Isotopes in the landscape:

carbon and nitrogen isotopes of domestic animals and their application to the archaeology of the Upper and Middle Thames Valley in the Neolithic to Roman periods

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Abstract

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carbon and nitrogen isotopes of domestic animals and their application to the archaeology of the Upper and Middle Thames Valley in the Neolithic to Roman periods

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This thesis deals with the development of farming landscapes in the Thames Valley from the Neolithic to the Roman period (4000 BCE – 410 CE). The focus is on the major domestic animal species, cattle, sheep and pig, and their roles in the agroecosystem, traced using carbon and nitrogen isotope ratios measured in collagen. The large dataset of faunal isotope values from a limited area, obtained from sites with extensive archaeological and environmental information, allowed a thorough characterisation of variability in isotope values, within and between species, sites, archaeological periods, and landscape regions.

Isotope ratios in a flock of modern sheep showed less variability than archaeological assemblages. Linear mixed models were used to analyse variation in isotope values in 1490 archaeological samples from 23 sites. The pattern of change over time differed for cattle, sheep and pig, reflecting both wide-scale environmental change and changes in animal management. $\delta^{13}C$ values of cattle and pigs reflected the loss of primary closed-canopy woodland. Pig management changed from an emphasis on woodland resources to a closer association with settlement and consumption of anthropogenic waste. Herbivore $\delta^{15}N$ values probably reflect variations in the intensity of pasture use and association with arable farming. Climatic cooling since the post-glacial thermal maximum cannot explain these varied trajectories of change.

Variation between sites in faunal isotope values was related to landscape regions. Faunal isotope values at individual sites were useful in site interpretation in the context of other evidence. The trend in pig and cattle $\delta^{13}C$ values with time was widely found in the UK, as expected if it represents forest clearance. In the Neolithic, cattle management was similar to the UK at central and eastern European Neolithic sites, but pig management was different.

Patterns of faunal isotope values and their changes over time, analysed in the context of archaeological and environmental information, can contribute to the interpretation of sites, and give a unique perspective on changes in farming practice and their effects on the landscape.

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"The country where he lives

is haunted

by the ghost of an old forest.

In the cleared fields

where he gardens

and pastures his horses

it stood once,

and will return."

Wendell Berry, *Window Poems 12*

Chapter 1

Introduction

This thesis deals with the development of farming landscapes in the Thames Valley from the Neolithic to the Roman period (4000 BCE – 400 CE). Farming is seen as a fundamental aspect of the human ecosystem which both responds to environmental conditions and alters those conditions, at local to landscape scales (Briggs et al. 2006; Butzer 1982; McGlade 1995; McGovern et al. 2007). The focus is on the major domestic animal species, cattle, sheep and pig, and their roles in nutrient cycling within the agroecosystem. Nutrient cycling is traced using carbon and nitrogen isotope ratios measured in the collagen of domestic animals. Patterns of isotope values and their changes over time are analysed in relation to environmental variables, to give a unique perspective on changes in farming practice and their effects on the landscape.

1 Archaeology in the landscape

Landscape approaches to archaeology are *"held together by three unifying themes. The first is the recognition of a dynamic, accretionary, humanly-constructed and maintained environment. The second is the conception of this landscape as a historically contingent entity. And the third is the notion of a recursive link between humans and their landscapes."* (Fisher and Thurston 1999, p. 361).

Integrating information from many sources and scholarly traditions (Anschuetz et al. 2001), such an approach can be applied to study of the development of farming in a particular area. Agricultural ecosystems can be studied by the methods of environmental archaeology (Evans and O'Connor 1999), and the use of landscape regions inferred from distributions of artefacts, sites, settlements, field systems, routes and boundaries (Thurston and Salisbury 2009). These are the traces of human activities, structured by historical contingency and social and cultural perceptions and traditions, as well as environmental conditions. Looking at changes over time gives insight into how a landscape is created by the dynamic interaction between people and their environment.

1.1 An ecological approach

An agricultural ecosystem (agroecosystem) could be seen as a transferable ecosystem (cf. “transported landscape”: Anderson 1952; Kirch 1982), maintaining an early stage of vegetation succession, with a high proportion of primary production to standing crop (and hence productivity), and rapid energy and nutrient cycling (Begon et al. 2006, p.504-505; Butzer 1982, p. 310). An agroecosystem is maintained, reproduced and extended by the activities of people in the landscape – the taskscape (Ingold 1993) – with potential for change and innovation as well as repetition and tradition (Bogucki 2000). Changes may be “adaptive” in a general sense, leading to higher or more consistent food yields, especially under changing circumstances, but are not necessarily driven by environmental change (e.g. Dietrich et al. 2012; Marciniak 2008; Zvelebil 2009). One cannot assume that farming techniques or use of landscape are simple responses to the need to maximise, say, energy gain or crop yields (Keene 1983). Ecological factors such as population growth (e.g. Lambrick 2009, pp. 377-380) and social factors such as the importance of gatherings and feasting (e.g. Dietrich et al. 2012) affect the choices made by farmers. Nevertheless there are environmental constraints affecting the use of landscape, such as the availability of water or forage for domestic animals, or, on a larger scale, variations in the length of the growing season in particular areas that affect which crops can be grown (Colledge et al. 2005, p. 150). It is likely that there will be some patterning in the use of landscape that is related to environmental factors, however mediated through human culture and history. The approach taken here is explicitly ecological, looking at the agroecosystem in the landscape in relation to environment, but does not assume that environment is the primary driver of agricultural change.

1.2 Nutrient cycling and stable isotopes

The focus here is on carbon and nitrogen cycling, which can be traced using stable isotopes (Bowen et al. 2010; Handley and Raven 1992; Peterson and Fry 1987; Szpak 2014). Carbon and nitrogen stable isotopes are widely used in food web analysis (Layman et al. 2007, 2012). This includes the analysis of diets of humans from archaeological sites, where isotope values of fauna can be used to estimate a local baseline (Schwarcz and Schoeninger 1991; Sealy 2001). In palaeontological and archaeological work isotope ratios have generally been measured in bone, the most frequently preserved biological tissue, and the isotope ratios of the plants at the base of the food chain inferred from those of herbivores. Carbon and nitrogen stable isotopes have been used to investigate ancient and modern faunal environments and ecological relationships (Ambrose and DeNiro 1986; Drucker et al. 2008; Fox-Dobbs et al. 2008; Sealy et al. 1987). The same principles have been applied to archaeological sites, mainly

in the context of investigating human diet (e.g. Bösl et al. 2006; Jay 2008; Stevens et al. 2010). More recently it has become possible to measure isotope ratios in charred crop remains (Fraser et al. 2011, 2013a,b; Kanstrup et al. 2012) and thus to integrate information from crops and animals in analysing human diets and the ecology of farming at archaeological sites (Bogaard et al. 2013; Fraser et al. 2013b; Lightfoot and Stevens 2012). Isotope ratios for ancient animal fodder and forage are rarely possible to obtain, and are therefore still inferred from herbivore values.

Stable isotope studies can help to integrate information about plants and animals at groups of sites, with potential to look at the ecology of farming at wider scales (e.g. Hedges et al. 2013, pp. 344-357). In the present study carbon and isotope values are measured in bone collagen from domestic animals, from archaeological sites of the Neolithic to Roman periods, within a limited area, and analysed in the context of associated archaeological and palaeoenvironmental information. The focus is on the management of, and use of landscape by, domestic animals. As domestic animals were an integral part of the agricultural system introduced into Britain with the Neolithic (Bogaard et al. 2013), interpretations inevitably include consideration of crop production and the farming system as a whole.

There is considerable variation in herbivore isotope values: at many archaeological sites the range in carbon or nitrogen stable isotope ratios of herbivorous cattle and sheep is as great or greater as the range in values of supposedly omnivorous humans (e.g. Hedges et al. 2013; Stevens et al. 2013). There is a large body of theory and experimental evidence showing that some of the variation in domestic animal isotope values is due to physiological processes occurring during digestion, metabolism, growth, development and reproduction, while some of it is due to variation in isotope ratios in their foods (Chapter 2). Herbivores feeding on resources from different habitats will reflect plant isotopic differences (if any), giving us an insight into the use of the environment by domestic herbivores, and hence by the humans who control their range and diet.

Both $\delta^{13}C$ (Heaton 1999; Tieszen 1991) and $\delta^{15}N$ values (Craine et al. 2009, 2015; Handley and Raven 1992; Högberg 1997; D. Robinson 2001) of plants reflect environmental differences, though not always in a straightforward way. For the herbivores, cattle and sheep, some variation in isotope ratios will reflect isotope values of plants in the environment, probably mainly graze but with a possible component of browse, mainly forage but also fodder. Pigs are more omnivorous than cattle and sheep and potentially feed on a wider range of foodstuffs including roots, fruits, fungi, invertebrates and wastes from human activities as

well as graze or browse, exploiting different aspects of the environment. Comparing pig isotopic values with those of the domestic herbivores may give insights into pig management by people and additional aspects of the way people used their environment. Stable isotope ratios of domestic animals should reflect both their use of the environment they encountered and changes in that environment over time, giving a new perspective on changes in framing practice and the development of the landscape.

2 Aims and objectives

This study aims to investigate the application of carbon and nitrogen stable isotope values of domestic animals to the archaeology of agroecosystems at scales from site to landscape. Patterned variation in isotope values in relation to environment and archaeology has the potential to aid interpretation of agricultural practice and environmental conditions at individual sites or areas within the landscape. Observation of changes over time illuminates how landscapes are created by the dynamic interaction between people and their environment.

To achieve this, the following objectives were set:

2.1 To obtain a suitable dataset of isotope measurements

This will require extensive sampling of domestic animal bone from a variety of sites and periods within a suitable area, and compilation of results from previously published studies. To account for the wide range in isotope values of domestic herbivores, sufficiently large samples will be needed for each site/period. A database of the isotope measurements will be compiled, including archaeological and environmental evidence from each site.

2.2 To characterise variation in domestic animal $\delta^{13}C$ and $\delta^{15}N$ values

2.2.1 Variation within and among species

Within-species variation will be examined in a sample of sheep from a single flock that vary in age, sex, breeding status and diet, to see what range of variation in isotope values might be expected due to these factors. This will be compared with the range found in samples from archaeological sites.

The isotope values of the three major domestic species will be compared. Consistent differences in isotope values among cattle, sheep and pig could reflect their digestive physiology as well as their diets. Differences in the *patterning* of isotope values of the three

species are likely to reflect different ways in which each species may be managed in relation to the environment, and hence agricultural practices.

2.2.2 Variation within and among sites and landscape regions

For each species, the variation and range of isotope values at individual sites reflects both within-species variation and the use of the environment at that site. Sites will be compared in order to estimate the amount of variation due to differences between sites, and significant differences between sites or groups of sites will be related to explanatory variables.

2.2.3 Variation over time

Previous work (e.g. Hamilton et al. 2009; Montgomery and Jay 2013, p. 189) has suggested that there may be long-term changes in faunal isotope values and patterning (see Chapter 4). A larger dataset will provide an opportunity to test these observations.

2.3 To relate variation in domestic animal $\delta^{13}C$ and $\delta^{15}N$ values to environmental variation, in space and time

To investigate variation in faunal isotope values in relation to environmental factors measured at sites, the available information needs to be summarised in a consistent way across sites.

2.3.1 Developing a suite of explanatory variables that can be used for statistical modelling

The variables need to be available for all sites or a reasonably large subset of sites, and consistent across sites. They will include geographical variables (latitude, longitude, elevation), climatic variables, archaeological variables (e.g. period, site type), and variables reflecting aspects of the sites' environments (e.g. soil type and vegetation cover) and ecology. Some biological remains, such as waterlogged plants and insects, snails or pollen spectra are commonly used in environmental interpretation. I will attempt to record these consistently and codify them using statistical classification techniques to produce biotic variables that are useful in comparing site environments.

Variables may be quantitative or categorical. Categorical divisions will reflect the tension between summarising the fine details available at some sites and including data from as many sites as possible, as well as achieving consistency across sites. Some variables that cannot be, or have not been, directly measured, such as climate variables and ancient soil types, will be estimated where possible using modern models and maps.

To investigate variation in faunal isotope values in relation to time, chronology also needs to be consistent across sites. The amount and precision of dating information is very variable

across sites, so instead of using radiocarbon dates, a system of periods and phases that can be consistently applied to the data will be developed. The system will be based on multiple lines of evidence from the site reports, including radiocarbon dates (where available) and material culture.

2.3.2 Statistical modelling

Once a suitable set of variables is developed, they will be entered into statistical models to examine their interrelationships and effects on faunal isotope values. Analysis and interpretation will focus on patterning in isotope ratios for the three major domestic animal species, in relation to the explanatory variables. This will require statistical methods that can deal with less-than-ideal datasets.

2.3.3 To relate variation in domestic animal $\delta^{13}C$ and $\delta^{15}N$ values to human use of landscape

The relationships between faunal isotope values and environment will be compared between sites grouped by e.g. period or landscape region, or at individual sites, interpreted in the context of patterning across the landscape. The results will be compared with the available environmental and archaeological information and interpretations based on these, to see whether useful insights into changes in agricultural practice can be gained from the measurements of faunal isotope values. On a wider scale, faunal isotope values from this study will be compared with results from the UK as a whole (reviewed in Chapter 4), and from the Neolithic in Europe.

More specific research questions are developed after the scientific background to the study (isotope systematics: Chapter 2) and environmental history of farming in the study area (Chapter 3) have been discussed.

The results are expected to give some insight into the causes and patterns of variability in faunal isotope values. This can inform the use of faunal isotope values as baselines in studies of human diet, and, more widely, provide a way of looking at human-environment interactions at site and landscape scales. It should be possible to suggest directions for further research that would significantly improve our understanding of domestic animal isotope values and their contribution to the interpretation of archaeological sites and landscapes.

2.3.4 Selection of the study area

The area studied needs to be small enough to avoid large-scale climatic effects on baseline isotope values (cf. Hedges et al. 2013), but large enough to include sites from a variety of

landscape regions encompassing variations in topography and underlying geology. It should be well known archaeologically, with material from sites with well-established stratigraphies, recorded in detail, archived, available and accessible. The environmental archaeology should be thoroughly studied, with a variety of lines of evidence available, enabling groups of sites to be compared and contrasted. The timespan should include recognisable shifts in factors such as agricultural practices and landscape use, as evidenced by, for instance, proportions of different crop and domestic animal species, or settlement patterns and landscape division, as well as in archaeologically defined cultures. It may also include long-term changes in climate and hydrology that could affect plant isotope values.

The area of the Upper and Middle Thames Valley fits these criteria well. This region is well known archaeologically (Allen et al. 1997; Booth et al. 2007; Hey et al. 2011; Lambrick et al. 2009; Morigi et al. 2011). There is environmental information from many sites, and based on this a general environmental history for the period covered. Differences in climate within the Thames Valley that might affect isotope ratios should be minimal, allowing other environmental factors to be investigated. The catchment area of about 10,000 km^2 includes a variety of habitats from chalk downland to river floodplain that can be investigated for environmental effects on faunal isotope ratios. The timespan (Neolithic to Roman periods) encompasses major cultural shifts, from the adoption of farming in the Neolithic, through the appearance of settlements and the division of the landscape in the Bronze Age, landscape reorganisation in the Iron Age, and inclusion in the Roman empire. For the later periods, (Lambrick 1992, 2009) has proposed models of land use organisation that can be tested within the present theoretical framework. There were also long-term changes in climate (Davis et al. 2003; Marcott et al. 2013) and hydrology (Robinson and Lambrick 1984, 2009, pp. 29-34). The study area is shown in Fig. 1.1 and its environmental history is described in detail in Chapter 3.

Sampling from occupation sites and farmsteads of varying sizes and lengths of occupation is preferred, as being more closely related to farming practice. For the earlier periods not many such sites are available, and samples from ritual/gathering sites are also used. Samples are not taken from Roman urban or military sites that potentially draw on a wide hinterland, because of the added complexity of interpretation.

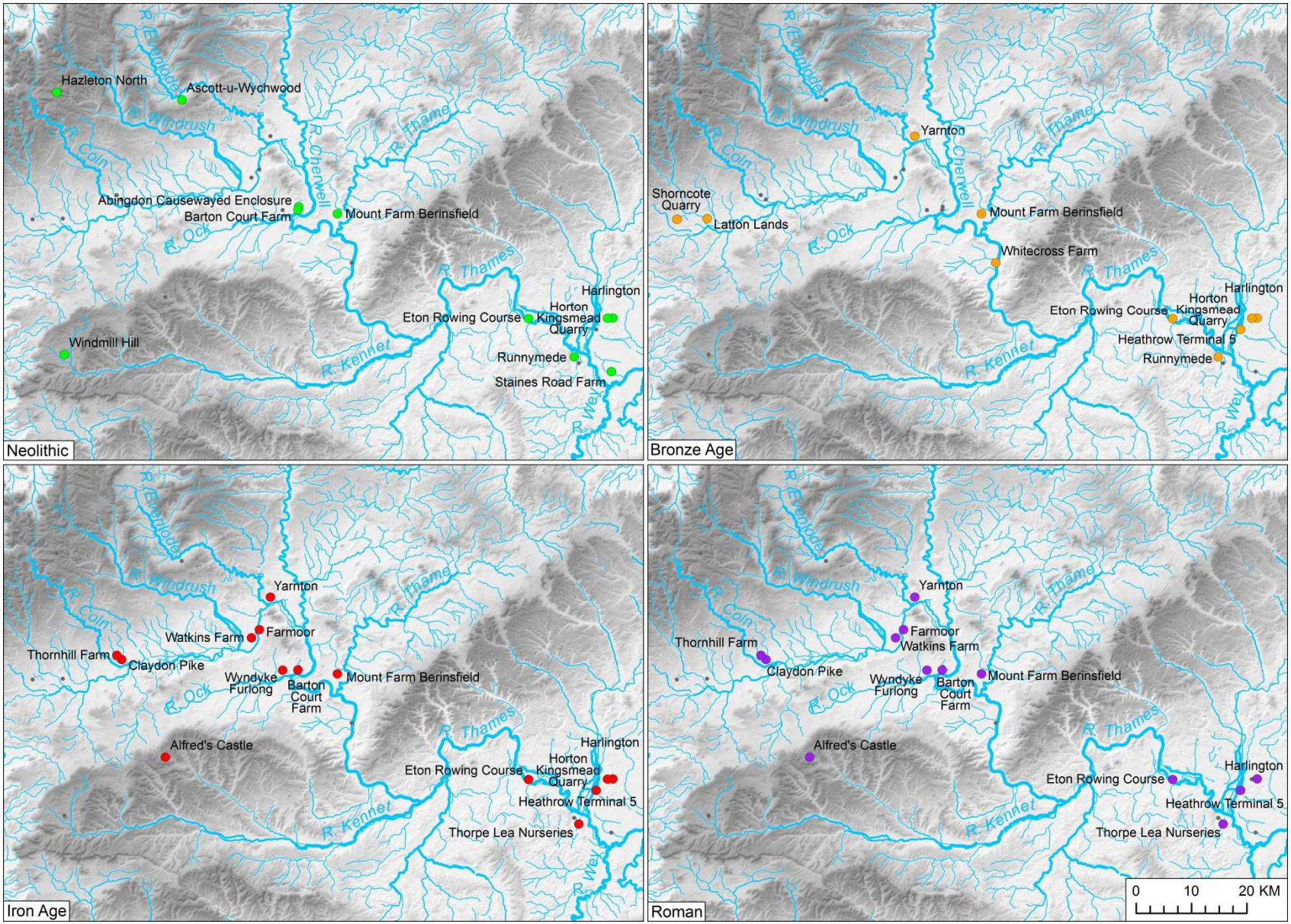
Neolithic
Hazleton North
Ascott-u-Wychwood
Abingdon Causewayed Enclosure
Barton Court Farm
Mount Farm Berinsfield
Windmill Hill
Eton Rowing Course
Horton Kingsmead Quarry
Harlington
Runnymede
Staines Road Farm
R. Evenlode
R. Windrush
R. Coln
R. Cherwell
R. Thame
R. Ock
R. Thames
R. Kennet
R. Wey
Bronze Age
Yarnton
Shorncote Quarry
Latton Lands
Mount Farm Berinsfield
Whitecross Farm
Eton Rowing Course
Horton Kingsmead Quarry
Harlington
Heathrow Terminal 5
Runnymede
Iron Age
Yarnton
Watkins Farm
Farmoor
Thornhill Farm
Claydon Pike
Wyndyke Furlong
Barton Court Farm
Mount Farm Berinsfield
Alfred's Castle
Eton Rowing Course
Horton Kingsmead Quarry
Harlington
Heathrow Terminal 5
Thorpe Lea Nurseries
Roman
Yarnton
Farmoor
Watkins Farm
Thornhill Farm
Claydon Pike
Wyndyke Furlong
Barton Court Farm
Mount Farm Berinsfield
Alfred's Castle
Eton Rowing Course
Harlington
Heathrow Terminal 5
Thorpe Lea Nurseries
0 10 20 KM

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Fig. 1.1 Map of the Upper and Middle Thames Valley showing the sites included in this study, for each period. *Green* Neolithic, *orange* Bronze Age, *red* Iron Age, *purple* Roman

3 Thesis structure

In Chapters 2 to 4 the background for this study is established.

Chapter 2 discusses the fundamentals of carbon and nitrogen stable isotope fractionation and cycling, and hence distribution of carbon and nitrogen stable isotopes in the environment. The feeding and digestive ecology (ecophysiology) of each of the study species is described, and what is already known about their isotope ecology. This provides a basis for generating specific predictions and questions about faunal isotope values in relation to the environment and isotope ecology across the landscape.

Chapter 3 reviews the environmental history of the Upper and Middle Thames Valley. First there is an overview of climate change in north-west Europe from the Neolithic to the Roman period. Then the geological/topographic regions used in the analysis of results, and the palaeohydrology of the river and environmental history, are described, based on recent reviews. This information is used, in combination with the principles of isotope ecology from Chapter 2, to generate specific research questions.

Chapter 4 reviews previous studies of faunal isotopes in the UK, comparing the means and variation of faunal isotope values from as many sites as possible from the Neolithic to Roman periods. This provides a background against which to compare the Thames Valley results, and suggests some questions than can be investigated in the more detailed dataset obtained in this study.

Chapter 5 describes the materials and methods used in this study. Details of the modern and archaeological samples and laboratory methods are given, with an assessment of measurement error. The statistical methods are described and explained. The variables used to summarise environmental and archaeological information are described, with explanation of how and why they were chosen and defined.

The results are given in Chapter 6. Variation in isotope values of a modern sheep sample is analysed in relation to age, sex, breeding status and diet, and the variation compared with that of archaeological samples. Isotope values and their trajectories through time are compared between species. Variation in faunal isotope values between sites in relation to environmental variables is analysed. Variation in faunal isotopes at individual sites, and in relation to the models proposed by Lambrick (1992, 2009), is explored.

In Chapter 7 the results are discussed. Variation between species and its patterning over time is explored. To act as a point of reference against which the results can be compared, a model is constructed that predicts expected faunal isotope values based on estimated values for key diet components. Between-site variation in isotope values of the three species is then related to environmental factors at the landscape scale.

Chapter 8 gives examples of interpretation using the framework established in previous chapters at site and landscape scales. Results from individual sites are compared to expected values from the model constructed in Chapter 7, showing how isotope measurements can contribute to site interpretation. The results from the Thames Valley are discussed in the context of similar studies from Britain and Europe.

Finally, in Chapter 9 the findings are summarised and the implications assessed, and suggestions are made for further work.

Chapter 2

Isotopes and ecology

This chapter outlines the principles of isotope ecology and its application in this study. First there is an account of isotope fractionation, carbon and nitrogen cycling and distribution in the environment, and the factors that affect these processes. Second, the physiology of cattle, sheep and pigs is considered, particularly how digestive processes and variation with growth, sex and age might affect collagen isotope values. Third, the feeding ecology of the three species is compared, again with a view to possible effects on collagen isotope values.

1 Introduction

Stable isotopes of carbon and nitrogen have been used to address many ecological questions, including trophic relationships between organisms and nutrient cycling in the environment (Michener and Lajtha 2007; D. Robinson 2001). Because they are frequently preserved and can be measured in bone, they are also commonly used in archaeology, most frequently in the study of human diet (e.g. Ambrose and Katzenberg 2000). Stable isotope composition of bone collagen of animals from archaeological sites is increasingly used to give a more complete picture of environmental relationships in agricultural ecosystems (e.g. Vaiglova et al. 2014). By examining trophic interactions between people, crops, domestic animals, and their environment, farming practices can be situated in an ecological context. Domestic animals have a central position in the farming system, gaining nutrients from the wider environment, recycling nutrients within the system, and providing nutrients (particularly fat and protein) for human consumption. Here, $\delta^{13}C$ and $\delta^{15}N$ values of bone collagen from domestic cattle, sheep and pigs are used to illuminate the ecology of early farming in the Thames Valley.

2 Isotope systematics

In this section the principles of isotope fractionation and the sources of variation in measured plant and animal isotope ratios are explored.

2.1 Fractionation

The atoms of an element can exist in different forms, or isotopes, all with the same number of protons/electrons, and hence the same chemical properties, but with varying numbers of

neutrons, and hence atomic weight. Some isotopes are unstable and decay radioactively (e.g. ^{14}C), but others are stable (e.g. ^{13}C, ^{12}C). The tiny mass differences between stable isotopes of the same element cause them to behave differently in physical processes and chemical reactions: the heavier isotope tends to react more slowly and the bonds it forms require more energy to break. For elements of low atomic number, the mass differences are large enough to lead to detectable differences in isotope ratios between substrates and products of a reaction or phase change, known as fractionation (Sharp 2007; Urey 1947).

Two kinds of fractionation are recognized (Sharp 2007, pp. 40-41). “Equilibrium” isotope effects arise in closed systems at chemical equilibrium. The rates of the forward and back reactions of any particular isotope are identical, and at isotopic equilibrium the isotopes of an element will be redistributed among (chemical) species or compounds in a way that depends on temperature, the mass ratio of the isotopes and bond properties. The isotopic composition of the compounds at equilibrium may not be identical, i.e. fractionation has occurred, but is constant at any particular temperature. The heavier isotope tends to accumulate in the species or compound with higher molecular mass, in the higher oxidation state, or, for phase changes, in the denser material. “Kinetic” isotope effects are irreversible, occurring in systems that are not in equilibrium: the rates of the forward and back reactions of any particular isotope are not identical, and the reaction may become unidirectional if reaction products are removed chemically or physically (e.g. by evaporation). Reaction rates depend on the relative masses and vibrational energies of the isotopes involved. The amplitude of kinetic fractionation effects is often greater than equilibrium effects, especially for unidirectional reactions (Sulzmann 2007). Light isotopes tend to react faster and become more concentrated in the products (e.g. isotopically light carbon in methane from ruminant digestion, Hedges 2003), while the substrate tends to be enriched in the heavier isotope. Even where individual physical, chemical or biological reactions involve considerable fractionation this may not alter stable isotope composition of the system as a whole, though compartments may differ (see e.g. Ambrose 1991). In irreversible reactions where all the substrate is consumed and converted to product there will be no overall fractionation.

For convenience, stable isotope compositions of carbon and nitrogen are usually reported as δ values, measured relative to a standard, given as parts per thousand (‰, per mil; equivalent to $\times 10^{-3}$) (Coplen 2011; McKinney et al. 1950).

$$\delta^{13}C = \left[\frac{(^{13}C/^{12}C)_{sample} - (^{13}C/^{12}C)_{VPDB}}{(^{13}C/^{12}C)_{VPDB}} \right] x1000$$

$\delta^{13}C$ is reported relative to a standard derived from a fossil belemnite from the PeeDee formation of South Carolina (PDB, 0‰ by definition (Craig 1957); subsequently redefined by the IAEA in Vienna, VPDB; Allison et al. 1995). The standard used for nitrogen is atmospheric nitrogen (AIR; Mariotti 1983).

The molecules involved in metabolic processes often retain an isotopic signature reflecting the reactions involved in their formation(e.g. Macko et al. 1986), and this can be used to trace nutrients through ecosystems (DeNiro and Epstein 1978, 1981; Peterson and Fry 1987; Tieszen and Boutton 1989; Wada et al. 1991; Handley and Raven 1992; McCutchan et al. 2003; Post 2002). For present purposes it is the ratios of the stable isotopes of carbon and nitrogen that are of interest.

2.2 Carbon in plants

2.2.1 Photosynthesis and carbon isotope discrimination in C3 plants

Food chains start with the primary producers, plants. Terrestrial plants obtain their carbon from atmospheric CO_2, and the major determinant of their tissue $\delta^{13}C$ values is the amount of fractionation that takes place during the fixing of atmospheric carbon by photosynthesis. CO_2 taken in by the plant goes through a series of processes and reactions, passing through various transformations (e.g. dissolution) before entering the Calvin-Benson cycle. All of them have associated isotope effects. The overall fractionation is not simply the additive result of the isotope effects, but mostly reflects the rate-limiting step or steps (O'Leary 1988; Park and Epstein 1960). Because plants need to control outward diffusion of water vapour as well as inward diffusion of CO_2, they are able to vary the rate of diffusion by opening or closing their stomata, potentially affecting the overall discrimination, so that plant tissue $\delta^{13}C$ values may vary in response to environmental conditions.

In “C3” photosynthesis, CO_2 from the air diffuses into the leaf via stomata, dissolves in the cell sap and diffuses to the chloroplasts, where carboxylation takes place. One molecule of CO_2 combines with the 5-carbon sugar ribulose 1,5-biphosphate in a reaction catalysed by the enzyme ribulose-1,5-bisphosphate carboxylase-oxygenase (RuBisCO) to produce two molecules of the 3-carbon compound (hence the term, C3), triphosphoglycerate, which then

enters the Calvin-Benson cycle (Hatch and Slack 1966). This step is irreversible and produces a fractionation of around –29‰ (Roeske and O'Leary 1984). Dissolution and hydration of CO_2, and diffusion of CO_2 in air and water each have smaller isotope effects (O'Leary 1988, Table 1), of which diffusion of CO_2 into the leaf, calculated as 4.4‰ (Craig 1954) is assumed to be the most important (Farquhar et al. 1989).

In aquatic C3 plants, $\delta^{13}C$ values are much more variable (O'Leary 1988). Carbon is available to aquatic plants as dissolved CO_2 or HCO_3^-, with $\delta^{13}C$ values depending on the source of the carbon (e.g. Fischer et al. 2007) and the kinetics of solution reactions. Diffusion rates in water are much slower than in air, so carbon supply is more likely to be limiting, and discrimination against $\delta^{13}C$ lower (Farquhar et al. 1989, pp. 517-518; Smith and Walker 1980). In fast-flowing water where mixing is good and carbon is readily available, $\delta^{13}C$ values may be similar to terrestrial plants, but in more sluggish waters discrimination may be much lower, and plant $\delta^{13}C$ values correspondingly higher (France 1995; Osmond et al. 1981; Raven et al. 1985; Richardson et al. 1984). These processes are unlikely to be relevant to the present study, as it seems unlikely that aquatic plants, or organisms higher up in aquatic foodchains such as fish, contributed any significant amount to the diets of prehistoric domestic animals in the Thames Valley.

2.2.2 Other photosynthetic pathways

As well as CO_2, RuBisCo catalyses the addition of O_2 to RuBP (oxygenation). In a series of energy-consuming reactions, one molecule of triphosphoglycerate is produced, and the O_2 is ultimately released as CO_2. This process is known as photorespiration (Ogren and Bowes 1971; Ogren 1984). The balance between carboxylation and oxygenation depends on the relative concentrations of CO_2 and O_2. In conditions of high light and high temperature, photosynthesis is rapid, and CO_2 is used up and O_2 produced faster; additionally, the rate of CO_2 diffusion into the leaf is likely to be lower because stomata close to limit water loss. Because of photorespiration, CO_2 fixation by RuBisCo becomes less efficient as temperature rises and CO_2 concentration drops (Ogren 1984). The net apparent fractionation associated with photorespiration is debated, but is unlikely to greatly affect $\delta^{13}C$ values in plant tissues (Ghashghaie et al. 2003).

In several terrestrial plant lineages, modifications of C3 photosynthesis that increase CO_2 uptake efficiency under conditions that promote photorespiration have evolved (Sage 2004). These pathways involve biochemical and anatomical modifications that concentrate CO_2 around RuBisCo, and have distinct $\delta^{13}C$ signatures (Ehleringer et al. 1997; Farquhar 1983;

Farquhar et al. 1989; Griffiths 1992; O'Leary 1981; Park and Epstein 1960). Essentially, CO_2 losses due to photorespiration are minimised and CO_2 uptake efficiency increased, at an energetic cost. In C4 photosynthesis the initial step in carbon fixation produces a 4-carbon compound, oxaloacetic acid, that is transferred to the site of RuBisCo and there releases CO_2 (Hatch 1987, 1992; Hatch and Slack 1966; Kanai and Edwards 1999). Discrimination against ^{13}C is much lower in this process (Farquhar et al. 1989, pp. 512-514) and leaf $\delta^{13}C$ values consequently much closer to the atmospheric value. CAM plants, mainly succulents adapted to extremely arid conditions, vary the pathway of CO_2 fixation, absorbing CO_2 at night in a process similar to C4 carbon fixation, and sometimes using C3 photosynthesis during the day (Kluge and Ting 1978; Osmond et al. 1973). In C4 plants $\delta^{13}C$ values are typically around –12‰ to –16‰, and $\delta^{13}C$ values of CAM plants vary in the range –10 to –20‰. These values are clearly distinguishable from those of C3 plants, around –25‰ to –29‰ (O'Leary 1988).

