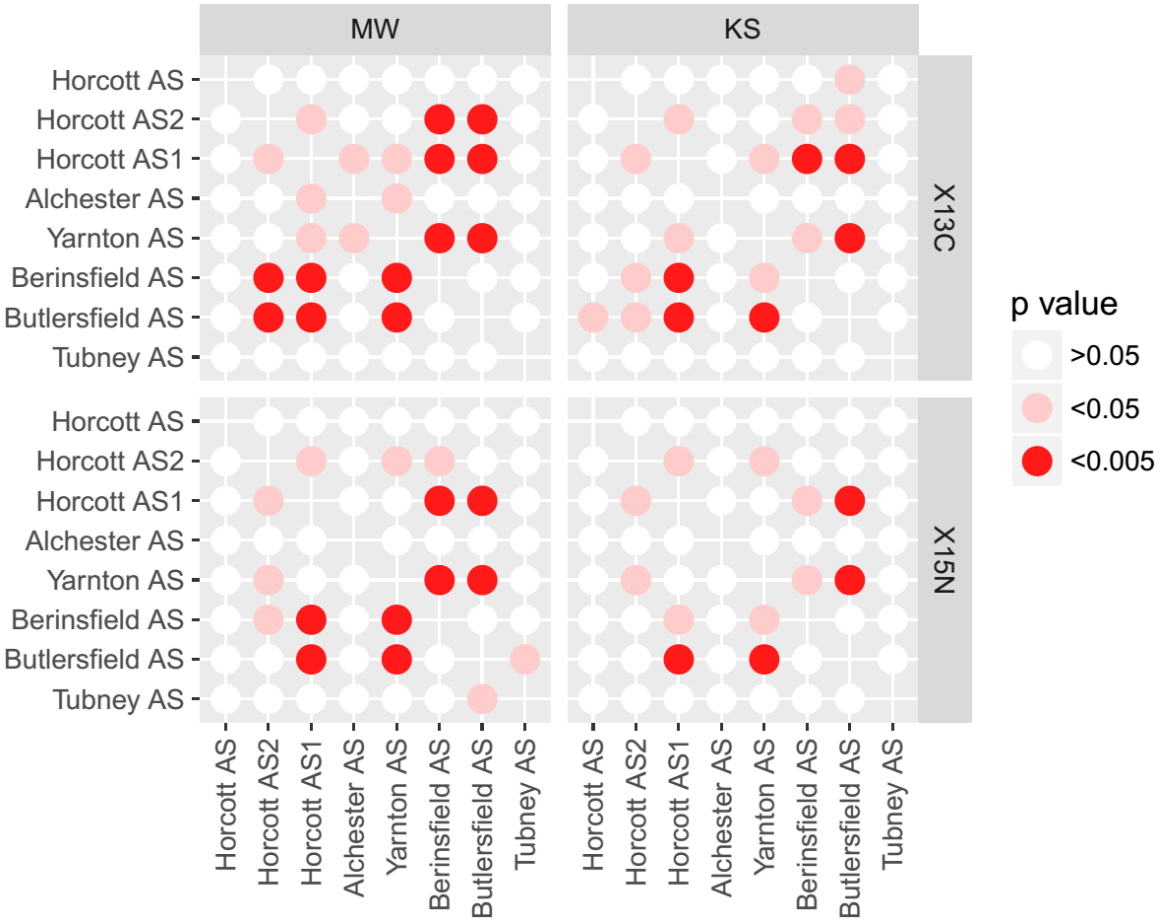


Fig.7.11 Statistical significance of difference in human stable isotope values among Anglo-Saxon Upper Thames Valley sites, upper rows: $\delta^{13}C$ values, lower rows: $\delta^{15}N$ values, left: Mann-Whitney U test, right: Kolmogorov-Smirnov test.

Therefore, there was also site-dependent isotopic difference in human diet to some extent in the Anglo-Saxon period. Despite the Romano-British period however, non-local food possibly became less available in the Anglo-Saxon period as a result of the collapse of Roman market economy and trade network (see Chapter 1 and Chapter 3). Therefore, the

difference in the amount of non-local food was equally small among Anglo-Saxon sites, which makes it difficult to attribute the site-specific difference to the accessibility to non-local food. Still, the explanation of the difference in $\delta^{13}C$ values as the difference in diet composition of plants may hold, although the plants that may have affected the human $\delta^{13}C$ values remains unidentified.

Finally, the sites with data across different time periods were examined whether there were any consistent trends. Notably, in respect to $\delta^{15}N$ values, the variance of humans does not necessary correspond to time period. Instead, the difference is site-dependent. For example, the $\delta^{15}N$ values at Yarnton is similarly dispersed both in the Romano-British and Anglo-Saxon periods, while at Tubney the $\delta^{15}N$ values are similarly less dispersed in both periods (Fig. 7.12). In addition, the variance of human $\delta^{15}N$ values does not necessarily covary with the variance of animal $\delta^{15}N$ values from the same site. For example, the cattle $\delta^{15}N$ values at Roman Tubney are dispersed even though the human $\delta^{15}N$ values are less dispersed. In contrast, it is the opposite case at Anglo-Saxon Berinsfield, where the cattle, sheep/goat, and pig $\delta^{15}N$ values are clustered even though the human $\delta^{15}N$ values are more dispersed. However, more data are needed, especially on animals, for further discussion.

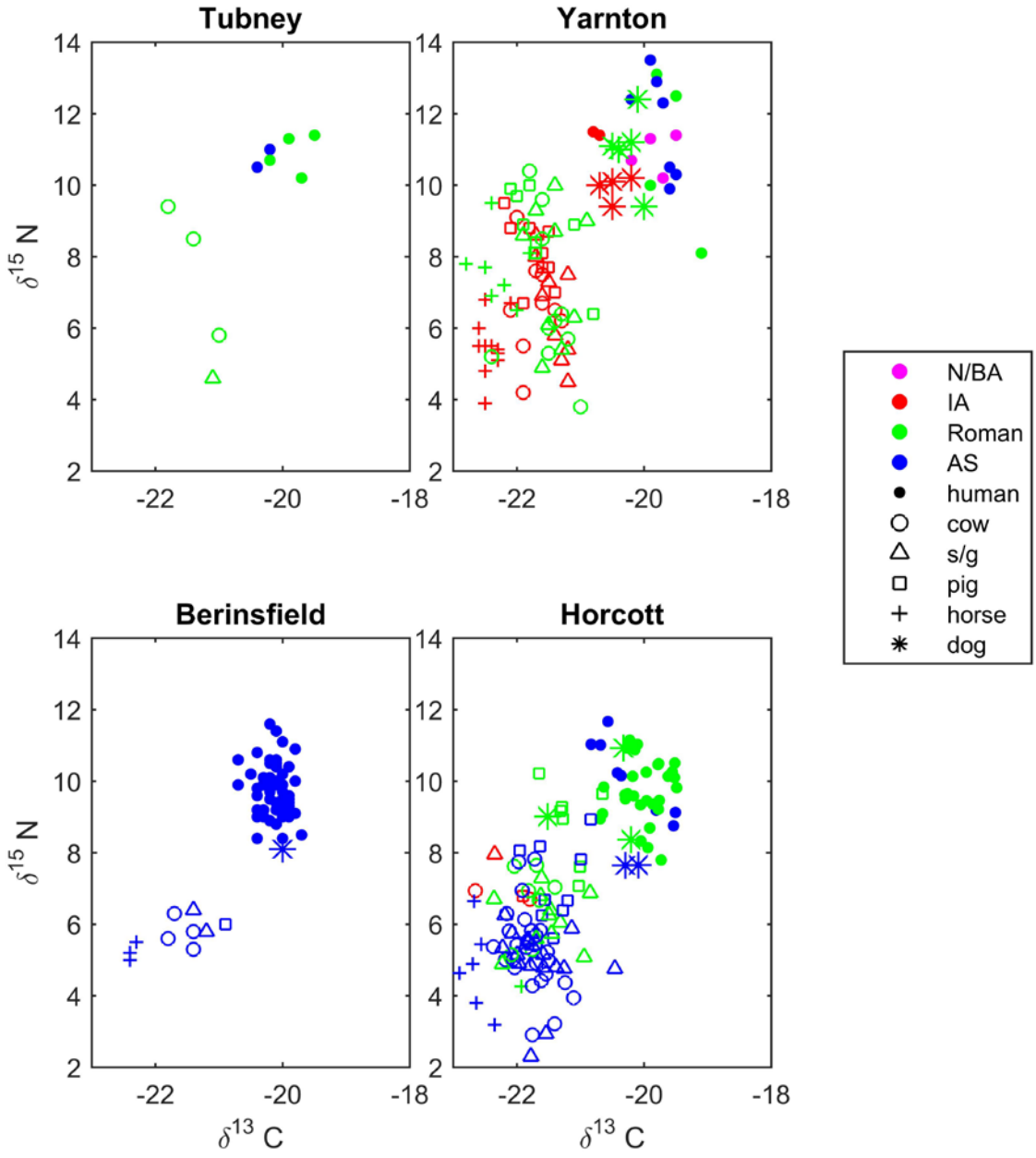


Fig 7.12 Collagen results from Horcott in comparison with other Upper Thames Valley sites. N/BA: Neolithic/Bronze Age, IA: Iron Age, AS: Anglo-Saxon, s/g: sheep/goats; x-axis: $\delta^{13}C$ values (‰), y-axis: $\delta^{15}N$ values (‰). Data from Cheung 2009, Lightfoot et al. 2009, Nehlich et al. 2011, Privat et al. 2002, and this study.

7.1.2.5. Summary of Human Diet from Collagen Results

The Phase 1 Anglo-Saxon humans dated to AD 400–550 had an isotopically different diet compared to the Romano-British individuals dated to AD 250–350 and the Phase 2 Anglo-Saxons dated to AD 600–700. This suggests that imported non-local food available in the Romano-British period ceased to be consumed after the collapse of the Roman economy and trade network, but by Phase 2 in the Anglo-Saxon period the diet becomes isotopically more similar to the Romano-British period to some extent, although whether the diet became identical is questionable.

Intra-site isotopic difference correlating with skeletal and burial characteristics was not outstanding. The exception is, however, the three Romano-British individuals from the multiple burial who were isotopically different from the rest of the Romano-British population buried in single burials. Their low $\delta^{13}C$ values could be reflecting the difference in diet composition of plants, although what plants are affecting their $\delta^{13}C$ values is not clear. An alternative explanation of their low $\delta^{13}C$ values is that they consumed a limited amount of non-local food. This could possibly be because they were of a lower social status who did not have access to imported food as others.

Inter-site differences were observed in both periods and there was no consistent pattern. However, there might be site-dependent differences which is consistent across time periods, although more data would be needed for further investigation.

7.2. Animal Husbandry from Enamel Carbonate Results

Here the enamel carbonate results are discussed in order to reveal various aspects of animal husbandry at Horcott. With the $\delta^{13}C$ values of tooth enamel carbonate, the feeding custom can be investigated. Namely, whether the food changed depending on the season, species or period can be deduced. Unlike $\delta^{13}C$ values, $\delta^{18}O$ values of enamel carbonate do not reflect the diet of the individual but reflect the seasonal variation during the enamel formation and have been used to deduce birth seasonality (see Chapter 4).

7.2.1. The $\delta^{13}C$ Values

In this section, the results from the $\delta^{13}C$ values of tooth enamel carbonate of cattle at Horcott will be compared with other published data as well as the results of sheep/goats. Then, what can be deduced from the differences between these species will be discussed.

7.2.1.1. Cattle

Comparison with Cattle Data from Other Sites

As noted in Chapter 6, in respect of $\delta^{13}C$ values of second (M2) and third permanent molars (M3), the rather small amplitudes show that the food consumed by the cattle were isotopically relatively constant regardless of seasonality, and slightly more so in the Anglo-Saxon period.

Following these observations, the results at Horcott were compared with data from other sites. There are limited amount of comparable sequential tooth enamel results of M2 and M3 of cattle from other British sites (Table 7.5). Among them, the sites located the closest to Horcott are, Irthlingborough, Northamptonshire, and Gayhurst, Buckinghamshire (Towers et al. 2011).

site	sample ID	period	graph ID	M1	M2	M3	source
start of growth				1/3 at birth	birth	0.5 to 1yr	
end of growth				0.5yr	1yr	1.5 to 2yrs	
Knap of Howar	KH Bos 1	Neolithic	NC11			+	Balasse and Tresset 2007
Knap of Howar	KH Bos 2	Neolithic	NC12			+	
Knap of Howar	KH Bos 3	Neolithic	NC13			+	
Knap of Howar	KH Bos 4	Neolithic	NC14			+	
Knap of Howar	KH Bos 5	Neolithic	NC15			+	
Irthlingborough	IRTH 3	Bronze Age	BC21		+	+	Towers et al. 2011
Irthlingborough	IRTH 7	Bronze Age	BC22		+	+	
Irthlingborough	IRTH 8	Bronze Age	BC23		+	+	
Irthlingborough	IRTH 9	Bronze Age	BC24		+	+	
Irthlingborough	IRTH B	Bronze Age	BC25			+	
Gayhurst	GAY 1	Bronze Age	BC31		+	+	Towers et al. 2011
Gayhurst	GAY 2	Bronze Age	BC32		+	+	
Gayhurst	GAY 4	Bronze Age	BC33		+	+	
Gayhurst	GAY 7	Bronze Age	BC34		+	+	
Gayhurst	GAY 8	Bronze Age	BC35			+	
Grimes Graves	GG839	Bronze Age	BC41	+	+	+	Towers et al. 2013
Grimes Graves	GG743	Bronze Age	BC42	+	+	+	
Grimes Graves	GG614	Bronze Age	BC43	+	+		
Grimes Graves	GGT10	Bronze Age	BC44	+	+	+	
Grimes Graves	GG120	Bronze Age	BC45	+	+		
Mine Howe	MH138	Iron Age	IC51	+	+	+	Towers et al. 2013
Mine Howe	MH0604	Iron Age	IC52	+	+	+	
Mine Howe	MH84	Iron Age	IC53	+	+		
Pool	PL0278	Viking	VC61	+	+	+	Towers et al. 2013
Pool	PL0330	Viking	VC62	+	+	+	
Pool	PL0339	Viking	VC63	+	+		
Pool	PL0344	Viking	VC64	+	+	+	
Pool	PL0386	Viking	VC65	+	+	+	

Table 7.5 List of enamel carbonate data of cattle from British sites; start and end of growth period of permanent molars from Hillson (2005: Table 3.3.).

sample ID	graph ID	Max C	Min C	Max-Min C	mean C	SD C	Max O	Min O	Max-Min O	mean O	SD O	source
KH Bos 1	NC11						27.1	24.3	2.8	25.7	0.9	Balasse and Tresset 2007
KH Bos 2	NC12						27.3	24.6	2.7	26.1	0.9	
KH Bos 3	NC13						26.9	24.5	2.4	25.8	0.7	
KH Bos 4	NC14						26.6	24.2	2.4	25.7	0.7	
KH Bos 5	NC15						26.3	24.7	1.6	25.6	0.5	
IRTH 3	BC21	-13.9	-14.9	1.0	-14.5	0.3	24.9	22.9	2.0	24.1	0.6	Towers et al. 2011
IRTH 7	BC22	-13.4	-15.4	2.0	-14.3	0.7	23.7	22.2	1.5	22.9	0.5	
IRTH 8	BC23	-14.5	-15.5	1.0	-15.1	0.4	25.2	22.4	2.8	23.6	1.0	
IRTH 9	BC24	-13.5	-15.1	1.6	-14.5	0.5	24.9	22.7	2.2	23.8	0.7	
IRTH B	BC25	-13.5	-14.1	0.6	-13.8	0.2	25.8	23.6	2.2	24.8	0.9	
GAY 1	BC31	-13.1	-14.1	1.0	-13.6	0.3	26.3	22.6	3.7	24.2	1.0	Towers et al. 2011
GAY 2	BC32	-14.2	-15.5	1.3	-14.8	0.4	25.8	22.8	3.0	24.3	1.0	
GAY 4	BC33	-14.3	-15.4	1.1	-14.8	0.4	25.3	22.6	2.7	24.2	1.0	
GAY 7	BC34	-14.2	-15.0	0.8	-14.5	0.2	25.7	23.0	2.7	24.2	0.8	
GAY 8	BC35	-13.8	-14.8	1.0	-14.3	0.3	24.8	23.1	1.7	23.8	0.6	
GG839	BC41	-11.6	-13.7	2.1	-12.7	0.9	26.6	23.2	3.4	24.8	1.1	Towers et al. 2013
GG743	BC42	-11.8	-13.6	1.8	-12.7	0.6	26.1	23.3	2.8	24.6	0.8	
GG614	BC43	-12.0	-13.6	1.6	-13.1	0.6	27.0	23.6	3.4	25.3	1.3	
GGT10	BC44	-11.3	-13.2	1.9	-12.7	0.5	27.2	23.3	3.9	24.8	1.3	
GG120	BC45	-12.9	-14.4	1.5	-13.9	0.6	24.9	22.7	2.2	23.7	0.8	
MH138	IC51	-12.2	-13.2	1.0	-12.6	0.3	26.6	23.6	3.0	25.0	0.8	Towers et al. 2013
MH0604	IC52	-11.7	-12.8	1.1	-12.2	0.4	26.3	23.5	2.8	24.7	0.9	
MH84	IC53	-12.1	-13.2	1.1	-12.4	0.3	26.4	23.7	2.7	24.7	1.1	
PL0278	VC61	-11.1	-12.0	0.9	-11.6	0.3	26.3	23.8	2.5	24.9	0.8	Towers et al. 2013
PL0330	VC62	-11.3	-12.3	1.0	-11.8	0.3	26.3	23.7	2.6	25.0	0.8	
PL0339	VC63	-11.7	-12.6	0.9	-12.1	0.3	26.8	23.9	2.9	25.1	1.2	
PL0344	VC64	-11.7	-12.6	0.9	-12.2	0.2	26.0	23.3	2.7	24.3	0.7	
PL0386	VC65	-11.0	-12.0	1.0	-11.6	0.3	26.9	23.7	3.2	25.1	0.9	

Table 7.6 Values calculated from enamel carbonate data of cattle from British sites (Max and Min $\delta^{13}C$ values calculated only from M2 and M2).

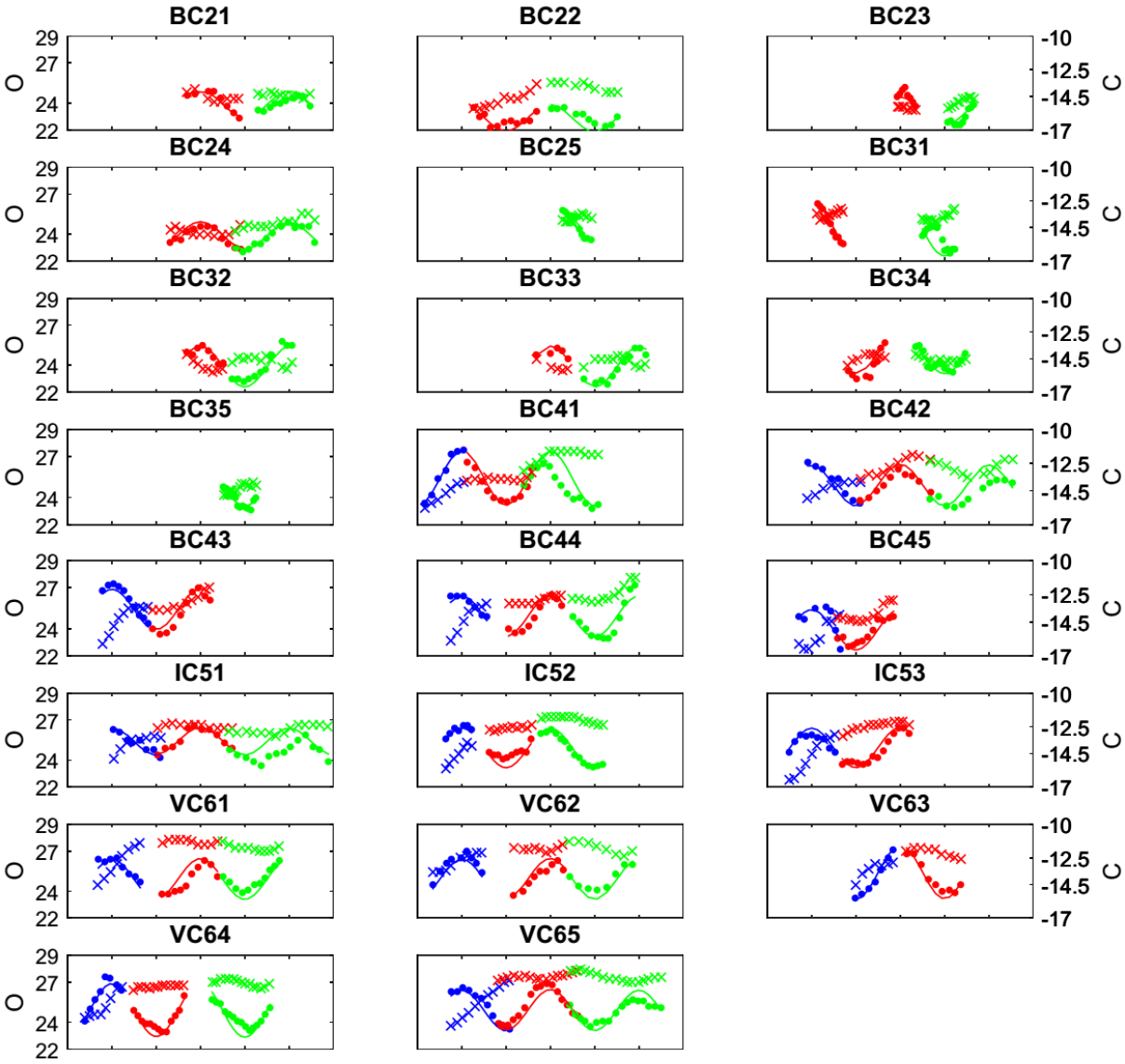


Fig. 7.13 Sequential enamel carbonate data of cattle from British sites; x-axis: time difference of enamel formation deduced from distance from enamel root junction, y-axis: right: $\delta^{13}C$ values (cross), left: $\delta^{18}O$ values (dot), solid line: modelled $\delta^{18}O$ value curve, blue: M1, red: M2, green: M3. Individuals indicated by graph ID. See Table 7.5 for matching sample ID with graph ID.