C4 plants outcompete C3 plants in environments where temperature and light levels are high and there is intermittent water stress, and so are found mainly in warm climates (Pyankov et al. 2010; Sage 2004; Stowe and Teeri 1978; Teeri and Stowe 1976). The climate of North-western Europe is temperate, and C4 species are a minor component of the native British flora (0.6% of species: Collins and Jones 1986; Fitter and Peat 1994). The few native British C4 species occur mainly in coastal dune, cliff, marsh and saltmarsh habitats (Fitter and Peat 1994; Long et al. 1975), distant from the study area. Although some C4 plants occur in areas where the major European crop species were first domesticated and may be found as crop weeds in South-eastern Europe, they do not appear to have reached as far north and west as Britain (Collins and Jones 1986; Coward et al. 2008). CAM plants are also rare in the native terrestrial flora, mainly occurring in coastal habitats or on rockfaces (Fitter and Peat 1994). It is unlikely, therefore, that C4 or CAM plants would have contributed much, or at all, to diets of prehistoric domesticated animals in the Thames Valley.

2.2.3 Variation in $\delta^{13}C$ values of C3 plants in response to environmental factors

The primary producers in the prehistoric Thames Valley, whether grasses, forbs or shrubs/trees, are likely to have used the C3 photosynthetic pathway. While the major factor determining C3 plant $\delta^{13}C$ values is the fractionation due to CO_2 fixation (Farquhar et al. 1989), other factors have some influence and contribute to the range of $\delta^{13}C$ values found in plant material (Farquhar et al. 1982, 1989; Ehleringer et al. 1986, 1988, 1993; Heaton 1999; O'Leary 1988; Tieszen 1991).

Farquhar et al. (1982, 1989) developed a model describing fractionation during carbon assimilation which has been widely used to investigate ecophysiological constraints and adaptations in terrestrial vascular plants. In a simple 2-stage model where discrimination Δ is considered as due to diffusion followed by carboxylation:

$$\Delta = a + (b - a)\, p_i/p_a \qquad \text{(Eq. 1)}$$

where a is the fractionation occurring due to diffusion in air, b is the net fractionation caused by carboxylation, and p_a and p_i are the ambient and intercellular partial pressures of CO_2, respectively (notation as in Farquhar et al. 1989).

Diffusion into and out of the leaf is controlled by opening or closing stomata. Where CO_2 can diffuse in, water vapour can diffuse out, and the optimum balance between the two depends on environmental factors such as humidity, temperature and partial pressure of atmospheric CO_2 (p_a). When water availability is low, stomata are closed to conserve water, so that the rate of CO_2 diffusion into the leaf is low compared with the rate of fixation, and p_i will also be low. Δ will tend towards a (4.4‰, Craig 1954), and leaf $\delta^{13}C$ value will be higher. When stomatal conductance is high, p_i will approach p_a, Δ will tend towards b (29‰, Roeske and O'Leary 1984), and leaf $\delta^{13}C$ value will be lower. p_i/p_a can be seen as a metabolic set point relating the trade-off between CO_2 assimilation and water loss in photosynthesis. In studies of natural ecosystems, plant $\delta^{13}C$ tends to be positively correlated with temperature (+0.1 to +0.4‰ per °C monthly temperature average), and negatively with water availability (around –0.1‰ per % relative humidity: summarised in Heaton 1999), in line with model predictions. $\delta^{13}C$ values of C3 plants would be expected to be higher in drier, warmer climates, as is the case (Arens et al. 2000; Heaton 1999; Kohn 2010).

Low light levels reduce the rate of CO_2 fixation and so increase p_i (Eq. 1), leading to lower leaf $\delta^{13}C$ in the shade, and within and below tree canopies, compared with outer crown leaves or open areas (there are also structural and physiological differences between sun and shade leaves: Lichtenthaler et al. 1981; Schleser and Jayasekera 1985). Another process tending to reduce $\delta^{13}C$ values in leaves close to the ground is assimilation of ^{13}C-depleted CO_2 derived from decomposition within the soil and/or respiration (Sternberg et al. 1989; Medina et al. 1991; van der Merwe and Medina 1989; Vogel 1978), and this effect would be greater below dense canopies where air movement is also restricted. The average $\delta^{13}C$ values for forest trees and plants growing on the forest floor may be 2–5‰ lower than for isolated trees and plants in open areas nearby, known as the canopy effect (Bonafini et al. 2013; Broadmeadow and

Griffiths 1993; France 1996; Heaton 1999; Tieszen 1991; van der Merwe and Medina 1989, 1991). Measurements and modelling suggest that the effect of light level is more important than CO_2 recycling (Broadmeadow and Griffiths 1993; Buchmann et al. 1997; Schleser and Jayasekera 1985; Sternberg 1989).

Tieszen (1991) and Heaton (1999) reviewed the likely magnitude of plant $\delta^{13}C$ responses to environmental factors, which must be taken into account when assessing the $\delta^{13}C$ value of plant food resources in the past. There is variation in $\delta^{13}C$ within and between individual plants, different species, or growth forms, at a range of geographic and temporal scales. Arens et al. (2000, Table 1) also reviewed ecological factors that affect plant $\delta^{13}C$ values, finding variation of up to 10‰ attributable to CO_2 recycling, low light levels, water stress, osmotic stress and altitude, and up to 5‰ attributable to growth form, deciduousness, sun vs. shade leaves, age and season.

In the Thames Valley, the most important effects on plant $\delta^{13}C$ values are likely to reflect water relations in a generally temperate climate without extremes of temperature or aridity, and the amount and type of woodland, via the canopy effect. Other things being equal, differences of a few per mil might be expected between plants from wet and well-drained habitats, or from open and shaded habitats. There is likely to be seasonal variation in line with temperature and rainfall, and there might also be variation in line with long-term climatic change (see Chapter 3, 1).

2.2.4 Within-plant variation in $\delta^{13}C$ values

Different plant parts may differ in $\delta^{13}C$ values. Fractionation can occur during metabolic reactions following CO_2 fixation, so that compounds differ in their $\delta^{13}C$ values: generally carbohydrates have the highest values, followed by protein, followed by lipids, with differences between carbohydrates and lipids of several per mil. This in turn leads to consistent differences between plant parts depending on their composition (Heaton 1999; Hobbie and Werner 2004; O'Leary 1981; Tieszen 1991). The roots of C3 plants are generally enriched in ^{13}C by 1–3‰ relative to leaves, and grains by 1–4‰ (Cernusak et al. 2009; Hobbie and Werner 2004). Lignin is depleted relative to cellulose so that woody plant parts tend to have lower $\delta^{13}C$ values (Benner et al. 1987; Schweizer et al. 1999). Other factors that contribute to within-plant variation include season of formation of plant parts, because environmental conditions vary over time, and position of leaves within the canopy (Heaton 1999). Where animals (or humans) consume different parts of a plant, these effects are large enough to be taken into account. For instance, pigs may eat more fruits and roots of plants

relative to leaves than cattle, so that the average $\delta^{13}C$ value of pigs' food would be higher than that of cattle feeding in the same environment (even more so if pig diets included mor fungi, see below 2.2.6).

2.2.5 Changes in atmospheric CO_2 over time

Plant $\delta^{13}C$ values depend on both the atmospheric $\delta^{13}C$ value and the atmospheric CO_2 concentration (pCO_2 or p_a), because this would affect p_i/p_a and hence discrimination Δ (Beerling 1996; Körner et al. 1988; Körner et al. 1991; Polley et al. 1993; Schubert and Jahren 2013; Schubert and Jahren 2015).

$\delta^{13}C$ values of modern terrestrial C3 plant tissues range from –37‰ to –20‰ with a global mean value of around –28.5‰ (Kohn 2010; O'Leary 1995). Over the Holocene, following a small reduction at the Late Glacial/Holocene transition, the atmospheric $\delta^{13}C$ value was about –6.5‰ (Leuenberger et al. 1992; McCarroll and Loader 2004). The widespread use of fossil fuels has reduced the atmospheric $\delta^{13}C$ value to about –8‰ at present (Keeling et al. 2005; Kohn 2010; Vaughn et al. 2010). This difference needs to be accounted for when comparing results from modern and ancient ecosystems (e.g. Drucker et al. 2008).

The atmospheric CO_2 concentration rose by about 80 ppmv across the Late Glacial/Holocene transition to a pre-industrial value of about 270 ppmv, which could lead to an increase in Δ of around 2‰, leading to lower plant $\delta^{13}C$ values (Schubert and Jahren 2015). Within the pre-industrial Holocene (about 9500 BCE onward) there was little change in pCO_2. Since the start of large-scale industrialisation around 1800 CE (Crutzen 2006; Smith and Zeder 2013; Steffen et al. 2007) atmospheric CO_2 concentration has risen to about 370 ppmv (Ehleringer and Cerling 1995; Kawamura et al. 2007; Keeling 1986; Keeling et al. 2001; Sigman and Boyle 2000).

Over the period studied here (4000 BCE – 400 CE), the $\delta^{13}C$ value and concentration of atmospheric CO_2 changed little, so plant $\delta^{13}C$ values should show no long-term trend due to changes in atmospheric CO_2 (Leuenberger 2007; McCarroll et al. 2009).

2.2.6 Fungi

Fungi (which are not plants) are mentioned here as potential food for pigs (Hohmann and Huckschlag 2005; Schley and Roper 2003; Skewes et al. 2007). Saprotrophic and mycorrhizal fungi have higher $\delta^{13}C$ values than their substrates and/or plants in several woodland ecosystems. There is considerable variation amongst fungal species, but a reasonable estimate of the ^{13}C enrichment relative to plants would be 4–6‰ (Hart et al. 2006; Henn and Chapela

2001; Högberg et al. 1999; Kohzu et al. 1999; McIlwee and Johnson 1998; Trudell et al. 2004). Saprophytic fungi, deriving their nutrition from dead wood, tend to have higher values than mycorrhizal fungi living in association with plant roots. If pigs (or any other animals) were consuming fungi regularly, it could affect their collagen $\delta^{13}C$ values. Fungi would need to make up 10-20% of the diet (depending on assumptions of the model) to shift pig collagen $\delta^{13}C$ by 1‰ (Hamilton et al. 2009).

2.3 Nitrogen in plants

Terrestrial plants cannot fix nitrogen directly from the atmosphere, but instead take it up via the roots as small soluble compounds ("mineral nutrients"). These may be the products of decomposition of organic matter by fungi and other soil microbes or of fixing of atmospheric nitrogen by bacteria, and plant $\delta^{15}N$ values ultimately depend on soil values which depend on nitrogen cycling in the soil (Handley and Raven 1992; Handley and Scrimgeour 1997; Högberg 1997; Nadelhoffer and Fry 1994). Many plants have "mycorrhizal" associations with symbiotic fungi (Selosse et al. 2006) that (among other things) mediate nitrogen uptake and thus affect plant $\delta^{15}N$ values (Hobbie and Högberg 2012). Some plants are associated with symbiotic nitrogen-fixing bacteria and have characteristically low $\delta^{15}N$ values (see below, 2.3.2). Soil nitrogen cycling is a complex process affected by many environmental biotic and abiotic factors, and plant $\delta^{15}N$ values are correspondingly variable.

2.3.1 Soil nitrogen cycling and $\delta^{15}N$ values

Fractionation occurs during the reactions involved in soil nitrogen cycling, with the products generally depleted in ^{15}N relative to the substrate. Loss of the products, e.g. N_2O resulting from denitrification or NO_3^- from nitrification, leaves soil nitrogen relatively enriched in ^{15}N. Both the $\delta^{15}N$ values of the various nitrogen pools (e.g. soil organic matter, soil solution, plants) and the isotopic fractionation factors vary widely (Pardo and Nadelhoffer 2010). Fractionation factors may be difficult to measure, so often the observed discrimination Δ ($\delta^{15}N_{substrate} - \delta^{15}N_{product}$) is reported. Δ may be quite small (e.g. 0–2‰ for N_2 fixation, 0–5‰ for mineralisation), larger but within a narrow range over several ecosystem types (e.g. 38–40‰ for NH_3 volatilisation), or very variable across ecosystems (e.g. 5–112‰ for nitrification, 11–75‰ for denitrification; Pardo and Nadelhoffer 2010, Table 11.1). The balance between the different processes depends on both physical conditions (e.g. temperature, moisture) and uptake characteristics of the plant community, leading to wide variation in net soil $\delta^{15}N$ values.

Soil $\delta^{15}N$ tends to increase with depth (Evans 2007; Hobbie and Ouimette 2009; Nadelhoffer and Fry 1988). The litter falling from plants is relatively ^{15}N-depleted, and becomes enriched as it moves down the soil profile and is broken down by microbial action, while the breakdown products available to plants tend to be depleted. This suggests that plant $\delta^{15}N$ values could be affected by rooting depth, another source of local variability in plant $\delta^{15}N$ values. In an agricultural context, where cultivated plants are typically short-lived and shallow-rooted, and the soil is regularly tilled, this may be less important (Szpak 2014).

2.3.2 Plant $\delta^{15}N$ values

Plant foliar $\delta^{15}N$ values are typically lower than soil $\delta^{15}N$ values because of fractionation during mineralisation and nitrification of bioavailable N. They also vary consistently according to the mycorrhizal associations of plants (Craine et al. 2009; Hobbie and Högberg 2012); plants associated with arbuscular mycorrhizae (–2‰), ectomycorrhizae (–3.2‰) and ericoid mycorrhizae (–5.9‰) have lower foliar $\delta^{15}N$ values than plants without mycorrhizae. "Diazotrophic" plants that have an association with nitrogen-fixing bacteria in root nodules (e.g. legumes) tend to have lower $\delta^{15}N$ values than other plants (Vitousek et al. 2002), because there is little fractionation associated with nitrogen fixation from the atmosphere, so the $\delta^{15}N$ value of assimilated nitrogen tends towards 0, rather than being enriched relative to air as most soil sources are. There is also some variation within the plant, depending on whether the N source is NH_4^+ or NO_3^-, the site of assimilation, whether a particular tissue is acting as a source or sink for N, and the distribution of macromolecules in different tissues or organs. Fruits, including grains, are systematically ^{15}N-depleted by 1–4‰ relative to leaves and stems (Szpak 2014). This is particularly relevant to estimation of human diets, which may include both animal and plant products: it cannot be assumed that the plant baseline is the same for both domesticated animals and people, if they are eating different parts of the same plants, let alone different plants.

The $\delta^{15}N$ values of the ecosystem pools can be seen as integrating the dynamics of the nitrogen cycle, rather than acting as tracers of particular processes (Robinson 2001). There is therefore no simple correspondence between soil type and plant $\delta^{15}N$ values, but rather heterogeneity at all scales. However, plant and soil $\delta^{15}N$ values are related, and some patterning is observed in the plant-soil system. $\delta^{15}N$ values of soils and plants are correlated with environmental variables, particularly climate, at both global and local scales (Amundson et al. 2003; Handley et al. 1999; Martinelli et al. 1999). Both plant and soil $\delta^{15}N$ values decrease with increasing mean annual precipitation (MAP) and decreasing mean annual

temperature (MAT)with a range of around 12‰, but the difference between plant and soil values decreases with increasing MAT and, less strongly, with decreasing MAP, with a range of around 16‰ (Amundson et al. 2003). The change in soil $\delta^{15}N$ with climate can be explained by the balance of input and loss processes and the attendant fractionations, while the change in plant-soil difference may additionally reflect plant N take-up and assimilation processes (Amundson et al. 2003, pp.5-6). Climate seems to have the greatest effect, but other factors that have been shown to affect soil $\delta^{15}N$ values are topography, parent material, soil age and land-use history.

In general, more "open" nitrogen cycling, with greater inputs, outputs and plant-available N, will lead to higher $\delta^{15}N$ values in soils and plants, while in ecosystems where N is limited and inputs and outputs are small relative to N cycling within the system, soil and plant $\delta^{15}N$ values are lower (Craine et al. 2009; Högberg et al. 2014; Martinelli et al. 1999). This relative enrichment occurs because more N is lost from open systems and routes of N loss are also more likely to be fractionating, so that the $\delta^{15}N$ values of the remaining N pools are likely to be higher. This may be important for animals grazing on grassland on limestone and particularly chalk. These ecosystems are likely to have low N availability, and in addition may have a higher proportion of leguminous species that are able to obtain nitrogen fixed from the atmosphere, both of which will lead to lower plant $\delta^{15}N$ values that may be passed to herbivores. In contrast, agricultural systems with high N inputs from manuring, high nutrient availability and high outputs via crop removal as well as system N cycling, are likely to have elevated soil and plant $\delta^{15}N$ values.

Plants growing in saltmarshes may have considerably higher $\delta^{15}N$ values (Britton et al. 2008, p. 2115), but this habitat is not found in the Thames Valley.

2.3.3 Archaeological implications

Szpak (2014) has reviewed ecological and archaeological studies of nitrogen isotope biogeochemistry, and discusses their application to two larger themes of direct relevance to this study: agricultural practices (use of animal fertilisers, burning of vegetation, tillage) and animal husbandry (grazing intensity and foddering).

Animal dung tends be enriched in ^{15}N compared to diet (about +2‰), while urine tends to be depleted (about –2.5‰) (Sponheimer et al. 2003; Sutoh et al. 1987; Table 1 in Szpak 2014). Animal-derived manures, however, typically have higher $\delta^{15}N$ values than expected, because many of the N cycling processes described in the previous section may act during collection, storage and application (Petersen et al. 1998), especially nitrogen losses from volatilisation

and denitrification. The effect on plant $\delta^{15}N$ varies between animal species – pig manure, for instance, raises plant $\delta^{15}N$ much more than cattle manure, both because of higher initial values and because of higher availability of mineralised (and hence plant-available) N (Bateman and Kelly 2007; Eghball et al. 2002). Measurements of crop plant N isotopes in both current traditional and archaeological systems have clearly shown elevated $\delta^{15}N$ values (up to +5‰ for cattle manure) due to manuring (Bogaard et al. 2007, 2013; Fraser et al. 2011, 2013). It is likely that these elevated $\delta^{15}N$ values will affect domestic herbivores, via crop residues and fallow grazing.

While burning releases nutrients into the soil, much N is lost by volatilisation, though on the other hand N locked up in organic matter may become mineralised and thus available to plants. The observed effects of burning vegetation are variable, depending on the original vegetation and the temperature and duration of fire (e.g. Huber et al. 2013; Schafer and Mack 2010). The commonest pattern is higher foliar $\delta^{15}N$ values (around +5‰) after burning followed by a gradual return to pre-fire values. In the context of this study, it is possible that fire was used in clearing forest or other vegetation to some extent, but the effects on plant and hence herbivore $\delta^{15}N$ values would be relatively transient.

Tillage is unlikely to have contributed greatly to changes in plant $\delta^{15}N$. The increase of $\delta^{15}N$ values with depth is most marked in forests, and may not even be seen in cultivated soils (see above, 2.3.1), so tillage is unlikely to change soil $\delta^{15}N$ values by mixing surface (depleted) and deep (enriched) soil fractions once areas of cultivation have been established.

Herbivore grazing is likely to affect nitrogen cycling in ecosystems including agricultural ones. Herbivores remove nitrogenous compounds from plants and deposit them on soil as urine and faeces, not necessarily in the same places. In this way, domestic herbivores can be an important part of the agricultural system, effectively collecting nutrients in uncultivated areas and importing them to cultivated areas (Bogaard 2012) as well as recycling nutrients within the agricultural system. The effects of herbivore grazing on N cycling in plant communities are not as consistent as the effects of manuring. In some, but not all, studies soil and plant $\delta^{15}N$ values tend to be higher in more intensively grazed areas (Table 2 in Szpak 2014), in keeping with the more open nature of nitrogen cycling (Singer and Schoenecker 2003). In areas where there is high NH_3 volatilisation, such as agricultural contexts with very intensive grazing, the uptake of ^{15}N-depleted gaseous compounds may lower $\delta^{15}N$ values in plant shoots. Acting in the opposite direction to the uptake of ^{15}N-enriched soil compounds, this can cause significant variability in foliar $\delta^{15}N$ within and between grazing areas,

especially if grazing intensity and distribution of animal waste is uneven (Erskine et al. 1998). This may not be relevant to less intensive ancient grazing regimes, however. It seems likely that grazing by domestic herbivores can raise plant and soil $\delta^{15}N$ values, particularly where it is more intensive or long-lasting than in undisturbed ecosystems, and may also raise variability of $\delta^{15}N$ values within the ecosystem.

Foddering is the provision of specific foods to domestic animals. These may be gathered, such as leaf fodder (Haas et al. 1996; Halstead et al. 1996; Halstead 1998; Rasmussen 1989, 1993) or hay, or may be residues from crop processing such as chaff or straw. Nowadays crops such as alfalfa, field beans or maize are grown specifically as fodder in intensive animal management systems, but it is uncertain how relevant that is to ancient management regimes. In general, because cultivated soils and crops are likely to be enriched in ^{15}N, fodder gathered away from cultivated areas might have lower $\delta^{15}N$ values. In support of this, $\delta^{15}N$ values of Neolithic wild red deer and aurochs are generally 1–2‰ lower than those of domestic cattle at the same sites (e.g. Hedges et al. 2013; Lynch et al. 2008), presumably reflecting lower $\delta^{15}N$ values in uncultivated areas.

Domestic herbivore collagen $\delta^{15}N$ values could potentially show considerable variation in $\delta^{15}N$ values according to the amount of their diets derived from areas unaffected by cultivation, pasture grazed at different intensities, grazing on cultivated land (e.g. aftermath or fallow grazing) and crop residues or by-products of crop processing, as well as the proportion of leguminous plants in the diet. Given the variation inherent in each of these sources, it is unlikely that one will be able to pinpoint precise dietary (and hence management or ecological) changes. In association with other information, however, such as crop weed assemblages that indicate crop growing conditions, or insect assemblages that indicate intensity of pasture use, and carefully chosen comparisons, nitrogen isotopes can potentially contribute to the analysis of farming practices and environmental changes.

2.4 Faunal collagen isotope values

Measurements on bone collagen of herbivores can be seen as averaging variation in plant isotope values over the time taken to form the collagen (months to years) and the proportion of that time spent feeding on plants from various habitats with different plant isotope values (Bump et al. 2007). In this thesis isotope ratios in collagen from different animals are compared. Before interpreting differences in isotope ratios between species as reflecting differences in dietary isotope values (and hence use of the environment), we need to consider

whether there are differences in digestive physiology that might lead to consistent offsets. During the breakdown, absorption and metabolism of ingested food there is clearly potential for isotopic fractionation to take place. This will only lead to overall differences in tissue isotope values if enriched or depleted products of metabolism leave the system i.e. are excreted (isotopic mass balance: Ambrose 1991; Hedges and Van Klinken 2000; Martínez del Rio and Wolf 2005).

2.4.1 Digestion

2.4.1.1 Ruminants

The ruminant digestive system depends on bacterial fermentation in the foregut to break down plant cell walls and release cell nutrients. Cattle and sheep are bulk-feeding ruminants, grass and roughage eaters (Hofmann 1989). They are highly adapted to eating and digesting plant foods with a high cellulose content such as grasses (Clauss et al. 2008). Grass is “plucked” using the prehensile tongue or cropped using the lower incisors acting against a hard ridge on the upper jaw, formed into a bolus by the tongue and rapidly swallowed. Further mechanical breakdown (rumination or “chewing the cud”) can take place later (reducing risk of predation) as the bolus can be passed by peristalsis in either direction in the oesophagus. The stomach is highly modified to support microbial fermentation. It is divided into four parts. In the rumen and reticulum liquid is added and food is churned by the muscular walls, while symbiotic bacteria and protozoa break down the cellulose and hemicellulose in the plant cell walls, a process requiring enzymes that mammals are unable to synthesise. The end products of bacterial fermentation are short-chain fatty acids, which are absorbed here and metabolised to glucose in the liver; glucose is not directly absorbed. Most protein is also broken down here to peptides and ammonia which are incorporated into microbial proteins, and amino acids which are later absorbed in the small intestine. Carbon dioxide and methane are produced, and isotopic fractionation can take place at this stage. The contents then pass into the omasum, where water, short-chain fatty acids and minerals are absorbed, and then the abomasum where acid digestion takes place, and microbial protein and undigested protein from the rumen are broken down to peptides. From here contents pass to the small intestine where a large proportion of digestion and absorption of nutrients and water takes place. Peptides are further broken down to amino acids, carbohydrates to glucose and lipids to fatty acids and glycerol, and absorbed. In the large intestine water and salt is absorbed, and finally wastes are eliminated via the anus, including undigested and unabsorbed food and gut bacteria (Stevens and Hume 1995; Van Soest 1994).

2.4.1.2 Non-ruminants

Non-ruminant herbivores lack the ability of ruminants to break down cellulose in stomachs highly specialised to provide a site for bacterial fermentation. Large grazing herbivores such as horses have highly hypsodont teeth that can mechanically break down cell walls, and some bacterial fermentation takes place in the large intestine, but compared to ruminants they are more reliant on digesting cell contents, obtain less energy from cellulose, and instead rely on greater throughput of plant matter (Janis 2008; Janis and Fortelius 1988). The pig, which is of interest here, is not a specialist grazer and has a more mixed diet including plant roots and underground storage organs as well as shoots, fruits, fungi, invertebrates and carrion (Grigson 1982; Schley and Roper 2003). Its teeth are brachydont with low, rounded cusps and its gastro-intestinal tract is much simpler. Digestion begins in the mouth where salivary amylases break down starches to sugars. The stomach is uncompartmented and holds food for a shorter time than in ruminants. In this low-pH environment proteins are broken down to peptides by pepsin, and the stomach contents then pass into the small intestine where peptides are further broken down to amino acids, sugars to glucose, and lipids to fatty acids. These small molecules are then absorbed and pass into the bloodstream. Digesta, including cellulose cell wall fragments, then pass into the large intestine. In the colon some bacterial fermentation of cellulose takes place, though less than for a ruminant of similar body size, as suggested by the much lower production of methane (Jensen 1996). Finally, water and salts are absorbed, and wastes eliminated via the anus (Stevens and Hume 1995). Because of the differences in digestive physiology, pig faeces contain more microbial protein as well as undigested cell walls. This higher protein content compared to ruminant dung helps to explain the greater effect on soil/plant $\delta^{15}N$ of manuring with pig dung (above, 2.3.3).

2.4.2 Isotopic fractionation

There is potential for fractionation at various points in during digestion and incorporation of food.

2.4.2.1 Carbon

For carbon isotopes, much discussion has centred around the difference in $\delta^{13}C$ values between diet and bioapatite in bone or enamel (apatite-diet spacing, $\Delta^{13}C_{apa\text{-}diet}$) or collagen (collagen-diet spacing, $\Delta^{13}C_{coll\text{-}diet)}$. In cattle, bacterial fermentation in the rumen/reticulum produces methane which is depleted in ^{13}C by over 30‰ relative to food (Crutzen et al. 1986; Rust 1981), and carbon dioxide which is correspondingly enriched by c.10‰ (Schulze et al. 1998)). This isotopically enriched carbon dioxide may diffuse into the blood and equilibrate

with dissolved inorganic carbon, eventually raising the $\delta^{13}C$ of developing bioapatite (Metges et al. 1990), thus adding a fractionation factor due to digestive physiology and increasing the apatite-diet spacing. Species which produce large amounts of methane, such as cattle and other ruminants, may therefore be expected to have a greater spacing between the isotope values of dietary carbon and bioapatite than less methanogenic species such as pigs. Passey et al. (2005) showed that this was the case in controlled feeding experiments on a variety of herbivores including cattle (ruminants) and pigs (non-ruminants), where diet compositions were similar. Kellner and Schoeninger (2007) reviewed earlier experimental studies on pigs, rats and mice and data from wild free-ranging fauna, and concluded that the wider spacing between $\delta^{13}C$ values in collagen and apatite in the wild fauna reflected their digestive physiology in which bacterial fermentation was important.

In herbivores collagen shows a shift of about +5‰ in $\delta^{13}C$ compared to diet, while in bioapatite the shift compared to diet is 9.5–13.5‰ (e.g. Ambrose and Krigbaum 2003; Lee-Thorp et al. 1989). The predicted $\delta^{13}C$ enrichment of apatite should be about 8‰ over diet, via equilibration of apatite carbonate/blood bicarbonate /dissolved CO_2 in the blood/expired CO_2 in breath (Hedges 2003). This is not far off observed values, but does not explain the range; also, the difference between collagen and apatite $\delta^{13}C$ ($\Delta^{13}C_{coll\text{-}apa}$) varies systematically with diet, being greater in herbivores than in carnivores, and greater in ruminants than other herbivores (Lee-Thorp et al. 1989; Passey et al. 2005). Krueger and Sullivan (1984) proposed a model in which the proportions of different, isotopically distinct, macronutrients in the diet affect the collagen-apatite spacing because of preferential "routing" to body tissues. Collagen carbon is mainly derived from protein and reflects this preferentially, while apatite reflects the whole diet (Ambrose and Norr 1993; Tieszen and Fagre 1993), including relatively ^{13}C-depleted lipids. Thus, collagen $\delta^{13}C$ values are most strongly influenced by those of dietary protein.

Fernandes et al. (2012), using a compilation of data from animal feeding experiments by Froehle et al. (2010, incorporating data from Kellner and Schoeninger 2007), found that $\delta^{13}C$ values of diet and apatite were strongly correlated, and, assuming that the carbon in apatite was derived from the whole diet, $\Delta^{13}C_{apa\text{-}diet}$ was 10.1±0.2‰. The correlation between $\delta^{13}C$ values of diet and collagen was much weaker, and regression analysis was used to determine the contributions of dietary protein, lipid and carbohydrate (the latter two combined as "energy"). This model gave a regression with a slope of 0.75 (i.e. 75% collagen carbon from dietary protein) and intercept of 4.8±0.2‰ ($\Delta^{13}C_{coll\text{-}diet}$), and the model predictions agreed well

with measured data from Lee-Thorp et al. (1989). The experiments of Jim et al. (2004, 2006) on rats suggested that 50-60% of collagen carbon was routed directly from the diet.

For present purposes, the important question is whether *collagen* ^{13}C is likely to be enriched over diet by different amounts in ruminants (e.g. cattle, sheep) and non-ruminants (e.g. pigs, horses). Cattle and sheep both produce large amounts of ^{13}C-depleted methane compared to pigs (Crutzen et al. 1986; Jensen 1996), because they use bacterial fermentation to break down cellulose. A proportion of the ^{13}C in collagen is derived from dietary carbohydrate via synthesis of non-essential amino acids. Passey et al. (2005) conclude that while $\Delta^{13}C_{apa\text{-}diet}$ should be affected by methanogenesis, $\Delta^{13}C_{coll\text{-}diet}$ should not, because the short-chain fatty acids produced by bacterial fermentation and metabolised in the liver are not enriched in ^{13}C. Nevertheless, some of the amino acids in collagen are synthesised *de novo* ("non-essential") and could include carbon that has equilibrated with ^{13}C-enriched blood carbon dioxide. This effect might be large enough to be detected in ruminants. There is some evidence that ruminant and non-ruminant collagen $\Delta^{13}C_{coll\text{-}diet}$ values differ. Comparison of measured collagen $\delta^{13}C$ values between ruminants and pigs is complicated by potential dietary differences, but grazing ruminants can be compared with grazing, non-ruminant equids. Equid collagen $\delta^{13}C$ values are consistently below those of bovids by 0.5–1.5‰ both for domesticates (e.g. Jay and Richards 2006; Privat et al. 2002; Stevens et al. 2013, and personal observations) and wild populations (e.g. Bocherens 2003; Bocherens and Drucker 2003; Stevens et al. 2010). In the studies cited the grazed plants were (probably) all C3 and there is no suggestion that bovids and equids were using different habitats, so this small but consistent difference may be due to differences in digestive physiology rather than diet, even though the pathway is not clear. By analogy, pig $\Delta^{13}C_{coll\text{-}diet}$ and hence $\delta^{13}C$ might also be lower compared to ruminants, other things being equal, though in practice it is likely that ruminant and pig diets will also differ (see below, 3.3).

2.4.2.2 Nitrogen

The $\delta^{15}N$ values of animal tissues are consistently enriched over diet, by 3–5‰ for bone collagen (Bocherens and Drucker 2003; Caut et al. 2009; DeNiro and Epstein 1981; Minagawa and Wada 1984; Robbins et al. 2005; Schoeninger and DeNiro 1984). The precise metabolic reason for this is still unclear (O'Connell et al. 2012). The non-essential amino acids, i.e. those synthesised *de novo*, are the most enriched in ^{15}N (Hare et al. 1991), implicating fractionation during transamination reactions (Macko et al. 1986) as a mechanism. In mammals, excreted nitrogen is mainly in the form of urea, and this is consistently depleted

in ^{15}N compared to body tissues (Steele and Daniel 1978; Sutoh et al. 1987, 1993). Mass balance arguments suggest that tissues should be correspondingly enriched, as is the case (Ambrose 1991). However, it remains unclear where precisely during protein metabolism and/or urea excretion fractionation occurs.