Compared to the results from Horcott cattle, Early Bronze Age cattle from Irthlingborough and Gayhurst have lower $\delta^{13}C$ values (Table 7.6). In fact, cattle from Irthlingborough and Gayhurst have the lowest $\delta^{13}C$ values among all English sites from various locations and periods. Moreover, their $\delta^{13}C$ value sequences tend to covary with their $\delta^{18}O$ value sequences, which reflect the seasonal cycle. The covariation between $\delta^{13}C$ and $\delta^{18}O$ values was not

observed in Horcott cattle, except for M3 of ROM cow 2 which shows a partial inverse covariation between $\delta^{13}C$ and $\delta^{18}O$ values. M2 and M3 of cattle GAY 2 from Gayhurst also showed an inverse covariation between $\delta^{13}C$ and $\delta^{18}O$ values while M2 and M3 of cattle IRTH 7 from Irthlingborough show a straightforward covariation between $\delta^{13}C$ and $\delta^{18}O$ values (BC32 and BC 22 in Fig. 7.13). The amplitudes (difference between maximum and minimum $\delta^{13}C$ values) of Irthlingborough cattle were slightly larger than those of Gayhurst cattle, but similar to those of Horcott cattle (Table 7.6).

Compared to the Horcott cattle, the $\delta^{13}C$ values of cattle from various periods in the Orkney Islands (Towers et al. 2013) are similarly enriched, but their amplitudes are smaller (Table 7.6). M2 and M3 of all five cattle from Pool dated to the Scandinavian Interface period (c. AD 800 – c. AD 950) and all three cattle from Mine Howe dated to the Iron Age (c.AD100—c.AD 400) have stable $\delta^{13}C$ value sequences, and the amplitudes of Orkney cattle tightly cluster around 1.0 ‰, smaller than those of Horcott cattle, which is around 1.5‰ (Table 7.6).

The $\delta^{13}C$ values of Middle Bronze Age (c. 1100 BC) cattle from Grimes Graves, Norfolk have intermediate features compared to results from other sites mentioned above (Towers et al. 2013). Their $\delta^{13}C$ values are about 1‰ lower than those of Horcott cattle, while their amplitudes are marginally larger than those of Horcott cattle (Table 7.6). An interesting feature of the $\delta^{13}C$ values of Grimes Graves cattle is that two out of five of them (GG839 and GGT10) have higher $\delta^{13}C$ values in their M3s than in their M2s (BC41 and BC44 in Fig 7.13). A similar trend can be observed in some of the Horcott cattle such as SAX cow 8, SAX cow 12, SAX cow d, and SAX cow h (Fig. 6.25 in Chapter 6). This may suggest that these cattle at Grimes Graves and Horcott were fed isotopically different food stuffs depending on their age, as opposed to a natural food selection by cattle themselves, although more similar data are needed to investigate this further.

site	sample ID	period	graph ID	M1	M2	M3	source
start of growth				1/3 at birth	birth	0.5 to 1yr	
end of growth				0.5yr	1yr	1.5 to 2yrs	
Er Yoh	EY Bos 1	Neolithic	NC101			+	Balasse and Tresset 2007
Er Yoh	EY Bos 2	Neolithic	NC102			+	
Er Yoh	EY Bos 3	Neolithic	NC103			+	
Bercy	BQS Bos1M3	Neolithic	NCA			+	Balasse et al. 2012 a
Bercy	BQS Bos2M3	Neolithic	NCB			+	
Bercy	BQS Bos3M3	Neolithic	NCC			+	
Bercy	BQS Bos4M3	Neolithic	NCD			+	
Bercy	BQS Bos5M3	Neolithic	NCE			+	
Bercy	BQS Bos6M3	Neolithic	NCF			+	
Bercy	BQS Bos7M3	Neolithic	NCG			+	
Bercy	BQS Bos8M3	Neolithic	NCH			+	
Bercy	BQS Bos9M3	Neolithic	NCI			+	
Bercy	BQS Bos11M3	Neolithic	NCJ			+	
Borduşani-Popină	PBORD Bos24	Chalcolithic	CCK		+		Gillis et al. 2013
Borduşani-Popină	PBORD Bos30	Chalcolithic	CCL			+	
Borduşani-Popină	PBORD Bos35	Chalcolithic	CCM			+	

Table 7.7 List of enamel carbonate data of cattle from continental sites; start and end of growth period of permanent molars from Hillson (2005: Table 3.3.).

There are also a few sites from continental Europe with tooth enamel results of cattle (Table 7.7). They are from a Neolithic site at Bercy, Paris, France (Balasse et al. 2012 a) and a Chalcolithic site at Borduşani-Popină, Romania (Gillis et al. 2013).

sample	graph ID	Max C	Min C	Max-Min C	mean C	SD C	Max O	Min O	Max-Min O	mean O	SD O	source
EY Bos 1	NC101						29.4	27.0	2.4	28.0	0.7	Balasse and Tresset 2007
EY Bos 2	NC102						28.9	25.8	3.1	27.5	1.1	
EY Bos 3	NC103						30.6	25.9	4.7	28.5	1.6	
BQS Bos1M3	NCA	-12.8	-14.4	1.6	-13.6	0.5	-3.7	-6.9	3.2	-5.3	1.1	Balasse et al. 2012 a
BQS Bos2M3	NCB	-12.9	-14.4	1.5	-13.6	0.5	-3.4	-6.9	3.5	-5.1	1.2	
BQS Bos3M3	NCC	-12.3	-13.1	0.8	-12.7	0.2	-4.6	-6.9	2.3	-5.8	0.7	
BQS Bos4M3	NCD	-11.9	-12.7	0.8	-12.2	0.3	-3.5	-5.6	2.1	-4.5	0.8	
BQS Bos5M3	NCE	-11.9	-12.7	0.8	-12.2	0.3	-3.5	-5.6	2.1	-4.5	0.8	
BQS Bos6M3	NCF	-11.6	-12.7	1.1	-12.3	0.4	-2.2	-5.4	3.2	-3.8	1.1	
BQS Bos7M3	NCG	-12.3	-14.4	2.1	-13.2	0.7	-1.9	-5.0	3.1	-3.1	0.9	
BQS Bos8M3	NCH	-13.3	-14.5	1.2	-13.9	0.4	-2.9	-4.8	1.9	-3.6	0.6	
BQS Bos9M3	NCI	-12.7	-13.7	1.0	-13.1	0.3	-2.4	-5.2	2.8	-3.8	0.8	
BQS Bos11M3	NCJ	-13.9	-14.7	0.8	-14.4	0.3	-3.6	-5.2	1.6	-4.2	0.4	
PBORD Bos24	CCK	-7.3	-10.2	2.9	-8.8	0.9	-3.9	-6.4	2.5	-5.3	0.9	Gillis et al. 2013
PBORD Bos30	CCL	-7.3	-10.6	3.3	-9.1	1.0	-5.6	-8.6	3	-7.0	0.8	
PBORD Bos35	CCM	-8.2	-11.4	3.2	-9.9	1.1	-4.9	-7.5	2.6	-6.3	0.9	

Table 7.8 Values calculated from enamel carbonate data of cattle from continental sites (Max and Min $\delta^{13}C$ values calculated only from M2 and M2).

Compared to Horcott cattle, the mean $\delta^{13}C$ values of Neolithic French cattle (graph ID: NCB–J in Table 7.8) are lower but their amplitudes are similar. However, unlike Horcott cattle, the majority of their $\delta^{13}C$ value sequences show a correlation with their $\delta^{18}O$ values (Fig. 7.14). In contrast, the Chalcolithic Romanian cattle (Tornero et al. 2013) have the highest mean $\delta^{13}C$ values of all British and continental European sites and their amplitudes

are the largest among all the sites already mentioned in this section (Table 7.8). In fact, their amplitudes of $\delta^{13}C$ values are larger than those of their $\delta^{18}O$ values, which is not the case in other sites. Furthermore, their $\delta^{13}C$ values neatly covary with the seasonal fluctuation of their $\delta^{18}O$ values, suggesting that the change in $\delta^{13}C$ values was strongly affected by seasonality.

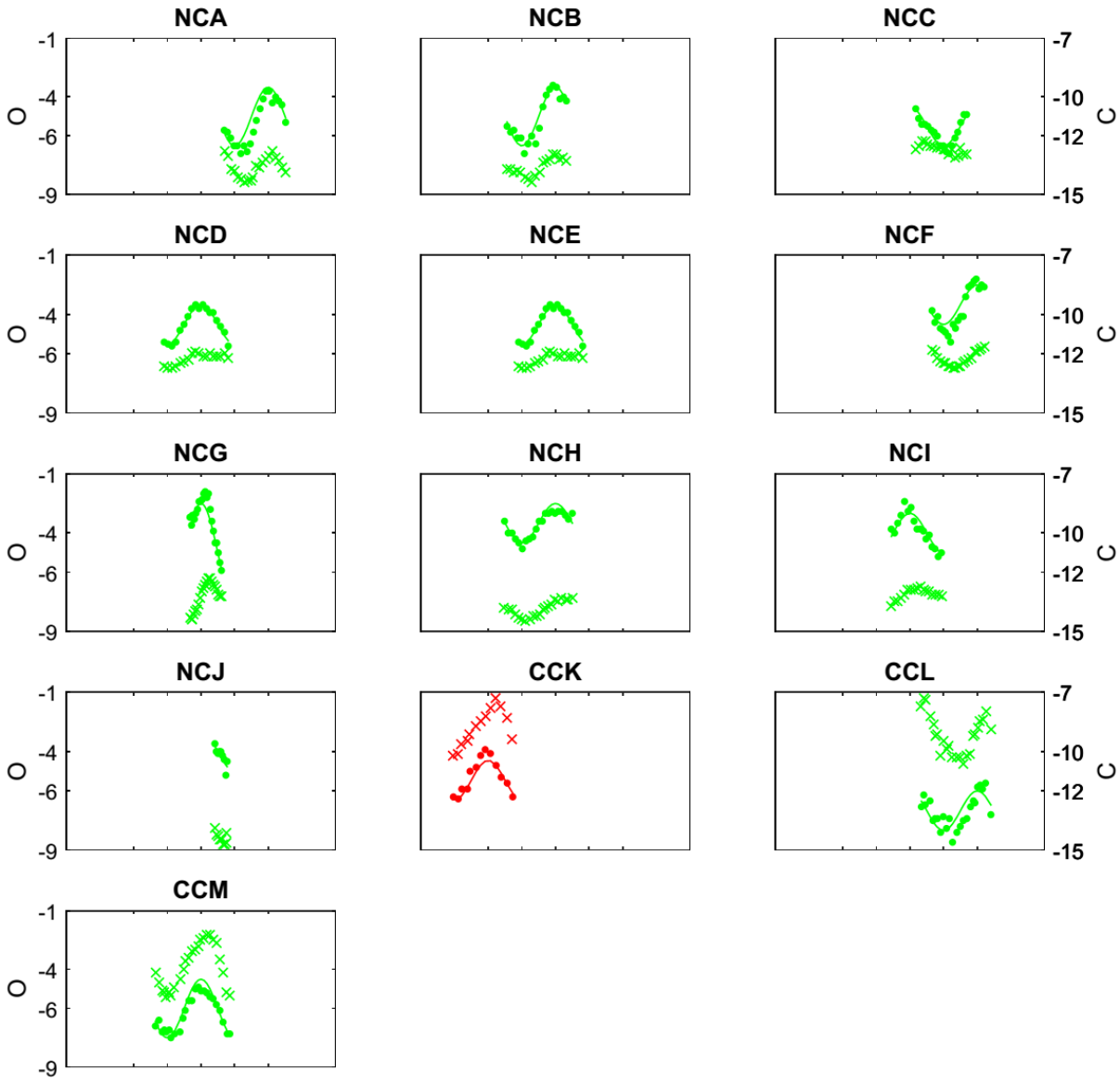


Fig. 7.14 Sequential enamel carbonate data of cattle from continental sites; x-axis: time difference of enamel formation deduced from distance from enamel root junction, y-axis: right: $\delta^{13}C$ values (cross), left: $\delta^{18}O$ values (dot), solid line: modelled $\delta^{18}O$ value curve, blue: M1, red: M2, green: M3. Individuals indicated by graph ID. See Table 7.7 for matching sample ID with graph ID.

Feeding Custom Deduced from the $\delta^{13}C$ Values of Cattle at Horcott

Following the observation in Chapter 6 which revealed that the diet of cattle at Horcott was isotopically relatively constant regardless of seasonality or period, what feeding custom possibly caused this phenomenon will be discussed here. Firstly, whether the change in the $\delta^{13}C$ values of cattle at Horcott is related to the seasonal cycle will be examined. Then, the possibility of practice of livestock housing influencing the feeding custom will be discussed. Finally, plants which could have been consumed by cattle at Horcott are discussed in light of archaeological, environmental, and historical evidence.

Only C_3 plants will be considered here, because generally speaking, C_4 plants are a minority in north-western Europe even today (see Chapter 4). Taking the factors which influence the C_3 plant $\delta^{13}C$ values into consideration (see Chapter 4), the seasonal fluctuation in $\delta^{13}C$ values of cattle enamel carbonate was examined.

The covariation between $\delta^{13}C$ values (reflecting the $\delta^{13}C$ values of food) and $\delta^{18}O$ values (reflecting seasonality) is clear in M2 and M3 of cattle from Neolithic French and Romanian sites (Fig 7.14). There are no comparable data from Neolithic cattle from Britain, but the covariation between $\delta^{13}C$ and $\delta^{18}O$ values in cattle from British sites from the later period is mostly undetectable (Fig. 7.13). This lack of strong covariation in cattle $\delta^{13}C$ and $\delta^{18}O$ values from the Bronze Age and later periods suggest that the food eaten by cattle in these periods did not isotopically change seasonally. Also, the lack of covariation is observed in Horcott cattle especially when the $\delta^{18}O$ values are the lowest, reflecting the lower temperature. For example, the $\delta^{13}C$ values of three Anglo-Saxon cattle (SAX cow 8, SAX cow 12, and SAX cow a) remain stable while the $\delta^{18}O$ values decline, reach the minimum value and increase

again (SC 208, SC 212, and SCa in Fig. 6.25 in Chapter 6). This may mean that the diets of cattle at Horcott during the winter were comprised of plants which were not growing in the same season. It looks as if they kept eating the same food as in summer throughout the winter. The relatively consistent $\delta^{13}C$ values at Horcott may reflect human management of the food fed to cattle especially during the winter when food was more limited. Food during the winter is crucial, especially when cattle are reared for milk. Even in the twentieth century, normally the months when milk cows were able to yield milk by just eating grass were from April till September (Biffen 1932: 539). In order to yield milk from October to March, extra food stuffs with high-nutrients had to be fed to the milk cows (Banham and Faith 2014: 126).

Apart from the limitation of food during the winter, the custom of feeding livestock may have been influenced by the practice of livestock housing. To what extent stalling cattle was common in Britain in the Roman and the Anglo-Saxon period is not clear. The Venerable Bede explained about Ireland that 'no-one there mows hay or builds stalls for his cattle as a provision against the cold of winter' (Miller 1890: I 1 28–9). This suggests that stalling cattle was common in AD eighth century in Northumbria, but the characteristic Germanic longhouses of North-western continental Europe which are argued to have housed the livestock close to the living spaces for humans are not found in Anglo-Saxon Britain (Hamerow 2012: 47).

Other written documents, such as Ælfric's *Colloquy* from the late tenth century AD refers to the practice of housing plough oxen overnight, although it also mentions that ox-herds often watch over their livestock outdoors at night (Garmonsway 1991: 21–22). Also in *Gerefa* dating to the 12th century, it is mentioned that to 'stall cattle' is a task for winter (Liebermann 1898: i 454), so seasonal and temporal housing of cattle may have been the common practice

in the late Anglo-Saxon period and in the Norman period. At Yarnton in the middle Anglo-Saxon period, ditches were interpreted as being used for animal enclosure, which may have been the general way of managing livestock at that time (Hey 2004: 45–6).

Given that the relatively constant $\delta^{13}C$ values at Horcott may reflect the human management of the food fed to cattle, especially during the winter, the food eaten by Horcott cattle in winter is discussed next. In order to investigate what plants were available for cattle at Horcott, environmental evidence from pollen, plant and insect remains from waterholes in addition to charcoal were compared. Each type of evidence provides a different aspect of the local vegetation at Horcott.

A layer of the fill of a waterhole at Horcott associated to Romano-British Phase 1 or 2 yielded some environmental evidence. Pollen and waterlogged plant remains show presence of grass land as well as arable fields (W. Smith in Hayden et al. forthcoming), which agrees with the insect remains indicating the presence of the same landscape (D.N. Smith in Hayden et al. forthcoming). In addition, tree pollen such as birch and ash possibly from woodland, alder and willow from wetter environments and hazel and elder possibly from hedges were identified (Rutherford in Hayden et al forthcoming).

The tree species identified by pollen are similar to those found from the dung levels at middle Neolithic sites in Switzerland (see Chapter 2), and grow in open landscapes. However, waterlogged plant and insect remains did not suggest that trees were present near the waterhole (W. Smith, D.N. Smith in Hayden et al. forthcoming). In addition, another waterhole associated to Romano-British Phase 4 or early Anglo-Saxon period yielded waterlogged plant remains and limited insect remains suggesting continuity of the

environment, open grassland or pasture as well as arable fields and without trees (W. Smith, D.N. Smith in Hayden et al. forthcoming). Therefore, environmental evidence indicates that the vegetation at Horcott was grassland and arable fields with some trees typical of open landscapes.

Notably, insect remains from Horcott were similar to those from other Upper Thames Valley sites such as Farmoor, Oxfordshire (Lambrick and Robinson 1979), Minges Ditches, Oxfordshire which show evidence of woodland clearance followed by a landscape of pasture and arable fields after 1500 BC (Allen and Robinson 1993). Furthermore, beetles (Coleoptera) identified at Horcott from contexts dated to the Romano-British period and the Anglo-Saxon period indicate the presence of grazing livestock (D.N. Smith in Hayden et al. forthcoming). The proportion of beetles associated to animal dung as opposed to the total number of identified individuals was 16% in a Romano-British waterhole and 20% in an Anglo-Saxon waterhole (Hayden et al. forthcoming: Table 11.21). They were the second most common type in both periods following those associated to grassland and pasture, suggesting that livestock were grazing on a pastoral landscape.

Unlike waterlogged remains, charcoal reflects the tree species biased by human utilisation of trees for fuel. For example, charcoal from a Roman corn-drier was dominated by *Fraxinus excelsior* (ash) with a few fragments identified as *Quercus sp*. (oak) and *Maloideae* (hawthorn group) (Challinor in Hayden et al. forthcoming). Charcoal from a Roman cremation burial (context no. 3343) was dominated by *Prunus* (blackthorn/cherry) including some identified as *Prunus. Spinosa* type (blackthorn), while charcoal from another cremation

burial (context no. 4593) was a mixture of *Quercus* (oak), *Prunus spinosa/domestica* (blackthorn/wild plum), *Maloideae* (hawthorn group) and *Cornus sp*. (dogwood or cornel) (Challinor in Hayden et al. forthcoming). In Anglo-Saxon contexts, charcoal from the corn drier (context no. 8808) were all *Quercus sp.* (oak), while charcoal from the Anglo-Saxon cremation burial (context no. 4906) was dominated by *Fraxinus excelsior* (ash) (Challinor in Hayden et al. forthcoming). In contrast, there was a wider variety of tree species identified from the charcoal from four SFBs: *Ulmus sp*. (elm), *Quercus sp*. (oak), *Corylus avellana* (hazel), *Populus/Salix* (poplar/willow), *Prunus sp*. (cherry/blackthorn), *Maloideae* (hawthorn group), *Cornus sp*. (dogwood/cornel), *Acer campestre* (field maple) and *Fraxinus excelsio*r (ash) (Challinor in Hayden et al. forthcoming).

The preferred habitat of these tree species can indicate the type of landscape they were found. For example, ash is common in a relatively open landscape because it requires light to thrive (Challinor in Hayden et al. forthcoming). In an environment with abundant light, it grows fast and is competent in colonising open landscapes (Challinor in Hayden et al. forthcoming). Presence of ash suggests that the landscape remained open or there were several episodes of woodland regeneration (Challinor in Hayden et al. forthcoming). Therefore, the environmental evidence does not suggest that there was a dense woodland. Instead, there were tree species adapted to open landscapes. Among them, *Corylus sp*. (hazel), *Alnus sp*. (alder), *Salix sp*. (willow), and *Fraxinus sp*. (ash) have direct evidence of leaf foddering from middle Neolithic sites in Switzerland, where remains of twigs and leaves from these tree species were found from dung levels (see Chapter 2). Therefore, it is possible that the same tree species were consumed by cattle at Horcott as well.

Besides trees, the main plants in open landscapes are grass species, including hay. Hay is commonly consumed by cattle and has similar $\delta^{13}C$ values as other C_3 plants. However, there are seasonal differences in plant $\delta^{13}C$ values. Hay is grown in the summer when it is drier and warmer, possibly resulting in having elevated $\delta^{13}C$ values compared to other plants available in winter for feeding the livestock (see Chapter 2). If hay was consumed by cattle, it may result in constantly high $\delta^{13}C$ values in the enamel sequence.

Although there was no environmental evidence such as pollen, macroscopic plant remains, invertebrate remains, and molluscs indicating the presence of hay meadows at Horcott, other Upper Thames Valley sites such as at Romano-British Farmoor and Yarnton in the middle Anglo-Saxon period have botanical evidence of hay meadows (see Chapter 2). So it would not be surprising if hay meadows existed at Horcott in the Romano-British and middle Anglo-Saxon periods. Still, there is no evidence of hay meadows in the early Anglo-Saxon period in the Upper Thames Valley, which may indicate that the practice of hay making was not common in the region for a while after the end of the Romano-British period.

Other plants grown in open landscapes are crop plants. Alternatively, cattle at Horcott could have been fed crop wastes or legumes harvested in summer when it is warmer and drier which possibly had elevated $\delta^{13}C$ values compared to plants growing in winter. When the amplitudes of cattle $\delta^{13}C$ values are compared, there is no difference between the Romano-British and Anglo-Saxon cattle, but the mean $\delta^{13}C$ values of Roman cattle are slightly higher than those of Anglo-Saxon cattle (Table 6.7 in Chapter 6). It is possible that feeding crop waste also caused the slight elevation of the $\delta^{13}C$ values of Roman cattle. Additionally, results by Girard et al. (2011) show that manured hayfield $\delta^{13}C$ values were marginally elevated than unmanured hayfield $\delta^{13}C$ values. Therefore, the possible reason for crop plants

having elevated $\delta^{13}C$ values could be due to growing in summer when it is warmer and drier, in addition to the slight elevation caused by manuring.

In summary, it is plausible that cattle at Horcott were fed on open woodland resources such as leaves, young branches and barks of trees, grassland resources including hay, or arable resources such as crop wastes (see Chapter 2), although there is no direct evidence from dung. In any case, the consistent $\delta^{13}C$ values of cattle at Horcott was probably the result of humans managing the food fed to cattle especially during the winter.

7.2.1.2. Sheep/Goats

Comparison with Sheep/Goat Data from Other Sites

As observed in Chapter 6, the food of sheep/goat at Horcott were apparently more isotopically affected by seasonality than that of cattle. Following this observation, sheep/goat data from other sites were compared with the data at Horcott (Tables 7.10 and 7.12). Unfortunately the only published data relevant for comparison were from a Neolithic site dated to the fourth millennium BC at Bercy, Paris, France (Balasse et al. 2012 a). Like Horcott, sheep/goats from Neolithic Bercy had $\delta^{13}C$ values that tend to covary with their $\delta^{18}O$ value sequences which reflect the seasonal cycle (Fig. 7.15).

Site	sample ID	period	graph ID	M1	M2	M3	source
start of growth				1/2 at birth	birth	1yr	
end of growth				9 months	1yr	2yrs	
Knap of Howar	KHovis1	Neolithic	NS11			+	Balasse and Tresset 2007
Knap of Howar	KHovis2	Neolithic	NS12			+	
Knap of Howar	KHovis3	Neolithic	NS13			+	
Holm of Papa Westray	HPWN ovis 2	Neolithic	NS21			+	Balasse and Tresset 2007
Holm of Papa Westray	HPWN ovis 3	Neolithic	NS22			+	
Holm of Papa Westray	HPWN ovis 4	Neolithic	NS23			+	
North Ronaldsay	NRovis1	Modern	MS31			+	Balasse and Tresset 2007
North Ronaldsay	NRovis3	Modern	MS32			+	
North Ronaldsay	NRovis4	Modern	MS33			+	
North Ronaldsay	NRovis5	Modern	MS34			+	

Table 7.9 List of enamel carbonate data of sheep from British sites; start and end of growth period of permanent molars from Hillson (2005: Table 3.3.).

sample ID	graph ID	Max C	Min C	Max-Min C	mean C	SD C	Max O	Min O	Max-Min O	mean O	SD O	source
KHovis1	NS11						27.8	24.4	3.4	25.8	1.2	Balasse and Tresset 2007
KHovis2	NS12						27.8	23.9	3.9	25.8	1.4	
KHovis3	NS13						28.0	24.2	3.8	25.7	1.3	
HPWN ovis 2	NS21						28.5	25.9	2.6	26.8	0.8	Balasse and Tresset 2007
HPWN ovis 3	NS22						28.2	26.0	2.2	26.8	0.7	
HPWN ovis 4	NS23						27.8	26.0	1.8	26.7	0.6	
NRovis1	MS31						27.0	25.8	1.2	26.2	0.4	Balasse and Tresset 2007
NRovis3	MS32						28.9	26.4	2.5	27.1	0.7	
NRovis4	MS33						28.6	26.1	2.5	27.2	0.8	
NRovis5	MS34						28.6	26.5	2.1	27.3	0.6	

Table 7.10 Values calculated from enamel carbonate data of sheep from British sites (Max and Min $\delta^{13}C$ values calculated only from M2 and M2).

site	sample ID	period	animal	graph ID	M1	M2	M3	source
start of growth					1/2 at birth	birth	1yr	
end of growth					9 mths	1yr	2yrs	
Er Yoh	EYovis1	Neolithic	sheep	NS101		+		Balasse and Tresset 2007
Er Yoh	EYovis2	Neolithic	sheep	NS102		+		
Er Yoh	EYovis3	Neolithic	sheep	NS103		+		
Er Yoh	EYovis4	Neolithic	sheep	NS104		+		
Er Yoh	EYovis5	Neolithic	sheep	NS105		+		
Bercy	BQS Ovis1M2	Neolithic	sheep	NSA		+		Balasse et al.2012 a
Bercy	BQS Ovis2M2	Neolithic	sheep	NSB		+		
Bercy	BQS Ovis3M2	Neolithic	sheep	NSC		+		
Bercy	BQS Ovis4M2	Neolithic	sheep	NSD		+		
Bercy	BQS Ovis5M2	Neolithic	sheep	NSE		+		
Cheia	CHE Ovis 01.M2	Chalcolithic	sheep	CSJ		+	+	Tornero et al. 2013
Cheia	CHE Ovis 02.M2	Chalcolithic	sheep	CSK		+	+	
Cheia	CHE Ovis 03.M2	Chalcolithic	sheep	CSL		+	+	
Cheia	CHE Ovis 04.M2	Chalcolithic	sheep	CSM		+	+	
Cheia	CHE Ovis 05.M2	Chalcolithic	sheep	CSN		+	+	
Cheia	CHE Ovis 06.M2	Chalcolithic	sheep	CSO		+	+	
Cheia	CHE Ovis 09.M2	Chalcolithic	sheep	CSP		+	+	
Cheia	CHE Ovis 10.M2	Chalcolithic	sheep	CSQ		+	+	
Cheia	CHE Ovis 11.M2	Chalcolithic	sheep	CSR		+	+	
Cheia	CHE Ovis 12.M2	Chalcolithic	sheep	CSS		+	+	
Cheia	CHE Ovis 13.M2	Chalcolithic	sheep	CST		+	+	
Cheia	CHE Ovis 14.M2	Chalcolithic	sheep	CSU		+	+	
Cheia	CHE Ovis 15.M2	Chalcolithic	sheep	CSV		+	+	
Carmejane farm	Ovis 1216	Modern	sheep	MSa		+	+	Blaise and Balasse 2011
Carmejane farm	Ovis 0026	Modern	sheep	MSb		+	+	

site	sample ID	period	animal	graph ID	M1	M2	M3	source
Carmejane farm	Ovis 0522	Modern	sheep	MSc		+	+	Blaise and Balasse 2011
Carmejane farm	Ovis 0562	Modern	sheep	MSd		+	+	
Carmejane farm	Ovis 1511	Modern	sheep	MSe		+	+	
Carmejane farm	Ovis 9470	Modern	sheep	MSf		+	+	
Carmejane farm	Ovis 8143	Modern	sheep	MSg			+	
Carmejane farm	Ovis 9726	Modern	sheep	MSh			+	
Collet-Redon	Ovis MCR 3D	Neolithic	sheep	NSF		+		Blaise and Balasse 2011
Collet-Redon	Ovis MCR US182	Neolithic	sheep	NSG		+		
Collet-Redon	Ovis MCR 3B	Neolithic	sheep	NSH		+		
Collet-Redon	Ovis MCR 3C	Neolithic	sheep	NSI		+		
Rousay	ROU 01 M2	Modern	sheep	MSj		+		Balasse et al. 2012 b
Rousay	ROU 04	Modern	sheep	MSk		+		
Rousay	ROU 6	Modern	sheep	MSl		+		
Rousay	ROU 07	Modern	sheep	MSm		+		
Rousay	ROU 08	Modern	sheep	MSn		+		
Rousay	ROU 09	Modern	sheep	MSo		+		
Rousay	ROU 11	Modern	sheep	MSp		+		
Rousay	ROU 16	Modern	sheep	MSq		+		
Rousay	ROU 17	Modern	sheep	MSr		+		
Rousay	ROU 18	Modern	sheep	MSs		+		
Collet-Redon	Capra MCR 3D	Neolithic	goat	NGY		+		Blaise and Balasse 2011
Collet-Redon	Capra MCR US186	Neolithic	goat	NGZ		+		
Enkorika	Enkcapra1	Modern	goat	MGa		+		Balasse and Tresset 2007
Enkorika	Enkcapra2	Modern	goat	MGb		+		
Enkorika	Enkcapra3	Modern	goat	MGc		+		
Enkorika	Enkcapra4	Modern	goat	MGd		+		

Table 7.11 List of enamel carbonate data of sheep and goat from non-British sites; start and end of growth period of permanent molars from Hillson (2005: Table 3.3.).

sample ID	graph ID	Max C	Min C	Max-Min C	mean C	SD C	Max O	Min O	Max-Min O	mean O	SD O	source
EYovis1	NS101						30.6	25.6	5.0	27.9	1.6	Balasse and Tresset 2007
EYovis2	NS102						32.3	25.5	6.8	28.5	2.4	
EYovis3	NS103						31.3	26.5	4.8	29.5	1.7	
EYovis4	NS104						26.6	22.4	4.2	24.8	1.6	
EYovis5	NS105						30.0	27.8	2.2	29.2	0.8	
BQS Ovis1M2	NSA	-11.5	-14.1	2.6	-12.9	0.9	-4.2	-7.6	3.4	-5.6	1.4	Balasse et al.2012 a
BQS Ovis2M2	NSB	-13.2	-14.7	1.5	-13.9	0.6	-1.5	-5.9	4.4	-3.4	1.4	
BQS Ovis3M2	NSC	-13.1	-15.3	2.2	-14.2	0.8	-1.2	-5.3	4.1	-3.1	1.4	
BQS Ovis4M2	NSD	-10.3	-13.0	2.7	-11.4	0.9	-2.9	-5.4	2.5	-4.1	0.8	
BQS Ovis5M2	NSE	-11.8	-13.9	2.1	-12.8	0.8	-2.3	-7.1	4.8	-3.9	1.7	
CHE Ovis 01.M2	CSJ						-2.5	-8.5	6.0	-4.9	1.9	Tornero et al. 2013
CHE Ovis 02.M2	CSK						-2.0	-8.3	6.3	-4.6	2.1	
CHE Ovis 03.M2	CSL						-2.9	-7.4	4.5	-5.0	1.4	
CHE Ovis 04.M2	CSM						-0.1	-9.0	8.9	-4.3	2.9	
CHE Ovis 05.M2	CSN						-1.6	-8.5	6.9	-4.0	2.1	
CHE Ovis 06.M2	CSO						-1.3	-6.6	5.3	-4.3	1.8	
CHE Ovis 09.M2	CSP						-0.5	-7.2	6.7	-3.3	1.8	
CHE Ovis 10.M2	CSQ						-2.3	-7.7	5.4	-5.0	1.7	
CHE Ovis 11.M2	CSR						-0.9	-7.0	6.1	-3.6	2.1	
CHE Ovis 12.M2	CSS						-1.0	-7.7	6.7	-4.5	2.0	
CHE Ovis 13.M2	CST						0.9	-5.8	6.7	-2.1	2.0	
CHE Ovis 14.M2	CSU						-0.5	-8.2	7.7	-3.9	2.5	
CHE Ovis 15.M2	CSV						-1.4	-7.5	6.1	-3.9	1.9	
Ovis 1216	MSa						-1.1	-6.2	5.1	-3.5	1.7	Blaise and Balasse 2011
Ovis 0026	MSb						-0.5	-6.6	6.1	-3.2	2.0	
Ovis 0522	MSc						-1.6	-7.0	5.4	-3.6	1.6	

sample ID	graph ID	Max C	Min C	Max-Min C	mean C	SD C	Max O	Min O	Max-Min O	mean O	SD O	source
Ovis 0562	MSd						-1.1	-6.8	5.7	-3.5	1.5	Blaise and Balasse 2011
Ovis 1511	MSe						-0.6	-7.2	6.6	-4.0	2.2	
Ovis 9470	MSf						-0.2	-5.6	5.4	-2.7	1.9	
Ovis 8143	MSg						-1.8	-5.5	3.7	-4.2	1.3	
Ovis 9726	MSh						-1.2	-4.7	3.5	-2.7	1.4	
Ovis MCR 3D	NSF						1.5	-2.1	3.6	-0.7	1.0	Blaise and Balasse 2011
Ovis MCR US182	NSG						1.3	-0.8	2.1	0.5	0.8	
Ovis MCR 3B	NSH						1.7	-0.9	2.6	0.3	0.9	
Ovis MCR 3C	NSI						0.4	-1.8	2.2	-0.8	0.9	
ROU 01 M2	MSj						-2.3	-6.3	4.0	-4.3	1.5	Balasse et al. 2012 b
ROU 04	MSk						-2.3	-6.5	4.2	-4.4	1.5	
ROU 6	MSl						-2.4	-5.7	3.3	-4.2	1.1	
ROU 07	MSm						-1.7	-4.6	2.9	-3.2	1.1	
ROU 08	MSn						-2	-4.7	2.7	-3.3	0.9	
ROU 09	MSo						-2.6	-6.2	3.6	-4.4	1.4	
ROU 11	MSp						-2.4	-6.4	4	-4.3	1.5	
ROU 16	MSq						-2.8	-6.4	3.6	-4.5	1.4	
ROU 17	MSr						-2.2	-5.9	3.7	-4.1	1.4	
ROU 18	MSs						-2.3	-5	2.7	-3.6	0.9	
Capra MCR 3D	NGY						1.3	-1.6	2.9	0.0	1.0	Blaise and Balasse 2011
Capra MCR US186	NGZ						1.8	-0.7	2.5	0.9	0.9	
Enkcapra1	MGa						36.3	32.5	3.8	34.9	1.2	Balasse and Tresset 2007
Enkcapra2	MGb						38.2	33.2	5.0	35.7	2.1	
Enkcapra3	MGc						37.1	33.3	3.8	34.7	1.3	
Enkcapra4	MGd						36.9	34.7	2.2	36.0	0.9	

Table 7.12 Values calculated from enamel carbonate data of sheep and goats from non-British sites (Max and Min $\delta^{13}C$ values calculated only from M2 and M2).

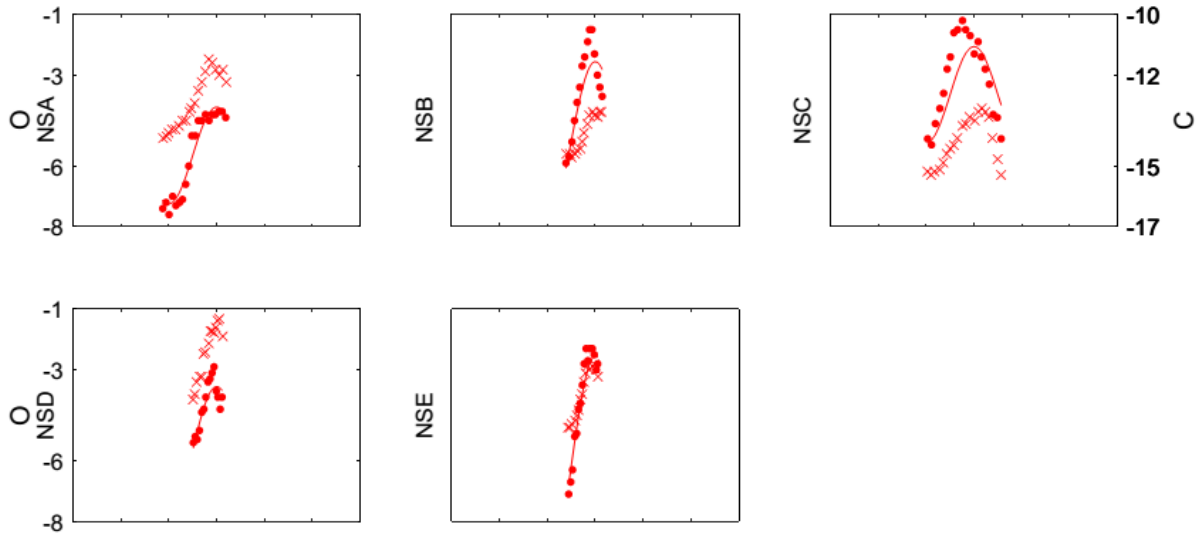


Fig. 7.15 Sequential enamel carbonate data of sheep/goats from Bercy, Paris, France by Balasse et al. (2012); x-axis: time difference of enamel formation deduced from distance from enamel root junction, y-axis: right: $\delta^{13}C$ values (cross), left: $\delta^{18}O$ values (dot), solid line: modelled $\delta^{18}O$ value curve, blue: M1, red: M2, green: M3. Individuals indicated by graph ID. See Table 7.11 for matching sample ID with graph ID.

Feeding Custom Deduced from the $\delta^{13}C$ Values of Sheep/Goats at Horcott

Next, what feeding custom possibly caused seasonal change in $\delta^{13}C$ values of sheep/goat enamel carbonate is examined. First, the influence of the type of livestock housing practice on the feeding custom will be discussed. Next, plants which were possibly fed to sheep/goats at Horcott are discussed in light of archaeological, environmental, and historical evidence.

Seasonal fluctuation observed in sheep/goat $\delta^{13}C$ values suggest that unlike cattle, sheep/goat food was less managed by humans at Horcott. Compared to cattle, the practice of housing sheep seems to have been more adapted to mobility. Ælfric's *Colloquy* mentions that shepherds moved the folds for their flocks regularly (Garmonsway 1991: 22). According to *Rectitudines Singularum Personarum*, peasants spent the night at their lord's sheep fold

(Liebermann 1898: i 441). A similar practice was also mentioned in Ælfric's *Colloquy*, in which the given reason of rounding up the flock in a fold at the end of the day was 'so that the wolves do not eat them.'(Garmonsway 1991: 22). According to Banham and Faith (2014: 148), this practice of shepherds staying with their flocks existed until as late as in the nineteenth century in England. Banham and Faith (2014: 148: footnote 24) note that the folds found in charter boundaries and landmarks give an impression that they were immobile structures for sheltering at night rather than mobile structures. Still, whether the sheep were kept indoors in winter in the Romano-British period and in the early Anglo-Saxon period is not clear. Since there are no structures that seem to have been used for this purpose dating from the fifth to the seven centuries AD, and no longhouses (as mentioned above), this seems highly unlikely in the early Anglo-Saxon period. If they were not sheltered seasonally, they may have consumed plants available in each season, leading to seasonal fluctuation in tooth enamel carbonate $\delta^{13}C$ values.