The ^{15}N enrichment of animal tissues over diet ($\delta^{15}N_{tissue-diet}$, "trophic level enrichment") is widely used to estimate the position of consumers in the food chain. However, diet is not the only factor affecting faunal $\delta^{15}N$ values: there is also variation related to climate and physiology (Ambrose 1991). Sponheimer et al. 2003 found considerable variation in hair keratin $\delta^{15}N$ values between different herbivore species, and also within species depending on the amount of protein in the diet. This study shows the potential for inter-individual variation in $\delta^{15}N$ and $\Delta^{15}N_{tissue-diet}$ values, but it is not clear that collagen values would be as variable in response to short-term changes, since bone collagen integrates dietary values over a longer period than hair keratin. Ambrose (1991) explained differences in $\Delta^{15}N_{collagen-diet}$ between a range of East African mammals by variation in rates of urea excretion that was related to water balance. Plant $\delta^{15}N$ values varied between ecosystems, being positively correlated with temperature and aridity, but this only accounted for about a third of between-species variation in herbivore $\delta^{15}N$. Within ecosystems, drought-tolerant species that were able to produce highly concentrated urine, and therefore conserve water by using less of it for nitrogen excretion, had higher collagen $\delta^{15}N$ values than others, while obligate drinkers that produced less concentrated urine had lower values. Under heat and water stress, herbivores eat less, and the rate of excretion of ^{15}N-depleted urea is higher relative to nitrogen intake than when water is plentiful, leaving body tissues more enriched. The protein and water content of the diet and physiological and behavioural mechanisms for avoiding heat stress also affect animals' drought tolerance, but nevertheless there was a good correlation between maximum osmolarity of the urine and collagen $\delta^{15}N$ values in a range of East African herbivores, as predicted by the urea excretion model.

Herbivores in the Thames Valley are unlikely to be exposed to the extremes of heat and aridity experienced by East African herbivores. Nevertheless, there could be physiological differences between species in drought tolerance, and seasonal or spatial variation in forage quality (nitrogen availability) that could affect nitrogen excretion and possibly collagen $\delta^{15}N$ values.

Sheep are able to produce more concentrated urine than cattle (Ambrose 1991; Hoogendorn et al. 2010), and so would be better adapted to conditions where water availability was restricted. Sheep could be kept further from water and/or need watering less frequently than cattle, and might therefore show slightly higher collagen $\delta^{15}N$ values than cattle even when dietary $\delta^{15}N$ values were similar. The same would apply to the difference between sheep and pigs, which have an even lower ability than cattle to produce concentrated urine (Sjaastad et al. 2010). In this case, though, there are also likely to be dietary differences that could obscure the distinction.

Variation in nitrogen (protein) content of forage or fodder could affect herbivore bone collagen $\delta^{15}N$ values, with $\Delta^{15}N_{keratin\text{-}diet}$ being greater on high-protein diets (Sponheimer et al. 2003a,b). It would be hard to disentangle such variation from variation in diet or in plant $\delta^{15}N$ values and variation due to water availability (if any), though there might well be a regular seasonal effect. It is also likely that bone collagen, which integrates the dietary $\delta^{15}N$ signal over longer than hair keratin, would show a smaller effect. Again, it is not clear whether there would be a predictable or measurable difference between ruminants and pigs, or between sheep and cattle, for this reason.

3 Animal ecophysiology

The domestic herbivores have major ecological functions in early agricultural systems. They import nutrients, obtaining them from wild grasses, browse and other low-quality foods and making them directly available to people via milk, blood or meat. The import of nutrients to cultivated crops via manure is at least as important (Bogaard 2005). They can also be seen as contributing to the dynamics of the system by storing nutrients (the “walking larder”, Clutton-Brock 1989) and by their effects on the landscape, contributing to clearance by reducing or preventing woodland regeneration.

Each of the three major domestic species (cattle, sheep and pig) has its own ecological niche, a term that encompasses both the range of conditions within which a species can survive and prosper, and its role within the ecosystem (Elton 1927; Hutchinson 1957). The niche includes all of the interactions between a species and its biotic and abiotic environment. Here, the main concern is with the “trophic niche”, encompassing food selection and preferences, nutrient assimilation, habitat selection and use, effects on vegetation, and competitive or facilitative effects on other animals – in this case, interaction with people. For the ruminants, cattle and sheep, their different sizes imply that their realised niches are likely to be different (Demment

and van Soest 1985; Illius and Gordon 1987, 1992; Hofmann 1989; Belovsky 1997). Pigs are not ruminants, and are less adapted to grazing or browsing and more omnivorous, though still mainly herbivorous (Schley and Roper 2003). Because of their different trophic niches, each species could be seen as sampling or filtering the environment in a slightly different way. Their collagen $\delta^{13}C$ and $\delta^{15}N$ values reflect their trophic niches, as well as (and probably more than) interspecific differences in physiology, so comparing these values for different species at different times or places can give a more nuanced picture of the environment and the ways in which it is being used and altered by people and their domestic animals.

There are difficulties in inferring the trophic niches of animals 6000 years ago: both the animals and their environments have changed. Much of the information is derived from studies of modern populations, but the wild progenitors of domestic pigs and cattle are both extinct in Britain, and the wild progenitor of the domestic sheep has never lived there. Feral populations descend from domesticated ones that were already more or less genetically distinct from their wild ancestors (Larson and Fuller 2014). Modern wild or feral populations may occupy habitats that are far from their ancestral range (e.g. feral cattle in Australia) or altered to a greater or lesser extent by human activities. Modern husbandry regimes operate under different economic conditions and may be based on very different principles; historical or ethnographic analogies need to be drawn with caution. Similarly, modern habitats may not provide good analogues for ancient ones: for instance, Peterken (1996) has concluded that no primeval forest now exists in Europe. There has been much recent controversy about the hypothesis of Vera (2000), who suggested that the ancient, natural Holocene woodland may have been much more open in structure than previously believed, with the open structure being maintained by large herbivores (see e.g. Bradshaw et al. 2003; Mitchell 2005). This has direct implications for the interpretation of carbon stable isotope values of Neolithic animals.

3.1 Cattle

Cattle are well adapted to grazing, with skull morphology and digestive physiology (2.4.1.1) suited to ingestion and breakdown of large quantities of grass (Clauss et al. 2008). They are classed as bulk-feeding ruminants, grass and roughage eaters by Hofmann (1989). There is some evidence of habitat use and feeding ecology from historical observations of aurochs and from modern observations of feral domestic cattle.

3.1.1 Aurochs feeding ecology

The following is based on the extensive work of van Vuure (2005). The wild progenitor of domestic cattle (*Bos taurus*) is the aurochs (*Bos primigenius;* nomenclature according to

Gentry et al. 2004), which became extinct in Europe in the 17th century, and which is not recorded from Britain after the Bronze Age (Lynch et al. 2008; Legge 2010). The northern limit of the aurochs' distribution in Europe roughly coincided with the southern edge of the boreal forest zone, suggesting that it was adapted to the mixed and deciduous forest zones. The idea of the aurochs as a forest animal comes partly from the recorded circumstances of its latest survival in an extensively forested area in Poland southwest of Warsaw, where it was deliberately protected for hunting. It is quite possible that in the earlier Holocene before major anthropogenic landscape change the aurochs preferred more open habitats, in line with its clear adaptation as a grazer rather than a browser, and that its association with densely forested habitats was the result of exclusion from the agricultural landscape, competition with domestic animals and hunting. Van Vuure (2002, p.7) sees the north-west European landscape as "originally… covered by extensive forests, interlarded with fens and bogs" (*pace* Vera 2000), and suggests that "In a predominantly forested landscape, where it had to compete with two other specialized grazers (viz. European bison and wild horse), it must have been constantly in search of open areas." These open areas could have been, for instance, sedge marshes along watercourses and treefall gaps and glades. Hall (2008) tested the (modern) landscape associations of late Pleistocene and postglacial finds of several species in Britain, and found that finds of aurochs were more commonly associated with low-lying, flat, relatively fertile areas, which may have supported a relatively open forest and marsh vegetation in postglacial times, with openness possibly maintained by large herbivore grazing (Svenning 2002). The medieval Polish accounts (van Vuure 2005) confirm that aurochs were mainly grazers, also eating acorns in autumn and the branches of bushes and trees in winter (and they were fed hay as part of the management regime).

Schulz and Kaiser (2007, abstract) used tooth mesowear to reconstruct the diet of Holocene aurochs in Denmark, and found a shift towards lower abrasion only in the latest period, the Sub-Boreal (c. 5000- 2500 BP). They interpret the previous high degree of abrasion as indicating that earlier aurochs were not using the core areas of dense forests in the Atlantic period, but were restricted to more open habitats and forest margins. The shift towards greater use of forested habitats may have been a response to competition from domestic stock that appeared in the Sub-Boreal (see also Noe-Nygaard et al. 2005, Noe-Nygaard and Hede 2006).

3.1.2 Evidence from modern feral or free-ranging cattle

The domestic cattle that arrived in Britain in the early 4th millennium BC were descendants of cattle domesticated in the Near East perhaps 4000 years earlier (Vigne et al. 2011), and there is little if any evidence that they interbred with the local wild aurochs in Britain or indeed in

Europe (Edwards et al. 2007; Bollongino et al. 2008; but see Achilli et al. 2008, 2009; Stock et al. 2009; Bonfiglio et al. 2010). The genetic history of domestic cattle is no doubt complex and possibly obscured by the late- and post-medieval development of documented breeds, but perhaps we can learn something about their "natural" behaviour and habitat preferences by studying feral cattle, descended from domestic cattle but no longer under the direct control of people (Kilgour 1974, 2012). The best-known example in Britain is the Chillingham herd in Northumbria (Hall 1989, 2006). These cattle preferred "lowland grassland" out of a range of available habitat types, though in certain circumstances "ash/alder woodland" was also classed as attractive (Hall 1988). In the New Forest (Hampshire) free-ranging domestic cattle showed strong preference for grassland habitats, and 70-80% of their diet consisted of grasses, with the remainder mostly heather; woodland was mainly used for rumination and shelter (Pratt et al. 1986, Putman et al. 1987). Freely ranging domestic cattle in mixed habitats in North America show preference for grassland though will browse when they have to (Legge 2010).

Taken together, the evidence suggests that cattle are mainly grazers, though they will also browse if necessary, and can tolerate damp or marshy conditions. In so far as they use forest resources, they are likely to prefer more open areas with more ground cover, whether these are marshy/riverine or not – though the area they can range over is also constrained by water availability.

3.2 Sheep

3.2.1 Feeding ecology

Sheep, like cattle, are ruminants strongly adapted for grazing, classed as bulk-feeding ruminants, grass and roughage eaters by Hofmann (1989). This makes it unlikely that there will be major differences in diet between sheep and cattle, but there may be more subtle effects because of size, water relations or habitat preferences, as well as from differing management. There is less applicable evidence of habitat use than for cattle. Domestic sheep in Britain, whether feral or not, are far from the climate and habitat of their wild progenitor. Many studies are of different, though closely related, species (e.g North American mountain sheep), which differ fundamentally in their social behaviour – the reason why they have never been domesticated (Diamond 2002) – and hence possibly in their use of landscape. Current populations of feral domestic sheep in the Mediterranean (mouflon) or in temperate climates (e.g. in New Zealand or north-western Britain) occupy marginal habitats and may not be good analogues for domestic sheep in early farming.

A potential source of confusion in archaeological assemblages is that fragmentary sheep and goat remains are difficult to distinguish (Zeder and Lapham 2010; Zeder and Pilaar 2010), and are usually grouped together as “sheep/goats”. This uncertainty applies just as much to samples selected for isotopic analysis. Goats are intermediate feeders (Hofmann 1989) with a greater percentage of browse in the diet (e.g. Heroldová 1996) and greater selectivity of plant parts, and could well have diets that differ isotopically from those of sheep. Goat was present in Britain from the early Neolithic (Serjeantson 2011), but in spite of attention to this problem by faunal analysts goat is rare (<5%) or absent at the great majority of prehistoric and Roman period sites, with a few exceptions such as the Uley religious complex (Woodward and Leach 1993). It is possible, then, that a small proportion of the “sheep” sampled for this project are in fact goats. This may add to the scatter in “sheep” values but is unlikely to be a major source of bias in the Thames Valley data.

The wild progenitor (*Ovis orientalis*) of domestic sheep (*Ovis aries*) is a grazer/ bulk feeder, able to use steep slopes as well as flatter areas. Many studies of wild and feral sheep centre around the interaction between feeding, predator avoidance and social behaviour, which all play a part in determining the distribution of sheep within their habitat. Sheep generally show a strong preference for habitats with abundant grazing, even when these occupy only a small proportion of the study area (e.g. Mysterud et al. 1999; Tsaparis et al. 2008), and may use areas of greater cover for shelter rather than feeding. Sheep are tolerant of dry conditions and able to range much further from water than cattle. When plenty of fresh forage is available and heat stress is low they may be able to survive without standing water, though they will be more productive if they can drink (Schmidt-Nielsen 1965). Domestic sheep are susceptible to foot-rot and liver fluke, particularly under wet conditions (though less so on saltmarshes where the pathogens are suppressed), which could make wet pastures less suitable for sheep (Graham and Egerton 1968).

3.2.2 Sheep and cattle compared

The different sizes of sheep and cattle may affect diet selection. Though they broadly occupy similar feeding niches as grazers/bulk feeders, smaller species tend to be more selective and may use higher-quality forage (less roughage, higher nitrogen content) when available. For instance, Grant et al. (1985) studied sheep and cattle grazing together on hill grassland in southern Scotland, and found that there was a higher content of forbs in sheep diets. The differences could be explained by (1) the different heights at which sheep and cattle grazed in relation to differences in plant (part) distribution, (2) the greater ability of sheep to select from fine-scale mixtures, and (3) the greater readiness of cattle to graze tall, more fibrous

components. On American rangelands, feral sheep can range further from water than feral cattle, and tend to have a greater proportion of forbs in their diet, though still predominantly grazers (Schwartz and Ellis 1981). Sheep and cattle using summer graze on rangelands are more productive together than either species alone (Cook 1954), because sheep can utilise shorter swards than cattle and cattle can utilise coarser, taller grasses, which may also facilitate subsequent sheep grazing in these areas.

Both sheep and cattle preferentially select legumes when given a choice between legumes and grass: on an intake basis, offered 50% grass/50% legume they will take c. 70% legume (reviewed by Rutter 2006, who concludes: "This supports the hypothesis that ruminants eat mixed diets in order to balance the supply of nutrients (principally C and N) to the rumen so as to optimise the efficiency of microbial protein synthesis."). Since legumes have $\delta^{15}N$ values that are on average lower than those of grasses and other herbs, their presence and proportion in pasture/fodder could potentially affect sheep and cattle isotope values.

Sheep and cattle may show somewhat complementary use of the overall environment, with sheep able to utilise steeper slopes at a greater distance from water while cattle may deal better with coarse vegetation and wet pasture. If there are consistent differences in plant $\delta^{15}N$ values between local vegetation types – as there may well be for, say, chalk grassland compared to woodland or riverine pasture – this could lead to differences in collagen $\delta^{15}N$ values.

3.3 Pig

3.3.1 Feeding ecology

The wild progenitor (*Sus scrofa*) of domestic pigs (*Sus domesticus*), is still found on the European continent, though wild boar became extinct in Britain in the 17th century (O'Connor and Sykes 2010). Wild boar and feral pigs feed on a wide range of foods, reviewed for European wild boar by Schley and Roper (2003), who found that the bulk of food consumed consisted of plant material. This falls into four major categories: mast (acorns *Quercus* spp., beechnuts *Fagus sylvatica* and sweet chestnut *Castanea sativa*); roots (e.g. of bracken *Pteridium aquilinum*), bulbs and tubers; green plant matter; and agricultural crops (e.g. cereals, potatoes). Wild boar diets always included at least one energy-rich plant food. The volume of animal food in the diet ranged between 2 and 11%, though it was found in over 90% of stomach content samples (Massei and Genov 2004). Among animal foods insects, earthworms and birds and mammals (presumably mostly as carrion) were consumed most

consistently. Diets varied in composition and breadth by season, year and region, largely depending on the availability of different foods. Fungi, which should be widely available in European wild boar habitats, were surprisingly rarely reported: Schley and Roper (2003) comment that this may well be because fungi are rapidly digested compared to plant material and so not often observed in stomach contents or faeces (but see Hohmann and Huckschlag 2005; Skewes et al. 2007). Schley and Roper (2003) conclude that "wild boar are opportunistic omnivores whose diet, in any particular instance, is largely determined by the relative availability of different food types."

Wild boar spend a considerable part of their feeding time "rooting", i.e. turning over the top few centimetres of soil with their snouts and tusks, in search of underground plant parts, insect larvae, earthworms and hypogeal fungi. The effect of this soil disturbance on the environment may be marked, depending on boar density, and both negative and positive effects have been noted: damage to plants by e.g. root exposure, reduction of herbaceous plant cover and local extinction of some species, and soil loosening and erosion on steep slopes on one hand, and on the other hand increases in nutrient cycling and plant species richness, and seed dispersal via faeces (Massei and Genov 2004). In favourable circumstances wild boar are capable of rapid reproduction and increase in population density. At the northern edges of their range they are probably limited by low winter temperatures, snow cover and winter food supply (e.g. Rosvold et al. 2010), and elsewhere by vegetation productivity (Melis et al. 2006). Pigs are not well adapted to hot, arid climates, and require access to water and shade/protection from direct sunlight (though the latter may be less important for wild boar with hairy coats than for modern pale-skinned, hairless pigs).

3.3.2 Pigs and ruminants compared

Though pigs are primarily herbivorous, they are less well adapted to grazing than the ruminants, sheep and cattle, and while fresh grass may constitute a large part of the diet of free-range pigs at some times of year, they eat a much wider range of plant, and other, foods than sheep and cattle. In farming, pigs are to some extent complementary to sheep and cattle, exploiting different niches, and because they breed relatively rapidly, population numbers can be rapidly adjusted to take advantage of plentiful food supply, to offset poor food supply, or to provide meat for particular occasions, or for the market. Meat and fat are the principal products of pigs (apart from manure; Halstead and Isaakidou 2011), since, unlike sheep or cattle, they provide neither milk nor traction. They can effectively recycle nutrients within the agricultural system, making use of a wider range of agricultural surpluses and/or processing wastes than the ruminants, as well as supplying richer manure. They can also feed on human

food waste and excreta where these are not returned to the fields as manure. Traditional systems of pig management such as the *dehesa* system in south-west Iberia (Hadjikoumis 2012) exploit the availability of acorns and other tree fruits to fatten pigs seasonally, and similar systems were used in Britain in the medieval period (Grigson 1982; Rackham 1980), though perhaps not as universally as sometimes supposed (Hamilton and Thomas 2012). It may well be possible to distinguish free-range and more intensive, settlement-based systems of pig husbandry isotopically (Hamilton et al. 2009; Hamilton and Thomas 2012).

4 Causes and extent of variation in faunal isotopes

As shown in the previous sections, variation in isotope values within or between species depends on many factors, some physiological and some dietary. For this project, it is the dietary factors that are of interest, because they reflect the environment and the way it is used. Variation between individuals due to e.g. growth or reproductive state will appear as unexplained variation in the analyses. Here I briefly discuss possible causes of variation in isotope values.

4.1 Within-species variation

Within-species variation in faunal collagen isotope values can be surprisingly high: e.g. at Danebury hillfort, cattle $\delta^{13}C$ and $\delta^{15}N$ values had ranges of 1.7‰ and 4.7‰, respectively (n=39), at least as much as the difference between trophic levels, within one herbivorous species (Stevens et al. 2010a). Some of this variation is attributable to individual physiological variation, and some to variation in dietary values.

4.1.1 Individual physiological variation

Some variation might be expected between individuals because of non-dietary factors such as age, sex, growth, nutritional stress, reproductive state, disease, or physiological changes in response to diet quality or water availability.

4.1.1.1 Age

While there is little evidence that age *per se* affects animal isotope values, some things that change with age, such as growth rate, pregnancy, reproductive parity and suckling/weaning (discussed under diet 4.1.2), may. Effects are more likely to be detectable in $\delta^{15}N$ values because of the relatively large trophic level effect in nitrogen metabolism and excretion.

4.1.1.2 Growth rate, pregnancy, reproductive parity

Martínez del Rio and Wolf (2005) show, using mass-balance models, that if an animal is in positive nitrogen balance (excreting less nitrogen than it assimilates, with the excess incorporated in new body tissues), its $\delta^{15}N$ value should decrease. Though some studies have found no relationship between $\delta^{15}N$ and growth rate (e.g. Minagawa and Wada 1984), there is some evidence for this effect. Jenkins et al. (2001) compared $\delta^{15}N$ in blood of mothers and suckling offspring of several mammalian species, and found that the enrichment over diet $\Delta_{blood\text{-}diet}$ was about 4‰ in mothers and about 2‰ in their offspring (whose diet was maternal milk). Part of the 2‰ difference might reflect the high quality of milk protein, which would also reduce $\Delta_{blood\text{-}diet}$ (4.1.1.5) in infants compared to mothers, but part can probably be attributed to rapid growth/positive nitrogen balance of the infants. This difference should be reflected in collagen $\delta^{15}N$, but is likely to be attenuated because of the slower turnover of collagen compared to blood. Hobson et al. (1993) compared juvenile quail on identical diets that were either sufficient to maintain body weight but not grow, or *ad libitum*, allowing them to grow. They found that the growing quail $\delta^{15}N$ values were significantly lower than those of the "maintenance" group in various tissues, by about 1‰ in collagen. In contrast, Waters-Rist and Katzenberg (2010), in a study of children and adolescents in an archaeological human population (thus avoiding issues of diet quality that might affect infant $\delta^{15}N$ values), found no significant relationships between collagen $\delta^{15}N$ values and growth rate within or between bones. They suggest that this is because collagen turnover is relatively slow even in growing adolescents. The $\delta^{15}N$ values from the lab experiments suggest that collagen $\delta^{15}N$ values might be affected by rapid growth rates by up to around 1‰, but any effect is likely to be less in older individuals and may well be undetectable.

On the same logic, one would expect maternal $\delta^{15}N$ to decline during pregnancy. Fuller et al. (2004) found a negative correlation between growth rate and $\delta^{15}N$ measured in hair in 10 pregnant women, as predicted, with overall changes of 0.5-1‰. This might include changes due to other physiological mechanisms such as urea retention, and the effect might well be attenuated in collagen because of its slower turnover rate. Nitsch et al. (2010) failed to find any effect of parity (estimated as number of recorded births) on rib collagen $\delta^{15}N$ values of 60

women from the Spitalfields cemetery. Modelling showed that while in ideal circumstances effects might be large enough to be detected (around 0.4‰), this depended on collagen turnover rate and time since giving birth.

4.1.1.3 Nutritional stress, disease

When an animal is in negative nitrogen balance, in contrast, its tissue $\delta^{15}N$ values should increase (Martínez del Rio and Wolf 2005). ^{15}N enrichment occurs because of the transamination reactions involved in protein metabolism (2.4.2.2), and an animal which is not obtaining enough protein in its diet catabolises its own tissues, causing further enrichment. Hobson et al. (1993) measured tissue values of $\delta^{15}N$ in female Ross's geese, which during incubation do not feed, lose a significant proportion of tissue mass, and are therefore in negative nitrogen balance. $\delta^{15}N$ increased by 1-2‰ over the 4-week incubation period, as predicted. Fuller et al. (2006) found elevated $\delta^{15}N$ values (up to 1‰) in hair of pregnant women suffering nutritional stress and weight loss due to hyperemesis. It is likely that collagen $\delta^{15}N$ values would be affected, but transiently, and by a smaller amount, because of the longer turnover time. Where disease leads to nutritional stress and/or weight loss, bone collagen formed at the time can show $\delta^{15}N$ values increased by 1-2‰ (Katzenberg and Lovell 1999).

More generally, periods of low food intake, or other stresses leading to weight loss and negative nitrogen balance, could raise animal $\delta^{15}N$ values, but the magnitude of the effect, particularly in collagen, is uncertain – perhaps around 1‰.

4.1.1.4 Sex

The metabolic changes due to pregnancy in mammals affect females and not males, and might give rise to differences in $\delta^{15}N$ between the sexes. In a large sample of humans from the LBK period in Central Europe, female collagen $\delta^{15}N$ values were significantly lower than those of males by 0.2‰ overall (Hedges et al. 2013, pp 354-355). This is a small difference, within measurement error, and female $\delta^{15}N$ values were only significantly lower than those of males at 3/10 cemeteries with large samples; but they were never higher. Several other studies have found that females have lower $\delta^{15}N$ values than males (reviewed in Nitsch et al. 2010), variously attributed to dietary differences possibly linked to status and/or the effect of pregnancy, the latter particularly where there was no significant difference in $\delta^{13}C$. The modelling of Nitsch et al. (2010) suggests that in humans any effect of pregnancy at a population level is likely to be small and only occasionally detectable. In other mammals the same may apply.

Wild mammals may go through periods of poor food supply or stress and subsequent weight loss, which would be expected to increase collagen $\delta^{15}N$ values (4.1.1.2), and in some cases this might apply differentially to the sexes, e.g. during rut in male deer, but I know of no published studies that have found such a difference.

4.1.1.5 Diet quality

In the context of collagen $\delta^{15}N$ values, "diet quality" refers to the suitability of dietary protein in terms of the balance of amino acids, particularly the essential amino acids not synthesised by the body. On high-quality diets (e.g. mothers' milk), close to 100% of the protein will be incorporated, whereas on lower-quality diets more total protein will be needed to supply the essential amino acids, and the excess of other amino acids will be deaminated and excreted, potentially increasing $\delta^{15}N_{tissue\text{-}diet}$ (2.4.2.2). Robbins et al. (2005), in a careful meta-analysis of feeding studies where metabolic requirements for protein were met but not exceeded, found a general trend across trophic levels: animals eating milk or fish (high-quality protein) had lower $\delta^{15}N_{blood\text{-}diet}$ than carnivores (lower quality) or ruminants (lower still). Within trophic levels, or within species, some variation in $\delta^{15}N_{tissue\text{-}diet}$ may be due to the quantity of protein in the diet as well as the quality. In controlled feeding experiments Sponheimer et al. (2003a) found that herbivores on high-protein diets had *higher* $\delta^{15}N_{hair\text{-}diet}$ values, which he explained by the balance of nitrogen excretion/loss between urine (usually ^{15}N-depleted compared to diet) and faeces (usually ^{15}N-enriched compared to diet). Thus, tissue $\delta^{15}N$ values might vary due to both quality and quantity of protein in the diet, and these are likely to vary seasonally and between habitats. It is hard to arrive at an estimate of effect size, but Sponheimer et al. (2003a) found differences of 1.5 – 2.8‰ in $\delta^{15}N_{hair\text{-}diet}$ in their experiments. The consequent $\delta^{15}N$ signal in collagen is likely to be attenuated compared to that in hair and will integrate variation over a much longer time.

Collagen $\delta^{13}C$ may also be affected by the quantity of protein in the diet, because of routing (2.4.2.1). Where there is enough protein in the diet, the $\delta^{13}C$ value of collagen mainly reflects that of protein, but on low-protein diets, some amino acids in collagen are synthesised from other macronutrients and so would reflect their $\delta^{13}C$ values (Jim et al. 2006; Codron et al. 2011). Again, it is difficult to estimate the size of such an effect.

4.1.1.6 Water availability

As discussed above (2.4.2.2) tissue $\delta^{15}N$ values might be higher under conditions of water shortage.

4.1.1.7 How much variation in isotope values can be explained by individual physiological factors?

It is not always easy to disentangle the various effects, even in studies conducted in controlled laboratory conditions, let alone estimate their importance in living or archaeological populations. Many of the factors discussed here might affect $\delta^{15}N$ values by up to 1-2‰ and $\delta^{13}C$ values by somewhat less. This could explain some, but by no means all, of the variation in faunal isotope values seen at sites like Danebury (Stevens et al. 2010a), or in the present study.

4.1.2 Diet

Animal isotope values reflect their diets on an individual and population level. The age-related change due to the transition from suckling to the adult diet (weaning) is mentioned here, as it may have a large effect in young mammals. For this reason, in this study samples were taken from adults only (as far as possible; Chapter 5, 1.2.2), so at a population level results should not be affected. Apart from this, patterns in the isotopic values of animal diets should contain information about the animals' diet composition and feeding environment, which this study aims to interpret.

4.1.2.1 Suckling

In mammals there is a major diet shift early in life as young are weaned, shifting from 100% mothers' milk to a diet closer or identical to that of adults. The difference in diet composition is reflected in offspring tissues and is likely to outweigh the more subtle metabolic effects mentioned above (4.1.1.2, 4.1.1.5). There is a large literature on isotopic changes due to weaning in human populations (Fogel et al. 1989; Fuller et al. 2006; archaeological literature reviewed in Waters-Rist and Katzenberg 2010 pp173-176). Generally infant collagen $\delta^{15}N$ values are 1-3‰ higher than maternal values, and $\delta^{13}C$ values up to 1‰ higher. Jenkins et al. (2001), in a study of a range of mammals, found that overall offspring plasma $\delta^{15}N$ values were about 1‰ higher than their mothers', with some variation reflecting lipid content of milk. Balasse and Tresset (2002) found that calf dentine $\delta^{15}N$ values were up to 2.5‰ higher than the mean adult collagen value at Bercy, similar to human values. The $\delta^{13}C$ values of suckling mammals are also often higher than those of their mothers by about 1‰ (Jenkins et al. 2001, Fuller et al. 2006).

4.1.2.2 Diet

The diets of domesticated animals are controlled by people in both space and time. This may be achieved by controlling animal access to areas of the landscape (foraging) or by provision of particular foods (foddering). Variation in plant $\delta^{13}C$ and $\delta^{15}N$ values can lead to variation in

collagen values, and so where there are systematic differences in plant values across the landscape, and systematic patterns of landscape use by herbivores and the people that manage them, this can be reflected in herbivore collagen values. C3 plant isotope values may vary by up to 10‰ (above, 2.2.3, 2.3.2), and though this variation is averaged over space and time in herbivore collagen (Bump et al. 2007), it could still make a large contribution to variation in herbivore isotope values.

Specifically, plants growing in deep shade may have $\delta^{13}C$ values 5‰ lower than in open areas (Bonafini et al. 2013). Plants growing in well-watered environments may also have $\delta^{13}C$ values lower by about 1‰ than plants in drier environments (Lynch et al. 2008, p. 1032). Fungi (eaten by pigs) have $\delta^{13}C$ values up to about 5‰ higher than plants in the same habitat, and may also have slightly higher $\delta^{15}N$ values (Hamilton et al. 2009). Manuring has been shown to increase plant $\delta^{15}N$ values by up to 10‰ (Fraser et al. 2011; Kanstrup et al. 2011), while nitrogen-fixing legumes have lower $\delta^{15}N$ values than other plants by up to 5‰ (Fraser et al. 2011). Areas of previous cultivation and settlement that have been abandoned have elevated plant and soil $\delta^{15}N$ values years or centuries later (Commisso and Nelson 2010; Koerner et al. 1997). Within-plant variation e.g. between grain and rachis (grain up to 2.5‰ higher $\delta^{15}N$; Bogaard et al. 2013) or sun and shade leaves (shade leaves up to 5‰ lower in $\delta^{13}C$) may also be important.

Considering the range of habitats available to domestic animals in the Thames Valley over the period considered here, it is likely that there is sufficient consistent variation in plant isotopes that they will be isotopically distinguishable to some extent. Dense woodland is likely to have lower plant $\delta^{13}C$ values, for both understorey plants (graze) and lower leaves of trees (browse, leaf fodder). Fungi are likely to be commoner in old woodland with a high proportion of dead wood, and have higher $\delta^{13}C$ and possibly $\delta^{15}N$ values than plants. Areas used for crops are likely to be in more open areas and have higher plant $\delta^{13}C$ values, and to be manured and have considerably higher plant $\delta^{15}N$ values. Areas in and around settlements, even when uncultivated, are also likely to have higher plant $\delta^{15}N$ values because of accumulation of waste from food processing and disposal, excretion and higher rates of nitrogen cycling. Pasture is likely to have higher plant $\delta^{13}C$ values than dense woodland, but $\delta^{15}N$ values may depend on intensity of use, increasing if dung accumulation increases. Wet pasture may have slightly lower plant $\delta^{13}C$ values than drier pasture, though the effect is not as strong as the effect of dense shade. Plant communities with high proportions of legumes (e.g. hay, chalk turf) may have somewhat lower $\delta^{15}N$ values overall, though the effect of this on herbivore

values may also depend on selectivity by the animals. There is some evidence that plant $\delta^{15}N$ values in chalk and perhaps also limestone plant communities are generally lower, either because of tighter nitrogen cycling which reduces nitrogen loss and hence fractionation, or a high proportion of legumes which compete better on nitrogen-poor soils.

4.1.3 How much variation in isotope values can be explained by individual diet variation?

There is clearly scope for a good deal of variation in dietary isotopic values, depending on how resources are used. Differences between habitats are likely to be averaged to some extent because of seasonal variation: for instance, cattle might feed in high-$\delta^{13}C$/low-$\delta^{15}N$ extensive pastures in the growing season, but be given low-$\delta^{13}C$ leaf fodder in winter, and have limited access to high-$\delta^{15}N$ cultivated /manured areas after harvest. Diets of individual animals might also vary because of differential access of their owners to resources (cf. Fraser et al. 2013). At a population level, animal isotope values should reflect the resources available to the site, but there could be a good deal of variation within this at various temporal/spatial scales.

4.2 Between-species variation

Between-species variation in isotope values could reflect differences in digestive physiology and/or in water relations. Consistent differentiation in food selection within habitats or time spent in different habitats could also lead to consistent differences between species.

4.2.3 Physiology

The different digestive physiologies of ruminants versus pigs could lead to pig collagen $\delta^{13}C$ values around 1‰ below those of ruminants, other things being equal, though in practice this would probably be outweighed by dietary differences (3.3.2). The greater drought tolerance of sheep could lead to slightly higher collagen $\delta^{15}N$ values in sheep compared to cattle (3.2.2).

4.2.4 Diet

Cattle and sheep are both herbivorous bulk feeders, with similar diets. Within habitats sheep may be more selective of plant parts than cattle, can nibble shorter turfs, and may eat a higher proportion of forbs (section 3 above), while cattle are better able to eat tall, coarse vegetation. Where there is consistent variation in isotope values between plant parts or communities this might be reflected in herbivore values, but it is hard to assess the overall importance of this variation. The proportion of food derived from different habitats, as forage or fodder, is likely to have a greater effect. Cattle seem better adapted than sheep to shadier and/or wetter environments, where plants would have lower $\delta^{13}C$ values. Sheep are able to range further from water and tolerate more arid environments, which could lead to higher $\delta^{15}N$ values in

sheep, though the importance of this in the Thames Valley region may not be great. Sheep are perhaps more likely than cattle to have access to crop-growing areas, e.g. to graze the aftermath ,or to graze cereals during early growth for weed control, because they are smaller, lighter and less damaging to soil structure. This should also tend to raise sheep $\delta^{15}N$ values compared to cattle. The extent to which sheep and cattle were fed on crop processing wastes such as chaff or straw could be quite variable, depending on their availability, and also on the need to keep animals in good condition (e.g. cattle needed for ploughing), the availability of forage, the access of owners to such resources, and the availability of labour. The same would apply to leaf fodder, or fodder crops including pulses (though there is no evidence for fodder crops in the relevant periods). This could lead to within-species differences in isotope values, but also between-species differences where management was consistently different.

Pigs are more omnivorous than cattle and sheep (3.3). Although mainly herbivorous, they are likely to have a higher proportion of animal protein and/or wastes including excrement in the diet and hence higher collagen $\delta^{15}N$ values. They may, like sheep, have greater access to crop-growing areas than cattle at certain times of year, because they can be useful in turning over soil and reducing crop pests, and because of their omnivorous habits may be useful in consuming settlement wastes. All of these would tend to raise pig $\delta^{15}N$ values compared to ruminants. Pigs may also eat different plant parts compared to ruminants: roots, tubers and fruits tend to be ^{13}C-enriched compared to leaves and stems (2.2.4), and pigs eat underground plant parts and make use of seasonal woodland resources such as mast (beech fruits, acorns). They also eat fungi with considerably higher $\delta^{13}C$ values and possibly also $\delta^{15}N$ values than plants in similar habitats. Feeding in dense woodland would lower pig $\delta^{13}C$ values compared to herbivores feeding in open areas, but this would be counteracted by eating foods that were more ^{13}C-enriched than herbivore diets.

Hamilton et al. (2009) suggested that two possible modes of pig management led to contrasting patterns of pig isotope values in the UK archaeological record. In the free-ranging mode, pigs made considerable use of woodland resources, and were able to consume large amounts of fungi which led to higher collagen $\delta^{13}C$ values, while $\delta^{15}N$ values were not much higher than those of cattle and sheep. In the village-pig mode, pigs spent more time feeding around settlements, and had higher $\delta^{15}N$ values than cattle and sheep, but woodland resources, particularly fungi, were much less available, so their $\delta^{13}C$ values were similar to those of cattle and sheep. The change in patterns of resource use reflected environmental change, specifically the loss of dense primary woodland with high biomass of fungi.

4.2.5 How much between-species variation in isotope values can be explained by diet variation?

There may be small differences in collagen isotope value between cattle, sheep and pigs because of physiological factors, but they do not seem sufficient to explain the magnitude of some differences and consistent patterns that are observed (Chapter 4, Chapter 6). In particular, they cannot explain changes in these patterns over time. Physiological variation is probably more important within species (because of variation over individual life histories) than between species.

5 Conclusion

Consistent patterning in plant isotope values in relation to environmental variation could lead to consistent differences between habitats in plant $\delta^{13}C$ and $\delta^{15}N$ values (2.2,2.3 above). Variation in faunal collagen $\delta^{13}C$ and $\delta^{15}N$ values reflects physiological variation at individual and species level (4.1, 4.2), and also dietary variation (4.1.2), which potentially reflects consistent differences between habitats in plant isotope values. Cattle, sheep and pigs function differently within the agroecosystem (3.1, 3.2, 3.3), each species having its own niche. Changes in the landscape and the way in which people use it will be reflected in patterning of faunal $\delta^{13}C$ and $\delta^{15}N$ values, in ways that this thesis goes on to explore.

Chapter 3

Environmental history of the Upper and Middle Thames

This chapter provides an account of the environmental history of the Upper and Middle Thames. First there is an overview of climate change in north-west Europe from the Neolithic to the Roman period. Then the geological/topographic regions used in the analysis, the palaeohydrology of the river and the environmental history are described, based on several recent reviews. This information is used to generate more detailed research questions.

1 Introduction

The Thames Valley is one of the most extensively studied regions of England in terms of its archaeology and environmental history (Allen et al. 1997; Booth et al. 2007; Hey et al. 2011; Lambrick et al. 2009; Morigi et al. 2011). This provides an essential context in which to investigate the application of stable isotopes to archaeological and environmental questions.

Over the period examined in this thesis, the climate of north-western Europe was gradually cooling (section 2 below). While there is not much scope for large-scale climatic variation within the study area, there are contrasts in geology and topography, and changes in river hydrology over time (section 3 below). Vegetation composition and cover also changed greatly over the period studied (section 3 below), and all of these factors could potentially affect both farming practice and isotope values. The way in which people used the land was both affected by and contributory to changes in vegetation and hydrology (French et al. 2005; Grant et al. 2011; Robinson and Lambrick 1984). Changes in land use and human population density have been inferred from archaeological studies of settlement occurrence, distribution and form, and of land division and enclosure, as well as from environmental evidence. Farming practice has been reconstructed both from environmental evidence and the remains of crops and domesticated animals at sites (Booth et al. 2007; Lambrick et al. 2009; Hey et al. 2011).

Changes in land use and farming practice were also enmeshed with cultural change. Neolithic and early Bronze Age societies are characterised by ephemeral settlement evidence, with most

evidence coming from ritual and ceremonial sites. Between the beginning and end of the Bronze Age, not necessarily at the same time everywhere, there was a profound change, with long-term settlements appearing and extensive, formalised land division. From this time, it is possible to recognise a wide variety of settlement types, and there is increasing evidence for social stratification and specialisation through the Iron Age. Contact with the Roman empire and eventually the Roman conquest of Britain profoundly affected both cultural development and farming practice (Albarella et al. 2008; Booth et al. 2007; Hey et al. 2011; Lambrick et al. 2009; van der Veen et al. 2008).

Within this context, the study of stable isotopes of domestic animals can contribute to our knowledge of the processes underlying changes in the relationship between people and their environment.

2 Climate

The recent reconstruction of global temperature change by (Marcott et al. 2013) shows that after early Holocene warming, temperatures plateaued from 9500 to 5500 BP (7550–3550 BCE), followed by long-term cooling from 5500 till recently, of about 2.0°C in the North Atlantic sector. In agreement, a large-scale synthesis of pollen data by (Davis et al. 2003) shows that over the period 4000 cal BCE to 400 CE the climate of North-Western Europe fluctuated with a generally downward trend from the Holocene thermal maximum, when mean temperature of the warmest month was about 1.5°C higher than the pre-industrial average and the mean temperature of the coldest month about 1°C lower. At a millennial scale variations in the Earth's orbit and tilt account well for European palaeoclimatic variation, but at shorter timescales other factors come into play, such as variations in solar radiation, volcanic activity, and complex feedbacks between ocean, atmosphere, sea ice and vegetation (Wanner et al. 2008). The broad climatic trend encompasses considerable variation in detail and at more local scales.

Temperature is only one way of summarising climate: variations in precipitation and seasonality (the distribution of weather over the year) are also important in determining growing conditions and hence plant species distribution (which is essentially what pollen records reflect). Geographical factors such as exposure, aspect and altitude, geology and soil type are also important locally.

There have been many attempts to link climatic fluctuations with specific archaeological or historical events, usually via their effects on agricultural production (for the timespan

considered here): a few examples follow. Bonsall et al. (2002) suggested that the apparently rapid appearance and spread of agriculture in Ireland, Britain and southern Scandinavia, after a delay of up to a millennium compared to adjacent regions of Europe, was linked to climatic amelioration around the Holocene thermal maximum. Gronenborn (2009) linked Holocene climatic fluctuations and phases of the spread of agriculture and development of Neolithic societies across Europe. At a more local scale, Arbogast et al. (2006) examined detailed evidence from Alpine lake villages, and found that the proportion of wild fauna correlated positively with lake levels, reflecting precipitation, and suggested that the food supply was supplemented by hunting during periods of low agricultural productivity. This study depended on precise dating of linked environmental and archaeological data by dendrochronology, avoiding the problems of "wiggle-matching" between time-series of different kinds of data with different time resolutions and precisions which are inherent in the large-scale examples.

Closer to the Thames Valley, Stevens and Fuller (2012) looked at summed probabilities of direct radiocarbon dates on crop and wild plants, taking these as a proxy for human population (following Collard et al. 2010). These showed a striking pattern, in all regions of Britain, of a steep increase in the summed dates from soon after 4000 cal BCE, peaking around 3700 cal BCE. Dates on cereals fall thereafter, though dates on wild foods decline more gradually, and there is another sharp decline in dates on cereals at around 3350 cal BCE, the transition to the Middle Neolithic. It has been suggested that there was a shift to a more mobile pastoralist society; from the evidence of Stevens and Fuller (2012), there was also a considerable decline in population: "*The most likely explanation for simultaneous abandonment of cereal agriculture and population collapse after 3350 cal BC is climatic deterioration"*. A similar study in Ireland, with careful and critical compilation of dating evidence, shows a very similar pattern of "boom and bust", again (cautiously) linking a decline in dated cereal evidence and afforestation with climate deterioration (Whitehouse et al. 2014).

However, the European evidence fits less well with a climatic explanation. Shennan and Edinborough (2007), Shennan (2009) and Shennan et al. (2013) use this technique to model changes in population in several north-west European countries. Their dates are not confined to plant material, because they are less interested in the details of subsistence change, but a similar pattern of a sharp rise in population with the advent of agriculture, followed by decline, is seen in Poland, Germany, Belgium, and the Netherlands (however, their evidence from Ireland is seriously skewed by including dates which were rejected by Whitehouse et al. 2014). Crucially, although the patterns are similar, they are not contemporary, but reflect the

different dates at which farming was established, and populations are rising or stable after 3300 cal BCE in Germany and Poland while declining elsewhere. Shennan et al. (2013) found little convincing evidence for a climatic explanation. These results require confirmation by compiling rigorously selected dates, but if robust, suggest a pattern common to the establishment of farming communities, in western Europe at least. Patches of environment suitable for the farming system ("niches") are rapidly occupied and exploited and population grows until a limit is reached. At this point lifeways have to adapt and the niche may be extended in various ways: there may be e.g. changes in the crop species spectrum (Colledge et al. 2005), biological changes in domesticates (Larson et al. 2007; Lister et al. 2009), new ways of managing crops and animals (such as increased emphasis on pastoralism), or niche widening by exploitation of different environments. Climate change could be a contributory factor, but is not necessarily a determining one.

Climate proxy data obtained from peat-bog stratigraphies in northwest Europe including Britain (e.g. Barber et al. 2003; Barber and Langdon 2007; Charman et al. 2009; Mauquoy et al. 2008) show changes to wetter/colder conditions at various periods, including at the Bronze Age/Iron Age transition in Britain. This climatic deterioration has been invoked as an explanation for cultural change (e.g. Burgess 1985; Van Geel et al. 1998; but see Buckland et al. 1997). Apart from the inherent problems of correlating stratigraphies from various proxy sampling sites and those from archaeological sites, and of the scale of the observed effects, it is questionable whether climatic change would affect other areas in the same way as marginal Upland Zone settlement. A review by Dark (2006) found little evidence for wholesale abandonment of land across Britain as a whole, or for regional patterning in land-use change, concluding that:

"...there is clear evidence for climatic deterioration in the first millennium cal BC, but the human response in terms of land use was variable...Climate deterioration in the late Bronze Age and Iron Age did not cause widespread settlement abandonment and long-term land-use change across Britain. More sites show an increase than decline of agricultural activity/woodland clearance in this period." (Dark 2006, p. 1392).

While climatic variation undoubtedly can and does affect the success of agricultural regimes it may not be the only explanation for changes seen in the archaeological record.

A related but separate question is whether climate change is likely to directly affect isotope values of plants and hence of herbivore collagen. On the largest scales of millennia, hundreds

of kilometres (Hedges et al. 2013; Van Klinken et al. 1994), or major climate change, there may be detectable effects on $\delta^{13}C$ and $\delta^{15}N$, as seen at the late-Glacial/Holocene transition (e.g. Drucker et al. 2008; Hedges et al. 2004; Stevens and Hedges 2004; Stevens et al. 2008). At smaller scales more local effects are likely to overwhelm any climatic signal – indeed, that is why large datasets are needed to detect it. At a large scale, variation of 2°C in mean annual temperature could have a detectable effect on measured isotope values. Van Klinken et al. (1994) found a significant trend in $\delta^{13}C$ values of archaeological wood, charcoal and bone samples from northwest to southeast in Europe, and significant correlations with variables such as July temperature (positive) and precipitation (negative); the slope of the relationship between bone collagen $\delta^{13}C$ and (modern) July temperature was about 0.2‰ per °C. Similarly, Hedges et al. (2013) found that across the LBK distribution from Alsace to Hungary, $\delta^{13}C$ in faunal collagen was significantly correlated with mean summer temperature, and the slope of the relationship was about 0.3‰ per °C. Many studies in plants, including historic series of tree rings (Table 1 in Heaton 1999; Leavitt et al. 2010) show similar relationships. Climatic effects on the C3 plants at the base of the foodchain are likely to be passed on to herbivores and higher trophic levels. While the Thames Valley region is not expected to show significant spatial variation in climate (statistically tested in Chapter 6), it is possible that, over the period covered by this study, there could be a trend to slightly more depleted $\delta^{13}C$ values in collagen of up to 0.5‰ due to a cooling climate. Relationships between $\delta^{15}N$ and climate are much less clear-cut, at least where extremes of aridity or temperature are not involved, though in general one would expect a positive correlation with temperature and negative correlation with precipitation, other things being equal (Chapter 2; Pardo and Nadelhoffer 2010).

3 Environments in space and time

The following sections draw heavily on recent reviews of the evidence. The environmental history of the gravel terraces of the Middle and Upper Thames valley has been reviewed in Booth et al. (2007), Lambrick et al. (2009), Morigi et al. (2011) and Hey et al. (2011). The environmental history of the chalk downlands, including the Berkshire Downs, has been reviewed by Allen and Scaife (2007) and Allen and Gardiner (2009). The environmental history of the Cotswolds is less well characterised (Straker et al. 2008; Wilkinson and Straker 2008) but has been studied at the two Cotswold sites included here (Benson and Whittle 2007; Meadows et al. 2007; Saville 1990).

3.1 Regions of the Thames Valley: geology and soils

The Upper Thames extends from its source near Cirencester, draining the Jurassic limestone hills of the Cotswolds, to the Goring Gap where it divides the Cretaceous chalk Downs from the Chilterns. The Middle Thames extends from the Goring Gap to the uppermost tidal reach of the river near Kingston (Fig. 3.1). For the purposes of this study, the Upper Thames region is defined as the area within the catchment of the Upper Thames river and its tributaries, including the dip slope of the Cotswolds, the Oxford Clay vale, and the Corallian ridge. The Middle Thames region is the area within the catchment of the Middle Thames and its tributaries, including the dip slopes of the chalk Downs and Chilterns.

Below the Cotswolds, the Upper Thames meanders across the low-lying Oxford Clay vale, flanked by extensive river terrace deposits of calcareous gravels mainly derived from the Cotswold limestones. The terraces formed as a result of changes in flow of the river over a series of large-scale Pleistocene glacial/interglacial climate episodes and accompanying changes in sea level. The lowest level is the current floodplain, flanked by the successively older and higher first (Northmoor or “floodplain” terrace), second (Summertown-Radley) and third (Wolvercote) terrace. Patches of higher and older terraces also survive (Morigi et al. 2011). Much of the archaeological evidence (including most samples analysed for this project) comes from these gravels (Allen et al. 1997), from both ceremonial and domestic sites.

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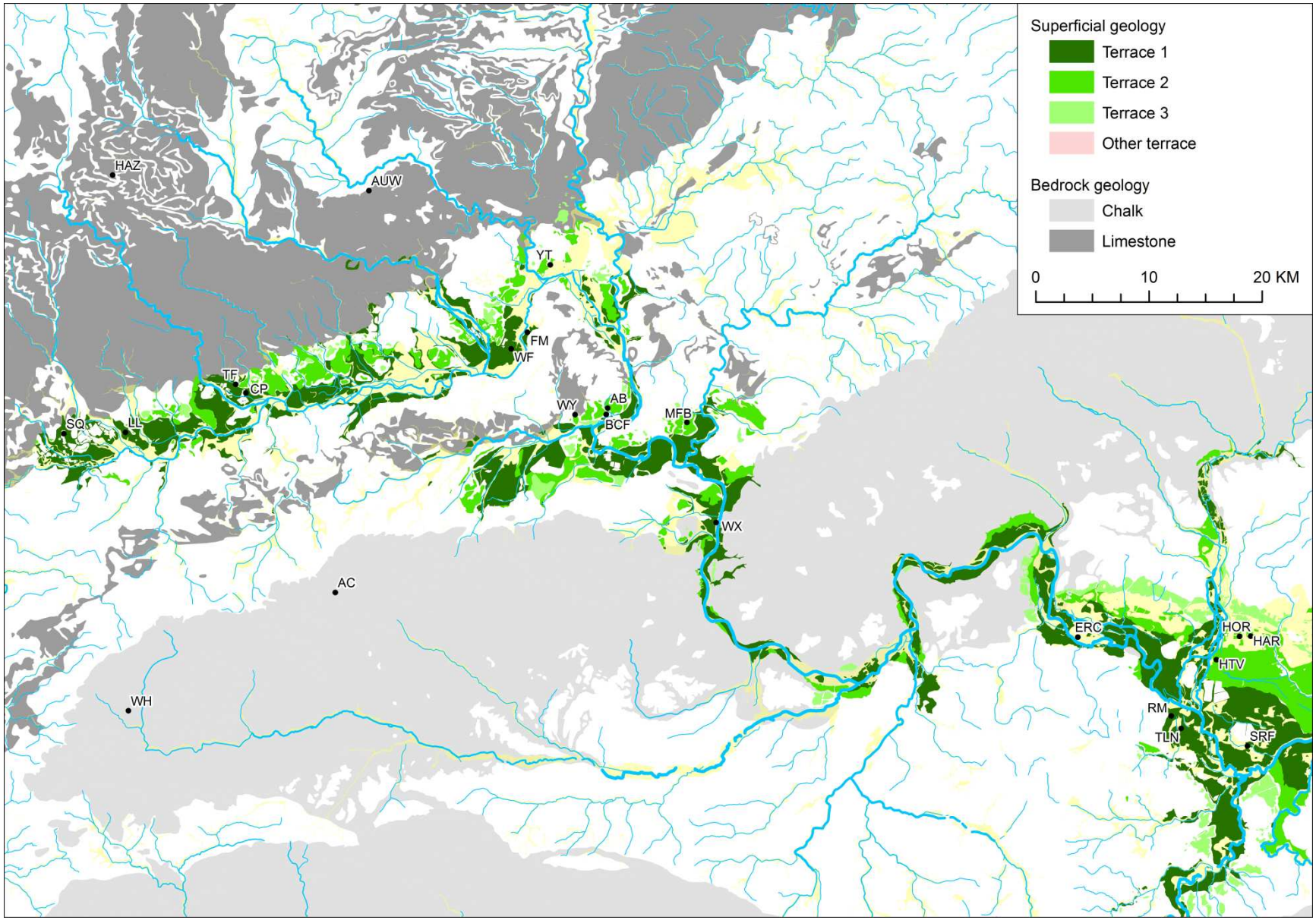
Fig. 3.1 Map of the Upper and Middle Thames Valley showing the sites included in this study in relation to geology. Site abbreviations: *AB* Abingdon Causewayed Enclosure, *AC* Alfred's Castle, *AUW* Ascott-under-Wychwood, *BCF* Barton Court Farm, *CP* Claydon Pike, *ERC* Eton Rowing Course, *FM* Farmoor, *HAR* Harlington, *HAZ* Hazleton, *HTV* Heathrow Terminal 5, *HOR* Horton, *LL* Latton Lands, *MFB* Mount Farm Berinsfield, *RM* Runnymede, *SQ* Shorncote Quarry, *SRF* Staines Road Farm, *TF* Thornhill Farm, *TLN* Thorpe Lea Nurseries, *WF* Watkin's Farm, *WX* Whitecross Farm, *WH* Windmill Hill, *WY* Wyndyke Furlong, *YT* Yarnton


Superficial geology
Terrace 1
Terrace 2
Terrace 3
Other terrace
Bedrock geology
Chalk
Limestone
0
10
20 KM
HAZ
AUW
YT
FM
WF
TF
CP
SQ
LL
WY
AB
BCF
MFB
WX
AC
WH
ERC
HOR
HAR
HTV
RM
TLN
SRF

The soils developing on the Cotswold limestone are calcareous and easily worked, but often shallow and brashy (with broken rubbly rock between the soil and the subsoil), while the soils on Oxford Clay are relatively intractable and may suffer from impeded drainage, though they can be cultivated and today are mostly ploughed. On the gravel terraces the original soils were light, free-draining, stone-free argillic brown earths, which have since had limestone gravel incorporated by cultivation, countering a tendency to acidification. The alluvial clays of the floodplain have mainly been deposited in the last 2000 years (see below, 3.2) and seal thin soils over gravel (Robinson 2011). On the Corallian ridge, between the Downs and the river, thin calcareous soils developed on the overlying limestone, lighter and more acid soils on the Greensand, and heavier soils on the clay (no sites on the Corallian ridge were sampled).

South of the Goring Gap, the chalk ridge of the Downs drains into the Kennet, which joins the Middle Thames at Reading. On the Chalk, thin, free-draining alkaline rendzina/brown earth soils developed, with less tractable and more acidic soils developing over patches of clay-with-flints. The Middle Thames crosses a low-lying vale underlain by sands and clays, flanked by extensive terraces. The younger terraces, homologous to those of the Upper Thames (Shepperton, Taplow, and Lynch Hill terraces), are mainly formed from flint eroded from the Chalk (Morigi et al. 2011).

The soils developing on the Middle Thames gravels were light and free-draining, but in contrast to the Upper Thames, usually acidic, as were those on the London Clay. This has implications not only for vegetation and agriculture, but also for the survival of bones and collagen, which is lower in more acid conditions. The Middle Thames floodplain has similar alluvial clay soils to those of the Upper Thames (Robinson 2011).

For the purposes of analysis, I have distinguished four regions in the Upper Thames valley, based on geology, soils and topography: floodplain, 1st terrace, 2nd terrace (including higher terraces) and Cotswold limestone. The four regions of the Middle Thames are floodplain, 1st terrace, 2nd terrace (including higher terraces) and chalk (Fig. 3.1; Chapter 5, 4.3.2).

3.2 Palaeohydrology of the Thames

By the start of the Neolithic in the early 4th millennium cal BCE, the river regime in the Upper Thames valley was fairly stable, with little evidence of large-scale channel migration. Soils were forming on the floodplain, which at this stage was free-draining with a seasonally low water table and little if any overbank flooding. In the Early Bronze Age (c. 2500–1500 cal BCE) conditions remained similar: even low areas were above flood levels and the floodplain

had much in common with the first gravel terrace. In the Middle Thames, there were zones of palaeochannel migration and backswamp formation early in the Holocene in the lower areas of the floodplain, which received a covering of alluvial clay (the Staines Alluvial Deposits), making them distinct from the first gravel terrace. In both the Upper and Middle Thames the river was unmanaged and well-vegetated with clean, calcareous water throughout the Neolithic and Bronze Age (Robinson 2011).

From the Middle Bronze Age onwards, there is evidence of rising water tables. It is possible that water tables were also rising in the Middle Thames region, though harder to detect because the floodplain was already wet. In the Upper Thames the rise in the water table continued into the Iron Age, with seasonal flooding evidenced by the appearance of causeways and drainage ditches, though from biological evidence the water was still clear with low sediment loads. In the Middle Iron Age (around 150 cal BCE) the character of flooding changed, with increasing alluviation, and this continued into the Roman period. It is likely that developments in the Middle Thames were similar.

The rising water table and onset of clean-water flooding in the Upper Thames reflects extensive tree clearance in the catchment, which would increase run-off and surface water flow (Robinson and Lambrick 1984, 2009a, pp. 31-33). The onset of general alluviation from the Late Iron Age onward is attributed to increasing cultivation, exposing soil and increasing erosion, especially on the slopes of the region which had previously mainly supported woodland or grassland. As discussed above, changes in climate have also been implicated, with episodes of cooler and wetter climate in the 1st millennium cal BCE which may have led to higher rainfall in the Upper Thames and contributed to flooding and erosion. Robinson and Lambrick (1984, 2009a) argue that water tables began to rise before the climatic downturn, and that the extent of flooding and alluviation were greater in the Roman period when the climate was warmer and drier again. Thus while climate changes have contributed to the hydrological changes, the main factor was the environmental impact of expanding clearance and cultivation by people in the Thames catchment. Macklin et al. (2005) identify a climatic “system switch” at around 1050 cal BCE (3000 cal BP, Late Bronze Age) related to widespread increases in frequency and severity of flooding in catchments throughout Britain, suggesting climate forcing; this does seem to be later than the start of rising water tables in the Upper Thames. Two other episodes of increased flooding, around 600 cal BCE (2550 cal BP, Early Iron Age) and 300 CE (1650 cal BP, Roman period) occurred at times of warmer, drier

climate, and therefore suggest “a greater importance of human activity and land-use changes as factors controlling flooding during this period”.

3.3 Vegetation and land use

3.3.1 Sources of evidence

The palaeoenvironmental evidence for the Thames Valley comes from various sources: palaeosols, pollen profiles, waterlogged sediments, carbonised plant remains, molluscs, and animal bones (Hey et al. 2011, pp.160-161).

Palaeosols. Most palaeosols on the Thames gravels have been destroyed by subsequent ploughing, but some survive under alluvial or colluvial (terrace-edge) deposits. On the limestone and chalk uplands, palaeosoils may be sealed under monuments such as barrows and give useful information on local environments and land use at the time of building.

Pollen profiles. There are not many available for the Upper Thames, because developing peat surfaces are generally lacking and the soils are often calcareous, though some pollen is preserved in waterlogged sediments. An exception is Daisy Banks Fen near Abingdon where sediments span the 4th to the mid-2nd millennia cal BCE (Parker 1998). Some non-waterlogged sites on the terraces of the Middle Thames have deposits acidic enough to preserve pollen. Since much of the pollen data comes from archaeological sites (in contrast to many areas in the north and west of Britain), there is a bias in the evidence towards the areas with known archaeological sites, and knowledge of vegetation away from such areas is sketchy.

Waterlogged sediments. Waterlogged sediments in deep archaeological features are very rare on the gravels before the Middle Bronze Age, and are also found in palaeochannels on the floodplain some of which have experienced sedimentation from the Neolithic onwards. Waterlogged sediments yield palaeobotanical evidence from pollen, macroscopic plant remains including seeds, leaves, twigs and wood (Jacomet 2012), and also insect remains. Insects are extremely useful in identifying e.g. old woodland with its characteristic dead-wood and other specialist fauna, grassland used for grazing (proportion of dung beetles) and the occurrence of synanthropic faunas from settlements (Carrott and Kenward 2001). Again, there is bias in the evidence towards areas used by people, or where archaeological sites are more easily found, and less information about the hinterland.

Carbonised plant remains. These are common on occupation sites and are often recovered by sampling and flotation. Charcoal can often be identified to species and deposits of carbonised

cereals give information about crops grown and cereal processing, while weed seeds can give insight into cultivation conditions and methods, though interpretation of such assemblages is not uncontroversial (Stevens 2003; van der Veen and Jones 2006; Van der Veen 2007).

Mollusc shells. Preservation of mollusc shells, both aquatic and terrestrial, depends on pH, and they do not survive well in acidic conditions. As Thames water is calcareous, shells often survive in palaeochannel sediments, and on limestone or chalk soils that have not decalcified snail shells often give useful environmental information (Davies 2008; Evans 1972).

Animal bone. Preservation of animal bone is similarly dependent on pH. As well as the obvious information on subsistence obtained from bones of domestic or prey animals, bones of smaller species such as mice, voles and amphibia can give environmental information (O'Connor 2000). While animal bone is generally well preserved in the Upper Thames, collagen preservation can be very poor at sites where water tables have varied, and in the Middle Thames this problem is exacerbated by the more acidic nature of the gravels.

3.3.2 Neolithic

By 4000 cal BCE the climate had stabilised at 1-2°C warmer than the (pre-industrial) present, with higher rainfall than previously, and vegetational succession had reached a climax mixed woodland community. Many lines of environmental evidence suggest that forest cover was extensive at the start of the Neolithic in southern Britain. (Bennett 1989; Godwin 1975; Peterken 1996; Woodbridge et al. 2014). There are two contrasting interpretations of its structure: the “high forest” hypothesis (Birks 2005), implying a closed canopy with relatively few open habitats and low large-herbivore populations (e.g. Godwin 1975; Peterken 1996), and the “wood pasture” hypothesis (Vera 2000) where grazing and browsing by large ungulates leads to a shifting mosaic of open and wooded habitats. Palaeoecological evidence favours the closed-canopy hypothesis for pre-Neolithic Britain (Mitchell 2005; Svenning 2002; Whitehouse and Smith 2010). Although it also indicates the presence of locally significant open areas, the role of grazers in maintaining these seems to be minimal (Whitehouse and Smith 2010). Over the Neolithic period (c. 4000-2500 cal BCE) open conditions became more extensive at the expense of woodland. The evidence from early Neolithic sites often suggests locally open habitats, whether these were clearings or clearances (Allen 2005, p. 83; Brown 1997).

In the Thames Valley much of the evidence comes from at or near the sites themselves, and may therefore be biased towards open areas, while the extent of woodland in the “hinterland” is often unclear; excavated sites in the Upper Thames are highly concentrated on the gravels,

for various reasons (Allen et al. 1997). At Hazleton North on the Cotswold limestone (Saville 1990; Meadows et al. 2007) primary lime woodland was cleared by 4080–3800 cal BCE, and cereals cultivated in small plots. By the time of barrow construction in 3695–3650 cal BCE, cultivation had ceased and hazel scrub dominated the vicinity. At Ascott-under-Wychwood, too, a pre-barrow clearance episode was followed by woodland regeneration (Benson and Whittle 2007). The progressive clearance of the landscape may have proceeded patchily, possibly with a shifting mosaic of grassland /scrub /woodland reflecting land-use at local scales (Smith 1984); there is frequent evidence of episodes of clearing and regeneration. Tree-throw holes at Drayton were interpreted as resulting from deliberate clearance in the early to middle Neolithic related to construction of the cursus, and again in the late Neolithic/early Bronze Age when there was occupation at the site (Barclay et al. 2003). On the chalk Downs, Allen and Scaife (2007) have questioned whether the original forest cover was dense and complete, suggesting that there may have been areas of more open park-like forest or even grassland. Again, the evidence tends to come from archaeological sites, which may well have been concentrated in more open areas.

The Elm Decline, characterised by a substantial fall in the proportion of elm (*Ulmus* sp.) pollen, has been widely observed over north-west Europe (Clark and Edwards 2004; Huntley and Birks 1983; Iversen 1941; Rackham 1980; Ten Hove 1968; Troels-Smith 1960). There is often a coincident rise in the proportion of grass (Gramineae) pollen and the appearance of pollen of light-demanding herbs such as ribwort plantain (*Plantago lanceolata*), and there may also be evidence of anthropogenic effects including a rise in charcoal and the appearance of cereal pollen (Parker et al. 2002). It was originally interpreted as due to climatic change, and indeed used as a marker for the start of the "Sub-Atlantic" pollen phase (e.g. Iversen 1941). Troels-Smith (1960) suggested that the elm decline was caused by the use of elm as a fodder plant by early farmers, and that it marked the appearance of the Neolithic in north-west Europe. While there is direct evidence for the use of leaf fodder at Alpine lake villages and in north-west Europe (DeForce et al. 2013; Haas et al. 1996; Rasmussen 1989, 1993) there is none that I am aware of from Britain. Alternatively disease could have been responsible (Clark and Edwards 2004; Watts 1961). Parker et al. (2002) reviewed the nature, timing and extent of the elm decline in Britain and Ireland, and showed that the elm decline across the British Isles was a "catastrophic uniform phased event", compatible with the idea of disease as a major factor, but also that it was probably the result of a unique and complex set of interrelated factors also involving human impact and climatic change:

"The broad correlation between the timing of the elm decline and the Mesolithic–Neolithic transition in the British Isles is unlikely to be mere coincidence, and we propose that human activity played an important role in dispersing disease via clearances that increased the habitat of the elm bark beetle...it is likely that the precise combination of factors varied from site to site and from region to region, in which case there may be no universal explanation that applies to all sites featuring the elm decline." (Parker et al. 2002, p. 28)

Farming communities may well have taken advantage of clearings arising from the death of elm trees, however caused. Further detailed analysis of pollen sequences accompanied by precise dating of changes and improved statistical methods (Parnell et al. 2008) may help to refine or even resolve the debate in Britain and in other areas of Europe.

In the Thames Valley the elm decline appears in several pollen diagrams dated to the early 4th millennium cal BCE. In the Upper Thames valley, at Daisy Banks Fen, Abingdon it was followed by substantial and permanent clearance, and closely followed by the appearance of cereal pollen (Parker 1998), while at Sidlings Copse, Beckley there was no more than a slight reduction in woodland shading (Day 1993). In the Middle Thames, at Thames Valley Park, Reading, it was close to the start of arable and pastoral agriculture as indicated by cereal-type pollen, weeds of cultivation and grassland plants such as *Plantago lanceolata* (Barnes et al. 1997), while at Moor Farm, Staines there was only slight evidence for woodland disturbance (Keith-Lucas 2000). At Runnymede there was no evidence of the elm decline, but while the coleopteran fauna was typical of old woodland with no hint of clearance, there was a steep rise in the occurrence of scarabaeoid dung beetles, possibly feeding on the dung of domestic animals grazing in woodland (Needham 2000). There is no universal pattern that applies to every site.