What were the sheep/goats eating to have seasonal change in $\delta^{13}C$ values of enamel carbonate? Being herbivores, sheep/goats at Horcott were probably consuming food similar to cattle discussed above. However, the sheep/goat husbandry may not have involved the practice of housing as much as cattle. This could have resulted in less feeding management by humans, which is probably the reason the $\delta^{13}C$ values of the sheep/goats at Horcott exhibit a covariation with the $\delta^{18}O$ values, an indication of more seasonal variation in sheep/goat food.

7.2.1.3. Difference between the δ^{13}C Values of Cattle and Sheep/Goats among Various sites

In order to investigate whether the differences observed between cow and sheep/goat δ^{13}C values at Horcott is site-specific or a general trend, data from other sites which have both cow and sheep/goat δ^{13}C values were compared with Horcott. If there were similarities among the same livestock species, it could be argued that the difference between cow and sheep/goat values is due to metabolic differences rather than differences in feeding strategy.

Unfortunately, only the Neolithic site at Bercy, Paris, France matched the criterion (Balasse et al. 2012 a). Similar trends observed at Horcott between cattle and sheep/goats can also be found at Bercy. Sheep at Bercy have less constant δ^{13}C values with a wider amplitude than cattle, which suggests that the food of sheep at Bercy was isotopically more affected by seasonality, like the Horcott sheep/goat.

In contrast to Horcott, however, the food consumed by the cattle at Bercy were more isotopically affected by seasonality. Seven out of ten Bercy cattle had δ^{13}C value sequences correlating with their δ^{18}O value curves which reflects the seasonal cycle (Fig 7.14).

In conclusion, although there were similar trends between Horcott and Bercy, there was also a difference in trends such as seasonal fluctuation of δ^{13}C values in cattle. This suggests that this difference is site-dependent rather than species-dependent. Therefore, the difference observed at Horcott between cattle and sheep/goats may be explained as a different feeding strategy depending on the livestock species rather than metabolic differences between the two livestock species. This supports the argument that the extent of food management by humans may have been different between cattle and sheep/goats at Horcott.

7.2.2. The $\delta^{18}O$ Values

This section focuses on the comparison between the birth seasonality of each livestock at Horcott deduced from their $\delta^{18}O$ values and the birth seasonality data from other sites.

7.2.2.1. Birth Seasonality of Cattle at Horcott

Firstly, the birth seasonality of cattle deduced from the $\delta^{18}O$ values will be examined. Next, the birth seasonality at Horcott will be compared with those from other sites and periods. The discussion focuses more on the results according to M2 because the error in birth season due to individual time difference in the formation of M2 tooth is smaller than M3 (see Chapter 4). The results according to M1 will not be discussed because they are few comparable data from other sites.

With respect to range, the birth season of the two Romano-British cattle from M2 was six months apart, which indeed is as far as two points can be from each other in a circular dimension (which is the characteristic of a year) (Fig. 6.27 in Chapter 6). The birth season of the Anglo-Saxon cattle from M2 was slightly shorter, which was maximum four and a half months apart.

Other birth seasonality results from previous studies were compared with the results from Horcott. Unfortunately, there are no contemporaneous sites from Britain and continental Europe with sequential data from cattle tooth enamel. Results from various British sites are dated to the Bronze Age, Iron Age and the Norse (Viking) period respectively (Towers et al. 2013). Results from Knap of Howar, the Orkney Islands and Er Yoh, Brittany, France are dated to the Neolithic period (Balasse and Tresset 2007) and other cattle from a Neolithic site

at Bercy, Paris, France were analysed by Balasse et al (2012 a). Following the procedure applied to the data from Horcott, the birth seasonality from the data from these various sites were deduced by using the modelled $\delta^{18}O$ value sequences (Figs 7.16 and 7.17).

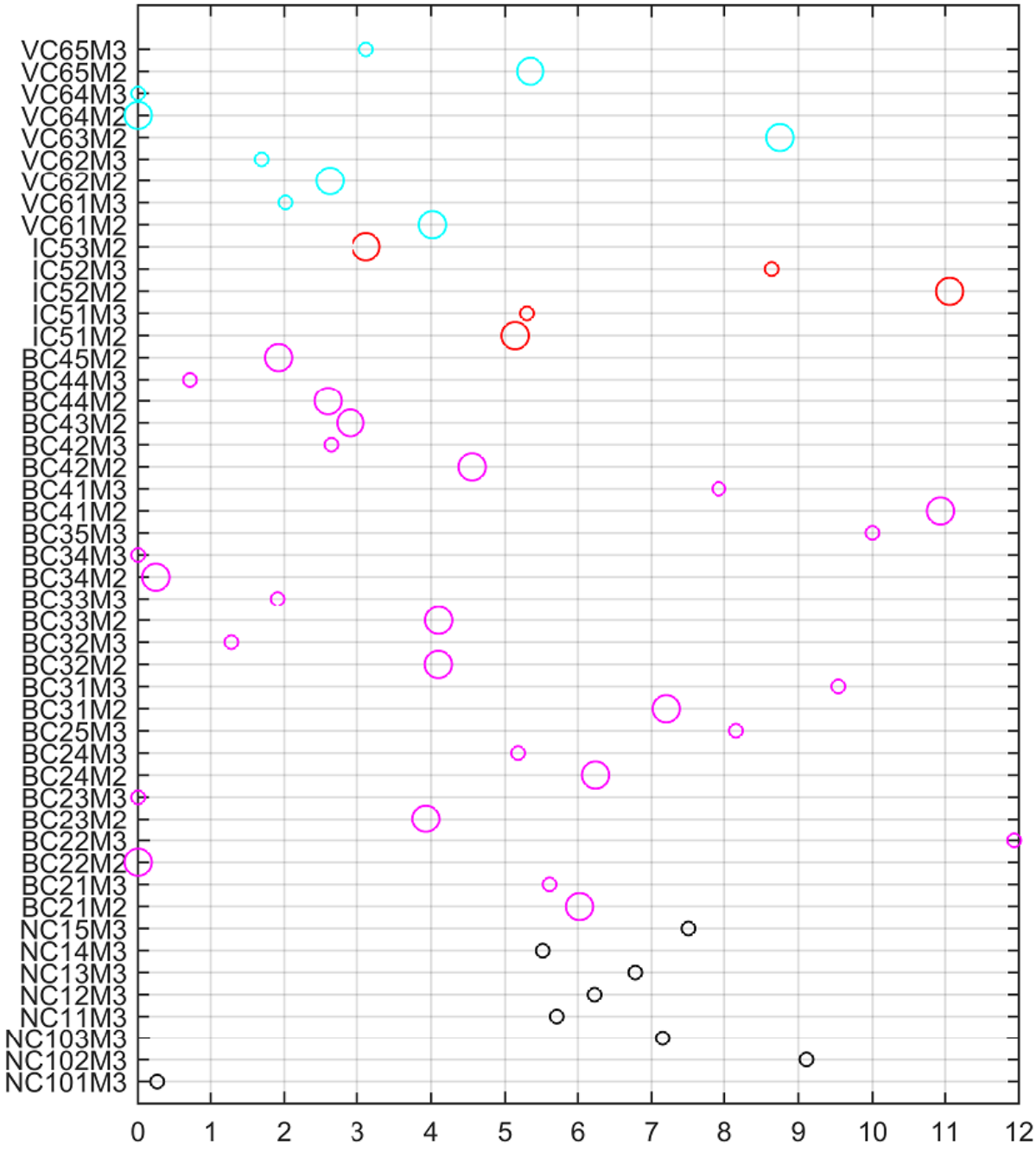


Fig. 7.16 Birth seasonality of cattle from British sites and Er Yoh from the method by Balasse et al. (2012 b); x-axis: months, y-axis: graph ID of samples (See Tables 7.5 and 7.7 for corresponding sample ID), black: Neolithic, pink: Bronze Age, red: IA, light blue: Norse (Viking) period, large circle: M2, small circle: M3.

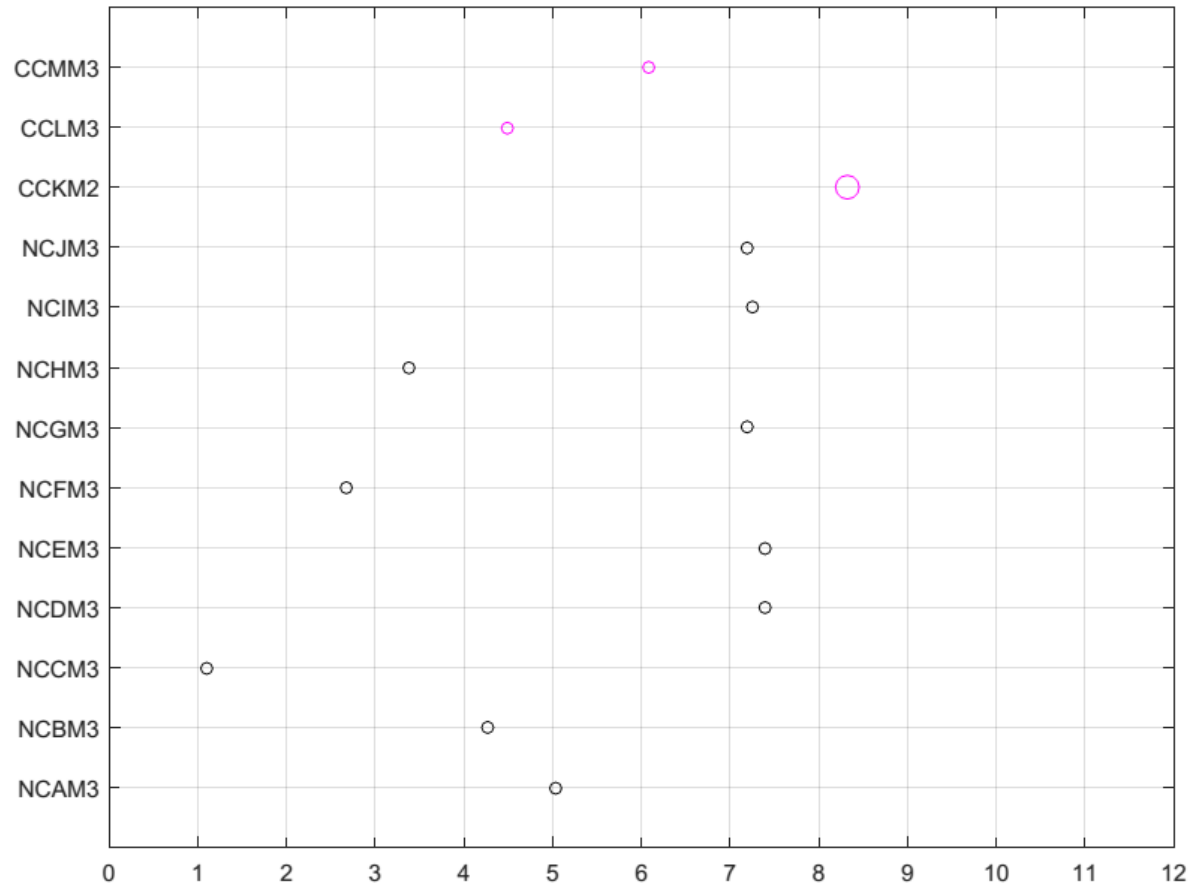


Fig.7.17 Birth seasonality of cattle from continental sites from the method by Balasse et al. (2012 b); x-axis: months, y-axis: graph ID of samples (See Table 7.7 for corresponding sample ID), black: Neolithic, pink: Chalcolithic, large circle: M2, small circle: M3.

Compared to Bronze Age cattle at Grimes Graves, Gayhurst and Irthlingborough (BC 21~BC 45 in Fig. 7.16), the birth season of cattle at Horcott is relatively short (Fig 6.27 in Chapter 6). The birth season of cattle at Romano-British Horcott was deduced from just two cattle which were the only individuals suitable for sampling, so it is possible that the birth season could be longer if more individuals suitable for sampling were available. Despite the larger number of cattle from Anglo-Saxon Horcott analysed however, the birth season of Anglo-Saxon cattle was confined to four and a half months, which is slightly longer than that of the Neolithic cattle at Knap of Howar, Orkney. Unlike the Orkneys, the reason for a short birth season at

Horcott cannot be explained by the climate (see Chapter 2) since other English sites have longer birth seasons.

What significance do different breeding strategies have for the humans that look after the livestock? Longer birth season is beneficial when livestock are reared for milk (see Chapter 2). But of course the amount of milk produced by a cow is not the same throughout the year (see Chapter 2). In addition, cattle may stop yielding milk while they are pregnant naturally or by human intervention (Banham and Faith 2014: 132). If cattle gave birth in spring or early summer, the mating had taken place from mid-summer and they would have stopped yielding milk while they were pregnant for nine months during autumn, winter and early spring (Banham and Faith 2014: 132). If the cattle were pregnant every year, they might yield milk only during the three months interval between pregnancies. Nevertheless, historical documents from early medieval Ireland in the seventh and eighth century AD mention that at least some of the cattle were regarded as being able to yield milk during the winter (Kelly 1997: 41). However, yielding milk during the winter is possible only if enough food was fed to cattle. Otherwise, they may stop yielding milk, possibly from November till May (Banham and Faith 2014: 113). Equally, shorter birth seasons also have benefits (see Chapter 2). Thus, it is possible that breeding of cattle was restricted by humans to a certain extent, especially in the Anglo-Saxon period at Horcott. The purpose could be maximising the productivity in limited food availability. It could also be maximising the efficiency of time and labour invested in animal breeding and avoiding time conflicts with other farming activities. In any case, cattle husbandry in the Anglo-Saxon period at Horcott seems to have been less focused on rearing cattle for milk production compared to the Romano-British period.

These conclusions regarding livestock rearing from birth seasonality results can be complemented by results from animal bone assemblages. Mortality pattern and interspecies ratio of cattle (see Chapter 2) were compared with the tooth enamel results. Due to the scarcity of Romano-British cattle mandibles that could be aged, the slaughtering pattern of Romano-British cattle cannot be discussed, but the mortality profile of Anglo-Saxon cattle suggests that they were reared for several purposes; meat, milk, and traction (Fig. 2.5 in Chapter 2). This agrees with the restricted birth seasonality indicating that Anglo-Saxon cattle were not reared primarily for milk production. In addition, interspecies ratio by NISP of livestock shows that cattle was not the predominant species in the Romano-British period, but became the predominant species in the Anglo-Saxon period. Therefore, it seems that even though cattle were not reared for milk, they were an important livestock in the Anglo-Saxon period.

7.2.2.2. Birth Seasonality of Sheep/Goats at Horcott

First, the birth seasonality results of sheep/goats at Horcott will be compared with the results available from other sites in various periods. Next, the significance of these birth seasons in light of livestock management will be discussed. As with cattle, the discussion focuses more on the results according to M2 and results according to M1 will not be discussed.

Contrary to cattle, the length of birth seasons of sheep/goats at Horcott, was slightly shorter in the Romano-British period than in the Anglo-Saxon period (see Chapter 6). In addition, sheep possibly had one major and one minor season (see Chapter 6).

Results from other British and continental European sites with tooth enamel sequence data from sheep and goats were compared with Horcott. As with cattle, there are no contemporaneous sites with sheep and goat tooth enamel results. Results from British sites are only from the Orkney Islands sampled from Neolithic and modern sheep (Balasse and Tresset 2007, Balasse et al. 2012 b). Other published $\delta^{18}O$ value sequence results come from continental European sites. They are from; Er Yoh, Brittany, France, dated to the Neolithic period (Balasse and Tresset 2007); a Neolithic site at Bercy, Paris, France (Balasse et al. 2012 a); modern and Neolithic sheep and goats from south-east France (Blaise and Balasse 2011); early Eneolithic (Chalcolithic) sheep from Cheia, Romania (Tornero et al. 2013). Following the procedure applied to the data from Horcott, the birth seasonality from the data from these various sites were deduced by using the modelled $\delta^{18}O$ value sequences (Figs 7.18 and 7.19).

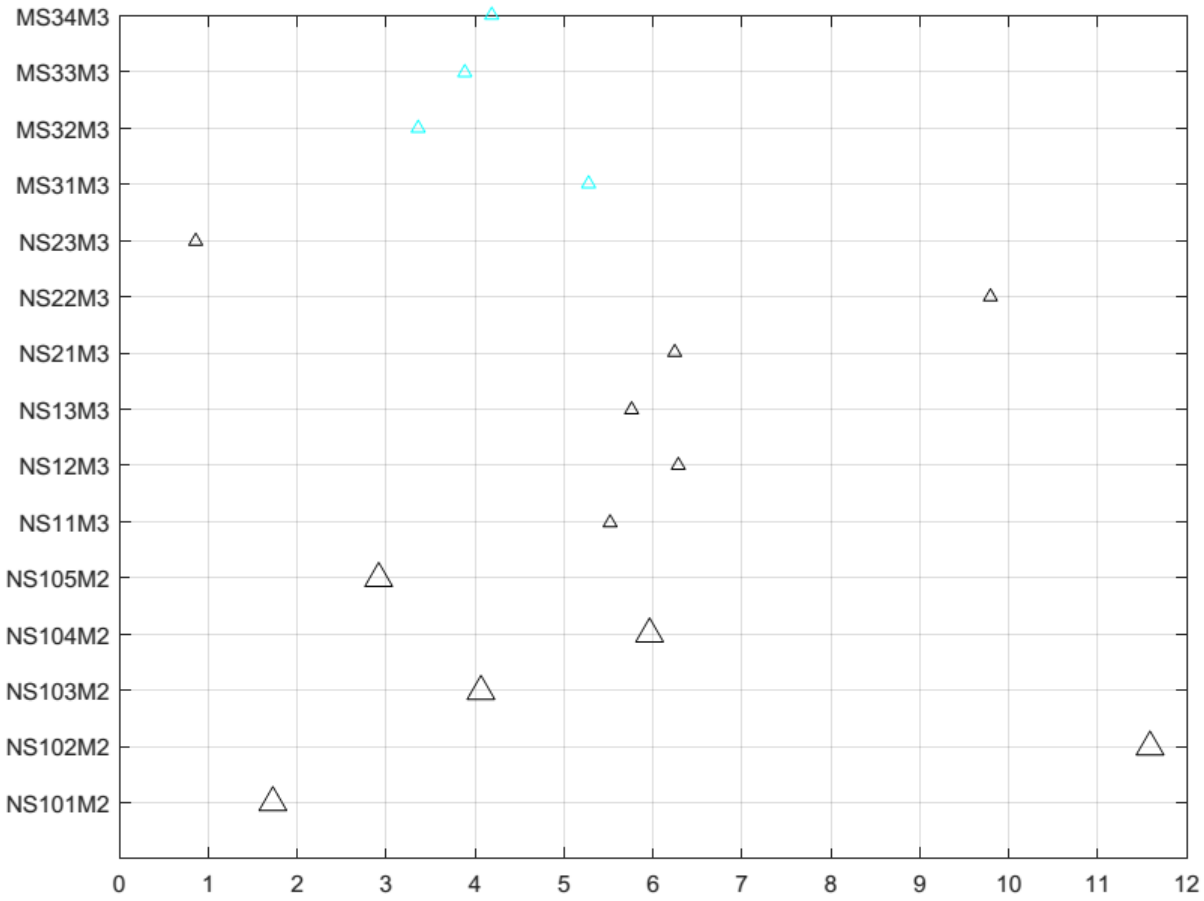


Fig. 7.18 Birth seasonality of sheep from British sites and Er Yoh from the method by Balasse et al. (2012 b); x-axis: months, y-axis: graph ID of samples (See Tables 7.9 and 7.11 for corresponding sample ID), black: Neolithic, light blue: modern, large triangle: M2, small triangle: M3.