Domestic animals are also likely to have had impacts on the dynamics of woodland vs clearing. The habitats most suitable for people with their crops and animals would be early successional, with rapid nutrient cycling allowing relatively high offtake as crops, gathered resources, graze and browse. The greatest variety of resources would be found in woodland edge habitats, which would increase in relative frequency as woodland became fragmented – the consumption of hazelnuts, for instance, is common on Neolithic sites (Moffett et al. 1989; Robinson 2000). While human population density is low, the amount of usable land may not be limiting, and the activities of domestic animals may promote and maintain clearance even without deliberate tree removal by people, opening up the forest around clearings in line with

population growth of both people and their stock (Buckland and Edwards 1984; Reimoser and Gossow 1996).

As pointed out in Lambrick et al. (2009, p.56), the effects of grazing pressure would vary through the year because of the annual variation in the growth rate of vegetation between the dormant winter period and the spring, summer and autumn growing season. Over winter much more land is required to feed a given amount of stock than in the growing season, which would be the limiting factor in expansion of flocks and herds. A higher density of stock could be kept through the winter if grazing and browsing were supplemented by stored leaf fodder and/or waste from processing of cereals or other plant crops, and grazing could also be managed to provide foggage (grass that has been allowed to grow tall by undergrazing in summer). Winter feeding and protection from predators allow domestic stock to be kept at a greater density than wild herbivores in the same areas (Bradshaw and Mitchell 1999). The subsequent reduction in tree regeneration because of domestic herbivore activity is important in opening the landscape (Reimoser et al. 1999), tipping the dynamics of the system in favour of the early-successional habitats suitable for Neolithic occupation. Perhaps the high density of domestic stock triggered cycles like those of the Vera model, which could become a runaway cyclical process, leading to population growth of both people and their flocks and herds (Robinson 2014).

The main cereal crops were emmer (*Triticum dicoccum*) and 6-row hulled barley (*Hordeum hexastichum*), with little evidence for pulses; flax (*Linum usitatissimum*) first appears in "Neolithic/Bronze Age" contexts (Tomlinson and Hall 1996). Weed floras suggest that Neolithic cereals were intensively cultivated in long-term, manured plots (Bogaard and Jones 2007). This is somewhat at odds with the lack of evidence for long-term settlement or enclosure, but in line with suggestions of repeated visits to particular areas (e.g. Eton Rowing Course, Allen et al. 2013).

Robinson (2011, p. 186) concludes that

"the overall impression of the landscape of the Middle and Upper Thames valley throughout the Neolithic is of a patchwork of stands of relatively undisturbed woodland: alder on the wettest areas of the floodplains but with lime and oak usually prominent on the gravel terraces; more open woodland in which domestic animals sometimes grazed; areas of grassland, some grazed, some with ceremonial monuments; a very few cultivation plots; and areas of thorn scrub."

Some areas, particularly around ceremonial complexes, remained permanently open, but most areas saw cycles of clearance and regeneration; areas on the clay slopes may have retained forest for longer.

Such a picture can perhaps accommodate both the steep population rise of the early Neolithic (Woodbridge et al. 2014), based on crop cultivation in small, intensively used patches, with the use of domestic animals to maintain fertility by importing nutrients from uncultivated habitats, whether woodland, scrub or grassland, and also the subsequent shift at around 3350 cal BCE, as described above, after which finds of cereal grains, and indeed any kind of storage or settlement, become rare (Stevens and Fuller 2012). This may represent a more extensive, pastoral, mobile lifestyle, with types of occupation that are archaeologically less visible. This in itself may bias the radiocarbon record on which population estimates are based, and it seems unlikely that cultivation ceased entirely – and there were certainly enough people, with their flocks and herds, to continue the building and use of ceremonial complexes and monuments, which may have increased in importance as gathering places if lifestyles were indeed more mobile.

3.3.3 Bronze Age

Evidence for environmental change in the Early Bronze Age (2500–1500 cal BCE) is sparse. Robinson (2011) sees this period as characterised by clearances on a larger scale and more likely to be permanent than in the Neolithic, especially on the Thames gravels, resulting in a landscape of lightly grazed grassland with thorn scrub, few cultivation plots and no evidence of field systems. Much woodland probably remained on the gravel terraces between monument complexes and in the tributary valleys, as well as in the hinterland.

The main cereal crops in the Bronze Age were spelt wheat (*Triticum spelta*), while emmer became less common, and 6-row hulled barley (*Hordeum vulgare*). Some new crops appear e.g. rye (*Secale cereale*), field bean (*Vicia faba*) and opium poppy (*Papaver somniferum*).

Environmental evidence for the Middle Bronze Age (1500–1000 cal BCE) in the Upper Thames is provided by pollen, insect and plant remains from fens, palaeochannels and monuments, and increasingly from waterlogged deposits from waterholes associated with settlements and fields marked out in the landscape. While there were still traces of mixed woodland and scrub (or hedges), the landscape around these sites was generally open. At Yarnton, there were moderately high proportions of scarabaeoid dung beetles, reflecting domestic animal grazing, and there were seeds characteristic of “a grazed variant of the damp flowery meadows MG5 and MG6 of the National Vegetation Classification (Rodwell 1992)”

(Lambrick and Robinson 2009, p. 36). Further up the river, at Latton Lands and Shorncote, there was more evidence for oak/lime/hazel woodland as well as scrub. Though gravel terraces of the main Upper Thames valley downstream of Lechlade had perhaps been largely cleared, there was probably still much woodland on terraces and floodplain of upper reaches of the valley, and in tributary valleys. Cereal pollen and weeds of disturbed ground attest to cereal cultivation. In the Middle Thames, there is a similar picture of rather open landscapes, including grassland, mixed scrub and cultivated land, though at some sites with higher levels of bracken, reflecting acidic soils and relatively low-intensity grazing. At Perry Oaks/Heathrow Terminal 5 there were high proportions of scarabaeoid dung beetles, reflecting a concentration of grazing animals, and also crop remains in some of the waterholes, as well as the earliest appearance of a beetle community characteristic of timber buildings and indoor spaces (Robinson and Lambrick 2009).

From the Middle Bronze Age onwards, in the Middle Thames and the Upper Thames valley downstream of Oxford, evidence of large-scale landscape organisation starts to appear, with linear boundaries and extensive systems of coaxial fields (Lambrick et al. 2009, Chapter 3; Yates 1999). Upstream of Oxford, at Yarnton and Cassington, possible boundaries have been found, but little or no evidence of fields. Evidence of cereals and other crops also became more plentiful, and populations were also on the rise; Stevens and Fuller (2012) suggest that: "*Rather than the Neolithic, it is perhaps the Middle Bronze Age that represents the real agricultural revolution for the British Isles, a period that established the subsistence base that supported the persistence of landscape modifications, agricultural population and social hierarchy over the millennia that followed.*"

These trends continued through the Late Bronze Age (1000–750 cal BCE). By the end of the late Bronze Age, the landscape of the Thames valley was more open, and larger areas of the gravel terraces were under cultivation. There were still expanses of lightly grazed grassland between settlements, and evidence of coppiced and managed woodland. The extent of clearance in the hinterland is uncertain. Waterlogged botanical evidence from the wells and waterholes that frequently occur scattered through Bronze Age field systems suggest that enclosures were mainly concerned with grassland management. Lambrick (2009) points out that a much greater area of enclosed land would be required to support a family's animals through the unproductive winter months than to grow crops in summer. He suggests that population growth raised pressure on the available cleared land, which stimulated both new clearance and more intensive use of available grazing resources. Land division might come

about as a way of formalising arrangements for sharing resources, and the proliferation of wells and waterholes, and scattered evidence of domestic occupation, suggests that this was on the basis of a small social unit such as a family. Cultivation would still be of the intensive, horticultural type suggested for the Neolithic (Bogaard and Jones 2007), and could take place within the field systems, which might also function to separate animals and crops at critical seasons, and to control manuring. This is also the date of the island sites with middens at Whitecross Farm in the Upper Thames and Runnymede in the Middle Thames, interpreted as gathering sites for people from a wide area (Cromarty et al. 2006; Needham and Spence 1996, pp. 242–248). The accumulation of reworked occupation waste, not necessarily on such a large scale, seems to be a feature of several other Thames Valley sites in the Late Bronze/Early Iron Age, and indeed further afield (Madgwick et al. 2012). Perhaps it is related to the increasing evidence of long-term or permanent settlement at this period (Lambrick et al. 2009, Chapter 4). On the chalk of the Berkshire Downs, large-scale linear land divisions may belong to the Late Bronze or Early Iron Age (Bowden et al. 1993). At any rate, a similar trend to large-scale landscape organisation seems to apply on the Downs, too.

Lambrick (1992) distinguished an episode of general discontinuity in the Middle Thames, with recurrent abandonment of Late Bronze Age settlements that apparently were not replaced or remodelled in the Early or Middle Iron Age, though they were sometimes resettled in the Late Iron Age or early Roman period. The Upper Thames region appears more prosperous and densely settled than the Middle Thames in the Iron Age, in contrast to the position in the later Bronze Age. At Dorney, the landscape was open with a strong pasture element, while upstream at Reading there was some relaxation of grazing on the floodplain. There is evidence of soil deterioration (acidification, formation of podsols, and nutrient loss) in some areas and less emphasis on stored arable products at settlements; overall arable agriculture probably occupied much less of the landscape than in the Upper Thames. It is not certain to what extent these changes reflect climatic or environmental deterioration; they may instead be linked to sociocultural changes such as a collapse in the prestige goods economy (Barrett and Bradley 1980), or the inhibition of arable expansion (and hence population growth) in the Middle Thames by the cultural value placed on large herds of cattle (Robinson 1984).

3.3.4 Iron Age

The Early Iron Age (750–400 cal BCE) was a period of change in the Upper Thames, with shifts in settlement pattern and land use. This is another point at which climate has been invoked as an explanation of such changes (Needham 2007; but see Buckland et al. 1997). There is less waterlogged evidence, partly because waterholes were going out of use, and

partly because there was less activity on the floodplain and other low-lying areas as water tables were rising (above, 3.2); e.g. at Yarnton, the Bronze Age settlement on the floodplain was replaced by one on the second gravel terrace (Hey and Timby 2011). By the Middle Iron Age (400–50 cal BCE), the gravel terraces were part of an organised agricultural landscape, with much more evidence of permanent year-round settlement. The main cereal being grown was spelt wheat, with 6-row hulled barley. New crops include oats (*Avena sativa*), pea (*Pisum sativum*), and turnip (*Brassica rapa*). The landscape on the floodplain and gravel terraces was very open. On the higher terraces charred cereal-processing remains and storage structures tend to be abundant, and sheep form a higher proportion of the animal bone, while cattle and horse are commoner at some lower-lying sites. There was more evidence of scrub or hedges, perhaps derived from woodland by clearance, and there may still have been woodland on the clay and limestone slopes of the hinterland. While grazing may have been the dominant land-use on the wetter, lower-lying land, it was also a key part of the mixed farming regime on the higher terraces (Lambrick et al. 2009). A detailed model for early Iron Age land use at Gravelly Guy, upstream of the part of the Thames Valley where formalised land enclosure was common, envisaged small occupation areas strung out among arable areas along the edge of the gravel terrace, surrounding a communal grazing area large enough to support stock through the winter (Lambrick and Allen 2004). On lower areas of the floodplain, such as at Farmoor, there is evidence of overgrazing and trampling which together with flooding and the start of alluviation was leading to the development of wet, rushy pasture (Lambrick and Robinson 1979).

In the Middle Thames, evidence is again scanty for the Early/Middle Iron Age, but rather than reflecting change in the pattern and location of activity, this may reflect a real decline in the number of settlements. The landscape was extensively cleared and dominated by grazed grassland. The trend towards more intensive management of the landscape and increase in cereal growing was not as strong as in the Upper Thames, and in some cases there is evidence of soil acidification and leaching and heathland formation, though not closely dated (Robinson and Lambrick 2009a, p. 48-49).

The Late Iron Age and Early Roman period (50 cal BCE – 150 cal CE) are hard to separate and are here taken together. The Late Iron Age of the Thames valley saw the emergence of coherent large-scale social polities with identifiable territories (recognised by material culture e.g. coinage) and territorial centres. There may also have been some landscape reorganisation, marked by a discontinuity in occupation at many settlements (Lambrick 1992), though

Lambrick (2009) is more inclined to see this as a culmination of longterm processes or a combination of continuing trends than a period of disruption and alteration. Seasonal flooding and alluviation were becoming widespread in the floodplain. At the same time, in the Upper Thames arable agriculture was increasing, and grassland was being ploughed up, both in low-lying areas (e.g. the floodplain at Yarnton) and higher up on gravel terraces and possibly valley sides – this again tending to increase both run-off and soil erosion. In some areas the landscape was reorganised, with fewer individual wells and waterholes among the fields: this could reflect a more communal organisation of stock management, with larger herds of animals being watered at rivers and streams rather than small herds kept at a smaller social scale (possibly larger "kin groups" as opposed to "families", though this is conjecture). The main cereal being grown was spelt wheat, with 6-row hulled barley. New crops and weeds reflect the influence of Roman agriculture, even before 43 CE. Pasture was also intensively used, with evidence of trampling and overgrazing, and high proportions of dung beetles. From the evidence of waterlogged wood, any remaining woodland (or hedgerow/scrub) was carefully managed to supply timber and wood (Lambrick et al. 2009). There were extended ditched enclosure systems associated with settlements, in the form of fields or paddocks possibly enclosed by hedges as well as ditches, and settlements were linked by ditched trackways. There is again evidence that sites specialised in different aspects of agriculture, with an emphasis on pastoralism at some sites e.g. Claydon Pike/Thornhill Farm, Watkins Farm and Farmoor, and on cereal growing, processing and storage at others, particularly those on the higher terraces.

Lambrick (2009, pp. 377–380), modelling population growth and land use, sees the area under both cultivation and intensive pasture increasing at the expense of rough pasture. To sustain an increasing population, intensified management of both (i.e. higher production per unit area) is needed. This fits with the environmental evidence, and suggests that through to the end of the Roman period, the valley of the Upper Thames was an organised, productive, mainly open agricultural landscape supporting a relatively high population. In the Middle Thames, Lambrick suggests that population growth was higher in the Bronze Age but slowed in the Iron Age, and in this scenario there is little need to intensify land use through the Late Iron Age/Early Roman period, though more land may have been taken into production as population grew. It is not certain why the pattern of population growth should be different – it could have reflected social or economic disruption, or ecological and land management problems such as water table rise and decline in soil fertility; there need not be a single explanation.

3.3.5 Roman period

The Roman Conquest of 43 CE strictly marks the end of the local Iron Age, but its effects on agriculture and settlement could not be instantaneous – the effects of proximity to the Roman Empire during and after the conquest of Gaul had been felt for at least a century (Cunliffe 2005) and local ways of doing things continued into the Roman period. In the earlier 2nd century CE, at least in the Upper Thames, many of the extensive rural settlements of the previous couple of centuries ceased to be occupied, while many of those newly established in the 2nd century continued into the later Roman period (Booth et al. 2007, p.8). Dating is often imprecise, but a middle Roman period up to the mid-3rd century CE, and a late Roman period in the late 3rd/4th century CE can be distinguished on the basis of pottery, metalwork and coins, though there are problems using these on rural sites where finds may be sparse and many features not closely dated (Lambrick 2010).

In the Upper Thames, seasonal flooding and alluviation continued through the Roman period. While flooding events at sites are not always particularly closely dated, the evidence is consistent with a continuing rise in flood levels, with site adaptations such as provision of drainage ditches or embankments, shifts to drier ground e.g. gravel "islands" in the floodplain alluvium. Closer to the source, above Lechlade, flooding was not as extensive. In the Middle Thames the extent of flooding also increased during the Roman period (Booth et al. 2007, pp. 18-19).

The main crops continued to be spelt wheat and 6-row hulled barley, with much less evidence for bread wheat *Triticum aestivum* which occurs sporadically. A greater variety of crops were being cultivated, including peas, beans, flax and other horticultural crops such as herbs and fruit, a trend continued from the Late Iron Age/Early Roman period. New arable weeds also appeared along with new crops. Van der Veen et al. (2008) have reviewed the evidence for new (imported/introduced) plant foods in Roman Britain. Exotics such as grapes, figs and olives were imports that were almost exclusively consumed by the Roman military and people in the major towns. Herbs such as coriander, celery and dill reflected Roman foodways and have a similar distribution, though their presence in the countryside increased from the middle Roman period, and they may have been locally cultivated. New types of vegetables such as carrot, cultivated fruit varieties such as apples and plums, and nuts such as walnuts, were more widely available in the countryside, at least in the south-east, and in many cases continued in cultivation after the end of the Roman period. This represented a change in the agricultural system, with new horticultural techniques, and the development of "market gardens" to supply urban or military demand. Indeed, van der Veen et al. (2008) suggest that

this represents a major change in the agricultural economy, which was now producing not only for local consumption or tribute, but for a cash economy (including taxation) and military/urban supply. Exactly how these changes affected different categories of rural producer sites, from villa to complex farm to small settlement, is less clear, and varied geographically. The evidence for large-scale cereal processing (for grain and beer), from both charred plant remains and the presence of corndriers on sites, also increases through the Roman period, similarly reflecting change in the agricultural economy (Van der Veen and O'Connor 1998).

The earliest (botanical) evidence for hay meadows comes from Claydon Pike, dated to the early 2nd century CE (Miles et al. 2007), and a waterlogged deposit of cut hay was found in a 2nd century CE pit at Farmoor (Lambrick and Robinson 1988). Management for hay (excluding animals in the spring, cutting and drying the long grass and associated vegetation in the summer, followed by aftermath grazing) produces a distinctive vegetation type, which was not present in the Upper Thames before the Roman period (Booth et al. 2007, p. 22).

In parallel with changes in cultivation, there were changes in animal management over the Roman period. Preliminary results from the "Rural Settlement of Roman Britain" project (Allen 2014) confirm some of the trends for southern Britain noted in King (1999) and Albarella et al. (2008). From the Early Roman period (2nd century CE) cattle become more common at sites at the expense of sheep/goat. In the "Central belt" area, which includes the Thames Valley, cattle predominated over sheep particularly at larger farms and villas, less so at smaller farms and nucleated settlements. Age profiles for cattle in the Roman period contrast with the Iron Age, with fewer young cattle being killed and cattle kept to older ages. This most likely reflects the increasing importance of cattle as providers of the traction needed for increased cereal production (Albarella et al. 2008). In contrast, there was little change in the age profiles for sheep/goat, and only a few sites where they are particularly common (one of which, Alfred's Castle, is included in this study). Thus, there is little evidence for intensification in wool production. Pigs showed little change in age profiles, being kept for meat and killed relatively young. Size changes in domesticated animals reflect closer attention to breeding and possibly imported stock, though larger animals appear at different times and not at all sites, suggesting considerable variation in the attention paid to stock breeding (Albarella et al. 2008).

Even more than in the Iron Age, in the Roman period the Thames Valley was an open agricultural landscape with stands of carefully managed woodland and hedges. Crop and stock

management were integrated at a wider scale, with some site specialisation according to site environments, and at least some of the farmland was intensively managed to produce exchangeable surpluses, supplying military and urban as well as local sites. There was little or no woodland on the gravel terraces, though there was some evidence of hedgerow trees. The floodplain was probably mainly or wholly used as pasture, with cereal cultivation and horticulture on the gravel terraces and increasingly on the clay hinterland, where cattle traction would have been important. The settlements in both the earlier and later Roman period had a range of habitats, with hedged horticultural plots and paddocks, weedy disturbed ground, decaying organic material, and timber buildings and indoor habitats revealed by their typical insect faunas. The intensity of occupation increased through the Roman period (Booth et al. 2007, pp. 20-29). By the Late Roman period exploitation of the Thames Valley landscape was at its most varied and intensive, a state not reached again until after the Norman Conquest.

4 Summary and research questions

The characteristics in terms of carbon and nitrogen cycling and hence isotope values of various environments likely to be found in the Thames Valley in the study period are summarised in Table 3.1. Based on this, some predictions can be made about how faunal isotope values might change over time, here framed as research questions.

4.1 Climatic cooling

The long-term trend of decline in mean annual temperature is likely to be no more than 1-2°C. This could lead to a decline in plant, and hence higher trophic level, $\delta^{13}C$ values of ≤0.5‰. The effect on $\delta^{15}N$ is even less certain, but is more likely to be a slight decline than a rise (section 2 above). Some archaeological changes have been attributed to episodes of climatic deterioration in the later 4th millennium cal BCE and the later 2nd millennium cal BCE. While the predicted changes in isotope values are small, not much larger than the analytical error of measurement and well within population variation, it is possible that they could be detected in a large dataset.

1. Is there any evidence for a long-term downward trend in $\delta^{13}C$ or $\delta^{15}N$ values?
2. Is there any evidence for shorter-term changes in line with climatic variation?

4.2 The extent of tree cover, clearance and land use

In all regions of the Thames Valley, tree cover was extensive at the start of the Neolithic. Evidence from pollen and beetle faunas suggests that cover was dense and that grazing pressure from the native large herbivore fauna was not sufficient to cause widespread opening of the forest canopy (*contra* Vera 2000), though clearings undoubtedly existed. The landscape became more open through the Neolithic, with many areas showing evidence of cycles of clearing and

regeneration, perhaps in response to the presence of domestic stock at consistently greater densities than native herbivores, as well as clearance for cultivation. By the end of the Neolithic the landscape was probably a mosaic of dense or more open woodland, scrubby or open grassland, and cultivated land. During the Bronze Age the gravel terraces were largely cleared, while woodland persisted on the clay slopes and higher up the valley and its tributary streams. From the Middle Bronze Age onwards, organised land division and permanent settlements appear, though most of the cleared land was probably pasture, with limited areas of intensive crop production. In the Iron Age clearance and cultivation extended to valley slopes and further up the main valley and its tributaries, and surviving woodland was patchy and very likely managed for timber and wood resources. In some areas the proportion of land used for arable increased, and there was some differentiation between settlements, some concentrating on cereal crops and others with a pastoral emphasis. In the Roman period the landscape remained open, and there may have been intensification of both arable and pastoral farming to produce marketable surpluses.

In the early Neolithic the forest cover was dense enough to produce a canopy effect, with lower $\delta^{13}C$ values in plants growing in shaded areas and hence herbivores and higher trophic levels. In plants $\delta^{13}C$ values can be reduced by up to 5‰ (Heaton 1999; Bonafini et al. 2013). The effect on herbivore bone collagen will depend on the proportion of their diet sourced from plants showing a canopy effect, whether supplied as graze or fodder. For domestic herbivores it will be less than the full effect seen in plants, because they are likely to graze in more open, grassy areas when possible.

1. Can we detect a canopy effect (lower $\delta^{13}C$ values) in domestic herbivores in the Neolithic, or in later periods?
2. Are there differences between the herbivore species in line with feeding/management strategies?
3. Do changes in faunal $\delta^{13}C$ values track changes in forest cover?

Next page:

Table 3.1 Environments of the Thames Valley and their characteristics in terms of carbon and nitrogen cycling and hence isotope values

Environment	Activity	Carbon	Nitrogen
Primary woodland (*Urwald*, wildwood) Lime > Elm, Oak, Hazel Closed canopy with some open areas, natural regeneration cycles (extent debatable) High amounts of dead/decaying wood and hence saprophytic fungi. Distribution of mycorrhizal fungi depends on tree species as well as soil/climate.	Preferential use of open areas for "garden agriculture" and stock keeping. "Passive" maintenance and extension of open areas by reducing regeneration. "Active" extension by tree removal, burning? Use of timber and other wood. Some use of woodland /woodland edge resources – hunting /gathering. Possible use of lime, elm as winter fodder (no direct evidence in UK)	Canopy effect in closed-canopy woodland leads to lower $\delta^{13}C$ in herbivores Variation in herbivore $\delta^{13}C$ reflects variability in habitat availability/use (including leaf foddering if applicable). Consumption of fungi by pigs leads to higher $\delta^{13}C$ values than herbivores	$\delta^{15}N$ generally medium/low in primary woodland, becoming higher/more variable as recycling via herbivores increases, perhaps with patches of higher $\delta^{15}N$. Patchiness of $\delta^{15}N$ distribution in primary vegetation uncertain. Active clearance, especially by fire, may produce transient nutrient flush and higher $\delta^{15}N$ values in vegetation.
Utilised woodland Oak>ash, hazel; decline in elm and (later?) lime Closed-canopy areas becoming rarer, open areas more common. Dead wood and fungi reduced Regeneration cycles in some areas?	Management of tree growth e.g. coppicing Other uses: as for primary woodland – see above. Grazing pressure of domestic herbivores increasing if larger herds are maintained through winter.	As woodland becomes more open canopy effect becomes less detectable and herbivore $\delta^{13}C$ becomes higher and less variable. Lower fungal biomass available to pigs, pig $\delta^{13}C$ declines, may still be higher/more variable than herbivores	Patchy distribution of available N in woodland and grazed / cultivated areas. $\delta^{15}N$ depends on N cycling regime, but likely to be higher in cultivated/grazed areas. Variation in herbivore $\delta^{15}N$ reflects variability in habitat availability and use. Scale of patchiness uncertain.

Environment	Activity	Carbon	Nitrogen
Extensively grazed grassland / scrub Regeneration cycles in some areas, depending on stock density. May be managed by seasonal grazing/exclusion Some "scrub" may be in form of hedges acting as boundaries: managing stock movements allowing controlled use of grazing, protection from predators, manure collection, exclusion from crops	Low stock density year-round, or higher stock density seasonally (e.g. foggage)	No canopy effect. Herbivore $\delta^{13}C$ is higher and less variable. Damp/wet grassland may have lower $\delta^{13}C$ Low fungal availability, pig $\delta^{13}C$ similar to herbivores	Grazing by stock relatively light, with most N cycling within vegetation rather than via herbivores. May be net export of N to cultivated areas via manure. Not much increase in N availability/ $\delta^{15}N$. Chalk grassland typically has low N availability, tight cycling of N within vegetation and a high proportion of legumes in the sward, all of which may contribute to low $\delta^{15}N$ compared to other grassland
Intensively grazed grassland/ meadow May be managed by seasonal grazing/exclusion. Hay meadows would be ungrazed till early summer when hay crop is removed, followed by aftermath grazing	High stock density, year-round or seasonal.	No canopy effect. Damp/wet grassland may have lower $\delta^{13}C$ Low fungal availability	As grazing pressure rises, increasing proportion of N cycling via herbivores (insect dung faunas appear). Higher N availability and $\delta^{15}N$. May be seasonal replacement of N via flooding. Higher available N, effect on $\delta^{15}N$ uncertain. Hay meadows may have lower $\delta^{15}N$ if they contain a high proportion of legumes, which could be reflected in stock fed on hay. May be net export of N via hay, and/or to cultivated areas via manure

Environment	Activity	Carbon	Nitrogen
Garden agriculture on open (cleared?) land Intensively cultivated areas within a generally wooded environment or among clearings/clearances used for grazing stock	Long-term cultivated plots require nutrient inputs via crop wastes, refuse, manure. Short-term cultivated plots use available nutrients and are then left fallow for natural renewal processes. Intensive care may include watering/ irrigation	No canopy effect. Low fungal availability Watering of crops could lower $\delta^{13}C$ – likely to be a small effect except under serious drought conditions	Available N exported from system as crops, probably faster than natural renewal rate; if not replaced available N will decline. Crop wastes may be fed to herbivores. Herbivores may import N from uncultivated areas via manuring, raising $\delta^{15}N$. N cycling becomes more rapid, increasing $\delta^{15}N$, particularly as recycling via herbivores increases. Cultivation of legumes would increase available N but lower $\delta^{15}N$. Patches of higher/lower $\delta^{15}N$ – scale of patchiness uncertain.
Extensive agriculture on larger areas of open land	Similar to garden agriculture but inputs of labour and nutrients per unit area are lower. More extensive soil disturbance e.g. by cultivation using animal traction, combined with clearance, may lead to soil erosion. Large-scale soil erosion changes hydrology, affecting other environments.	No canopy effect. Low fungal availability	Processes similar to garden agriculture, leading to patchiness of available N and $\delta^{15}N$ (not necessarily correlated), scale of patchiness uncertain. May be more risk of loss of available N, affecting overall balance of pasture / arable. Soil erosion may affect N availability / cycling. N exported in this way may reach other environments e.g. floodplain grassland.

Environment	Activity	Carbon	Nitrogen
Settlement or occupation			
Short-term ephemeral occupation	Occasional or seasonal. Hunting/gathering and/or short-term cultivation, animal penning by small groups.	Short-term clearances may reduce canopy effect temporarily	Short-term/ephemeral occupation may raise nutrient levels temporarily via food processing, waste disposal, animal penning, but effect will fade rapidly.
	Larger gatherings of many small groups at ceremonial sites.	As intensity of occupation or frequency of visits increases, woodland becomes more open, regeneration may be reduced, and canopy effect is reduced or disappears	Repeated large gatherings or regular visits to sites may result in accumulation of waste in middens
Long-term settled occupation	Long-term cultivation, intensive or extensive; animal penning, food processing, waste disposal, manure collection		Settled occupation may lead to long-term higher nutrient levels, increased nitrogen cycling and higher inputs of ^{15}N-enriched materials, leading to raised $\delta^{15}N$ in soils in and around the settlement: anthropogenic effect

Table 3.1 Environments of the Thames Valley and their characteristics in terms of carbon and nitrogen cycling and hence isotope values

The effect of forest clearance on soil, and hence plant, $\delta^{15}N$ is uncertain. There are several reasons why clearance might raise soil $\delta^{15}N$ values: a transient nutrient flush after tree removal, soil disturbance ($\delta^{15}N$ tends to increase with soil depth), increased inputs of urine and faeces from herbivores, and in general more open N cycling. If anything, then, $\delta^{15}N$ values in plants, and hence higher trophic levels, would be expected to rise over time, though it would be difficult to disentangle a clearance effect from other land-use changes that might also increase soil $\delta^{15}N$. On the other hand, more leguminous crops were being grown in the Roman period and damp meadow/hay meadow plant communities may have a high proportion of leguminous species, which tend to have lower $\delta^{15}N$ values.

4. Do faunal $\delta^{15}N$ values rise over time?
5. Do changes in faunal $\delta^{15}N$ values track changes in forest cover, or other land-use changes?

The Neolithic forest is likely to have been much richer in fungi, a potential food for pigs, than more open, managed woodland, because there would have been much more dead wood for saprophytes. Fungi tend to have $\delta^{13}C$ values 4-5‰ higher than photosynthetic plants in the same habitat, which would noticeably raise pig collagen $\delta^{13}C$ values if pigs were eating fungi in significant quantities. Other diet components such as fruits (including tree mast), roots and tubers also have higher $\delta^{13}C$ values than leaves, though this may be offset by lower leaf $\delta^{13}C$ values in shaded environments. On the other hand, pigs are thought of as woodland animals deriving a large part of their nutrition from forest resources such as acorns, and should therefore show a canopy effect, with lower $\delta^{13}C$ values than cattle and sheep. Pigs are also somewhat more omnivorous than cattle and sheep, deriving part of their diet from animal protein, and so may have higher collagen $\delta^{15}N$ values.

6. Do changes in pig $\delta^{13}C$ and $\delta^{15}N$ values track changes in forest cover, or other land-use changes?
7. Do pig $\delta^{13}C$ and $\delta^{15}N$ values show the same patterns as in cattle and sheep?
8. Can any differences found between pigs and domestic herbivores be explained in line with feeding/management strategies?

4.3 The hydrology of the river, vegetation and land use

Water tables in the Thames Valley started to rise in the Bronze Age because of increasing run-off from cleared land, more obviously in the Upper Thames than in the Middle Thames where some areas had been subject to flooding since the mid-Holocene. This led to seasonal

overbank flooding, changes in floodplain vegetation, and eventually at some sites shifts in settlement and cultivation to higher terraces, and/or the use of drainage ditches to control water levels. From the Late Iron Age and into the Roman period flooding continued, with increasing sediment loads in the river and alluviation, as cultivation extended onto valley slopes and soil erosion increased. There is botanical evidence of overgrazing and trampling in areas of wet pasture, the development of poor, rushy grazing land, and, in the Roman period, the appearance of hay meadows.

In general, plants from wetter habitats would be expected to show lower $\delta^{13}C$ and $\delta^{15}N$ values, other things being equal (Heaton 1999; Amundson et al. 2003), and there would be an increasing proportion of these habitats from the Late Iron Age onwards. At the same time, the proportion of densely wooded habitats was already low and any further decrease might not have much effect in raising overall $\delta^{13}C$ values. The effects on soil and hence plant $\delta^{15}N$ would probably depend on local factors – increased inputs of N from manuring, flooding, run-off and/or intensive grazing could lead to more open N cycling and higher $\delta^{15}N$ values, but higher proportions of leguminous, nitrogen-fixing species might lower average plant $\delta^{15}N$ in some plant communities such as damp pasture and hay meadow. Taken with the suggestion that some sites were specialising in grazing cattle on the damper ground (Robinson and Lambrick 2009), we might see changes in cattle $\delta^{13}C$ or $\delta^{15}N$ values at lower-lying sites, and perhaps greater differences between cattle and sheep. If we see the landscape as a mosaic of plant communities, the main effect of hydrological changes might be to add to their diversity.

At individual site level, it might be possible to relate environmental change, animal management and faunal isotope values, if the data are fine-grained enough. Lambrick (1992) proposed specific hypotheses of land use in the Upper Thames in terms of the balance between pastoral and arable farming, and between intensive and extensive arable farming, and how these might differ in different regions (e.g. floodplain or higher terraces). An effort was made to sample from different phases at the sites from which he drew his evidence, to test whether isotope values shifted accordingly

At a landscape scale there is likely to be greater diversity, which might be expressed as wider variation in isotope values both within and between sites.

9. Do average values or variability of faunal $\delta^{13}C$ and $\delta^{15}N$ values change over time, compared within or between sites?
10. If so, are patterns the same for all three species?

11. What is the relationship between these patterns and changes in environmental factors over time?
12. What is the relationship between local environmental factors and faunal isotope values when compared between sites?
13. Can observed differences between the species be explained in terms of different management or landscape use?
14. Is there any concordance with the hypotheses of Lambrick (1992) on land use change?

Chapter 4

Review of evidence: faunal isotopes in the UK

In this chapter previously published work on stable carbon and nitrogen isotopes of cattle, sheep and pig from archaeological sites in Britain is assembled. For each species, patterning in relation to latitude/longitude, geology/environment and period is examined, to provide a background for the Thames Valley study.

1 Introduction

Many archaeological and environmental changes seen in the Thames Valley are seen more widely in southern England or further afield in Britain, for instance progressive woodland clearance, the appearance of more permanent settlement during the Bronze Age, an increase in social complexity during the Iron Age and the effects of the Roman conquest (Hunter and Ralston 2009; Chapter 3, 3.3.5). There are also likely to be regional differences in farming or animal management that may affect faunal isotopes, such as seasonal fenland or salt-marsh grazing (Britton et al. 2008; Pryor 1996). To provide a background for comparison of the Thames Valley results, the published domestic faunal isotope data are collated, and analysed for broad trends in relation to geographical position, environment and archaeological period.

This review is based on all the published data available (as at October 2012) for carbon and nitrogen isotope values in domesticated cattle, sheep and pig from England, Wales and Scotland, covering the Neolithic to the Roman period. No published data were found from Northern Ireland or the Irish Republic. Site details are given in Table A1.1, and site references given there are not repeated in the text.

Data are presented as mean±SD per taxon per site (Table A1.2). The number of animals analysed per site is often rather small, so there is considerable uncertainty around many of the data points. The best data available are generally for cattle (the major exception is Madgwick et al. 2012, concentrating on pig), reflecting the better survival of cattle bone and perhaps its identifiability; sites with 10 or more measurements on cattle per period are in bold in Table A1.2 The majority of the data points in each period come from southern England. Discussion centres on the Neolithic and Iron Age for which more data are available. These data were

examined to see if there was any strong patterning in relation to geography, geology or period, bearing in mind the uneven coverage.

2 Results

2.1 Cattle

2.1.1 Geography

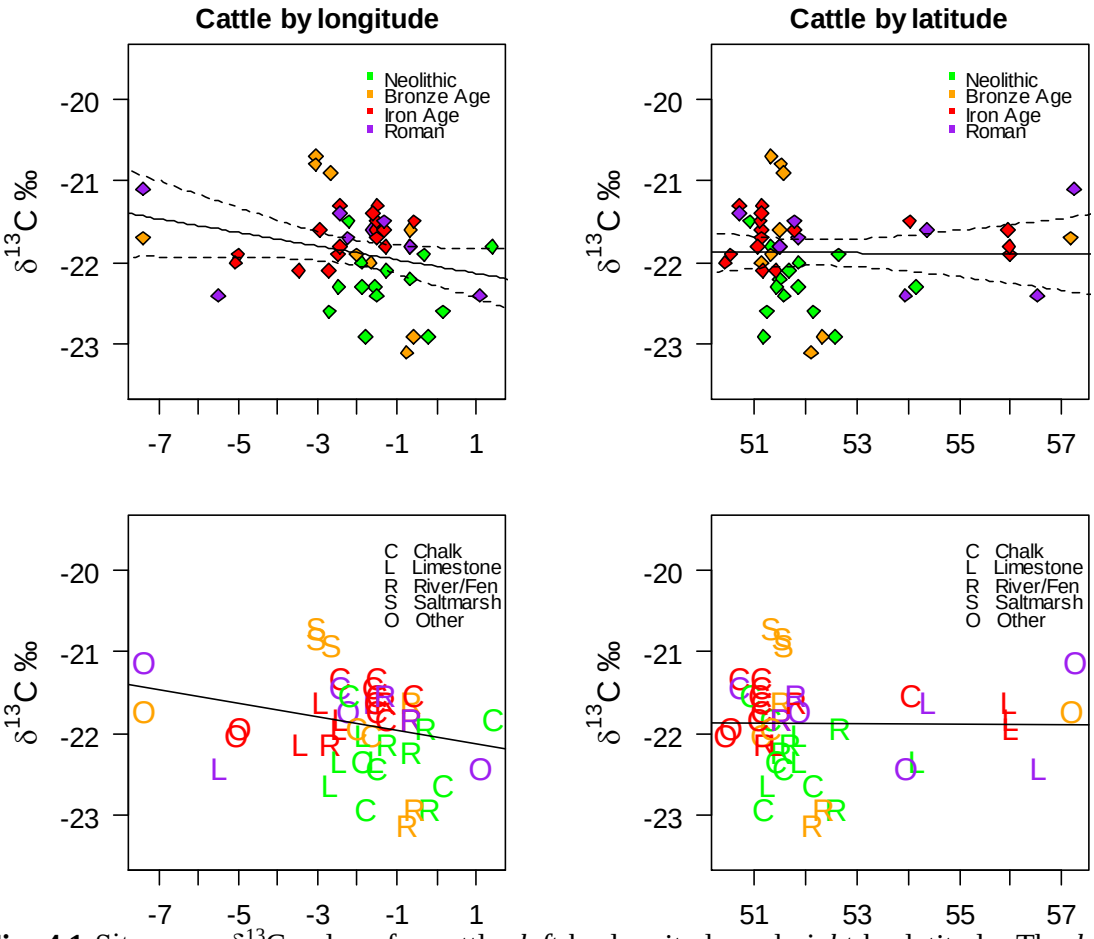


Fig. 4.1 Site mean $\delta^{13}C$ values for cattle, *left* by longitude and *right* by latitude. The *lower graphs* show the same data coded by geology/environment. The *solid line* is the linear regression line for the whole dataset, *dotted lines* show 95% confidence limits

Because the UK climate varies with geographical position – generally, wetter towards the west and colder towards the north – large-scale effects may be seen by plotting isotope values against latitude and longitude (e.g. Hedges et al. 2013; Van Klinken et al. 1994). The ranges in latitude and longitude are less than 10°, and any effect would need to be quite strong to show up amidst variation reflecting more local factors such as altitude, topography, aspect and

hydrology. Hamilton and Hedges (2013) found changes of about 1‰ in faunal $\delta^{13}C$ values over a range of 13° of longitude in Central Europe.

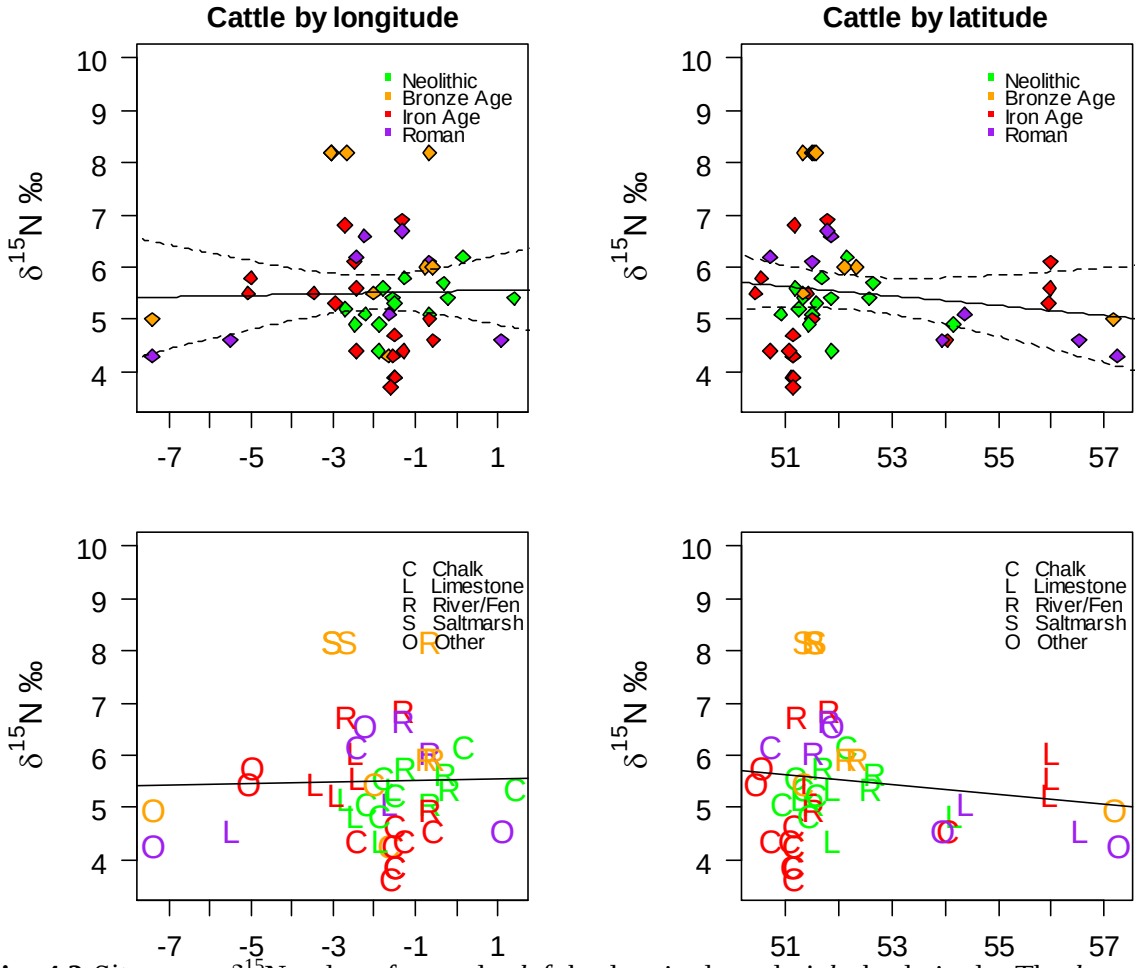


Fig. 4.2 Site mean $\delta^{15}N$ values for cattle, *left* by longitude and *right* by latitude. The *lower graphs* show the same data coded by geology/environment. The *solid line* is the linear regression line for the whole dataset, *dotted lines* show 95% confidence limits

There is no strong relationship of $\delta^{13}C$ or $\delta^{15}N$ values with latitude or longitude overall (Figs. 4.1, 4.2) or at any period. In the Iron Age, cattle $\delta^{13}C$ values are weakly positively correlated with longitude (Pearson, $y = 0.11x - 21.5$, $R^2 = 0.2999$, P=0.025; also significant in non-parametric Spearman rank test), but this relationship is not significant if the two westernmost points are omitted. It is in the expected direction, with lower $\delta^{13}C$ in the wetter west (Heaton 1999), but its significance remains to be confirmed.

2.1.2 Geology/Environment

The underlying geology of most of the sites can be broadly classified as Limestone, Chalk, or River valley/fen. Bone from environments with low pH tends not to survive well, so isotope measurements from such sites are generally not available, leaving large areas of the country blank. The other categories used were Saltmarsh and Other (this included urban sites, where the connection of faunal isotopes to underlying geology is unclear, one-offs, machair, and unknown).

The clearest connection with an environmental factor is the exceptionally high values in both $\delta^{13}C$ and $\delta^{15}N$ for cattle grazing on saltmarsh (mainly from Brean Down; Britton et al. 2008). Sheep from Brean Down also have relatively high $\delta^{13}C$ and $\delta^{15}N$ values. That aside, it is hard to see clear patterning of $\delta^{13}C$ in relation to environmental factors. There is a cluster of Iron Age sites on the chalk of the Hampshire Downs that seem to have rather high $\delta^{13}C$ values, but in the Neolithic chalk sites cover the entire range of values. River/fen sites in the Neolithic, Bronze Age and Iron Age have widely divergent values.

In the Iron Age there is a clearer pattern in relation to geology: cattle from sites on chalk have lower $\delta^{15}N$ values than those from sites on limestone, while those from riverine sites, except for Eton Rowing Course, have higher values. The chalk sites include Dorchester (Dorset) and Wetwang Slack (Yorkshire), though inevitably dominated by sites on the Hampshire chalk. In the Neolithic, however, any relationship is much less clear, with considerable overlap in cattle $\delta^{15}N$ values between limestone, chalk and riverine sites.

2.1.3 Time

The range in cattle $\delta^{13}C$ values in the Neolithic and Bronze Age is about 1.5‰ (2.5‰ if the Bronze Age sites with saltmarsh grazing are included). In the Iron Age and Roman periods the range is lower, about 1‰, a little wider if the far northwestern “Late Iron Age” sites of Bornais and Lismore are included. By contrast, the range in $\delta^{15}N$ is less than 2‰ in the Neolithic, but over 3‰ in the Iron Age. There are markedly fewer sites from the Bronze Age and Roman period, but the Roman range is close to that of the Iron Age at 2.4‰, while the Bronze Age range (without the saltmarsh values from Brean Down and Peterton) is even wider at 4‰. This is due to one site (Eton Rowing Course) with an exceptionally high value for cattle $\delta^{15}N$ based on only 3 individuals: without this point the range is less than 2‰. In general, the range in cattle $\delta^{13}C$ values is wider in the Neolithic and Bronze Age than later, while the range in cattle $\delta^{15}N$ values is lower in the Neolithic than in the Iron Age and Roman periods.

Patterning in $\delta^{15}N$, and possibly in $\delta^{13}C$, values in relation to geology seems clearer in the Iron Age than in the Neolithic, or in the Roman period with relatively few sites. The Bronze Age is clearly of particular interest because it is when the transition between the Neolithic and Iron Age patterns must have been occurring, but there are still too few sites to distinguish an overall trend. Cattle from Eton Rowing Course have exceptionally high $\delta^{15}N$ values, but this is based on few measurements. This is the only site in the dataset from which we have measurements for all four periods, and here cattle $\delta^{13}C$ is about 0.5‰ lower in the Neolithic than later, while $\delta^{15}N$ is similar in the Neolithic and Iron Ages, but 1‰ higher in the Roman period and 3‰ higher in the Bronze Age. With sample numbers of 3 to 6 per period, it is hard to know what significance to attach to this, except to note that the pattern of lower $\delta^{13}C$ in the Neolithic and higher variability in $\delta^{15}N$ in the Iron Age and Roman periods follows the pattern of the whole dataset.

2.2 Sheep/goat

2.2.1 Geography

Sheep $\delta^{13}C$ and $\delta^{15}N$ do not show any strong relationship with latitude or longitude (Figs. 4.3, 4.4), overall or at any period, except that, as for cattle, there is a weak but significant positive relationship with longitude in the Iron Age (Pearson, $y= 0.1352x - 21.263$, $r^2 = 0.2734$, $P = 0.0411$).

2.2.2 Geology/Environment

There is no clear relationship between sheep $\delta^{13}C$ and underlying geology. In the Neolithic the full range occurs on the chalk, with river/fen sites perhaps higher than limestone sites within that range; but sheep are relatively rare at this period (Serjeantson 2011) so this is based on sparse data. In the Iron Age there is a tendency for sheep $\delta^{13}C$ to be higher and $\delta^{15}N$ to be lower at chalk sites, and river/fen sites seem to have higher $\delta^{15}N$ values than other sites in the Iron Age and Roman periods. This pattern is dominated by the group of sites on the Hampshire chalk, so it is not certain whether it reflects local factors or can be generalised.

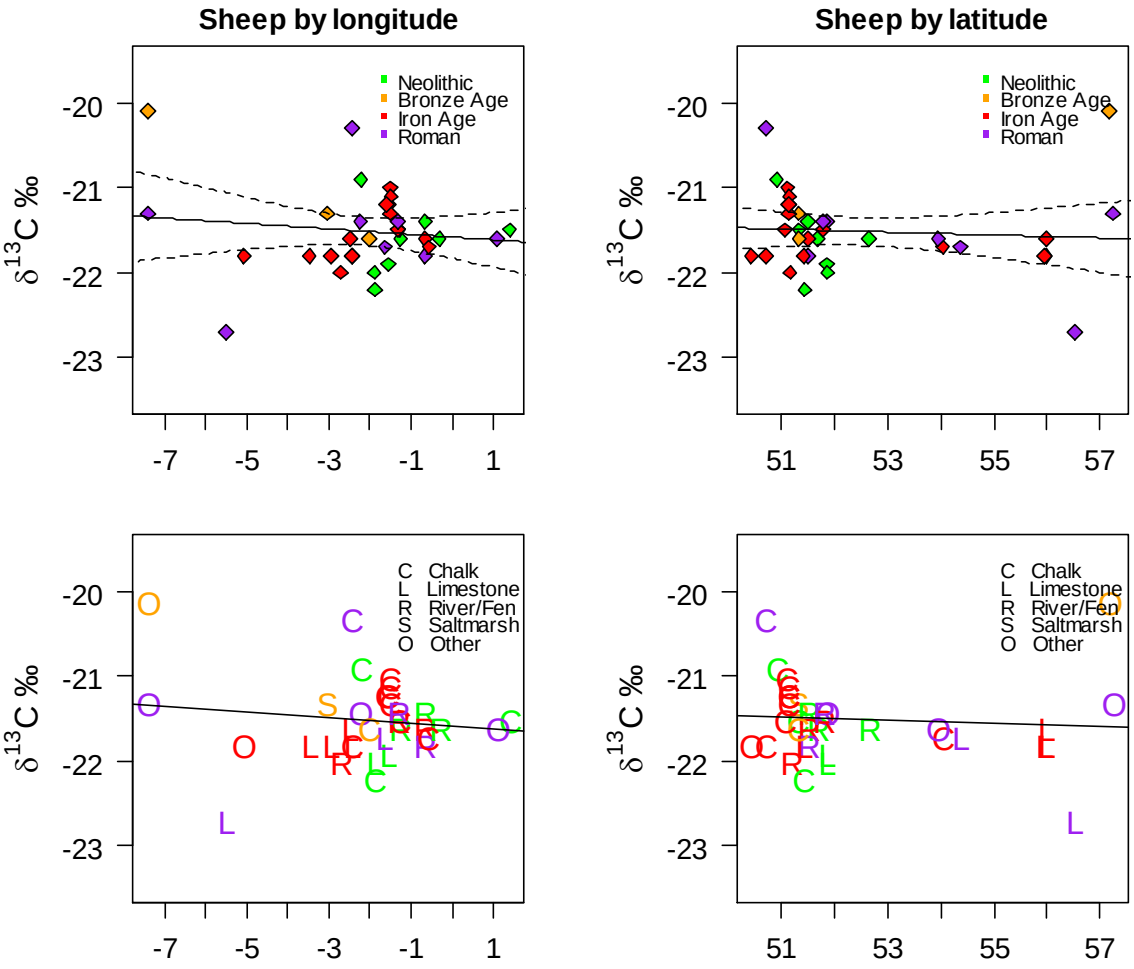


Fig. 4.3 Site mean $\delta^{13}C$ values for sheep, *left* by longitude and *right* by latitude. The *lower graphs* show the same data coded by geology/environment. The *solid line* is the linear regression line for the whole dataset, *dotted lines* show 95% confidence limits

The sheep from Brean Down do not show the exceptionally high $\delta^{13}C$ and $\delta^{15}N$ values seen in cattle, though the $\delta^{13}C$ value is the second highest and the $\delta^{15}N$ value the highest in the sheep dataset, so they are high compared to sheep at other sites. Sheep from Cladh Hallan have an exceptionally high $\delta^{13}C$ value, but a low-to-average $\delta^{15}N$ value. These are likely to reflect local management practices at these Bronze Age sites (below, 3.2).

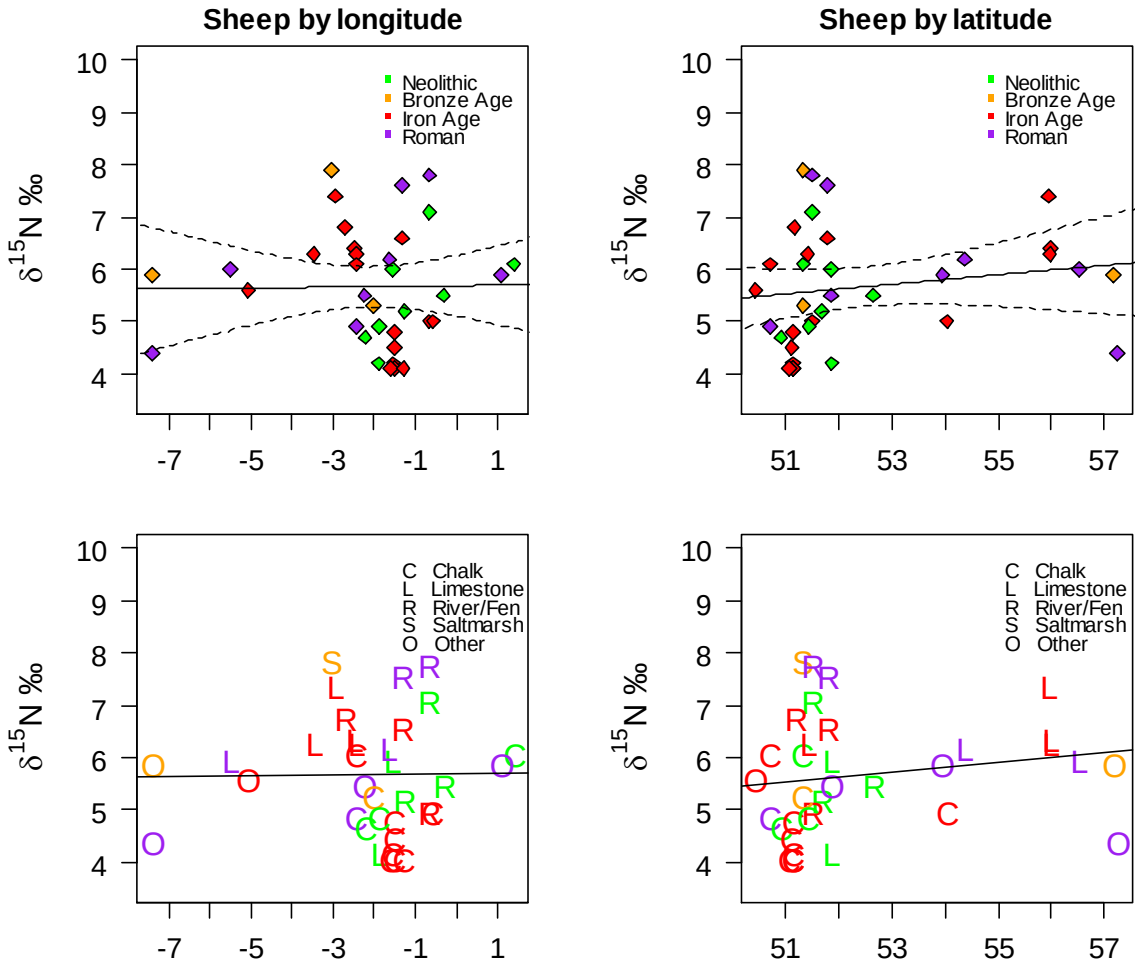


Fig. 4.4 Site mean $\delta^{15}N$ values for sheep, *left* by longitude and *right* by latitude. The *lower graphs* show the same data coded by geology/environment. The *solid line* is the linear regression line for the whole dataset, *dotted lines* show 95% confidence limits

2.2.3 Time

In the Neolithic the overall range in sheep $\delta^{13}C$ is smaller than for cattle, at 1.3‰, and not much greater than that in the Iron Age, 1.0‰. There is also less contrast between Neolithic and later $\delta^{13}C$ values, though Neolithic values are perhaps slightly lower, especially if the unusually high value from Hambledon (Dorset) is omitted (this is based on only 3 individuals). The range in sheep $\delta^{15}N$ values overall is about 4‰, or 3‰ in any given period, with little apparent change over time.

At Eton Rowing Course, sheep $\delta^{13}C$ is higher than that of cattle in the Neolithic and similar thereafter – or perhaps it is more accurate to say that cattle $\delta^{13}C$ is lower in the Neolithic, as sheep $\delta^{13}C$ does not change much – while sheep $\delta^{15}N$ is higher than that of cattle except in the

Iron Age. However, only in the Roman period is there more than 1 measurement on sheep, so this is not a strong basis for drawing conclusions.

2.3 Pig

2.3.1 Geography

There is no significant relationship of pig $\delta^{13}C$ or $\delta^{15}N$ with latitude or longitude overall or at any period (Figs. 4.5, 4.6).

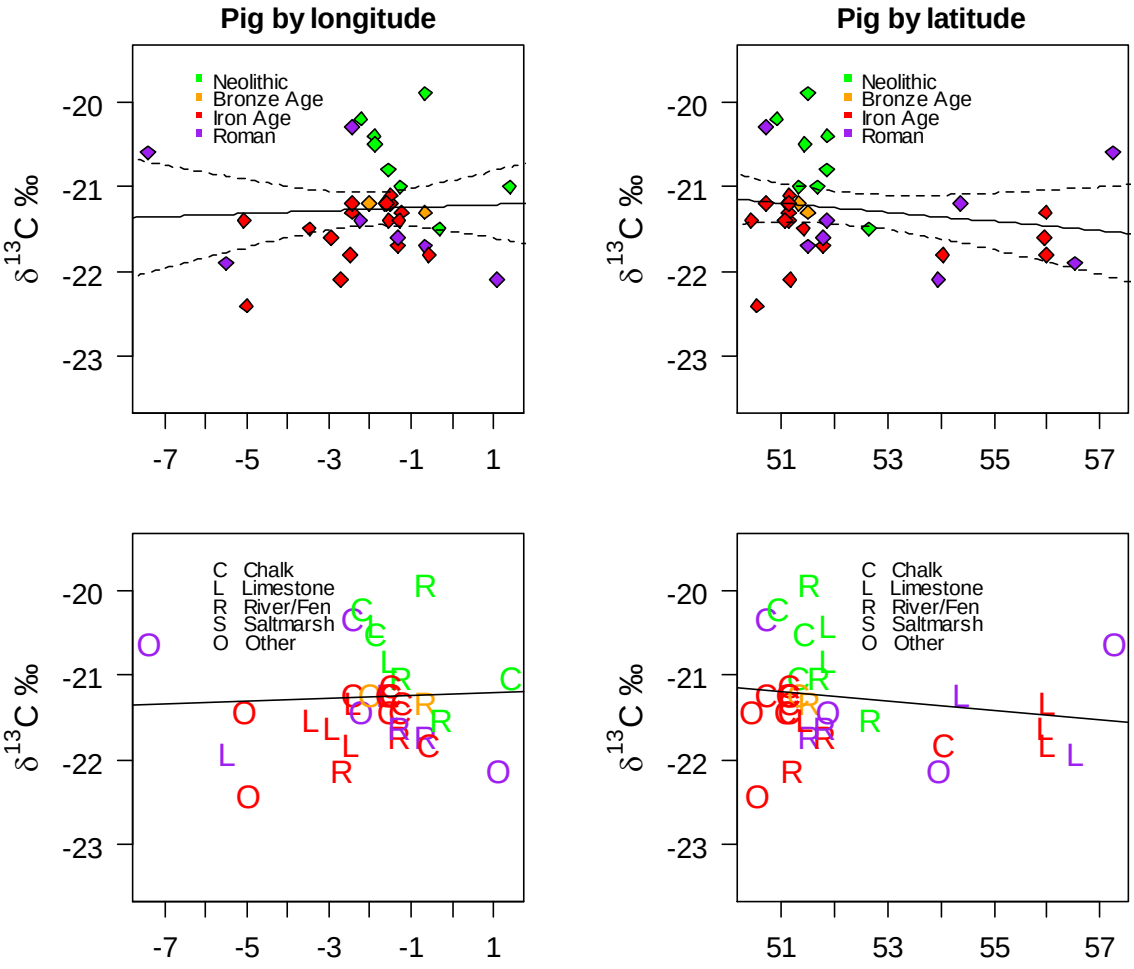


Fig. 4.5 Site mean $\delta^{13}C$ values for pig, *left* by longitude and *right* by latitude. The *lower graphs* show the same data coded by geology/environment. The *solid line* is the linear regression line for the whole dataset, *dotted lines* show 95% confidence limits

2.3.2 Geology/Environment

In the Neolithic the three river/fen sites cover the entire range of pig $\delta^{13}C$, while values from chalk and limestone sites are similar. In the Iron Age chalk sites tend to have higher $\delta^{13}C$ values than other types, but again this is dominated by the group of Hampshire chalk sites. There is no clear patterning in pig $\delta^{15}N$ in relation to geology.

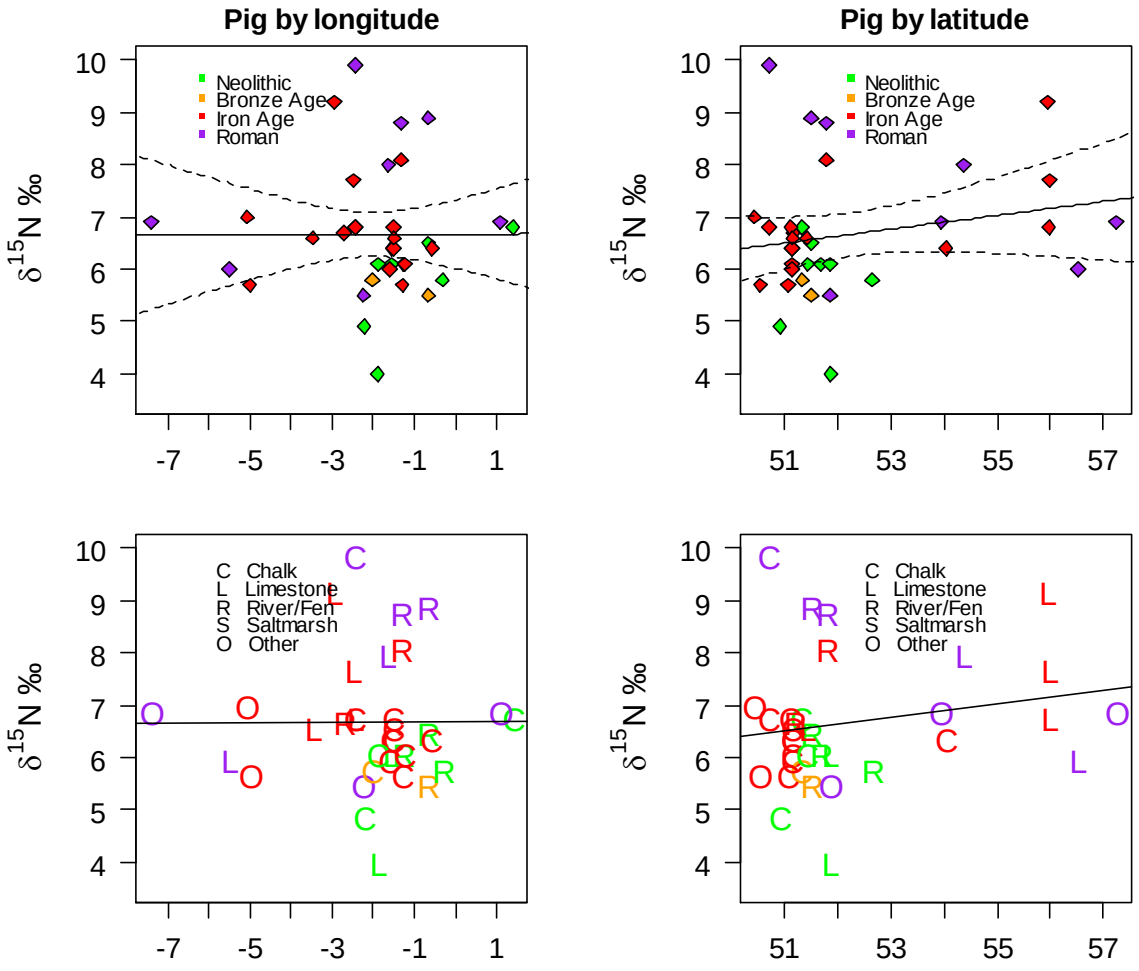


Fig. 4.6 Site mean $\delta^{15}N$ values for pig, *left* by longitude and *right* by latitude. The *lower graphs* show the same data coded by geology/environment. The *solid line* is the linear regression line for the whole dataset, *dotted lines* show 95% confidence limits

2.3.3 Time

The range in pig $\delta^{13}C$ values in the Neolithic is over 1.5‰, and they are distinctly higher than those at any other period, with very little overlap. By the Iron Age most pig $\delta^{13}C$ values are within the range –21.2 to –21.8‰, with two exceptions: Glastonbury Lake Village (–22.1‰) and a single value of –22.4‰ from Harlyn Bay, Cornwall. The range in pig $\delta^{15}N$

values does not seem to change consistently with time, though there is a tendency for Neolithic $\delta^{15}N$ values to be lower and Roman $\delta^{15}N$ values to be higher than Iron Age values.

It is hard to see any patterning in pig $\delta^{13}C$ or $\delta^{15}N$ values in relation to geology at any period. There are not many results for pigs at Eton Rowing Course, but they are consistent with the overall pattern of high $\delta^{13}C$ values in the Neolithic and high $\delta^{15}N$ values in the Roman period.