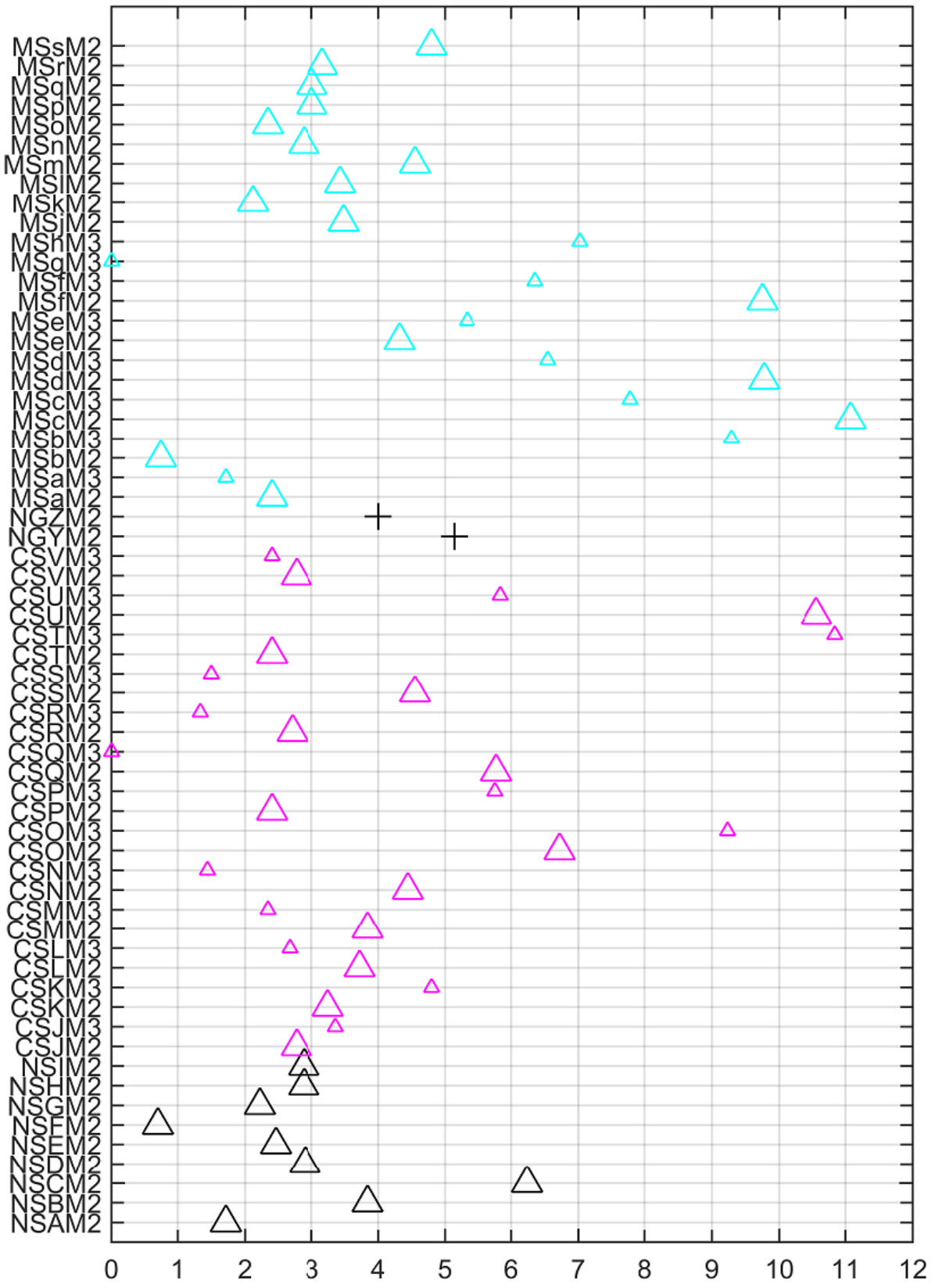


Fig. 7.19 Birth seasonality of sheep and goats from non-British sites from the method by Balasse et al. (2012 b); x-axis: months, y-axis: graph ID of samples (See Table 7.11 for corresponding sample ID), black: Neolithic, pink: Chalcolithic, light blue: modern, triangle: sheep, cross: goats, large marker: M2, small marker: M3

Comparing with other results, the birth season of sheep/goats at Horcott is neither long nor short (Fig. 6. 29 in Chapter 6). However, there are continental sites which show more than one birth season like at Horcott. For example, the birth season of sheep at the Eneolithic (Chalcolithic) site at Cheia, Romania span up to eight and a half months, but lambing does not seem to have occurred constantly throughout the period (CSJ~CSV in Fig.7.19). Instead, birth timings seem to form a group when lamb births peak during the birth season apart from a few outliers. Similarly, modern sheep from south-east France show more than one birth timings during the birth season of maximum seven months (MSa~MSh in Fig 7.19). Since there are no comparable results from mainland England, it is impossible to argue whether having more than one birth season like at Horcott was common in England. Nevertheless, Horcott is located in an intermediate latitude, so longer birth season is possible if humans did not consider it necessary to control the mating timing. One of the purposes of controlling the mating timing is maximising the productivity in when food availability is limited (see Chapter 2). Therefore, the dispersed birth season of sheep/goats at Horcott may suggest that birth season of sheep/goats was less controlled at Horcott. This may be because there was enough food for them to have multiple birth timings during the year.

In order to examine the birth season of past herds, modern sheep data with known birth dates are crucial as a reference. Conveniently, the birth dates of modern sheep from south-east France were recorded; three out of eight were born in January and February (MSa, MSb, and MSg in Fig. 7.19), one in April (MSh in Fig. 7.19) and four in September (MSc~f in Fig. 7.19) (Blaise and Balasse 2011). If the tooth formation timing had not changed through time, which would make the birth season all comparable regardless of periods, the birth seasons of the past can be deduced by comparing with the modern sheep with recorded birth dates.

Following this assumption, it can be deduced that the Neolithic sheep at various French sites were born in spring, Neolithic sheep at Knap of Howar, the Orkney Islands in summer, and Romanian Eneolithic sheep mostly in spring and summer. Regarding Horcott, most Romano-British and Anglo-Saxon Horcott sheep/goats were born within four months in spring and early summer except for one Romano-British sheep (ROM sg 1) and one Anglo-Saxon sheep (SAX sg 4), which were born in late autumn or early winter. Traditionally, lambing months of sheep in Britain were March and April in the lowlands and April and May in the uplands (Biffen 1932: 550). Hence, the birth seasons deduced from sheep tooth enamel sequences of British sites are wider than these traditional birth seasons of Britain except for the sheep from the Orkneys.

Next, the significance of these birth seasons in light of livestock management are considered. As already mentioned, a diverse birth season is beneficial when livestock are reared for milk (see Chapter 2). Compared to calves, the suckling period of lambs is shorter: lambs are weaned when they are 16 to 18 weeks old and spring born lambs on open range will wean in early autumn (see Chapter 2). Thus, autumn birth results in milk availability through the winter. Since there are sheep born in late autumn/early winter at Horcott, milk and dairy products could possibly have been an important food during the winter at Horcott.

However, the amount of food is limited in winter, so the challenge of having lambs born in autumn and winter is that lambs and their mothers may not be strong enough to endure the severe weather with limited nutrition. Even modern dairy sheep normally stop yielding milk in winter (Banham and Faith 2014: 113). Therefore, having lambs born later in the year is

beneficial only if there is enough food to feed them over the winter. The sheep born in late autumn/early winter at Horcott are ROM sg 1 and SAX sg 4 whose age at death was estimated as older than 1 year and 1–2 years respectively from their tooth eruption and wear. This means that these individuals survived the first winter as lambs. The fact that these two are the only individuals born in late autumn/early winter out of a total of 13 sheep from Horcott whose M2 or M3 were analysed indicates that autumn/winter birth was less common than spring/summer birth at Horcott.

Autumn/winter born sheep are also uncommon at the other European sites mentioned above. Examples of autumn/winter births deduced from M2 are, one Neolithic sheep at Er Yoh, Brittany, France (NS102 in Fig. 7.18) and one Eneolithic (Chalcolithic) sheep at Cheia, Romania (CSU in Fig. 7.19) besides the four modern sheep from south-east France which were born in September (MSc~f in Fig. 7.19). However, since the birth seasons are deduced from individuals who survived until their M2 or M3 formed, those who died before these teeth formed are not able to provide their birth seasons. Therefore, it is possible that more sheep were born in various seasons than the birth seasons from M2 and M3 indicate, but those who were not born in the optimal season died soon naturally or were slaughtered to save food for others, making them invisible in the birth seasons deduced from M2 and M3. Since, the survival of lambs born outside of the optimal season of spring and summer would depend on their nutritional condition when overwintering, the few sites where autumn/winter born sheep survived to become adults suggest that the at least some sheep at these sites were well fed to endure the severe condition.

In summary, both the Romano-British and the Anglo-Saxon humans at Horcott had access to sheep milk even after the main birth season in spring and summer. This may suggest that

birth season of sheep was not strictly controlled at Horcott regardless of period. Possible reasons for longer birth season of sheep are;

a) there was abundant food enough for some autumn/winter born lambs and their mothers to survive the winter

b) the inhabitants did not consider it necessary to control the breeding timings of sheep, or the inhabitants found it beneficial to have a dispersed birth season

which relates to the third reason;

c) sheep dairy products was an important food at Horcott

Since animal bone assemblages also reflect how animals were managed, mortality pattern and interspecies ratio of sheep/goats from animal bone assemblages at Horcott (see Chapter 2) were compared with the tooth enamel results. The mortality profile of sheep/goats show similar slaughtering patterns between the Romano-British and Anglo-Saxon periods, suggesting that they were reared for various purposes; meat, milk and wool (Fig. 2.6 in Chapter 2). However, this does not necessarily agree with the birth season of sheep/goats, which indicates that milk production was an important aspect of sheep/goat rearing at Horcott. In contrast, interspecies ratio by NISP shows that sheep/goat was the predominant species in the Romano-British period but not in the Anglo-Saxon period. The predominant species in the Anglo-Saxon period was cattle. This means that although the birth seasonality did not change from the Romano-British period to the Anglo-Saxon period, the importance of sheep/goats may have declined, or the importance of cattle may have increased in the Anglo-Saxon period.

7.2.2.3. Difference between the $\delta^{18}O$ Values of Cattle and Sheep/Goats among Various Sites

In order to investigate whether the differences observed between cow and sheep/goat $\delta^{18}O$ values at Horcott is site-specific or a general trend, data from other sites which have both cow and sheep/goat $\delta^{18}O$ values were compared with Horcott. First, the $\delta^{18}O$ value sequences between the cattle and sheep/goats from each site will be compared. Next, the birth seasonality between the cattle and sheep/goats from each site will be compared. If there were similarities among the same livestock species across all sites, it could be argued that the difference between cow and sheep/goat values is due to metabolic differences which are species-specific rather than differences in the environment, water supply or breeding control by humans.

Unfortunately, only three sites matched the criterion. They are; a Neolithic site at Bercy, Paris, France (Balasse et al. 2012 a); another Neolithic site at Er Yoh, Brittany, France (Balasse and Tresset 2007); and yet another Neolithic site at Knap of Howar, Orkneys, Britain (Balasse and Tresset 2007).

Overall, the range of $\delta^{18}O$ values vary from one site to another (Tables 6.7 and 6.9 in Chapter 6 and Tables 7.6, 7.8, 7.10, and 7.12). This is not surprising since the $\delta^{18}O$ values of tooth enamel carbonate reflect the temperature of the area in high and middle latitudes (see Chapter 4). Therefore, it is understandable for enamel carbonate $\delta^{18}O$ values to vary depending on the region. In other words, simply comparing the $\delta^{18}O$ values from different regions can lead to misleading arguments. However, since this section will only refer to the observable difference between the cow and sheep/goat $\delta^{18}O$ values from the same site, this problem is avoided.

Trends similar to those observed at Horcott between cattle and sheep/goats can be found at Bercy and Er Yoh: the ranges and amplitudes of sheep/goat $\delta^{18}O$ values are larger than those of cattle (Tables 7.8 and 7.12, Bercy: Figs. 7.15 and 7.20, Er Yoh: NC101–103 in Fig. 7.21, NS101–105 in Fig. 7.22). However, the difference between the cow and sheep/goat $\delta^{18}O$ values are less evident at Knap of Howar (Tables 7.6 and 7.10, NC11–15 in Fig. 7.21 and NS11–13 in Fig. 7.22). The amplitudes of sheep/goat $\delta^{18}O$ values at Knap of Howar are slightly larger than those of cattle, although this may be because most cattle did not have teeth which were long enough to exhibit an annual cycle. In addition, the maximum $\delta^{18}O$ values are similar between the cattle and sheep/goats at Knap of Howar. The fact that the difference between cattle and sheep/goats is not consistent among various sites suggests that the observed difference in $\delta^{18}O$ values between cattle and sheep/goats is not necessarily due to the metabolic differences of the two species. Rather, this difference may reflect how the livestock were managed by humans. As at Horcott, the sheep/goats at Bercy and Er Yoh may have been less managed by humans compared to cattle, but at Knap of Howar, both livestock species may have been managed in the same way.

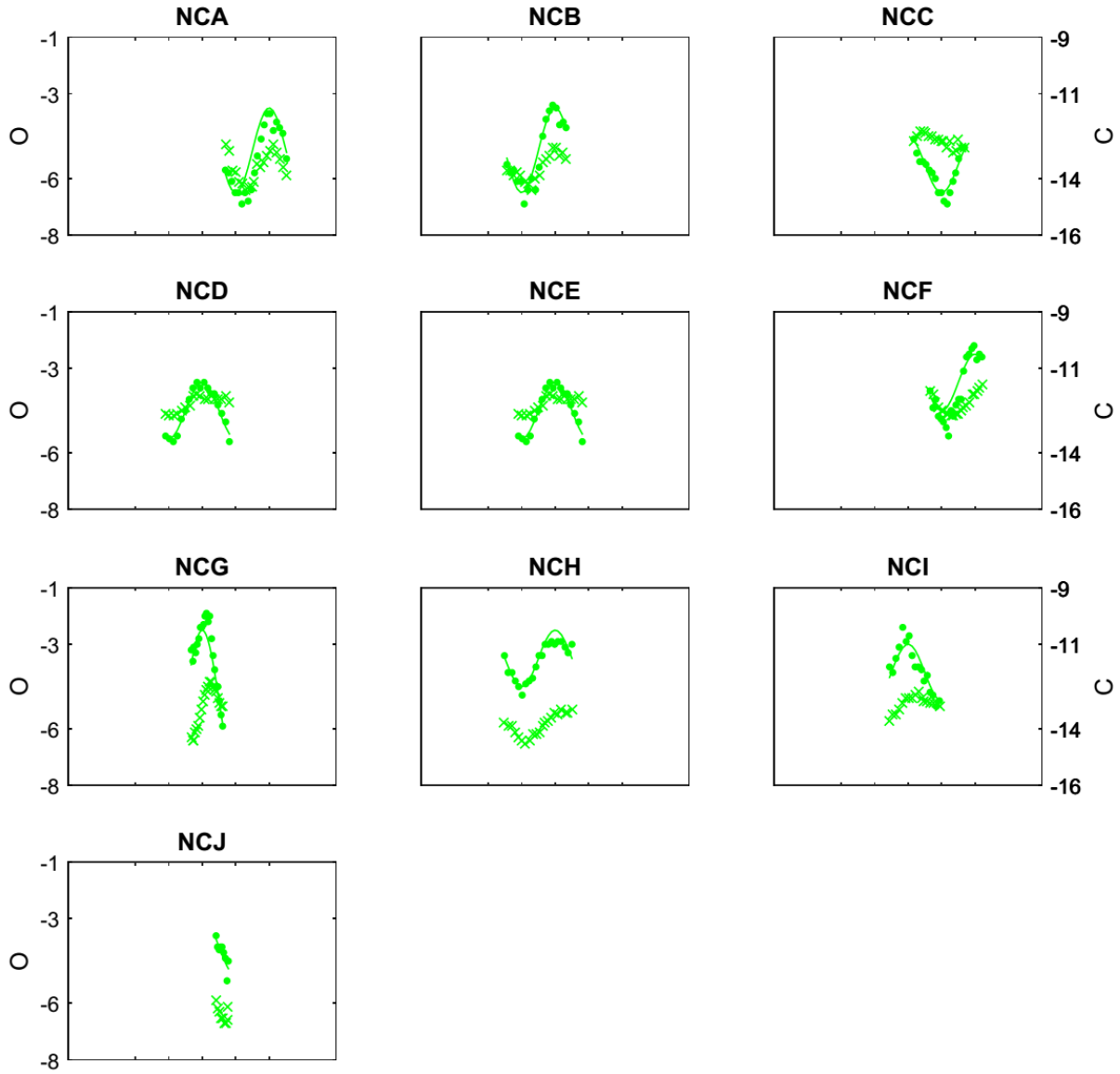


Fig. 7.20 Sequential enamel carbonate data of cattle from Bercy, Paris, France by Balasse et al. (2012); x-axis: time difference of enamel formation deduced from distance from enamel root junction, y-axis: right: $\delta^{13}C$ values (cross), left: $\delta^{18}O$ values (dot), solid line: modelled $\delta^{18}O$ value curve, blue: M1, red: M2, green: M3. Individuals indicated by graph ID. See Table 7.7 for matching sample ID with graph ID.

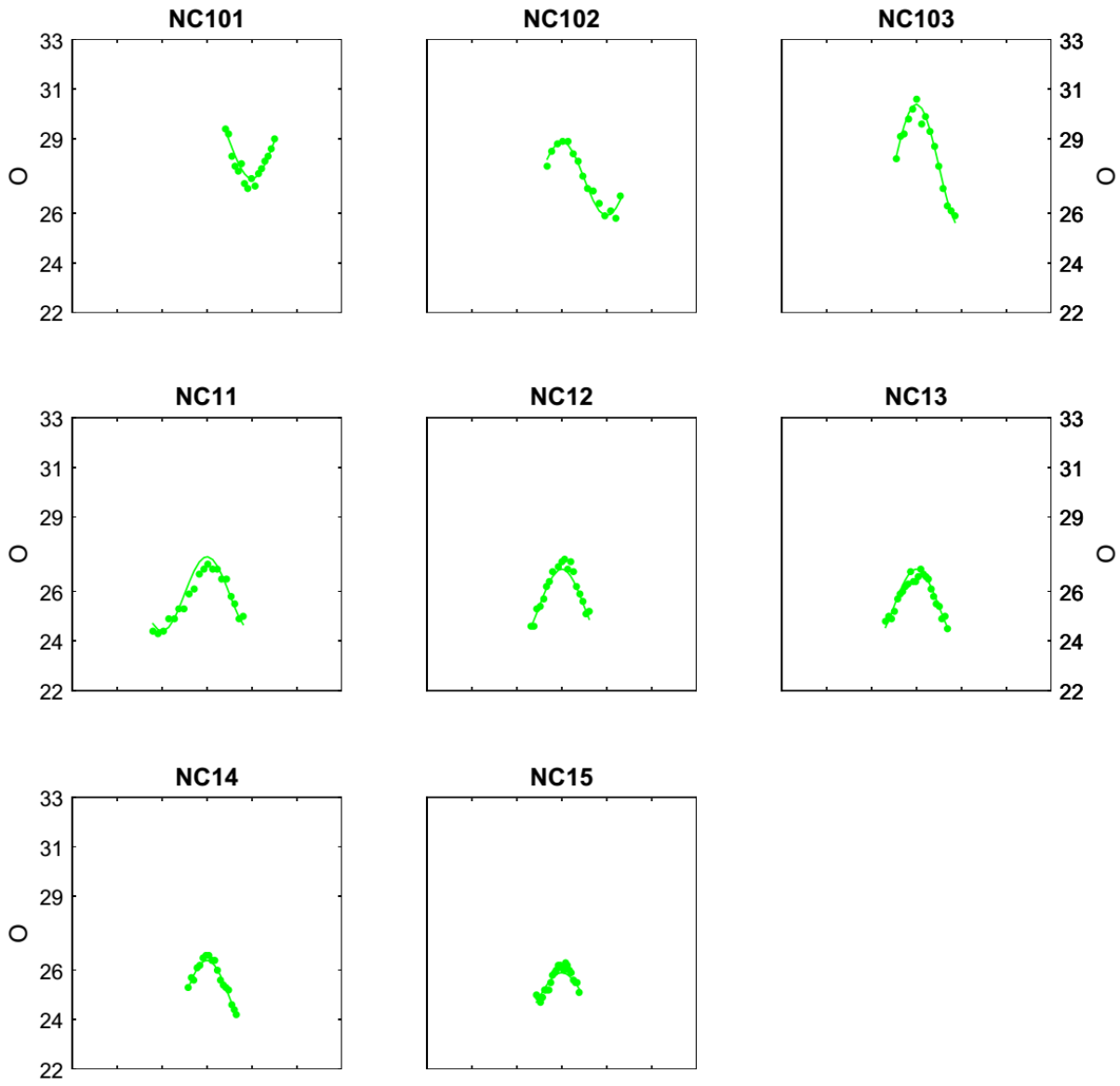


Fig. 7.21 Sequential enamel carbonate data of cattle from Er Yoh, Brittany, France and Knap of Howar, Orkneys, Britain by Balasse and Tresset (2007); x-axis: time difference of enamel formation deduced from distance from enamel root junction, y-axis: right: $\delta^{13}C$ values (cross), left: $\delta^{18}O$ values (dot), solid line: modelled $\delta^{18}O$ value curve, blue: M1, red: M2, green: M3. Individuals indicated by graph ID. See Tables 7.5 and 7.7 for matching sample ID with graph ID.

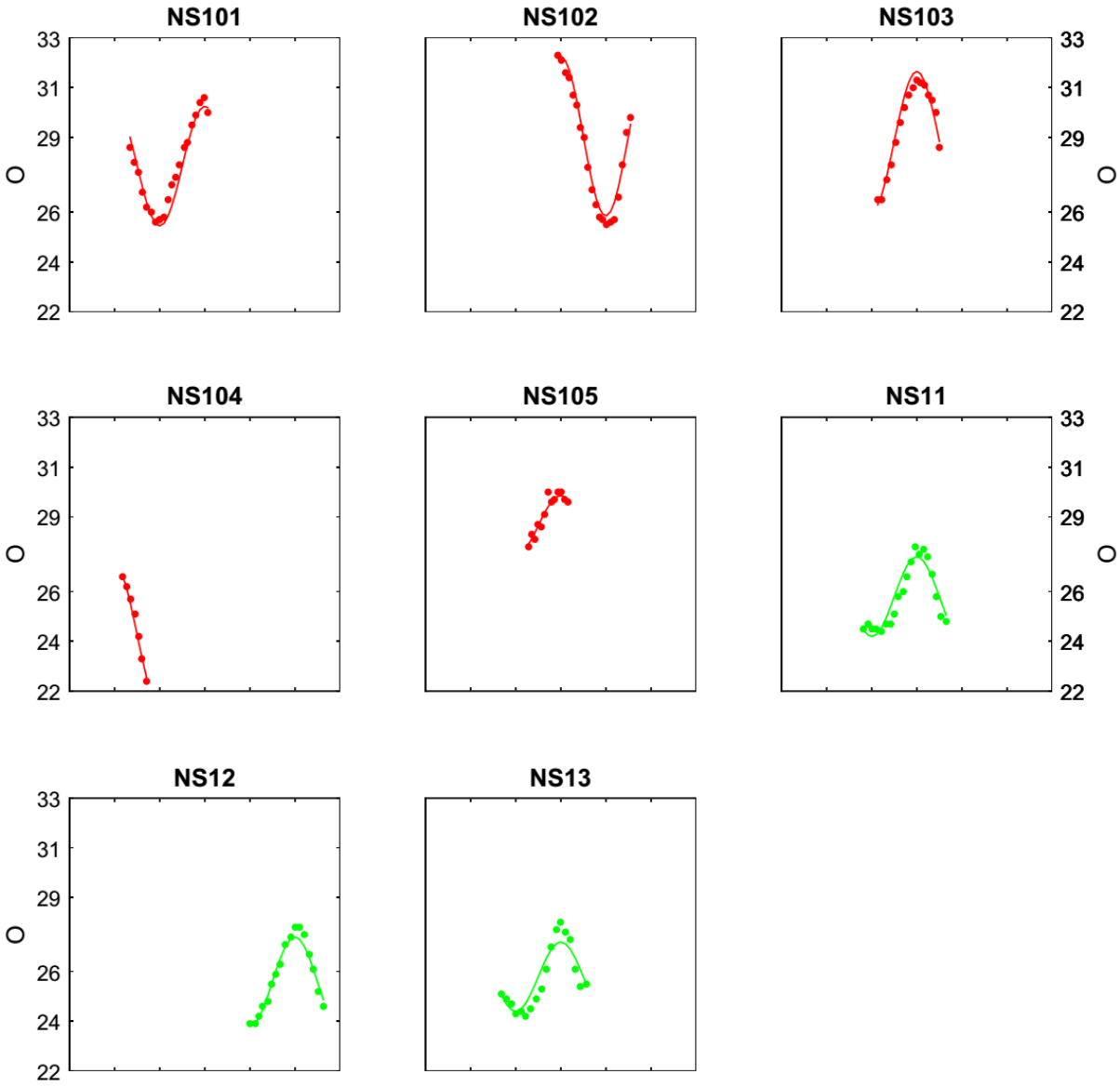


Fig. 7.22 Sequential enamel carbonate data of sheep/goats from Er Yoh, Brittany, France and Knap of Howar, Orkneys, Britain by Balasse and Tresset (2007); x-axis: time difference of enamel formation deduced from distance from enamel root junction, y-axis: right: $\delta^{13}C$ values (cross), left: $\delta^{18}O$ values (dot), solid line: modelled $\delta^{18}O$ value curve, blue: M1, red: M2, green: M3. Individuals indicated by graph ID. See Tables 7.9 and 7.11 for matching sample ID with graph ID.

In contrast, the birth seasons show a strong correlation with sites. At Er Yoh, not only sheep but also cattle had two birth seasons like those of Horcott sheep/goats (NC101–103 in Fig. 7.16 and NS101–105 in Fig. 7.18). At Knap of Howar, both cattle and sheep/goats had a restricted birth season in summer (NC101–103 in Fig. 7.16 and NS101–105 in Fig. 7.18), while at Bercy, both livestock species had an extended birth season from early spring to summer (NCA–NCJ in Fig. 7.17 and NSA–NSE in Fig. 7.19). This suggests that in Neolithic Europe, breeding control was not differentiated between cattle and sheep/goats. However, at Romano-British and Anglo-Saxon Horcott, the breeding control was different between cattle and sheep/goats. This supports the argument in section 7.2.2.4 that the birth season of sheep/goats was less controlled compared to the cattle at Horcott.

In conclusion, the inconsistency in the difference between cow and sheep/goat $\delta^{18}O$ values suggests that the difference between the two species reflects the difference in human management between cattle and sheep/goats rather than the metabolic differences of the two species. This supports the argument that the difference in birth seasons between the livestock species at Horcott reflect the difference in the level of breed control by humans.

7.2.3. Summary of Animal Husbandry from Tooth Enamel Carbonate Results

The $\delta^{13}C$ values of cattle were isotopically relatively constant regardless of seasonality or period. In contrast, the fluctuation of sheep/goat $\delta^{13}C$ values at Horcott seems to covary more with seasonality regardless of period. This suggests that, unlike cattle, the food of sheep/goats was isotopically affected by seasonality in the Romano-British and the Anglo-Saxon periods. Also, some of the Horcott cattle may have been fed isotopically different food depending on their age, but this was not the case for sheep/goats. The difference observed at Horcott between cattle and sheep/goats could be explained as a different feeding custom depending on the livestock species rather than metabolic differences. In conclusion, the food supply of cattle was possibly more controlled by humans than that of sheep/goats at Romano-British and Anglo-Saxon Horcott.

The birth season of cattle in the Romano-British period is slightly longer than that in the Anglo-Saxon period at Horcott. Thus, cattle breeding was possibly restricted by humans to a certain extent, especially in the Anglo-Saxon period. The purpose could be maximising the productivity in limited food availability, maximising the efficiency of time and labour invested in animal breeding, and avoiding time conflicts with other farming activities. In any case, cattle husbandry in the Anglo-Saxon period at Horcott may have been less focused on rearing cattle for milk production compared to the Romano-British period.

Regarding sheep/goats, however, there is not much difference in the length of birth seasons between the two periods. However, from both periods, some sheep were born outside of the

main season in spring and summer. This may suggest that the birth season of sheep was not strictly controlled at Horcott. Possible reasons for multiple birth season of sheep are;

a) good nutritional level which enabled some autumn/winter born lambs and their mothers to survive the winter

b) lack of necessity of controlling the breeding timings of sheep

c) importance of sheep dairy products

Chapter 8. Conclusion

The aim of this thesis was to explore changes in human diet and livestock management from the Romano-British to the Anglo-Saxon period in order to reveal how the cultural and economic differences impacted on daily eating habits and farming practices of the inhabitants. Stable isotope data collected from collagen extracted from bone and tooth dentine of humans, cattle, sheep/goats, pigs, horses, and dogs, and enamel carbonate extracted from tooth enamel of cattle and sheep/goats were analysed and the observed differences were tested for significance.

In this chapter, the main findings are summarised and evaluated in the light of the original aims and objectives. Following an evaluation of the achievements, I point to remaining gaps which could not be addressed in the context of this thesis, and end with some suggestions for future research.

8.1. Key Findings

The most notable finding to emerge from this study is that evidence for human dietary change, and shifts in animal husbandry can be substantiated. The economic and cultural shifts following the collapse of the Romano-British political and economic system are visible in the isotopic compositions of both humans and their domestic animals. The key findings mentioned in the discussion chapter are summarised here into two categories which are: a) those that indicate change, and b) those that indicate continuity.

8.1.1. Evidence for Change

Evidence for statistically significant differences between the two periods was found. Firstly, change was indicated in the diet of cattle, sheep/goat, and pigs, whose $\delta^{15}N$ values were elevated in the Romano-British period compared to the Anglo-Saxon period. The most likely explanation for this observation is fertilisation of the soil in the Romano-British period, which then raised the $\delta^{15}N$ values of soil and crops. Allowing animals to graze on manured fields possibly contributed to the elevation of animal $\delta^{15}N$ values. The food consumed by the animals itself probably did not change much but the change in the intensity of soil fertilisation contributed to the isotopic difference of the livestock's diet.

Secondly, there was a difference in the $\delta^{15}N$ values of adult pigs compared to those of piglets. The Romano-British adult pigs were higher in trophic level than the piglets whose $\delta^{15}N$ values are affected by a suckling offset, suggesting that they had a high proportion of animal protein in their diet when they were being fattened before killed. In contrast, the Anglo-Saxon adult pigs were lower in trophic level than the piglets, showing that their diet had a lower

proportion of animal protein compared to suckling piglets. Therefore, this difference in the trophic level of adult pigs in the two periods was probably caused by the different amount of animal protein fed to pigs for fattening them. This may be because pig husbandry in the Romano-British period was more market oriented, and people considered pigs as a profitable source which was worth putting extra effort and cost to fatten them.

Thirdly, change was indicated in the birth seasonality of cattle and sheep. Apparently, the birth season of cattle in the Anglo-Saxon period was slightly shorter (despite the larger sample size) compared to the Romano-British period whereas it was the opposite for sheep. Since it is harder to expand than restrict the birth season, this shows that extra human effort was made for cattle management in the Romano-British period, but the species in focus changed to sheep in the Anglo-Saxon period. Since longer birth season is beneficial for milk production, this may suggest that the preference of dairy products changed from cattle to sheep between the two periods. In other words, dairy products from cow's milk, which is more suitable for making butter, was preferred in the Romano-British period, whereas those from sheep's milk, which is more suitable for making cheese was preferred in the Anglo-Saxon period at Horcott.

Finally, change was indicated in human diet. The Anglo-Saxon humans from Phase 1 (AD 400–550) differed isotopically from the Romano-British inhabitants (AD 250–350) as well as from the Anglo-Saxon humans from Phase 2 (AD 600–700). The Anglo-Saxon Phase 1 inhabitants had lower $\delta^{13}C$ values which may be the result of differences in diet composition of plants, or consuming a limited amount of non-local food. Limited amounts of non-local food in the early Anglo-Saxon period can be explained as the result of the collapse of the Roman trading network, which would have diminished the population's access to imported food.

To summarise, the changes between the Romano-British period and the Anglo-Saxon period indicated from the stable isotope data at Horcott are;

a) Difference in the intensity of fertilisation of crop fields

b) Difference in the amount of animal protein fed to adult pigs when fattening them

c) Difference in the amount of non-local food in human diet

d) Difference in animal husbandry practices, especially with regard to managing birth seasonality

These changes that were identified enhance our understanding of: a) the difference in the strategy and the amount of human effort put in crop cultivation and livestock management, and b) the availability and preference of food for humans in the Romano-British and the Anglo-Saxon periods. Still, considerably more work will need to be done especially to determine the practice of controlling birth seasonality of herbivores in the past.

8.1.2. Continuity

Continuity has been argued where there is no statistically significant difference in isotopic composition between the two periods, although lack of evidence for isotopic distinctions does not necessarily mean a complete lack of change. Firstly, continuity was indicated in the feeding custom of cattle and sheep/goats. On the one hand, the $\delta^{13}C$ values of cattle at Horcott from both periods were isotopically relatively constant regardless of seasonality. On the other hand, the fluctuation of sheep/goat $\delta^{13}C$ values at Horcott seems to correlate more with seasonality regardless of period. This suggests that, unlike cattle, the food of sheep/goats was isotopically affected by seasonality in both periods. The difference observed at Horcott

between cattle and sheep/goats may be explained as a different feeding custom depending on the livestock species rather than metabolic differences between the two livestock species, because unlike the Horcott cattle, data of Neolithic cattle in continental Europe show a strong seasonal fluctuation in $\delta^{13}C$ values. Thus the food supply of cattle may have been more controlled by humans than that of sheep/goats at Horcott regardless of period.

Secondly, in both periods, some sheep/goats were born outside the main birthing seasons, which are spring and summer. This may suggest that the mating season of sheep/goats was not strictly controlled at Horcott, possibly because of good nutritional level, lack of necessity of breeding control, or high importance of sheep/goat dairy products as a food source.

8.1.3. Change and the Extent of Romanisation

Although change in lifestyle may correspond to the cultural change between the Romano-British period and the Anglo-Saxon period, the level of change experienced by each site may depend on the extent of Romanisation during the Romano-British period.

The extent of Roman cultural influence at Horcott has been assessed in Chapters 2, 3 and 5 from a range of archaeological evidence. The villa style part-masonry building, Samian ware imported from Gaul, and oyster shells found at Romano-British Horcott suggests that there was Roman influence. However, compared to more elaborate villas, evidence of other non-local food was scarce, suggesting that the lifestyle at Horcott was only partially Romanised. In addition, the animal bone assemblages do not indicate that the livestock were exported or imported, suggesting that it was a self-sufficient rural site. Thus, although some archaeological evidence show that Romano-British Horcott was a Romanised settlement, it

seems that the diet and animal husbandry practice was not affected much by Romanisation and Horcott was not incorporated into the market economy enough to have a wide variety of non-local food or to trade their livestock in the Romano-British period.

If a site had not received strong influence of Roman culture, it would not have experienced change and improvement during the Romano-British period in the first place and thus would not have been affected much by the collapse of the Roman Empire. Therefore, it is more likely to detect a clear change in Romanised towns with strong influence of Roman culture rather than in rural Romano-British sites where the influence of Roman culture was more limited. Therefore, it is not surprising that some stable isotopic evidence shows continuity given that the site remained rural in both periods while other evidence shows change, possibly reflecting Roman cultural influence at Horcott and its subsequent demise.

8.1.4. Evaluation of the Study

Prior to this study, there were few stable isotope data which examined the transition from the Roman to the Anglo-Saxon period, especially in a single site. Equally, there were few studies with enough animal data from a single site to argue about animal diet. Similarly, no study was found which carried out sequential sampling of tooth enamel on Roman and Anglo-Saxon livestock species. The data acquired in this study contributed to fill these gaps in literature.

Furthermore, it has enhanced our understanding of the level of strategic control of livestock management by herders. In addition, it has added to a growing body of literature regarding human control in animal feed (such as foddering) and livestock birth seasonality. And finally, this study demonstrated the significance of animal data in order to discuss human diet, and

the advantage of modelling enamel carbonate sequential data when analysing worn and shortened teeth.

However, there are limitations which this study could not overcome. For example, due to the small sample size of Romano-British cattle, the number of individuals suitable for enamel carbonate sampling was small, which may have biased the results. In addition, no comparable data of enamel carbonate in Roman and Anglo-Saxon Britain were available, which has resulted in a limited argument on animal husbandry, especially feeding practices and breeding control. Likewise, it was not possible to investigate in depth whether the pattern observed in enamel carbonate results at Horcott was a site-specific feature, a regional feature, or an overall trend in rural sites in Roman and Anglo-Saxon Britain in general. Furthermore, the small number of enamel carbonate samples suitable for deducing birth seasonality using the method by Towers et al. (2013) made it difficult to evaluate its advantages and disadvantages in contrast to the method by Balasse et al. (2012 b). If the debate on livestock management is to be moved forward, a larger dataset across time and place needs to be developed.

8.1.5. Recommendations for Future Research

Above all, more research is required on animal husbandry such as diet, foddering practices, and birth season control. More information on stable isotopes of tooth enamel would help us to establish a greater degree of accuracy on this matter. Similarly, in order to overcome the current limitations in discussing animal husbandry practice in Roman and Anglo-Saxon

Britain due to lack of data, more data from animals are needed from other contemporaneous sites.

A number of possible future studies using the same experimental set up are apparent. It would be interesting to assess the effects of human control in animal feed and birth seasonality in other regions in Britain in the Roman and the Anglo-Saxon periods. For example, a further study on tooth enamel carbonate sequential samples could assess whether practice of foddering for cattle was common in the Roman and the Anglo-Saxon periods. In addition, further research might investigate the commonality of autumn/winter births in sheep in order to determine whether autumn births of sheep occurred accidentally or deliberately.

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9. Appendix

Collagen results

Note: $\delta^{13}C$ values or $\delta^{15}N$ values are the mean values of two separate measurements.

Table S1. Normalised results of cattle at Horcott

context/phase	sample ID	bone/dentine	age	C/N ratio	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
5485	EIA cow 1	mandible	0-2yrs	3.3	-22.7	6.9
7476	EIA cow 2	mandible	>3yrs	3.3	-21.8	6.7
4234/P3	ROM cow A	upper M1 root	0.5-1yr	3.2	-22.0	7.6
4259/---	ROM cow B	upper M1 root	0.5-1yr	3.2	-21.8	6.9
4290/P3	ROM cow 1	mandible	>3yrs	3.3	-21.4	7.0
4303/P3	ROM cow C	upper M3 root	>3yrs	3.3	-22.1	5.1
4488/P3	ROM cow D	lower M1/2 root	0.5-1yr/ 2-2.5yrs	3.3	-21.6	6.7
4499-48/P3	ROM cow 2	mandible	>3yrs	3.2	-21.7	7.7
5140-18/---	ROM cow 3	right mandible	>3yrs	no collagen	no collagen	no collagen
10945/---	ROM cow E	upper M1 root	0.5-1yr	3.3	-21.8	5.3
670-24	SAX cow 1	mandible	1.25yrs	3.3	-21.9	6.9
692	SAX cow 2	mandible	1.5yrs	3.3	-21.5	5.0
SFB783	SAX cow 3	maxilla	0.5yrs	3.3	-22.1	5.0
5089	SAX cow 4	left maxilla	2.5yrs	3.2	-21.2	4.4
5089-40	SAX cow 5	right mandible	0.5-2.75yrs (1.5yrs from loose M2)	3.3	-22.0	7.7
5089-40	SAX cow 6	right mandible	0.5-1yr	3.2	-22.0	5.4
5090-80	SAX cow a	mandible	>3yrs	3.3	-22.2	5.0

8041-98	SAX cow b	right mandible	>3yrs	3.3	-21.8	4.3
8135	SAX cow 7	mandible	0.5yrs	3.3	-21.1	3.9
8323-69	SAX cow 8	left mandible	2yrs	3.3	-21.4	3.2
8323-14	SAX cow c	right mandible	>3yrs	3.2	-21.8	5.4
8323-39	SAX cow 9	left mandible	3yrs	3.3	-21.6	5.8
8323-7	SAX cow 10	left mandible	0.5yrs	3.2	-22.2	6.3
8480-28	SAX cow d	mandible	>3yrs	3.3	-21.8	2.9
8480-28	SAX cow 11	mandible	1.5yrs	3.3	-22.0	4.8
8706-74	SAX cow 17	left mandible	1.5yrs	3.3	-22.4	5.4
8707-25	SAX cow e	left mandible	>3yrs	3.2	-21.5	5.2
9128	SAX cow f	left mandible	>3yrs	3.2	-21.7	7.8
10043-25	SAX cow g	left mandible	>3yrs	3.3	-21.5	4.6
10044-16	SAX cow 12	right mandible	2.5-3yrs	3.2	-22.1	5.8
SFB9815	SAX cow 13	left mandible	3yrs	3.3	-21.7	5.4
10045-14	SAX cow 14	right mandible	1.5yrs	3.2	-21.9	6.1
10242-94	SAX cow h	left mandible	3yrs	3.2	-21.8	5.8
10242-94	SAX cow I	right mandible	>3yrs	3.2	-21.7	5.7
10242-94	SAX cow j	left mandible	>3yrs	3.2	-21.8	5.5
10242-94	SAX cow 15	left mandible	2yrs	3.3	-21.7	4.9
10242-94	SAX cow 16	right mandible	1.5yrs	3.3	-21.6	4.4