2.4 Patterns of faunal isotope values

Looked at individually, each species shows some patterning of $\delta^{13}C$ and $\delta^{15}N$ values in relation to geography, geology/environment and time. In the Iron Age, cattle and sheep show weak but significant positive relationship between $\delta^{13}C$ and longitude (i.e. $\delta^{13}C$ is higher towards the east), and tend to have higher $\delta^{13}C$ values and lower $\delta^{15}N$ values on chalk than other geologies, and possibly higher $\delta^{15}N$ at river/fen sites, but this pattern is not seen in the Neolithic. Both herbivore species show elevated $\delta^{13}C$ and $\delta^{15}N$ values at Brean Down, reflecting saltmarsh grazing. Cattle have distinctly low $\delta^{13}C$ values in the Neolithic and the range is also wider than at later periods, while the range in $\delta^{15}N$ is lower: these patterns are not seen in sheep. Pigs show much less patterning in relation to geography or geology, but show a distinct change over time, with high $\delta^{13}C$ values in the Neolithic and high $\delta^{15}N$ values in the Iron Age and especially the Roman period.

	Cattle $\delta^{13}C$	Cattle $\delta^{15}N$	Sheep $\delta^{13}C$	Sheep $\delta^{15}N$	Pig $\delta^{13}C$	Pig $\delta^{15}N$
Cattle $\delta^{13}C$			0.488 0.556			(0.324)
Cattle $\delta^{15}N$				0.722 0.719	 -0.350	
Sheep $\delta^{13}C$	** **			 -0.363	0.384 (0.327)	
Sheep $\delta^{15}N$		** **	 *		-0.351 -0.445	0.567 0.557
Pig $\delta^{13}C$		 *	* #	* *		
Pig $\delta^{15}N$	#			** **		

Table 4.1 Correlations between site mean $\delta^{13}C$ and $\delta^{15}N$ values of cattle, sheep and pigs. Coefficients are shown at *upper right* and significance at *lower left*. The *upper* figure in each box is the Pearson product-moment coefficient, the *lower* figure is Spearman's rho. For clarity, only correlations with a P-value of 0.10 or less are shown. Numbers of sites used in comparisons: Cattle:Cattle 48, Cattle:Sheep 35, Cattle:Pig 34, Sheep:Sheep 35, Sheep:Pig 32, Pig:Pig 34. Significance: # 0.10-0.05, *0.05-0.01,**<0.01

Correlations between $\delta^{13}C$ and $\delta^{15}N$ values of the three species are shown in Table 4.1. Cattle and sheep are generally well correlated, in line with the similarity in patterning described above. Pig $\delta^{13}C$ and $\delta^{15}N$ values correlate with those of sheep, but not cattle. Pig $\delta^{13}C$ shows a negative correlation with cattle and sheep $\delta^{15}N$, reflecting the different temporal patterns of change in these values. Results of parametric (Pearson's *r*) and non-parametric (Spearman's rho) tests are very similar though probably the latter are more appropriate – both are given for information.

3 Discussion

3.1 Geography

The only clear geographical pattern in the C and N isotope values of the domestic animals is the significant correlation of Iron Age cattle and sheep $\delta^{13}C$ values with longitude, and a similar, though not significant, trend in pigs. It is likely that this reflects a trend in plant $\delta^{13}C$ values from lower values in the wetter west to higher values in the drier east (it should be noted that the westernmost points are also the furthest north, and likely to be cooler as well as wetter). The change for all three animal species is about 0.6‰ over 5°, which seems consistent with expected values (Heaton 1999; van Klinken et al. 1994; Hedges et al. 2013). This is less than half of the overall range in $\delta^{13}C$ values in any period, and accounts for only 20–30% of the variance in $\delta^{13}C$ for each species, so it is not surprising that this trend has not been detected before in smaller datasets. It is consistent and should be borne in mind when comparing animal $\delta^{13}C$ values from different areas. However, if the trend is real, why is it only seen in the Iron Age?

It is perhaps not surprising that this pattern is not detected in the Bronze Age or Roman periods, with measurements from far fewer sites, but it is more disturbing that it is not seen in the Neolithic where (at least for cattle) the number of sites is not much lower than for the Iron Age. Many of these sites, however, have measurements from rather few individuals, and overall the scatter is higher and the range in longitude smaller. Another possibility is that the major structuring factor for animals in the Neolithic was not climate (rainfall), but the degree of use of forest resources. Forest cover may not have varied greatly with longitude, at least in the early Neolithic which is the source of most of the data. The difference in $\delta^{13}C$ values between plants growing under dense canopy cover and out in the open may be as much as 5‰ (Bonafini et al. 2013; Heaton 1999), potentially a source of variability that could mask any climatic trend. This idea could be tested with enough samples from enough sites and an

independent measure of forest cover in the vicinity of the sites, e.g. from pollen or invertebrate records, but that is not practical at present.

3.2 Geology/environment

It has previously been suggested that animals from sites on chalk tend to show low $\delta^{15}N$ values (e.g. Hamilton and Hedges 2011), and it has been noted that riverine sites such as Yarnton and Eton Rowing Course tend to have high $\delta^{15}N$ values (Lightfoot et al. 2009; Stevens et al. 2012). Are these suggestions borne out in the larger dataset? In the Iron Age there is a fairly clear pattern in relation to geology: cattle, and possibly sheep, from the sites on chalk have lower $\delta^{15}N$ values than those from sites on limestone, while those from riverine sites, except for Eton Rowing Course, have higher values. In the Neolithic, however, any relationship is much less clear, with considerable overlap in cattle $\delta^{15}N$ values between limestone, chalk and riverine sites. The trend in $\delta^{13}C$ values seems to be the opposite, with higher cattle and sheep $\delta^{13}C$ values on chalk. These data are however dominated by the sites on the Hampshire chalk and it is not clear whether this is a local or a general phenomenon. Any patterning in the Neolithic is much less clear, and as argued above this may reflect the greater influence of variation in use of forest resources when there was still enough dense woodland to affect plant $\delta^{13}C$ values significantly on a landscape scale.

Low $\delta^{15}N$ values in plants on chalk soils may reflect the tight nitrogen cycle in environments with low N availability (Chapter 2, 2.3.2). Plant communities on chalk may also include a higher proportion of legumes, which are adapted to low-N environments and can fix their own atmospheric nitrogen, leading to lower $\delta^{15}N$ values. It is less obvious why plants from wetter sites such as floodplain or fen should have higher $\delta^{15}N$ values: it may be related to nutrient deposition during flooding, or nitrogen cycling in wet environments. If the trend to higher $\delta^{13}C$ values on chalk is substantiated, it may reflect greater openness at these sites, and/or greater water stress affecting plant $\delta^{13}C$ values. Variations in animal $\delta^{13}C$ and $\delta^{15}N$ values are reflecting variation in plant values on a landscape scale.

The higher cattle and sheep $\delta^{13}C$ and $\delta^{15}N$ values at Brean Down, and the high single cattle values from two other Bronze Age Severn Estuary sites, have been convincingly attributed by Britton et al. (2008) to the use of saltmarsh grazing. The two sheep from Bronze Age Cladh Hallan (South Uist) with very high $\delta^{13}C$ values compared to other Neolithic/Bronze Age sheep, or to cattle at the same site, do not have correspondingly high $\delta^{15}N$ values, and it seems possible that they were grazing on seaweed (Balasse et al. 2005, 2009; Mulville et al. 2009).

In both of these cases the use of unusual foodstuffs/environments could be seen as an aspect of animal management by people, broadening the resource base.

3.3 Time

There are rather few data from the late Neolithic or Bronze Age and these are widely scattered, so the main comparison is between the early Neolithic and the Iron Age to Roman periods.

Cattle clearly have lower $\delta^{13}C$ values, and pigs have higher $\delta^{13}C$ values and lower $\delta^{15}N$ values, in the Neolithic than later. This is consistent with the findings of Hamilton et al. (2009), and is based on a larger dataset. That study concludes that the most likely explanation is the greater use of closed-canopy forest resources by cattle and pigs in the Neolithic, which lowers cattle $\delta^{13}C$ values because they were feeding on plants subject to the canopy effect, but raises pig $\delta^{13}C$ values because they were consuming considerable quantities of fungi, with higher $\delta^{13}C$ values. The lower pig $\delta^{15}N$ values suggest that in the Neolithic pigs were free-ranging, but that in the Iron Age and, on the current evidence, in the Roman period as well, they were kept under closer control at settlements, with a higher proportion of anthropogenic waste in the diet.

In the Neolithic there is overlap between sheep and cattle $\delta^{13}C$ values, but sheep seem to lack the lowest $\delta^{13}C$ values shown by cattle, and have consistently slightly higher $\delta^{13}C$ values than cattle at 7/8 Neolithic sites. This suggests that sheep made less use of forest resources than cattle, feeding in more open environments and/or having a lower proportion of forest-derived browse in their diet (including fodder). By the Iron Age and Roman periods there is no clear difference between sheep and cattle $\delta^{13}C$ values, and both herbivores have a wide range of $\delta^{15}N$ values which do not differ consistently.

The lack of data from the later Neolithic and earlier Bronze Age is particularly frustrating because this is likely to have been a period of transition in landscape use (Chapter 3, 3.3.3). Madgwick et al. (2012, Fig. 5, p. 136) show that pig $\delta^{13}C$ values from the midden sites of Potterne (Bronze Age) and Llanmaes (early Iron Age) are, as would be expected on an environmental explanation based on deforestation, towards the “Iron Age” end of the Neolithic distribution.

3.4 Implications for this study

The data from this study will provide more examples to test these trends. The study area was deliberately chosen to minimise large-scale environmental differences in climate, so change with latitude/longitude is unlikely to be detected. Contrasts between sites on different geologies may be detectable, and together with site-level environmental information may show patterning related to animal husbandry, agricultural strategies and use of the landscape.

The most striking pattern to emerge is the contrast in cattle and pig $\delta^{13}C$ and $\delta^{15}N$ values between the Neolithic and Iron Age/Roman periods. As argued by Hamilton et al. (2009) this is likely to reflect environmental change at the landscape scale – deforestation – with concomitant changes in animal management. In the smaller arena of the Thames Valley, elements of this hypothesis can be tested.

1. Is the same pattern seen in the Thames Valley dataset?
2. Can isotopic changes be related to environmental change at the site level?
3. Do Bronze Age data from the Thames Valley show a transitional character between the “Neolithic” and “Iron Age” patterns?

Chapter 5

Materials and Methods

This chapter covers the materials and methods used in the study. Carbon and nitrogen isotope values of bone collagen were measured in 80 sheep from a modern flock to assess variation in a modern population, and in 1910 samples of cattle, sheep and pig from archaeological sites. The details of sample selection are given for both groups. Laboratory methods are then described, and details of measurement error given. The statistical methods used are explained, with details of the variables used in the analysis.

1 Materials

1.1 English Heritage sheep

The Sheep Project was developed by English Heritage to create a large modern research collection of domestic sheep skeletons of known life history to better understand sheep management in the past (Popkin et al. 2012). This provides a unique opportunity to look at variation in isotope values within a single flock in relation to diet, sex, age and breeding status, all factors which may affect isotope values (Chapter 2, section 4)

The sheep were raised at the Scottish Agricultural College (SAC) at Roslin, Penicuik, on a diet entirely of local grazing with some supplemental hay and grass pellets. Sheep were derived from a first generation of animals, bred from ewes of the unimproved Shetland type raised in the Voe area of Shetland, and rams of the pure Shetland breed bought at Lerwick Auction Market, also on Shetland. The lambs were born and raised at SAC, pastured on two different nutritional levels (“Low” diet: unimproved pasture; “High” diet: improved pasture with supplementary hay during snow cover), and slaughtered at uneven intervals in either August/September or November/December (“Slaughter Groups”). Animals in a given slaughter group were not necessarily born or killed in the same year. The animals were raised on two adjacent fields, at an altitude of 200m. The high-plane pasture (Knowes Field) consisted of well-drained rotational grassland while the low-plane field (Daisy Dell) consisted of poorly drained native grassland. Males were either entire (“Male”) or castrated (“Castrate”), and females were bred “Early” (first lamb at 2 years old) or “Late” (first lamb at 3 years old) or not bred (“Unbred”) (details in Popkin et al. 2012). The skeletons were

prepared by English Heritage at Portsmouth by boiling/simmering, defleshing with enzymes (neutrase, biotex), and degreasing with acetone (Davis and Payne 1992). Samples consisted of a small piece of rib from each animal.

Comparisons were between males on high and low diets and females on low diets that were bred early or unbred. Samples were taken from 80 individuals, with 4 replicates in each category for each slaughter group (Table 5.1). The first three categories were analysed in May 2008, and the unbred females were analysed in January 2009. As a check on consistency, 20 samples that had been measured in May 2008 were run along with the samples measured in January 2009. Sample $\delta^{13}C$ and $\delta^{15}N$ values were measured using standard RLAHA protocols (below, section 2).

Sex	Diet	Bred	Slaughter group / age (years.months)					Total
			5 / 2.7	6 / 3.4	7 / 3.7	8 / 4.4	9 / 4.7	
Male	High		4	4	4	4	4	20
Male	Low		4	4	4	4	4	20
Female	Low	Early	4	4	4	4	4	20
Female	Low	Unbred	4	4	4	4	4	20
Total			12	12	12	12	12	**80**

Table 5.1. Individuals used in the English Heritage sheep study

1.2 Archaeological faunal samples

The Upper and Middle Thames Valley was chosen as a suitable area to conduct a study of prehistoric domestic animal isotopes for the following reasons. This region is well known archaeologically (Allen et al. 1997; Booth et al. 2007; Hey et al. 2011; Lambrick et al. 2009; Morigi et al. 2011; Chapter 3). Material from a variety of sites excavated in the last 40 years is well recorded, archived, available and accessible. There is a wide range of environmental evidence, with detailed studies at many sites, and based on these a good environmental history for the period covered. The area of about 10,000 km^2 includes a variety of habitats from chalk downland to river floodplain, while fairly homogenous climatically. The timespan (Neolithic to Roman periods) encompasses major cultural shifts, from the adoption of farming in the Neolithic, through the appearance of settlements and the division of the landscape in the

Bronze Age, landscape reorganisation in the Iron Age and inclusion in the Roman empire. These cultural shifts are connected with changes in land use and farming practice that are likely to be reflected in isotope values of domestic animals. There were also long-term changes in climate and hydrology (Chapter 3). For the later periods, Lambrick (Lambrick 1992, 2009) has proposed models of land use/ landscape organisation that can be tested using isotopes from domestic animals (Chapter 3).

1.2.1 Site selection

Sites were chosen to provide as good a coverage as possible of the Upper and Middle Thames Valley, taking into account period, landscape-region, availability of archaeological and environmental information, and preservation and accessibility of the material (Figs. 1.1, 3.1). Sites with faunal remains from more than one period were prioritised, so that variation over time at single sites as well as over regions within the study area could be examined. Once the archive had been located and permission obtained for sampling, samples were taken at the storage facility using a portable sample kit. Details of all sites included in the study, including archaeology, environmental evidence, and references, are given in Tables A1.3–A.1.5 and brief site descriptions in Appendix 2. References for study sites are not repeated in the text.

1.2.2 Sample selection

The aim was to obtain 15 samples from adults of each species (cattle, sheep, pig) per phase/period of interest per site. At some sites there was not enough securely stratified/phased and identifiable material to do this, and in other cases poor collagen preservation reduced the number of measurements, so this coverage was not always achieved. Species identifications were made according to the author's experience using the usual criteria (Hillson 1996; Schmid 1972). It is not always possible to distinguish sheep and goat, particularly in fragmentary material, but definite goat bones were not sampled, and definite sheep bones were preferred (Boessneck 1969; Zeder and Lapham 2010; Zeder and Pilaar 2010). Goat is generally rare in British assemblages (Albarella et al. 2008; Hambleton 2008; Serjeantson 2011), though present from the Early Neolithic, and the overwhelming majority of sheep/goat fragments are likely to be from sheep. The taxon "sheep/goat" is referred to as "sheep" hereafter. As far as possible, only adults were sampled. In fragmentary material it is not always possible to be certain that a bone is from an adult animal – e.g. if only one epiphysis is present – but definite juvenile bones were avoided (based on tooth wear and epiphyseal fusion, Grant 1982; Silver 1969) and definite adult bones were preferred. No attempt was made to select by sex since it is rarely possible to sex individual skeletal elements, particularly if they are incomplete. I assumed that the proportions of sex classes (male, female, castrate) would approximately

reflect those present in the death assemblage. Cortical bone was preferred to cancellous bone where possible. A small amount of bone (0.5–1 g) was removed using a small circular saw, placed in a ziplock bag and labelled with the site, context, species and anatomical element, and the period/phase as far as known at the date of sampling. For some sites that were still being excavated or in the post-excavation analysis stage, the context information was not yet fixed, and phasing was subsequently changed. In some cases (e.g. Alfred's Castle) this meant that samples were excluded because they no longer fell within the study period.

Site	n sampled	n collagen extraction failed	n rejected: failed quality test	Total other	Total failed or rejected on quality criteria	n accepted	*% accepted*
Alfred's Castle	114	0	1	22[a]	1	91	*99*
Barton Court Farm	210	6	27	0	33	177	*84*
Claydon Pike	238	123	10	0	133	105	*44*
Farmoor	65	20	0	0	20	45	*69*
Harlington	68	22	9	0	31	37	*54*
Heathrow Terminal 5	59	3	7	1[b]	10	48	*83*
Horton	79	57	14	0	71	8	*10*
Latton Lands	51	47	0	0	47	4	*8*
Mount Farm	137	9	3	0	12	125	*91*
Runnymede	144	0	28	0	28	116	*81*
Shorncote Quarry	6	0	0	0	0	6	*100*
Staines Road Farm	35	0	1	1[c]	1	33	*94*
Thornhill Farm	87	38	0	18[d]	38	31	*44*
Thorpe Lea Nurseries	133	1	23	0	24	109	*82*
Watkin's Farm	107	36	51	1[c]	87	19	*18*
Whitecross Farm	60	14	4	0	18	42	*70*
Wyndyke Furlong	96	5	1	0	6	90	*94*
Yarnton	221	6	0	3[e]	6	212	*97*
	1910	387	179	46	566	1298	*70*

Table 5.2 Sample numbers by site (cattle, sheep and pig) sampled for this project.
Notes: [a]1 unphased, 21 post-Roman, [b] post-medieval, [c] identification uncertain, [d] unphased, [e] mislabelled/no data

Collagen extraction and isotope measurement took place at the RLAHA. A total of 1910 samples of cattle, sheep and pig from 18 sites were processed (Table 5.2).

Published measurements from 5 additional sites were included in the dataset (Table 5.3). The causewayed enclosures at Abingdon and Windmill Hill were sampled and analysed as part of the Causewayed Enclosures Project (Hamilton and Hedges 2011; Whittle et al. 2011) and full laboratory details were available. The other three sites (Ascott-under-Wychwood: Hedges et al. (2006); Eton Rowing Course: Stevens et al. (2012); Hazleton: Hedges et al. (2008)) were

analysed at RLAHA using standard methods, but details were only available as published (Table 5.3).

Site	n sampled (cattle, sheep, pig)	n collagen extraction failed	n rejected: failed quality test	Total other	Total failed or rejected on quality criteria	n accepted	*% accepted*
Abingdon	58	0	1	1[a]	1	57	*98*
Ascott-u-Wychwood	Details not available					41	
Eton Rowing Course	47	Details not available			13	34[b]	*72*
Hazleton	Details not available					14[c]	
Windmill Hill	51	1	3	1[d]	4	46	*90*
						192	

Table 5.3 Sample numbers by site (cattle, sheep and pig) for previously published sites.
Notes: [a] recent date, [b] includes 6 datapoints from radiocarbon dating , [c] omits "probable sheep" and "probable pig", [d] identification uncertain

2 Laboratory methods

2.1 Sample preparation and measurement

Sample processing followed the standard protocol used at RLAHA (O'Connell and Hedges 1999). Collagen was extracted from 0.5–1.2 g of bone per sample. Any superficial material was removed from the bone by shotblasting with aluminium oxide powder. The bone was crushed, ideally to 0.5- to 1-mm chunks, though in practice chunk size depended on bone preservation. Samples were demineralised in 0.5M HCl at 4°C for up to 7 days, rinsed 3 times with deionised water, and gelatinised in a pH 3 solution for 48 h at 75°C. The solution was filtered (8-µm Ezee filters), frozen and freeze-dried. Between 2.0 and 2.5 mg of dried collagen was loaded into a tin capsule for isotope ratio measurement. In 2012–2013, when a few late runs were done, 1–1.5 mg of dried collagen was used, according to the new standard practice following machine adjustments.

Isotope ratios were measured at RLAHA by continuous flow isotope ratio mass spectrometry (CF-IRMS), using an automated Carlo Erba carbon and nitrogen elemental analyser coupled with a continuous flow isotope ratio monitoring mass spectrometer (SerCon Geo 20/20). Each sample was measured in at least two separate runs, and the result for each sample is given as the mean of all measurements from accepted runs. Internal secondary standards were used to correct for measurement drift and to check consistency over the run. Until November 2008 the drift correction standard was nylon and alanine was used to check consistency, and after that

date the drift correction standard was alanine and a bovine liver standard (NIST 1577b) was used to check consistency. In 2012–2013 additionally a modern cattle collagen standard, a modern seal collagen standard, and a sucrose standard (IAEA-CH-6) were used. Masses of standards were similar to those of collagen samples. Results from runs where the standards indicated inconsistent measurements were discarded and the runs were repeated. Inconsistent measurements could generally be traced to a cause such as an air leak, mechanical problems or the need for a column change. Results are reported in unit per mil (‰) and $\delta^{13}C$ and $\delta^{15}N$ values were measured relative to the VPDB and AIR standards respectively (Gonfiantini et al. 1995; Mariotti 1983).

2.2 Analytical precision

From February 2007 to November 2008 analytical error, based on repeated measurements of nylon standards, was ±0.09‰ (standard deviation) for $\delta^{13}C$ and ±0.28 for $\delta^{15}N$. From December 2008 to February 2010, based on repeated measurements of alanine standards, it was ±0.15‰ for $\delta^{13}C$ and ±0.30 for $\delta^{15}N$. In 2012-2013, based on repeated measurements of alanine standards, it was ±0.09‰ for $\delta^{13}C$ and ±0.11 for $\delta^{15}N$. The measured values for the standards over these periods are shown in Table 5.4. The IRMS measurements are accurate (comparison with expected values in Table 5.4) and overall precision is ±0.15‰ for $\delta^{13}C$ and ±0.30‰ for $\delta^{15}N$, or better.

Measured in:		2007-2008			2008-2010			2011-2012		
Standard	Expected $\delta^{13}C$	$\delta^{13}C$	n	SD	$\delta^{13}C$	n	SD	$\delta^{13}C$	n	SD
Nylon	-26.1	-26.1	369	0.09						
Alanine	-26.9	-26.8	65	0.18	-26.9	405	0.15	-26.9	55	0.09
Bovine liver	-21.1				-21.4	98	0.13			
Standard cow bone	-24.3							-24.3	12	0.12
Seal bone	-13.4							-13.3	8	0.04
Sucrose	-10.4							-10.4	10	0.08
	Expected $\delta^{15}N$	$\delta^{15}N$	n	SD	$\delta^{15}N$	n	SD	$\delta^{15}N$	n	SD
Nylon	-1.8	-1.7	369	0.28						
Alanine	-1.6	-1.6	65	0.24	-1.5	405	0.30	+1.6	55	0.11
Bovine Liver	+7.6				+7.6	98	0.38			
Standard bone	+7.8							+7.8	12	0.14
Seal	+17.3							+17.5	8	0.13
Sucrose	—									

Table 5.4 Expected and measured values for standards in IRMS runs over the periods when measurements for this study were made. The laboratory standards used were in-house standards, except for Sucrose (IAEA-CH-6) and Bovine Liver (NIST 1577b).

3 Statistical methods

3.1 The mean as measure of central tendency

In all analyses and plots the mean is used as the measure of central tendency. This is in keeping with a generally parametric statistical approach. The median might also be appropriate, particularly since there is no *a priori* reason to assume that the data are normally distributed, and the median is less affected by outliers than the mean. However, linear mixed models are used for most analyses (below, 3.3) and these do not require data to be normally distributed. In practice, the difference between the mean and the median isotope values at sites in these data is very small (generally <0.2‰ and in no case greater than 0.65‰). Where possible, standard deviation is used to describe dispersion (but see Chapter 6, 1.1 and 2.1).

3.2 English Heritage sheep

Group means were compared using general linear models (Grafen and Hails 2002). Because of the unbalanced design, these were equivalent to ANOVAs on subsets of the data in most cases. Analyses were blocked by slaughter group to account for differences due to age or season.

3.3 Thames Valley: statistical approach

The dataset included 1490 paired measurements of $\delta^{13}C$ and $\delta^{15}N$ values from 3 species of domestic animals at 23 sites, over up to 4 archaeological periods (sometimes subdivided into phases) at any one site. Because of the nature of the sampling process, and uneven preservation at different sites, the data were highly unbalanced, with sample numbers ranging from 0 to 46 per species/site/period. This presents challenges for conventional multivariate analysis based on linear modelling. Even more seriously, the data points from an individual site are not independent – it is likely that they will be more similar to each other than to data points from other sites (spatial autocorrelation), and it would be invalid to enter them as independent points in a linear model.

The approach adopted here used linear mixed modelling for the analysis (Bolker 2008; Bolker et al. 2009; Pinheiro and Bates 2006). Linear mixed models (LMMs; also known as multilevel models, hierarchical linear models, random-coefficient, random-effects models) can cope with unbalanced data, and can explicitly partition variance into intra-site and inter-site components (and higher-level components if appropriate). Not only does this deal with the problem of non-independence, it also allows insights into the sources of variance in the data. Both continuous and categorical variables can be used.

Here, 2-level models with individual $\delta^{13}C$ or $\delta^{15}N$ values as the first level and site as the second level were run using the lme4 package (Bates et al. 2014) in the R statistical computing language (R Core Team 2014). Models were fitted by restricted maximum likelihood estimation (REML). Linear mixed-effects models do not require the data to be balanced or normally distributed, but the residuals from model fitting should be normally distributed, and there can also be problems if variances differ systematically. Data did not require transformation to improve fit – i.e. linear models were generally appropriate. Only random-intercept models were fitted: random-slope models often did not run successfully (reflecting the relatively sparse nature of the data, in statistical terms; although this is an exceptionally large dataset in an archaeological context) or were not significantly better. Models can be compared to see whether inclusion of particular variables improves fit significantly, using a likelihood ratio test. This involves refitting the models using maximum likelihood estimation (ML) and comparing their deviances (–2×log-likelihood); the simpler model is preferred unless including the parameter significantly reduces the deviance. P-values are estimated by comparison with a χ^2 distribution.

Results are reported using the output tables from lme4. In lme4 P values are not reported, because it is uncertain how they should be calculated (Bates 2006; Bates et al. 2014, p. 34); t-values >2 indicate a significant effect, and confidence intervals can be calculated for the estimated coefficients. For indicative purposes only, P values calculated using the nlme package in R (Pinheiro et al. 2014) have been included in the tables in Chapter 5 (models were run in both packages and cross-checked).

3.3.1 Example of analysis using lme4

In the simplest analysis (Table 5.5) the effect of species on $\delta^{13}C$ is modelled. The first three lines describe how the model was fitted (REML), give the model formula ($\delta^{13}C$ by species – "fixed" effect – with site as grouping factor – "random" effect), and give the name of the data file. The value of the REML criterion at convergence (when it is minimum) was 2436.1. This is the deviance, or –2×log-likelihood.

The scaled-residuals table gives an idea of the distribution of the residuals, which are examined in more detail when checking the model. Here, the median is close to 0 and the values for first and third quartiles very similar, so the distribution is symmetrical about 0 as would be expected for normally distributed residuals. Data file, REML criterion and scaled residuals are omitted in the model summaries shown in Appendix 3, for clarity.

```
Linear mixed model fit by REML ['lmerMod']
Formula: δ13C ~ sp + (1 | site)
  Data: tv

REML criterion at convergence: 2436.1

Scaled residuals:
   Min      1Q  Median      3Q     Max
-3.9614 -0.5850  0.0130  0.6039  5.1263

Random effects:
 Groups   Name        Variance Std.Dev.
 site     (Intercept) 0.02071  0.1439
 Residual             0.29113  0.5396
Number of obs: 1490, groups:  site, 23

Fixed effects:
            Estimate Std. Error t value
(Intercept) -21.82955    0.03907  -558.7
spPig         0.63153    0.03667    17.2
spSheep       0.18652    0.03241     5.8

Correlation of Fixed Effects:
        (Intr) spPig
spPig   -0.332
spSheep -0.379  0.424
```

Table 5.5 lme4 summary output table for the effect of species on $\delta^{13}C$. A linear mixed model was fitted to the whole dataset to show the effect of species on $\delta^{13}C$ values, using site as a grouping factor.

The random-effects table shows the effect of including site as a grouping factor. In the null model where site is not so included, the "intercept" is the grand mean of the reference species, cattle. Each data point differs from this by a certain amount ("residual error"). It would be possible to calculate, say, the mean difference for each species at each site, but no account would be taken of the fact that something at a given site might influence each species in a similar way. In the mixed model, each site is allowed to have a different grand mean ("intercept"), and the residuals include this site-specific "error". It is then possible to calculate how much of the error variance is at the site level (between sites) and how much at the individual level (within sites). In this case, 0.021/(0.021+0.291=0.312) = 7.2% of the variance in $\delta^{13}C$ values is between sites, while the other 92.8% is within sites. We can check that including site in this way has a significant effect, by comparing the deviance in this model with one in which site is not so included. This was done using MLwiN (Rasbash et al. 2009a,b), alternative linear modelling software, which estimated the deviance of the null model as 2470 compared with 2436 in this model, so deviance has been considerably reduced. The effect of including site as a level-2 factor was significant at $P<0.001$. That means that there is significant spatial autocorrelation in the data, and it would be invalid to model the data

without taking account of that. The last line summarises the total number of observations used in the model and the number of groups used – in this case, the whole dataset of 1490 observations from 23 sites.

The fixed-effects table shows the estimates of the coefficients of the best-fit model, with the associated standard error which reflects the variability in the data. The t-value is simply the coefficient divided by the standard error, and if it is >2 suggests that the effect is significant. The "intercept" is the grand mean $\delta^{13}C$ value for the reference species, cattle. The pig coefficient is +0.63, i.e. pig $\delta^{13}C$ values are on average 0.63‰ higher than those of cattle, and the large t-value suggests that there is a vanishingly small probability that this is due to chance. The sheep coefficient is +0.19, again highly statistically significant, but of a similar magnitude to measurement error, suggesting caution in interpretation.

```
Linear mixed model fit by REML ['lmerMod']
Formula: δ13C ~ sp + per + (1 | site)
   Data: tv

REML criterion at convergence: 2432.8

Scaled residuals:
    Min      1Q  Median      3Q     Max
-3.9392 -0.5842  0.0060  0.6007  5.3698

Random effects:
 Groups   Name        Variance Std.Dev.
 site     (Intercept) 0.01987  0.1410
 Residual             0.28865  0.5373
Number of obs: 1490, groups:  site, 23

Fixed effects:
             Estimate Std. Error t value
(Intercept) -21.92165    0.05337  -410.7
spPig         0.62794    0.03653    17.2
spSheep       0.17756    0.03236     5.5
per2          0.01437    0.06287     0.2
per3          0.12847    0.05790     2.2
per4          0.20070    0.05730     3.5
```

Table 5.6 lme4 summary output table for the effect of species and period on $\delta^{13}C$. A linear mixed model was fitted to the whole dataset to show the effect of species and period on $\delta^{13}C$ values, using site as a grouping factor.

The table of correlation of fixed effects refers to correlations between estimates in the modelling, reflecting the variance/covariance structure, and is not of great importance in interpreting the model, so it is omitted hereafter.

Table 5.6 shows a model that includes both species and period as fixed effects, and site as the random effect. “Period” was entered as a categorical variable with 4 levels (Neolithic, Bronze Age, Iron Age, Roman period). The deviance is lower (2432.8) and so is total variance (0.020+0.289=0.309), suggesting that period has some explanatory effect. The grand mean $\delta^{13}C$ value for the reference species, cattle, and the coefficients for sheep and pig are close to those seen in the first model, and still highly significant. The reference period is the Neolithic. The coefficient for the Bronze Age (per2) is small and not significantly different, while those for the Iron Age (per3, 0.13) and Roman periods (per4, 0.20) are larger and differ significantly from the Neolithic.