Table S2. Normalised results of sheep/goats at Horcott

context/phase	sample no	bone	age	C/N ratio	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
6592	EIA sg 1	mandible	3-4yrs	3.3	-22.3	8.0
4115-32/P2	ROM sg 1	right mandible	>1yrs	3.3	-21.7	5.6
4115-32/P2	ROM sg 2	right mandible	>2yrs	3.3	-21.5	5.7
4259-16/---	ROM sg 3	maxilla	>2yrs	3.2	-21.5	6.4
4499-20/P3	ROM sg 4	right mandible	1-2yrs	3.3	-20.9	5.1
9724-11 ---	ROM sg 5	maxilla	>2yrs	3.3	-20.8	6.9
9727/P2	ROM sg 6	mandible	4-6yrs	3.2	-21.3	6.1
9736-20/P2	ROM sg 7	mandible	>2yrs	3.2	-21.6	7.3
10446/P2	ROM sg 8	mandible	3-4yrs	3.3	-21.6	6.8
10889-1/P4	ROM sg 9	left mandible	0.5-1yr	3.5	-22.4	6.7
10889-17/P4	ROM sg 10	left mandible	3-4yrs	3.5	-22.2	4.9
10889-17/P4	ROM sg 11	right mandible	0.5-2yrs	3.5	-21.5	6.3
201	SAX sg 1	right mandible	4-6yrs	3.3	-21.6	4.8
273	SAX sg 2	left mandible	3-4yrs	3.3	-21.3	4.8
411	SAX sg 3	right mandible	<2yrs	3.3	-22.1	5.7
535	SAX sg 4	left mandible	1-2yrs	3.2	-22.0	5.1
669	SAX sg 5	mandible	4-6yrs	3.2	-21.8	5.4
670-24	SAX sg 6	mandible	3-4yrs	3.2	-21.8	5.5
5089-20	SAX sg 7	left mandible	1yrs	3.3	-22.2	6.3
5089-20	SAX sg 8	right mandible	0.5-1yr	3.2	-21.6	5.2

5089-20	SAX sg 9	right mandible	3-4yrs	3.2	-21.8	5.6
5090-80	SAX sg 10	left mandible	≤2yrs	3.3	-21.8	2.3
5127-4	SAX sg 11	right mandible	0.5-2yrs	3.3	-22.0	4.9
5127-4	SAX sg 12	left mandible	2yrs	3.3	-21.4	4.8
8041-14	SAX sg 13	mandible	2yrs	3.3	-20.5	4.8
8041-14	SAX sg 14	mandible	0-2yrs	3.3	-22.2	5.3
10505-17	SAX sg 15	left mandible	3-4yrs	3.3	-21.5	2.9
10241-13	SAX sg 16	left mandible	0.5-1yr	3.3	-21.8	4.8
10241-13	SAX sg 17	right mandible	1-2yrs	3.3	-21.1	5.9

Table S3. Normalised results of pigs at Horcott

context/phase	sample ID	bone/dentine	age	C/N ratio	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
5737	EIA pig 1	pig right mandible	2.25yrs	3.3	-21.9	6.8
783/P3	ROM pig A	upper M3 root	1.5-2.5yrs	3.3	-21.7	10.2
4259-1/---	ROM pig 1	pig right maxilla	1yrs	3.3	-20.7	9.6
4488/P3	ROM pig 2	pig right mandible	1-2yrs	3.3	-21.3	9.2
4488/P3	ROM pig B	lower M1 root	0.5yrs	3.2	-21.0	7.6
9710-15/P2	ROM pig 3	pig left maxilla	≥1yrs	3.3	-21.3	9.3
9710-10/P2	ROM pig 4	pig left mandible	1.25yrs	3.3	-21.0	7.1
9724-21/---	ROM pig 5	pig mandible	0.75-1yr	3.3	-21.3	9.0
10681/P2	ROM pig 6	pig right maxilla	1.25yrs	no collagen	no collagen	no collagen
5089	SAX pig 1	pig maxilla	1.5yrs	3.3	-21.6	8.2
5113	SAX pig 2	pig maxilla	>1.25yrs	3.3	-21.4	5.6
5113	SAX pig A	lower M2 root	0.75 -1.25yrs	3.2	-21.3	6.4
6399	SAX pig 3	pig left mandible	0.5yrs	3.3	-21.0	7.8
8706-17	SAX pig B	lower M1 root	0.5yr	3.2	-22.0	8.1
8707-12	SAX pig 4	pig maxilla	0.5yr	3.3	-21.2	6.7
10242-132	SAX pig 5	pig mandible	>2.25yrs	3.4	-21.6	6.7
10505-28	SAX pig 6	pig right mandible	0.75yr	3.3	-20.8	8.9
10241-109	SAX pig 7	pig right mandible	2.25yrs	3.3	-21.6	6.2

Table S4. Normalised results of horses at Horcott

context/phase	sample ID	bone	age	C/N ratio	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
4259/---	ROM horse 1	left maxilla	>3.5yrs	3.3	-21.9	4.3
8323-69	SAX horse 1	mandible	0yr?	3.3	-22.7	4.9
8323-17	SAX horse 2	maxilla	3yrs	3.3	-22.9	4.6
8504-48	SAX horse 3	mandible	<1yr	3.3	-22.6	5.4
10043-25	SAX horse 4	mandible	>3yrs	3.3	-22.7	6.6
10043-25	SAX horse 5	mandible	<1yr	3.3	-22.6	3.8
10242-98	SAX horse 6	right maxilla	0.75yr	3.3	-22.3	3.2

Table S5. Normalised results of dogs at Horcott

context/phase	sample ID	bone	age	C/N ratio	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
859-17/P2	ROM dog 1	maxilla	>5mths	3.2	-20.2	8.4
4488/P3	ROM dog 2	mandible	>6mths	3.2	-21.5	9.0
4499-48/P3	ROM dog 3	mandible	>5mths	3.2	-20.3	10.9
10680/P2	ROM dog 4	mandible	>6mths	no collagen	no collagen	no collagen
665	SAX dog 1	maxilla	>6mths	3.2	-20.1	7.7
881	SAX dog 2	mandible	1-4mths	3.2	-20.3	7.6

Enamel carbonate results

Note: $\delta^{13}C$ and $\delta^{18}O$ values are the mean values of ten separate measurements.

Table S6a. Normalised results of tooth enamel carbonate of cattle at Horcott

sample ID	graph ID	teeth	$\delta^{13}C$ (‰)	$\delta^{18}O$ (‰)	distance from Enamel Root Junction (mm)
SAX cow h M1-1	h	M1	-12.9	24.2	2
SAX cow h M1-2	h	M1	-12.6	23.5	6
SAX cow h M1-3	h	M1	-13.4	23.7	10
SAX cow h M1-4	h	M1	-13.8	23.0	14
SAX cow h M1-5	h	M1	-14.0	23.4	18
SAX cow h M1-6	h	M1	-14.4	23.8	22
SAX cow h M2-1	h	M2	-12.0	23.0	2
SAX cow h M2-2	h	M2	-12.0	23.1	6
SAX cow h M2-3	h	M2	-12.8	23.8	10
SAX cow h M2-4	h	M2	-11.7	24.2	14
SAX cow h M2-5	h	M2	-11.5	24.7	18
SAX cow h M2-6	h	M2	-11.9	25.1	22
SAX cow h M2-7	h	M2	-11.9	25.6	26
SAX cow h M2-8	h	M2	-12.2	25.5	30
SAX cow h M2-9	h	M2	-12.6	25.2	34
SAX cow h M3-1	h	M3	-11.8	23.5	2
SAX cow h M3-2	h	M3	-11.5	23.6	6
SAX cow h M3-3	h	M3	-11.3	24.1	10
SAX cow h M3-4	h	M3	-11.5	24.8	14
SAX cow h M3-5	h	M3	-11.5	25.2	18
SAX cow h M3-6	h	M3	-11.5	25.8	22

SAX cow h M3-7	h	M3	-12.2	25.6	26
SAX cow h M3-8	h	M3	-12.3	25.3	30
SAX cow h M3-9	h	M3	-12.3	24.0	34
SAX cow h M3-10	h	M3	-12.2	23.2	38
SAX cow d M1-1	d	M1	-13.1	23.1	2
SAX cow d M1-2	d	M1	-13.3	24.3	6
SAX cow d M1-3	d	M1	-12.8	25.0	10
SAX cow d M1-4	d	M1	-12.9	25.3	14
SAX cow d M1-5	d	M1	-13.0	26.3	18
SAX cow d M2-1	d	M2	-12.1	24.6	2
SAX cow d M2-2	d	M2	-12.1	25.2	6
SAX cow d M2-3	d	M2	-12.9	25.7	10
SAX cow d M2-4	d	M2	-12.8	26.1	14
SAX cow d M2-5	d	M2	-13.1	25.7	18
SAX cow d M2-6	d	M2	-13.7	25.5	22
SAX cow d M3-1	d	M3	-11.8	24.3	2
SAX cow d M3-2	d	M3	-11.6	24.1	6
SAX cow d M3-3	d	M3	-11.7	25.1	10
SAX cow d M3-4	d	M3	-11.8	24.7	14
SAX cow d M3-5	d	M3	-12.2	23.8	18
SAX cow d M3-6	d	M3	-12.5	23.6	22
SAX cow d M3-7	d	M3	-12.4	23.6	26
SAX cow d M3-8	d	M3	-12.4	23.8	30
SAX cow d M3-9	d	M3	-12.1	24.2	34
SAX cow d M3-10	d	M3	-12.1	25.1	38
SAX cow a M2-1	a	M2	-12.5	23.9	2
SAX cow a M2-2	a	M2	-12.2	24.2	6
SAX cow a M2-3	a	M2	-12.3	24.8	10
SAX cow a M2-4	a	M2	-12.3	25.8	14
SAX cow a M2-5	a	M2	-11.8	26.0	18
SAX cow a M2-6	a	M2	-12.7	25.6	22

SAX cow a M2-7	a	M2	-13.0	25.2	26
SAX cow a M2-8	a	M2	-13.3	24.6	30
SAX cow a M3-1	a	M3	-12.4	23.2	2
SAX cow a M3-2	a	M3	-12.3	23.7	6
SAX cow a M3-3	a	M3	-11.9	24.4	10
SAX cow a M3-4	a	M3	-12.2	25.5	14
SAX cow a M3-5	a	M3	-12.1	25.3	18
SAX cow a M3-6	a	M3	-13.2	24.9	22
SAX cow a M3-7	a	M3	-12.6	23.9	26
SAX cow a M3-8	a	M3	-12.7	23.0	30
SAX cow a M3-9	a	M3	-12.7	22.7	34
SAX cow a M3-10	a	M3	-12.6	23.1	38
SAX cow a M3-11	a	M3	-12.4	23.6	42
ROM cow 1 M1+1	101	M1	-12.2	23.5	2
ROM cow 1 M1+1.5	101	M1	-12.7	23.5	4
ROM cow 1 M1+2	101	M1	-12.2	23.9	6
ROM cow 1 M2-0	101	M2	-11.8	24.5	2
ROM cow 1 M2+0.5	101	M2	-11.9	24.4	4
ROM cow 1 M2-1	101	M2	-12.1	25.3	6
ROM cow 1 M2+1.5	101	M2	-12.1	24.7	8
ROM cow 1 M2-2	101	M2	-11.1	24.9	10
ROM cow 1 M2+2.5	101	M2	-12.1	25.6	12
ROM cow 1 M2-3	101	M2	-12.1	26.2	14
ROM cow 1 M3-0.5	101	M3	-12.0	23.2	0
ROM cow 1 M3-0	101	M3	-11.5	24.0	2
ROM cow 1 M3+0.5	101	M3	-11.5	24.4	4
ROM cow 1 M3-1	101	M3	-11.7	25.7	6
ROM cow 1 M3+1.5	101	M3	-11.9	25.1	8
ROM cow 1 M3-2	101	M3	-12.3	26.0	10
ROM cow 1 M3+2.5	101	M3	-12.1	25.6	12
ROM cow 1 M3-3	101	M3	-12.1	25.8	14

ROM cow 1 M3+3.5	101	M3	-12.2	25.1	16
SAX cow 7 M1-1	207	M1	-12.6	25.4	2
SAX cow 7 M1-2	207	M1	-12.5	24.5	6
SAX cow 7 M1-3	207	M1	-12.5	24.4	10
SAX cow 7 M1-4	207	M1	-12.3	24.9	14
SAX cow 7 M1-5	207	M1	-12.1	24.8	18
SAX cow 7 M1-6	207	M1	-12.3	25.9	22
SAX cow 7 M1-7	207	M1	-12.7	26.9	26
SAX cow 7 M1-8	207	M1	-13.8	26.7	30
SAX cow 7 M1-9	207	M1	-14.9	25.9	34
ROMC2 M1-1	102	M1	-11.4	23.3	2
ROMC2 M1-2	102	M1	-11.5	24.2	6
ROMC2 M1-3	102	M1	-11.3	25.0	10
ROMC2 M1-4	102	M1	-11.4	25.8	14
ROMC2 M1-5	102	M1	-11.7	25.5	18
ROMC2 M2-1	102	M2	-10.9	25.6	2
ROMC2 M2-2	102	M2	-10.7	25.3	6
ROMC2 M2-3	102	M2	-11.7	25.1	10
ROMC2 M2-4	102	M2	-11.5	24.8	14
ROMC2 M2-5	102	M2	-11.4	24.2	18
ROMC2 M2-6	102	M2	-11.3	23.6	22
ROMC2 M2-7	102	M2	-11.2	23.0	26
ROMC2 M2-8	102	M2	-11.6	22.8	30
ROMC2 M3-1	102	M3	-11.4	25.3	2
ROMC2 M3-2	102	M3	-11.4	24.8	6
ROMC2 M3-3	102	M3	-11.4	24.1	10
ROMC2 M3-4	102	M3	-11.6	23.4	14
ROMC2 M3-5	102	M3	-11.1	22.8	18
ROMC2 M3-6	102	M3	-11.1	22.8	22
ROMC2 M3-7	102	M3	-12.2	24.3	26
ROMC2 M3-8	102	M3	-11.7	25.0	30

ROMC2 M3-9	102	M3	-11.3	24.5	34
SAXC12 M1-1	212	M1	-12.6	25.3	2
SAXC12 M1-2	212	M1	-12.5	25.2	6
SAXC12 M1-3	212	M1	-12.0	25.4	10
SAXC12 M1-4	212	M1	-11.8	26.3	14
SAXC12 M1-5	212	M1	-11.8	26.8	18
SAXC12 M1-5.5	212	M1	-12.6	26.6	20.0
SAXC12 M1-6	212	M1	-14.1	26.4	22
SAXC12 M1-7	212	M1	-14.7	26.0	26
SAXC12 M2-1	212	M2	-11.3	24.7	2
SAXC12 M2-2	212	M2	-11.7	25.1	6
SAXC12 M2-3	212	M2	-11.7	26.1	10
SAXC12 M2-4	212	M2	-11.8	27.3	14
SAXC12 M2-5	212	M2	-11.7	26.8	18
SAXC12 M2-6	212	M2	-12.4	25.9	22
SAXC12 M2-7	212	M2	-12.2	25.4	26
SAXC12 M2-8	212	M2	-12.5	24.8	30
SAXC12 M2-9	212	M2	-12.7	24.2	34
SAXC12 M3-1	212	M3	-11.8	23.9	2
SAXC12 M3-2	212	M3	-11.5	24.4	6
SAXC12 M3-3	212	M3	-11.7	25.3	10
SAXC12 M3-4	212	M3	-11.7	26.0	14
SAXC12 M3-5	212	M3	-11.9	24.9	18
SAXC12 M3-6	212	M3	-11.9	23.9	22
SAXC12 M3-7	212	M3	-11.9	23.7	26
SAXC12 M3-8	212	M3	-11.7	23.8	30
SAXC12 M3-9	212	M3	-11.7	24.1	34
SAXC12 M3-10	212	M3	-11.5	24.8	38
SAXC12 M3-11	212	M3	-11.5	25.9	42
SAXC12 P4-1	212	P4	-11.7	23.1	2
SAXC12 P4-2	212	P4	-11.8	23.7	6

SAXC12 P4-3	212	P4	-11.6	24.2	10
SAXC12 P4-4	212	P4	-11.6	24.9	14
SAXC12 P4-5	212	P4	-11.5	25.9	18
SAXC12 P4-6	212	P4	-11.7	25.7	22
SAXCa M1-1	a	M1	-13.6	23.5	2
SAXCa M1-2	a	M1	-13.2	23.7	6
SAXCa M1-3	a	M1	-13.3	24.1	10
SAXCa M1-4	a	M1	-13.7	24.2	14
SAXCa M1-5	a	M1	-13.3	24.8	18
SAXCa M1-6	a	M1	-13.2	25.2	22
SC2 M1+1	202	M1	-11.4	24.6	2
SC2 M1+2	202	M1	-11.7	24.7	6
SC2 M1+3	202	M1	-11.6	25.8	10
SC2 M1+4	202	M1	-11.9	26.3	14
SC2 M1+5	202	M1	-12.6	26.9	18
SC2 M1+6	202	M1	-13.1	27.0	22
SC2 M1+7	202	M1	-14.3	26.6	26
SC2 M1+8	202	M1	-15.2	26.2	30
SC2M2 1	202	M2	-11.6	25.2	2
SC2M2 2	202	M2	-11.7	25.4	6
SC2M2 3	202	M2	-12.1	25.3	10
SC2M2 4	202	M2	-12.2	25.1	14
SC2M2 5	202	M2	-12.3	24.9	18
SC2M2 6	202	M2	-12.3	24.5	22
SC2M2 7	202	M2	-12.4	24.0	26
SC2M2 8	202	M2	-12.3	23.9	30
SC2M2 9	202	M2	-12.4	23.3	34
SC2M2 10	202	M2	-12.2	23.8	38
SC2M2 11	202	M2	-11.8	24.6	42
SC8M2 1	208	M2	-11.9	24.3	2
SC8M2 2	208	M2	-12.1	25.2	6

SC8M2 3	208	M2	-11.9	26.5	10
SC8M2 4	208	M2	-12.3	26.7	14
SC8M2 5	208	M2	-12.6	26.6	18
SC8M2 6	208	M2	-12.8	26.1	22
SC8M2 7	208	M2	-13.0	25.5	26
SC8M2 8	208	M2	-13.2	24.9	30
SC8M2 9	208	M2	-13.0	24.6	34
SC8M2 10	208	M2	-13.0	24.3	38
SC9M3 1	209	M3	-11.4	25.4	2
SC9M3 2	209	M3	-11.3	25.9	6
SC9M3 3	209	M3	-11.9	26.5	10
SC9M3 4	209	M3	-12.3	25.9	14
SC9M3 5	209	M3	-12.3	25.5	18
SC9M3 6	209	M3	-12.5	24.9	22
SC9M3 7	209	M3	-12.5	24.5	26
SC9M3 8	209	M3	-12.5	24.7	30
SC9M3 9	209	M3	-12.3	25.1	34
SC9M3 10	209	M3	-12.7	24.7	38
SC14 M1+1	214	M1	-12.0	24.7	2
SC14 M1+2	214	M1	-11.8	24.5	6
SC14 M2+3	214	M1	-11.5	25.1	10
SC14 M2+4	214	M1	-11.2	26.1	14
SC14 M2+5	214	M1	-11.1	26.0	18
SC14 M2+6	214	M1	-11.8	26.8	22
SC14 M2+7	214	M1	-12.0	27.1	26
SC14 M2+8	214	M1	-13.0	27.0	30
SC14 M2+9	214	M1	-14.2	26.3	34
SC14M2 1	214	M2	-11.1	24.8	2.0
SC14M2 2	214	M2	-11.5	25.4	6.0
SC14M2 3	214	M2	-12.0	25.7	10.0
SC14M2 4	214	M2	-12.1	25.7	14.0
SC14M2 5	214	M2	-12.1	25.9	18.0

SC14M2 6	214	M2	-12.5	25.4	22.0
SC14M2 7	214	M2	-12.5	25.1	26.0
SC14M2 8	214	M2	-12.2	24.5	30.0
SC14M2 9	214	M2	-12.2	24.1	34
SC14M2 10	214	M2	-11.9	23.6	38
EC1 1-1	501	M1	-12.6	23.0	2
EC1 1-2	501	M1	-12.5	24.4	6
EC1 1-3	501	M1	-12.3	25.3	10
EC1 1-4	501	M1	-12.8	25.4	14
EC1 1-5	501	M1	-13.4	26.3	18
EC1 1-6	501	M1	-14.3	25.2	22
EC1 1-7	501	M1	-15.0	25.0	26
EC1 1-8	501	M1	-15.5	25.1	30
EC1 1-9	501	M1	-14.6	23.6	34
SC1 1-1	201	M1	-12.3	22.4	2
SC1 1-2	201	M1	-11.9	23.2	6
SC1 1-3	201	M1	-12.0	23.6	10
SC1 1-4	201	M1	-12.1	24.5	14
SC1 1-5	201	M1	-12.4	25.1	18
SC1 1-6	201	M1	-12.9	25.1	22
SC1 1-7	201	M1	-12.8	24.7	26
SC1 1-8	201	M1	-13.1	24.5	30
SC1 1-9	201	M1	-13.3	23.9	34
SC5 1-1	205	M1	-11.4	23.0	2
SC5 1-2	205	M1	-11.2	23.8	6
SC5 1-3	205	M1	-11.2	24.1	10
SC5 1-4	205	M1	-11.5	24.1	14
SC5 1-5	205	M1	-12.0	24.4	18
SC5 1-6	205	M1	-12.4	24.8	22
SC5 1-7	205	M1	-13.9	24.9	26
SC5 1-8	205	M1	-15.1	25.0	30

SC6 1-1	206	M1	-11.8	23.1	2
SC6 1-2	206	M1	-12.8	22.5	6
SC6 1-3	206	M1	-12.5	22.8	10
SC6 1-4	206	M1	-12.3	23.1	14
SC6 1-5	206	M1	-12.9	23.4	18
SC6 1-6	206	M1	-13.8	23.9	22
SC6 1-7	206	M1	-13.8	24.5	26
SC6 1-8	206	M1	-14.5	24.7	30
SC6 1-9	206	M1	-15.0	25.3	34
SC6 1-10	206	M1	-15.0	24.5	38
SC8 1-1	208	M1	-12.9	24.0	2
SC8 1-2	208	M1	-12.4	23.9	6
SC8 1-3	208	M1	-12.5	24.0	10
SC8 1-4	208	M1	-11.8	24.7	14
SC8 1-5	208	M1	-11.9	25.2	18
SC8 1-6	208	M1	-12.1	25.7	22
SC8 1-7	208	M1	-12.8	26.5	26
SC8 1-8	208	M1	-13.8	26.3	30
SC8 3-1	208	M3	-11.7	24.3	2
SC8 3-2	208	M3	-11.6	24.6	6
SC8 3-3	208	M3	-11.7	25.2	10
SC8 3-4	208	M3	-11.9	26.1	14
SC8 3-5	208	M3	-11.9	25.8	18
SC8 3-6	208	M3	-11.3	24.8	22
SC8 3-7	208	M3	-11.4	24.1	26
SC8 3-8	208	M3	-11.5	23.8	30
SC8 3-9	208	M3	-11.6	23.5	34
SC8 3-10	208	M3	-11.5	23.9	38
SC8 3-11	208	M3	-11.5	24.2	42
SC8 3-12	208	M3	-11.4	25.2	46

Table S6b. Normalised results of tooth enamel carbonate of sheep/goats at Horcott

sample ID	graph ID	teeth	$\delta^{13}C$ (‰)	$\delta^{18}O$ (‰)	distance from Enamel Root Junction (mm)
ES1 1-1	601	M1	-13.2	23.4	2
ES1 1-2	601	M1	-12.4	24.5	6
ES1 1-3	601	M1	-12.0	26.4	10
ES1 1-4	601	M1	-12.1	27.0	14
ES1 2-1	601	M2	-13.6	23.9	2
ES1 2-2	601	M2	-12.4	26.3	6
ES1 2-3	601	M2	-12.5	26.7	10
ES1 2-4	601	M2	-13.5	25.5	14
ES1 2-5	601	M2	-13.9	23.8	18
ES1 2-6	601	M2	-14.0	23.2	22
ES1 M3 1	601	M3	-13.0	24.4	2
ES1 M3 2	601	M3	-12.7	25.8	6
ES1 M3 3	601	M3	-13.7	25.4	10
ES1 M3 4	601	M3	-13.6	23.4	14
ES1 M3 5	601	M3	-13.8	22.5	18
ES1 M3 6	601	M3	-13.0	23.2	22
ES1 M3 7	601	M3	-12.6	24.7	26
RS1 M1 1	301	M1	-14.1	23.4	2
RS1 M1 1.5	301	M1	-14.1	23.2	4
RS1 M1 2	301	M1	-14.5	23.7	6
RS1 M1 2.5	301	M1	-13.3	24.3	8
RS1 M1 3	301	M1	-13.0	25.3	10
RS1 M1 3.5	301	M1	-13.2	25.8	12

RS1 M1 4	301	M1	-13.1	26.3	14
RS1 M1 4.5	301	M1	-13.2	26.0	16
RS1 M1 5	301	M1	-13.1	26.1	18
RS1 M1 5.5	301	M1	-13.4	26.9	20
RS1 M2 1	301	M2	-11.1	26.4	2
RS1 M2 2	301	M2	-11.6	26.0	6
RS1 M2 3	301	M2	-12.4	25.4	10
RS1 M2 4	301	M2	-13.8	24.6	14
RS1 M2 5	301	M2	-13.5	23.4	18
RS1 M2 6	301	M2	-13.1	22.9	22
RS1 M2 7	301	M2	-12.7	23.3	26
RS1 M2 8	301	M2	-12.4	23.6	30
RS4 M1 1	304	M1	-13.2	23.3	2
RS4 M1 1.5	304	M1	-13.2	24.0	4
RS4 M1 2	304	M1	-12.7	25.1	6
RS4 M1 2.5	304	M1	-12.5	25.9	8
RS4 M1 3	304	M1	-12.1	26.5	10
RS4 M1 3.5	304	M1	-12.2	26.6	12
RS4 M1 4	304	M1	-12.6	27.3	14
RS4 M1 4.5	304	M1	-12.5	27.4	16
RS4 M1 5	304	M1	-13.2	27.5	18
RS4 M1 5.5	304	M1	-13.3	27.2	20
RS4 M1 6	304	M1	-13.8	27.5	22
RS4 M1 6.5	304	M1	-14.0	26.6	24
RS4 M1 7	304	M1	-14.2	26.3	26
RS4 M2 1	304	M2	-11.7	25.9	2
RS4 M2 2	304	M2	-12.0	26.6	6
RS4 M2 3	304	M2	-12.9	26.0	10
RS4 M2 4	304	M2	-13.7	23.8	14
RS4 M2 5	304	M2	-14.0	22.8	18
RS4 M2 6	304	M2	-13.9	22.9	22
RS4 M2 7	304	M2	-13.6	23.3	26

RS4 M2 8	304	M2	-12.9	24.4	30
RS8 M1 1.5	308	M1	-13.2	24.3	4
RS8 M1 2	308	M1	-13.1	25.5	6
RS8 M1 2.5	308	M1	-12.5	26.5	8
RS8 M1 3	308	M1	-12.6	27.5	10
RS8 M1 3.5	308	M1	-12.3	27.8	12
RS8 M1 4	308	M1	-12.7	28.4	14
RS8 M2 1.5	308	M2	-12.6	24.2	4
RS8 M2 2	308	M2	-13.4	26.0	6
RS8 M2 3	308	M2	-14.2	26.2	10
RS8 M2 4	308	M2	-14.9	24.4	14
RS8 M2 5	308	M2	-14.5	23.0	18
RS8 M2 6	308	M2	-14.8	23.0	22
RS8 M2 6.5	308	M2	-14.6	22.1	24
RS10 M2 1	310	M2	-11.5	24.4	2
RS10 M2 2	310	M2	-11.0	26.5	6
RS10 M2 3	310	M2	-11.7	26.4	10
RS10 M2 4	310	M2	-11.7	24.5	14
RS10 M2 5	310	M2	-11.8	23.1	18
RS10 M2 6	310	M2	-11.5	22.9	22
SS1 M2-1	401	M2	-11.9	24.4	2
SS1 M2-2	401	M2	-12.2	25.9	6
SS1 M2-3	401	M2	-13.1	26.1	10
SS1 M2-4	401	M2	-13.8	22.9	14
SS1 M2-5	401	M2	-13.4	23.0	18
SS1 M3-1	401	M3	-12.5	22.8	2
SS1 M3-2	401	M3	-11.8	23.1	6
SS1 M3-3	401	M3	-11.8	25.8	10
SS1 M3-4	401	M3	-12.6	26.7	14
SS1 M3-5	401	M3	-13.7	24.2	18

SS1 M3-6	401	M3	-13.4	22.0	22
SS2 M1-1.5	402	M1	-13.4	21.7	4
SS2 M1-2.5	402	M1	-12.7	23.8	8
SS2 M1-3.5	402	M1	-12.0	25.8	12
SS2 M1-4	402	M1	-11.8	26.6	14
SS2 M2-1	402	M2	-12.7	25.9	2
SS2 M2-2	402	M2	-12.6	27.2	6
SS2 M2-3	402	M2	-13.3	26.7	10
SS2 M2-4	402	M2	-13.6	25.1	14
SS2 M2-5	402	M2	-13.3	23.3	18
SS2 M2-5.5	402	M2	-13.9	22.1	20
SS2 M3-1	402	M3	-12.5	25.5	2
SS2 M3-2	402	M3	-13.0	26.9	6
SS2 M3-3	402	M3	-13.6	24.3	10
SS2 M3-4	402	M3	-13.8	24.2	14
SS2 M3-5	402	M3	-13.7	22.9	18
SS2 M3-6	402	M3	-13.3	24.6	22
SS2 M3-7	402	M3	-12.5	25.7	26
SS4 M1-1	404	M1	-13.2	23.1	2
SS4 M1-1.5	404	M1	-12.5	24.2	4
SS4 M1-2	404	M1	-12.5	24.9	6
SS4 M1-2.5	404	M1	-12.2	25.5	8
SS4 M1-3	404	M1	-12.0	25.1	10
SS4 M1-3.5	404	M1	-12.4	25.5	12
SS4 M1-4	404	M1	-13.0	26.1	14
SS4 M1-4.5	404	M1	-12.8	25.5	16
SS4 M1-5	404	M1	-13.5	25.7	18
SS4 M1-5.5	404	M1	-13.7	25.5	20
SS4 M2-2	404	M2	-13.1	25.5	6
SS4 M2-3	404	M2	-13.3	22.8	10

SS4 M2-4	404	M2	-13.3	22.0	14
SS4 M2-5	404	M2	-12.9	22.0	18
SS4 M2-6	404	M2	-12.5	22.6	22
SS4 M2-7	404	M2	-12.2	23.5	26
SS4 M2-8	404	M2	-12.2	24.6	30
SS6 M1-2.5	406	M1	-12.2	24.6	8
SS6 M1-3	406	M1	-11.9	25.2	9
SS6 M1-3.5	406	M1	-12.0	25.3	12
SS6 M1-4	406	M1	-11.8	25.5	13
SS6 M1-4.5	406	M1	-12.0	25.3	16
SS6 M2-1.5	406	M2	-13.4	23.6	4
SS6 M2-2	406	M2	-11.4	24.2	6
SS6 M2-3	406	M2	-11.6	25.0	10
SS6 M2-4	406	M2	-12.3	25.4	14
SS6 M2-5	406	M2	-15.1	26.0	18
SS6 M2-6	406	M2	-14.0	22.9	22
SS6 M2-6.5	406	M2	-14.4	22.8	24
SS6 M3-1	406	M3	-13.1	23.2	2
SS6 M3-2	406	M3	-12.5	23.9	6
SS6 M3-3	406	M3	-12.3	25.0	10
SS6 M3-4	406	M3	-13.2	24.8	14
SS6 M3-5	406	M3	-14.1	23.0	18
SS6 M3-6	406	M3	-14.4	22.2	22
SS6 M3-7	406	M3	-13.7	22.9	26
SS6 M3-8	406	M3	-12.9	23.4	30
SS6 M3-9	406	M3	-12.3	23.7	34
SS17 M1-1	417	M1	-14.1	23.1	2
SS17 M1-2.5	417	M1	-14.0	22.4	4
SS17 M1-2	417	M1	-13.8	22.1	6
SS17 M1-2.5	417	M1	-13.4	23.2	8
SS17 M1-3	417	M1	-12.9	24.3	10

SS17 M1-3.5	417	M1	-13.1	24.7	12
SS17 M1-4	417	M1	-12.9	24.5	14
SS17 M1-4.5	417	M1	-12.8	25.1	16
SS17 M1-5	417	M1	-13.0	25.4	18
SS17 M1-5.5	417	M1	-13.0	25.6	20
SS17 M1-6	417	M1	-13.3	25.5	22
SS17 M2-2	417	M2	-12.4	26.9	6
SS17 M2-3	417	M2	-13.1	27.2	10
SS17 M2-4	417	M2	-13.8	26.2	14
SS17 M2-5	417	M2	-14.1	24.0	18
SS17 M2-6	417	M2	-13.9	22.4	22
SS17 M2-7	417	M2	-13.8	22.1	26
SS17 M2-8	417	M2	-12.9	23.0	30
SSA M1-1+2	A	M1	-12.9	25.0	2
SSA M1-1.5	A	M1	-12.9	25.2	4
SSA M1-2	A	M1	-12.8	26.0	6
SSA M1-2.5	A	M1	-12.9	26.1	8
SSA M1-3	A	M1	-13.0	26.8	10
SSA M1-3.5	A	M1	-12.9	27.0	12
SSA M1-4	A	M1	-13.5	27.0	14
SSA M2-1	A	M2	-13.9	25.4	2
SSA M2-2	A	M2	-13.7	26.0	6
SSA M2-3	A	M2	-14.1	25.1	10
SSA M2-4	A	M2	-14.2	22.9	14
SSA M2-5	A	M2	-13.9	22.2	18
SSA M2-6	A	M2	-13.3	23.3	22
SSA M3-1	A	M3	-15.0	25.4	2
SSA M3-2	A	M3	-14.9	24.7	6
SSA M3-3	A	M3	-14.8	22.0	10
SSA M3-4	A	M3	-14.5	22.4	14
SSA M3-5	A	M3	-14.1	23.3	18

SSA M3-6	A	M3	-13.4	24.8	22
SSA M3-7	A	M3	-13.4	25.4	26
RS8 M3-1	308	M3	-13.5	25.7	2
RS8 M3-2	308	M3	-14.5	26.7	6
RS8 M3-3	308	M3	-14.6	24.3	10
RS8 M3-4	308	M3	-15.1	23.0	14
RS8 M3-5	308	M3	-13.8	24.1	18
RS8 M3-6	308	M3	-13.6	24.8	22
RS8 M3-7	308	M3	-12.5	25.9	26
RS8 M3-8	308	M3	-12.9	26.5	30
RS6 M2-1.5	306	M2	-12.4	25.0	4
RS6M2 2	306	M2	-11.7	27.5	6
RS6M2 3	306	M2	-11.9	28.2	10
RS6M2 4	306	M2	-12.7	28.6	14
RS6M2 5	306	M2	-13.3	26.4	18
RS6 M3 1.5	306	M3	-11.9	25.7	4
RS6 M3 2	306	M3	-11.8	28.5	6
RS6 M3 3	306	M3	-12.7	27.6	10
RS6 M3 4	306	M3	-13.6	25.6	14
RS6 M3 5	306	M3	-13.6	24.9	18
RS6 M3 6	306	M3	-13.4	25.1	22
RS6 M3 6.5	306	M3	-13.1	24.7	24
RS10 M3-1.5	310	M3	-11.9	25.6	4
RS10 M3 2	310	M3	-11.7	27.8	6
RS10 M3 3	310	M3	-12.5	28.1	10
RS10 M3 4	310	M3	-13.1	26.8	14
RS10 M3 5	310	M3	-13.1	25.2	18
RS10 M3 6	310	M3	-12.8	25.2	22
RS10 M3 7	310	M3	-12.3	26.7	26
SS12 M1 1.5	412	M1	-13.0	24.5	4

SS12 M1 2	412	M1	-12.5	25.8	6
SS12 M1 2.5	412	M1	-12.6	26.3	8
SS12 M1 3	412	M1	-12.3	27.0	10
SS12 M1 3.5	412	M1	-12.9	27.1	12
SS12 M1 4	412	M1	-13.2	26.4	14
SS12 M3 2.5	412	M3	-13.0	26.3	8
SS12 M3 4	412	M3	-13.5	24.4	14
SS12 M3 5	412	M3	-13.8	22.9	18
SS12 M3 6	412	M3	-13.2	24.3	22
SS12 M3 7	412	M3	-12.5	25.8	26
SS12 M3 8	412	M3	-12.1	26.5	30
SS12 M3 7	412	M3	-12.5	25.8	26
SS12 M3 8	412	M3	-12.1	26.5	30
SS12 M2 1	412	M2	-12.5	24.8	2
SS12 M2-2	412	M2	-13.0	26.7	6
SS12 M2-3	412	M2	-13.3	26.1	10
SS12 M2-4	412	M2	-13.6	24.4	14
SS12 M2-5	412	M2	-13.1	22.9	18
SS12 M2-6	412	M2	-12.8	22.5	22

Cheng (2009)														
sk. no.	bone	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	period	sex	age category	no.of burial single/multiple	orientation	position supine/prone	coffin nails/stone lining	grave goods	decapitated	age	grave goods
SK93	R Fibula	-19.8	9.5	RB	m	old	s	N	s	N	N	N	60+	
SK103	R Femur	-19.9	9.4	RB	m	old	s	N	s	N	N	N	50+	
SK122	L Tibia	-19.5	9.8	RB	m	prime	s	N	s	N	N	Y	30-35	
SK147	L Femur	-20.2	9.6	RB	m	mature	s	S	s	N	N	N	40-50	
SK212	R Fibula	-20.2	10.1	RB	f	old	s	N	s	c	N	N	45+	
SK222	L Tibia	-20.3	9.5	RB	m	mature	s	N	f-s	N	Y	N	35-45	3 boot cleats
SK256	L Fibula	-20.1	8.3	RB	f	old	s	N	s	N	N	Y	60+	
SK271	L Fibula	-19.9	8.7	RB	m	prime	s	N	s	c	N	N	25-30	
SK306	L Tibia	-19.8	10.5	RB	f	old	s	N	s	c	Y	Y	50+	4 boot cleats
SK357	L Femur	-20.3	10.9	RB	m	old	s	N	s	N	N	N	45+	
SK363	L Tibia	-20.3	9.6	RB	f	old	s	N	p	N	N	N	50-60	
SK384	L Arm	-20.0	9.5	RB	m	old	s	N	s	N	N	Y	45+	
SK397	L Fibula	-19.7	7.8	RB	m	old	s	N	p	N	N	N	45+	
SK407	L Femur	-20.3	9.7	RB	f	young	s	N	s	N	N	N	19-20	
SK467	L Femur	-20.7	9.1	RB	m	mature	m	S	s	N	N	N	40-50	
SK471	R Fibula	-19.9	8.1	RB	m	old	s	N	p	N	N	N	45+	
SK512	L Tibia	-19.8	9.2	RB	m	mature	s	N	p	N	Y	Y	40-50	burnt deposit
SK519	R Arm	-20.7	9.0	RB	m	mature	m	S	s	N	N	N	35-45	
SK520	R Fibula	-20.6	9.8	RB	m	old	m	S	s	N	N	N	50+	

Table 7b Burial characteristics of humans at Horcott and collagen data from Cheng (2009)

this study														
sk. no.	bone	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	period	sex	age category	no.of burial single/multiple	orientation	position	coffin nails/stone lining	grave goods	decapitated	age	grave goods
SK96	rib	-20.1	9.3	RB	f	young	s	N	s	N	N	N	18-19	
SK114	rib	-20.2	11.2	RB	m	adolescent	s	N	s	c	N	N	16	
SK219	rib	-19.8	9.2	AS2	m?	adolescent	s	W	p	s	Y	N	12-15	Fe knife, Cu alloy strap, Fe buckle, potsherds
SK250	rib	-19.5	9.1	AS2	?	adolescent	s	W	f-p	N	Y	N	11-13	Fe knife, potsherds, animal bones
SK119	rib	-20.7	11.0	AS1	f	mature	s	W	s	s	N	N	40-50	
SK229	rib	-20.8	11.0	AS1	f	old	s	W	s	c	Y	N	60+	Roman pot, A-S pot
SK157	rib	-20.1	11.0	RB	m	mature	s	S	s	N	N	N	40-44	
SK187	R Femur	-20.1	10.9	RB	f	prime	s	S	s	c	N	N	30-40	
SK111	rib	-20.4	10.2	AS1	?	child	s	W	s	c+s	Y	N	7-9	fragment Roman millstone
SK254	rib	-19.5	8.8	AS2	?	child	s	W	s	N	Y	N	8-10	Fe knife
SK108	rib	-20.0	10.3	RB	m	prime	s	N	s	N	N	N	30-40	
SK434	rib	-19.6	10.3	RB	m	young	s	S	p	N	N	N	18-22	
SK194	rib	-19.5	10.1	RB	m	mature	s	N	s	c	N	N	35-40	
SK345	rib	-19.8	10.5	RB	f	prime	s	N	s	N	N	N	25-35	
SK404	rib	-19.9	9.4	RB	f	prime	s	N	s	c	N	N	30-34	
SK180	rib	-20.4	10.2	AS1	f	old	s	W	s	s	Y	N	50+	s/g bone frag
SK87	rib	-20.6	11.7	AS1	?	child	s	W	s	c	N	N	6	
SK192	rib	-19.6	10.1	RB	m	prime	s	N	s	N	N	N	28-30	
SK305	rib	-19.5	10.5	RB	f	prime	s	N	s	N	Y	Y	24-29	charred plant remains

Table 7a. Burial characteristics of humans at Horcott and normalised collagen data from this study