Finally, we can test whether the second model including period provides a significantly better fit to the data than the first (Table 5.7) using the “anova” function in lme4 (this is a method of comparing models, not an ANOVA as conventionally understood).

```
refitting model(s) with ML (instead of REML)
Data: tv
Models:
tv.mod1c: δ13C ~ sp + (1 | site)
tv.mod2c: δ13C ~ sp + per + (1 | site)
         Df    AIC    BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
tv.mod1c  5 2431.2 2457.8 -1210.6   2421.2
tv.mod2c  8 2420.9 2463.4 -1202.5   2404.9 16.334      3  0.0009685 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Table 5.7 Output from lme4 comparing two linear mixed models using the “anova” function (not an ANOVA, see text). *mod1c* is the name of the model shown in Table 5.5 and *mod2c* is shown in Table 5.6.

For technical reasons it is preferable (and more conservative) to compare model fits obtained using a maximum likelihood rather than a restricted maximum likelihood criterion, so the models are refitted accordingly (first line of output). The name of the data file and the formulas for the fitted models are then listed. The table gives the degrees of freedom for each model, and various indicators of model fit: AIC (Akaike information criterion), BIC (Schwarz Bayesian information criterion) (Bates 2010 p.8), log-likelihood, and deviance calculated as –2×log-likelihood. The difference between the deviances (2421.2 – 2404.9 = 16.3) follows a χ^2 distribution with a df of 3 in this case (the number of extra degrees of freedom in the more complex model), which is significant at $P<0.001$. It is therefore statistically justified, and preferable, to use the more complex model – or to put it simply, period matters.

The validity of the fitted models depends on the assumptions that the residuals are normally distributed, the variance is homogenous across the fitted values of the model and that the relationship between the predictor variable and the response variable is linear. Models were checked using the "plot.merMod" function (see Appendix 4). The output tables referred to in Results are in Appendix 3, and selected R scripts used for the analysis are given in Appendix 4.

3.4 Thames Valley: archaeological and environmental variables

One of the reasons for choosing the Thames Valley as a study area was the availability of good archaeological and environmental information for many of the sites. To examine the research questions (Chapter 1, Chapter 3) using the approach adopted here, this information needed to be summarised into a consistent set of variables that could be entered into the linear mixed models.

The information available for each site is summarised in Appendix 2 (Gazetteer). Information was taken from the original site description where possible (as published, or unpublished information supplied by the excavators for sites still being excavated or undergoing post-excavation analysis). In some cases information was available from reviews of the environmental evidence (Chapter 3). The excavations have taken place over the last 40 years, and in that time there have been changes in archaeological techniques, recording, analysis, archiving, dating and reporting. There are also taphonomic differences between sites which mean that the full range of evidence is not available at every site. For the purposes of this study, it was important to summarise information in a way that was reasonably consistent across sites, and this has meant the use of broad categories. The fine details of individual site development are inevitably lost, but it means that a wide range of sites with a large amount of data can be compared. Tables of the variables for each site, as entered into the Access database, are given in Appendix 1 (Table A1.3–A1.5).

3.4.1 Archaeological variables

3.4.1.1 Chronology: Period

The most direct approach to chronology would be to use calibrated radiocarbon dates. These are not available for all the sites included here, or in some cases are several decades old, and both measurement technology and reporting have changed, so that it is not easy to make direct comparisons between sites. Plateaux in the calibration curve make radiocarbon dating problematic in some periods, e.g. the Iron Age (800 BCE – 43 CE). It is sometimes more meaningful to use chronological divisions based on material culture and/or stratigraphy at

particular sites, especially where there may be problems of residuality (e.g. Mount Farm Berinsfield), but these are not always comparable across sites (though in some cases they may be more useful than broad radiocarbon dates). In a study such as this it is important to account for chronological change, but in many cases samples could not be assigned a precise age, only a date range based on various lines of evidence. Instead of date being entered as a continuous variable, categorical variables "period" *per* and "phase" *pha* were used.

Term	Code	From	To
Neolithic	**NEO**	**-4000**	**-2200**
Early Neolithic	EN	-4000	-3000
Middle Neolithic	MN	-3500	-2700
Late Neolithic	LN	-3000	-2200
Early Bronze Age	EBA	-2500	-1500
Bronze Age	**BA**	**-2500**	**-700**
Middle Bronze Age	MBA	-1600	-1000
Late Bronze Age	LBA	-1000	-700
Iron Age	**IA**	**-800**	**43**
Early Iron Age	EIA	-800	-400
Middle Iron Age	MIA	-400	-100
Late Iron Age	LIA	-100	43
Roman	**RO**	**43**	**410**

Table 5.8 Classification of archaeological **periods** (*bold type*) as used in the National Monuments Record. Dates are in calendar years BCE/CE

A broad conventional classification into four periods was used to assign periods to every site. These are based on the list of terms in use in the National Monuments Record of the former Royal Commission on the Historical Monuments of England, now maintained by English Heritage (http://www.fish-forum.info/i_apl_e.htm , last accessed 17 November 2014). The period subdivisions (e.g. Early Neolithic) in Table 5.8 are *not* the same as those used in the analysis. They were used in conjunction with available information in site reports on period/phasing as assigned by the excavator, radiocarbon dates, local sequences of site type and material culture, and stratigraphy, to assign periods and phases (see below 3.3.1.2) as used in the analysis, for each site. Although there is some overlap in dates between subdivisions and even periods in Table 5.9, in almost all cases it was possible to unambiguously assign periods as used here. The main exceptions were at sites where there was no very clear distinction between the latest Iron Age and the earliest Roman period. This is not just lack of

information or confused stratigraphy, but reflects the nature of the transition. These cases were assigned to the latest phase of the Iron Age in the classification used here.

The most important way of accounting for chronology in the analysis was the categorical variable "period" *per*, with 4 levels: Neolithic, Bronze Age, Iron Age, Roman (Table 5.9). The periods are broadly defined, and of different lengths in terms of years (calendar or radiocarbon), but have the advantage that they can be clearly and consistently assigned.

3.4.1.2 Chronology: Phase

For the purposes of analysis each period was subdivided into four phases. These were assigned in the same way as the periods, using all the available information, and were intended to be comparable across sites. They do not necessarily correspond exactly with the phasing used by site excavators. Phase (*pha*) was entered into the model as a categorical variable with 16 levels (Table 5.9).

Period	Period code	Phase	Phase code	Phase in site report	Approximate dates (calendar years)
Neolithic	1	EEN	1	Pre-barrow	4000-3800 BCE
		EN	2	Early Neolithic	3800-3300 BCE
		MN	3	Middle, Early/mid, Mid/late Neolithic, Peterborough Ware	3300-2900 BCE
		LN	4	Late Neolithic, Grooved Ware	2900-2500 BCE
Bronze Age	2	EEBA	5	Neolithic-Bronze Age, Early Beaker	2500-1900 BCE
		EBA	6	Early, Early/Mid Bronze Age	1900-1700 BCE
		MBA	7	Middle Bronze Age, Bronze Age	1700-1200 BCE
		LBA	8	Late Bronze Age, LBA3, LBA5, Late Bronze Age /Early Iron Age	1200-800 BCE
Iron Age	3	EIA	9	Early Iron Age	800-400 BCE
		MIA	10	Early/Mid, Middle Iron Age Iron Age	400-100 BCE
		LIA	11	Mid/Late, Late Iron Age	100-50 BCE
		LLIA	12	Late Iron Age/Roman, Late Iron Age/Early Roman	50 BCE-43 CE
Roman period	4	ER	13	Early Roman, Early Romano-British, Romano-British 1, 1^{st}-2^{nd} century CE	43 -150 CE
		MR	14	Early/Mid Romano-British, Romano-British, 2^{nd}-3^{rd} century CE	150-250 CE
		LR	15	Romano-British 2, 3^{rd} century CE, 3^{rd}-4^{th} century CE	250-350 CE
		LLR	16	Late Romano-British, Romano-British 3, 3^{rd}-5^{th} century CE, 4^{th} century CE	350-410 CE

Table 5.9 Periods and phases used in the analysis. *N* Neolithic, *BA* Bronze Age, *IA* Iron Age, *R* Roman period, *EE* earliest, *E* early, *M* middle, *L* late, *LL* latest. Dates based on Booth et al. (2007), Lambrick et al. (2009), and Hey et al. (2011)

Lambrick (1992) discussed the dynamics of agricultural change in the Iron Age/Roman period in the Thames Valley. He identified some discontinuities in settlement pattern which were linked to a model of agricultural development across the landscape. In order to compare this model with changes in isotope values, the Iron Age/Roman phases (Table 5.9) were regrouped into "Lambrick phases", *phL* as follows: *i1* = pha 9,10,11; *i2* = pha 12; *r1* = pha 13,14; *r2* = pha 15,16. Phase (*phL*) was entered as a categorical variable with 4 levels.

3.4.1.3 Site type

The site type was assigned according to the site description. The categories used were: Enclosure (including causewayed enclosure, ring ditch, enclosure/barrow); Barrow (long barrow); Midden (Late Bronze Age riverside middens at Runnymede and Whitecross Farm); Occupation (domestic remains, mainly enclosed or unenclosed settlements with domestic/habitation structures); Villa (occupation with Roman villa building). The type of a given site could change between periods or phases. The first three types were mostly sites where people assembled rather than sites of permanent occupation, and include most Neolithic and Bronze Age sites. The last two types were sites of (mostly) permanent occupation, and include all the Iron Age and Roman period sites. This reflects the nature of the archaeological record: settlement sites are rare in the Thames Valley before the later Bronze Age. Site type was entered as a categorical variable *type* with 5 categories: *1* Barrow, *2* Enclosure, *3* Midden, *4* Occupation, *5* Villa.

3.4.2 Environmental variables

3.4.2.1 Classifying site environments

It was originally hoped that environmental variables could be combined to produce a useful, objective classification of site environments. Information on abiotic and biotic variables was taken from the site description. In addition to the variables described below (3.3.2.2–3.3.2.8), molluscs, plant macro-remains and beetles were recorded for each site where the evidence was available. Each of these has been used as an indicator of local environments at some of the sites studied. Groupings were based on those used by environmental archaeologists in the site reports. The environmental analysis at many of the sampled sites had been done by the same small group of experts, which made it easier to group the evidence consistently. Pollen, and weed seeds occurring in charred cereal assemblages, are also useful in environmental interpretation, but it was difficult to record these systematically. They were taken into account in attributing vegetation type, and the percentage of arboreal pollen was entered as a variable.

Mollusc shells (snails) were assigned to 8 groups representative of different environmental conditions: Aquatic, Marsh/fen/pond (slum), Rock rubble, Arable, Open grassland, Open calcareous grassland, Shaded hedge/tall vegetation, Woodland. Macroscopic plant remains were assigned to 10 groups: Aquatic/riverine, Marsh/fen, Pasture/grazed, Meadow, Hedge/scrub, Old woodland, Secondary/ managed woodland, Wet arable, Dry arable, Disturbed. Beetles were assigned to 14 groups: Aquatic, Marsh/aquatic, Pasture/dung, Meadow, Wood and trees, General disturbed/arable, Sandy/dry disturbed/arable, Dung/foul, Lathridiidae, General synanthrope, Stored grain pests, Stuctural timbers, Roots in grassland, Heathland and Moorland. The presence/absence of each of these groups at sites where data was available was recorded.

The idea was to use ordination methods similar to those used by ecologists to produce a classification based on the pattern of occurrence of snails, beetles or plant macro-remains (Gauch 1982). For each type of information, each site-period combination was considered as a sampling unit (Pielou 1984), entered as a row in the data matrix, with the presence/absence of each group of snails, beetles or plant macro-remains as the columns. The analysis was done in R using the vegan package (Oksanen et al. 2013) and the labdsv package (Roberts 2013). A dissimilarity matrix was constructed using various measures (binary distance or Bray-Curtis dissimilarity) and principal coordinate analysis (PCO) (Gower 1966) applied to it. The resulting points (one for each site-period) were plotted on the first two coordinate axes. Each group could be distinguished in the plot, to see whether they tended to co-occur in a way that might be useful for classification. Agglomerative, hierarchical cluster analysis of the dissimilarity matrix was used to construct dendrograms showing relationships of the site-periods.

There was some patterning in the distribution of sites in the distance/dissimilarity ordination space. For snails and plants, the limestone/chalk sites were distinct from the floodplain/first-terrace sites (and second-terrace sites for snails; no information for beetles). For beetles, there was little overlap between floodplain and first-terrace sites, though second terrace sites overlapped both. There were also some contrasts in occurrence of different groupings. Aquatic and slum snails did not co-occur with woodland snails, except at Neolithic Runnymede. For beetles there was a good deal of overlap between groups. Plants of wet arable, but not dry arable, tended to co-occur with plants of marsh and fen. Hedge/scrub plants tended not to co-occur with meadow plants.

However, it was difficult to pick out clear groups that were likely to be useful in subsequent analysis, apart from the obvious chalk/limestone flora and snail fauna. Even if groups based on the classification methods turned out to have significant relationships with $\delta^{13}C$ or $\delta^{15}N$, interpretation would be difficult. Coverage was also incomplete: of a total of 49 site-periods, 18 had information on snails, 22 on beetles and 34 on plant macro-remains. In some cases this was because analyses had not been published, but in others it was due to taphonomic factors – e.g. beetles are preserved by waterlogging, so are not found at dry sites, while snail shells do not survive in acid conditions.

Test analysis using the plant data (which had the best coverage of sites), either using groups based on the classification methods or eigenvalues for the first two axes of the PCO, showed no significant relationships with $\delta^{13}C$ or $\delta^{15}N$. This approach seemed unlikely to be useful in the main analysis, and so was not pursued further. In order to enter some environmental information for every site, broad classes of region (3.3.2.3) and vegetation (3.3.2.6) were used. These were based on the same environmental evidence, combined and evaluated for each site.

3.4.2.2 Geographical variables

Three continuous geographical variables were used: *longitude*, *latitude* and *elevation* above sea level (m). Where this information was not available from the site description, variables were estimated using Ordnance Survey maps.

3.4.2.3 Regions

At the broadest scale, the *Upper* and *Middle* Thames Valley could be considered separately. Within each of these areas, four "regions" *reg* based on bedrock and surface geology, soils and topography were distinguished (Chapter 3.1). For the Upper Thames these were: *1 floodplain, 2 1st terrace, 3 2nd and higher terraces* and *4 limestone* (Cotswolds). For the Middle Thames they were: *1 floodplain, 2 1st terrace, 3 2nd and higher terraces* and *5 chalk* (Berkshire Downs). This gave five categorical variables in all, since the terraces were the same in both areas. Eyots (e.g. Runnymede) were included in the floodplain category. Most sites classified as being on the 2nd and higher terraces were in fact on the 2nd terrace. Heathrow Terminal 5 and Harlington are on the Taplow gravel terrace (overlain by silt and brickearth), which is the 3rd terrace up from the river locally but geologically equivalent to the 2nd terrace in the Upper Thames (Morigi et al. 2011 p2,18). Some potential regions were not included in the classification because they contained no sampled sites – e.g. the clay vale, or the Corallian ridge between the upper Thames and the Berkshire Downs.

There is some overlap between "region" and two other variables: elevation and soils. Because the study area is a river valley cutting through the local strata, elevation is related to both bedrock and surface geology, with limestone or chalk uplands at high elevations and river terrace deposits at low elevations. There is also a relationship between geology and the type of soils that develop in an area, e.g. alkaline, free-draining soils developing on chalk or limestone. It is probably the nature of local soils that is the important factor as far as human use of the landscape for agriculture is concerned, but it is difficult to find direct, detailed evidence of soil types for a particular site and period (see below 3.3.2.4). For this reason a more general geological variable, region, that could be assigned for all the sites, was considered useful. Inevitably, it overlapped with elevation as well as soils. The effects of this overlap on the model results were examined (Chapter 6), and region emerged as a useful environmental variable.

If the information was not available from the site description, British Geological Survey maps were used to estimate the variable (http://mapapps.bgs.ac.uk/geologyofbritain/home.html).

3.4.2.4 Soils

Precise information on soils for a given site/period was rarely available in a form that could be consistently applied. Where soil types at/around a site are mentioned in excavation reports, the information is often based on surface geology, present-day use or other environmental information (e.g. weed types), as well as or instead of direct observations of ancient soil profiles. Conditions at a site can change over time, e.g. overbank alluviation and flooding changing soils on the floodplain in the Late Iron Age/Roman period, or deliberate drainage, so modern soils are not always a good guide. Different systems of soil description are used in excavation reports, making it hard to summarise the information consistently. Taking all this into account, three categorical variables were used to describe soils: *soil type*, *soil pH* and *drainage* (Table 5.10). None of them could be applied to all sites, because of missing information.

Variable	Category and *abbreviation*				
Soil type *stype*	clay/silt *cs*	clay/loam *cl*	loam/brown earth *lb*	sandy loam *sl*	rendzina *rz*
Soil pH *sph*	Alkaline *alk*	Neutral *neut*	Acid *ac*		
Soil drainage *sdrain*	fast-draining *fast*	medium-draining *med*	None classified as slow-draining		

Table 5.10 Soil variables used in linear mixed models

When the information was not available from the site description, British Geological Survey maps were used to estimate the variable where possible (http://mapapps.bgs.ac.uk/geologyofbritain/home.html)

3.4.2.5 Climatic variables

There was undoubtedly large-scale climate change over the four and a half millennia covered by this study (Chapter 3, 2). It is not easy, however, to predict the precise effect of this at the scale of an individual site, even for the present day. While it is theoretically possible to run current detailed climate models backwards and link them to specific places via GIS modelling, that is beyond the scope of this study. Instead, modern recorded climatic data are used. The interest here is in whether *differences* in climate variables between sites can be linked to differences in isotope values, not in the absolute values of those variables, which in any case would be estimates of uncertain validity. For the time interval studied here, modern climate data should show similar patterning in relation to topography, even though absolute values may differ between the present day and the different periods covered.

Climate variable	Description
PMS	Mean monthly Pcp50 Summer (mm/month)
PMW	Mean monthly Pcp50 Winter (mm/month)
PDRMS	Days/month with rainfall Summer
PDRMW	Days/month with rainfall Winter
TMS	Mean monthly air temperature Summer (°C)
TMW	Mean monthly air temperature Winter (°C)
TDRS	Mean monthly temperature range Summer (°C)
TDRW	Mean monthly temperature range Winter (°C)
TDFS	Days/month with ground frost Summer
TDFW	Days/month with ground frost Winter
RHS	Mean monthly Relative Humidity Summer (%)
RHW	Mean monthly Relative Humidity Winter (%)
SPCS	Sunlight hours % of maximum Summer
SPCW	Sunlight hours % of maximum Winter
WRS	Mean monthly wind run Summer (km/h)
WRW	Mean monthly wind run Winter (km/h)
ETOS	Mean monthly evapotranspiration (Penman-Monteith, mm/d) Summer
ETOW	Mean monthly evapotranspiration (Penman-Monteith, mm/d) Winter

Table 5.11 Climate variables used in linear mixed models. *Pcp50* 50% probability precipitation, *Summer* April-September, *Winter* October-March

Rather than try and link data from specific weather stations to the 23 sites included here, the climate parameters for modelling were taken from the International Water Management Institute World Water and Climate Atlas (IWMI Atlas, http://wcatlas.iwmi.org), which is based on data from the Climatic Research Unit, University of East Anglia, UK (CRU, UEA http://www.cru.uea.ac.uk). The IWMI model refers to present-day climate (1961-1990). The data, averaged for each month, are spatially smoothed and processed at a 10-minute resolution, allowing values to be closely linked to specific sites. Each was further averaged over "winter" (October-March) and "summer" (April-September) to reduce the number of variables while retaining a seasonal signal. This gave a total of 18 continuous variables, listed in Table 5.11.

Principal components analysis (PCA; Fig. 6.8) showed that the climate variables were highly intercorrelated, with most of the variance accounted for on the first PC axis. For ease of interpretation climate variables were entered singly, rather than extracting PC scores, bearing in mind that they are in any case only large-scale approximations to the climate in the Neolithic-Roman period.

3.4.2.6 Vegetation

As for soils (3.3.2.4), it was difficult to extract information on local vegetation types from site reports in a consistent way. The availability of detailed evidence and the level of interpretation varied both between sites and within sites for different periods. Different lines of evidence included pollen, charcoal, waterlogged plant remains, insects (particularly beetles), remains of crop weeds, and snails. Each of these has different taphonomic characteristics, and each is found (or reported) only at a subset of sites. Various clustering and classification methods derived from ecology were tried, but with limited success. For the purposes of linear modelling, each site was assigned a single vegetation type (Table 5.12). This is a considerable simplification of the evidence, but broader categories could be more consistently applied. Individual site interpretations have changed to some extent as examples and experience have built up over time, but the reviews of evidence in Booth et al. (2007), Lambrick and Robinson (2009), and Hey et al. (2011) were useful in maintaining consistency in interpretation. Vegetation type (*vt2*) is a categorical variable with eight categories, listed in Table 5.12.

As well as dominant vegetation type, openness on a 5-point scale and percentage of arboreal pollen were assigned where possible. These three measures were highly correlated in a categorical PCA (Fig. 6.11: omits openness which loads almost identically to vegetation type), and only vegetation type (*vt2*) was used in further analysis.

vt2 category	Vegetation type in site description
1	Woodland, Woodland clearing
2	Clearing/scrub, Scrub/grass, Lightly grazed grassland
3	Grassland/scrub/hedge, Grassland/scrub/arable
4	Grassland, Grassland/pasture/meadow in any combination
5	Calcareous grassland
6	Grassland/arable in any combination
7	Open/dry arable
8	Wet grassland/pasture
9	*Disturbed – not dominant at any site, omitted from analysis*

Table 5.12 Vegetation type (*vt2*) variables used in linear mixed models

3.4.2.7 Plant remains at sites

The presence/absence of remains of various cultivated and gathered plants at individual sites was recorded as a categorical variable. Absence of a particular category at a given site may be due to taphonomic factors – absence of evidence is not evidence of absence. The plants included were: emmer *Triticum dicoccum*, spelt *T. spelta*, bread wheat *T. aestivum*, 6-row hulled barley *Hordeum vulgare*, flax *Linum usitatissimum*, pea *Pisum sativum*, bean *Vicia faba*, *Brassica* spp., opium poppy *Papaver somniferum*, herbs (includes coriander *Coriandrum sativum*, celery *Apium graveolens*, dill *Anethum graveolens*, summer savoury *Satureja hortensis*), fruit (includes cultivated *Prunus* spp., *Malus domestica*, possible pear *Pyraster pyraster*), crab or cultivated apple (uncertain) *Malus* sp., hazel nuts *Corylus avellana* and sloe *Prunus spinosa* (nomenclature according to Dorofeev et al. 1979; Stace 1997). Positive evidence of hay (as at Farmoor and Claydon Pike) was also included here. Other plants noted but not included in the analysis because they occurred at only 1 site, or the identification was uncertain, were: rye *Secale cereale*, fig *Ficus carica*, box *Buxus sempervirens*, grape *Vitis vinifera*, hemp or hop (*Cannabis/Humulus*, uncertain), osier *Salix* sp., einkorn *Triticum monococcum*, pignut *Conopodium majus* and celandine *Ranunculus ficaria*.

3.4.2.8 Animal remains at sites

The proportions of the three major domesticated species, cattle *Bos taurus*, sheep/goat *Ovis aries/Capra hircus* and pig *Sus domesticus*, based on NISP (number of identified specimens) were calculated, using information from the animal bone report for each site where available (nomenclature according to Gentry et al. 2004). The numbers for Neolithic Runnymede were taken from Serjeantson (2011). As mentioned above (1.2.2) goat is rare on British sites, and the overwhelming majority of sheep/goat samples are likely to be from sheep. The proportions

could be entered directly into the analysis as continuous variables, one for each species. Alternatively, a variable called *pattern* was used, with three levels: cattle>sheep>pig, cattle>pig>sheep, and sheep or pig>cattle. The presence/absence of domestic horse *Equus caballus* was recorded as a categorical variable. Dog *Canis familiaris* was ubiquitous and was not included in the analysis. The presence/absence of remains of various wild (presumably hunted) animals at individual sites was also recorded: aurochs *Bos primigenius*, red deer *Cervus elaphus*, roe deer *Capreolus capreolus*, and wild boar *Sus scrofa* (deer nomenclature according to Gentry et al. 2004; Grubb 2000), based on the identifications given in the site report. These data are available in the database. Hare, rabbit and badger were excluded because hare and rabbit might be confused in identification and rabbit and badger might have been introduced by burrowing.

4 Data archive

The data from this project will be deposited with the Arrchaeology Data Service for permanent storage, and will be available from the website: http://archaeologydataservice.ac.uk/

This chapter has described the materials and methods used in this thesis. In the next chapter the results are given.

Chapter 6
Results

In this chapter the results of $\delta^{13}C$ and $\delta^{15}N$ measurements are reported and analysed. Measurement precision and quality are assessed. The within-flock variation of the English Heritage sheep is analysed and compared with that seen in sheep from archaeological assemblages. Variation in $\delta^{13}C$ and $\delta^{15}N$ values at the Thames Valley sites is analysed with respect to species, archaeological and environmental variables, and changes over time. The patterning of faunal isotope values at sites is examined to look for changes in the relationship between species linked to changes in landscape use. Changes at individual sites with more than one period (or phase in some cases) are examined. Finally changes in faunal isotope values are compared with a model for farming development in the Thames Valley (Lambrick 1992, 2009).

Details for Thames Valley sites are given in Appendix 2, and references for individual sites are not repeated in the text.

1 Modern samples: precision and quality

1.1 Measurement error

The English Heritage sheep samples were run within the same period as the archaeological samples, and are included in the overall estimate of analytical precision (Chapter 5, 2.1.2) of ±0.15‰ for $\delta^{13}C$ and ±0.30‰ for $\delta^{15}N$ or better.

It was also possible to check analytical precision separately for a subset of these samples. To check that all the acetone used for degreasing had been removed, 10 samples were prepared in duplicate, one set as described above and one set with three additional rinses in deionised water, before shotblasting and crushing. A two-way ANOVA with preparation and replicate run nested within sample showed that there were no significant differences between preparations or runs ($P>0.50$), and the differences found were very small (Table 6.1).

Assuming that there was in fact no differential effect from the acetone treatment/extra rinses, this gives the opportunity to estimate the variation due to sample preparation, by comparing the results from the two separate preparations, and due to variation in measurement, by comparing the duplicate runs for each sample. For comparisons based on only two replicates,

$\delta^{13}C$ ‰									
Sample	T1A	T1B	T2A	T2B	Difference T1A-T1B	Difference T2A-T2B	Difference T1A-T2A	Difference T1B-T2B	SD all
EH1	-24.5	-24.5	-24.5	-24.5	0.02	0.02	0.04	0.03	0.02
EH2	-24.5	-24.5	-24.4	-24.4	0.00	0.10	0.10	0.09	0.06
EH3	-24.8	-24.8	-24.7	-24.7	0.04	0.14	0.10	0.06	0.06
EH4	-24.6	-24.4	-24.5	-24.5	0.15	0.06	0.09	0.04	0.06
EH5	-24.7	-24.6	-24.7	-24.6	0.07	0.10	0.03	0.04	0.04
EH6	-24.6	-24.7	-24.6	-24.6	0.14	0.15	0.01	0.11	0.07
EH7	-24.2	-24.1	-24.3	-24.3	0.14	0.23	0.09	0.00	0.11
EH8	-24.5	-24.6	-24.6	-24.6	0.03	0.03	0.06	0.01	0.03
EH9	-24.4	-24.4	-24.4	-24.4	0.04	0.06	0.02	0.01	0.03
EH10	-24.2	-24.3	-24.4	-24.4	0.02	0.19	0.21	0.18	0.11
Mean or RMS					**0.06**	**0.11**	**0.08**	**0.06**	**0.07**
$\delta^{15}N$ ‰									
Sample	T1A	T1B	T2A	T2B	Difference T1A-T1B	Difference T2A-T2B	Difference T1A-T2A	Difference T1B-T2B	SD all
EH1	6.8	7.0	6.6	7.1	0.22	0.40	0.18	0.06	0.21
EH2	6.8	6.6	6.9	6.7	0.23	0.31	0.08	0.14	0.13
EH3	5.9	5.9	6.1	6.1	0.06	0.22	0.28	0.22	0.15
EH4	5.9	6.4	6.0	5.8	0.50	0.44	0.06	0.59	0.26
EH5	5.4	5.4	5.8	5.5	0.02	0.35	0.37	0.11	0.17
EH6	6.3	6.3	6.4	6.3	0.08	0.05	0.13	0.07	0.06
EH7	6.2	6.5	6.1	6.2	0.01	0.24	0.25	0.13	0.16
EH8	6.5	6.5	6.1	6.1	0.00	0.33	0.33	0.34	0.19
EH9	6.3	6.4	6.0	6.7	0.02	0.38	0.36	0.31	0.28
EH10	6.2	6.3	6.3	6.3	0.15	0.00	0.15	0.05	0.07
Mean or RMS					**0.13**	**0.27**	**0.22**	**0.20**	**0.18**

Table 6.1. Results of replicate runs of English Heritage sheep samples EH1-10. *T1* standard protocol, *T2* standard protocol + 3 rinses, *A,B* separate mass spectrometer runs, *Difference* absolute difference between runs, *SD* standard deviation of all 4 runs. The "mean" of the SDs is the root mean square (*RMS*) calculated as $\sqrt{(\text{mean}(SD^2))}$

standard deviation does not provide a good estimate of variation, so here the absolute difference between the two replicates is used. On this basis, the error due to measurement (analytical precision) was ±0.06-0.11‰ for $\delta^{13}C$ and ±0.13-0.27 for $\delta^{15}N$ (means of differences in Table 5.4). Error due to preparation was ±0.06-0.08‰ for $\delta^{13}C$ and ±0.20-0.22 for $\delta^{15}N$, no greater than analytical error. Overall error was ±0.07‰ for $\delta^{13}C$ and ±0.18 for $\delta^{15}N$ (standard deviation, based on 4 measurements). This is less than the analytical error alone (based on repeated measurements of standards: Chapter 5, 2.1.2) for 2007-2008. This may be because these are the results of a few runs over a few weeks. Minor variations in IRMS measurements may occur over time and slightly lower analytical precision over long periods (Jardine and Cunjak 2005).

One batch of 20 (unbred females) was analysed 8 months later than the others, and in the meantime the lab protocol for setting up the runs had changed: alanine rather than nylon had become the principal internal reference, and bovine liver the secondary internal reference instead of alanine. To check for consistency, 20 samples from the earlier batch were re-run alongside the later batch. The results were significantly different from the original, with values on average 0.18‰ lower for $\delta^{13}C$ and 0.30‰ higher for $\delta^{15}N$ (for each isotope, $P \leq 0.001$, matched-pairs t-test, n=20, 20). It was not possible to re-calibrate the runs using the internal standards. The difference could have been due to variation in instrument factors over time (Jardine and Cunjak 2005), the change in run set-up or deterioration in storage of the collagen from the earlier batch. However, closer inspection showed that the third (8 months later) run was significantly different from the second run, but not from the first. More likely these results do not reflect systematic variation over time, though they do suggest a difference between the runs over the shorter period within which the first and second repeat samples were run. The difference was not far outside 1 SD for overall precision (1.1 above), though it was clearly statistically significant. The main reason for checking the repeatability over time was that the $\delta^{15}N$ values for the unbred females (the last batch of samples) were clearly higher than those of the other groups, and it was important to establish whether this was because of variation in measurement over time. For this reason, the results from the later batch were adjusted by +0.2‰ for $\delta^{13}C$ and –0.3‰ for $\delta^{15}N$ before analysis.

1.2 Sample quality

Results from samples with collagen yields <1% or molar C/N ratios <3.1 or >3.5 (Ambrose 1990; DeNiro 1985), were considered unreliable and were not included in the analysis. For the English Heritage sheep, preservation was excellent, as expected for modern bone. Molar C/N ratios (calculated from mass spectrometry results as weight carbon/weight nitrogen×14/12) were 3.10–3.52, sample %collagen (calculated as (sample collagen weight/bone weight)×%carbon×(1/0.4)) was 13.1–28.7%, percent carbon by weight in collagen (calculated from mass spectrometry results as yield of carbon/sample weight) was 37.0-52.8%, and percent nitrogen was 13.5–19.0%. All sampled bones provided sufficient collagen and no results were rejected because of poor quality indicators.

1.3 Variation in a modern population: English Heritage sheep

The English Heritage sheep were studied to establish the range and pattern of variation in bone collagen $\delta^{13}C$ and $\delta^{15}N$ values in adult sheep from a single flock. Individuals varied in age, sex, breeding status and diet (details in Chapter 5, 1.1), and the effects and relative

importance of these factors were investigated. Finally, variation in this flock was compared with the range of variation in archaeological samples from the Thames Valley.

1.4 The effects of age, sex, diet and breeding status

Results are shown in Table 6.2. Group means were compared using general linear models (GLMs) (Grafen and Hails 2002); because of the unbalanced design, these were equivalent to ANOVAs on subsets of the data in most cases. Analyses were blocked by slaughter group to account for differences due to age or season.

1.4.1 Slaughter group (age)

Fig. 6.1 shows that there is no overall trend for either $\delta^{13}C$ or $\delta^{15}N$. While there may be a small seasonal effect for $\delta^{13}C$ (groups 6 and 8, killed in September, are higher than groups 5, 7 and 9, killed in December) the overlap of the notches suggests that it is not statistically significant. In the GLMs, when diet and breeding status were taken into account, the effect of slaughter group on $\delta^{15}N$ was not significant, but the effect on $\delta^{13}C$ was ($P=0.016–0.038$, depending on the model). However, this does not seem to reflect a trend (Table 6.2), and using slaughter group as a blocking factor in the GLMs should account for this variation. We can conclude that in these sheep (adults aged 2.5–5 years) there is no systematic trend in $\delta^{13}C$ or $\delta^{15}N$ values with age.

1.4.2 Sex

Comparisons of the effect of sex are complicated by the presence of bred and unbred ewes, with no equivalent for rams, and rams on high and low diets, with no equivalent for ewes. Here comparisons are made between sheep on the low diet only. In pairwise comparisons between rams and ewes, $\delta^{13}C$ values for rams and unbred ewes were not significantly different, but those of early-bred ewes were significantly lower than either, by 0.3-0.4‰. For $\delta^{15}N$, rams and early-bred ewes were not significantly different, but unbred ewes were significantly higher than either, by about 1‰ (Fig. 6.1). In GLMs omitting males on the high diet, the effect of sex on $\delta^{13}C$ and $\delta^{15}N$ values was not significant, but the effect of breeding status was highly significant ($P<0.001$). This suggests that breeding status of females may be an important contributor to differences between the sexes in isotope values (below, 2.1.4).

1.4.3 Diet

The “high” and “low” diets refer to feeding on improved pasture, with hay supplementation in winter, and unimproved pasture, respectively. The simplest way to avoid confoundment with other factors is to contrast only the rams on high and low diets. Males on the low diet had $\delta^{13}C$

$\delta^{13}C$														
			Slaughter group / age (years, months)											
Sex	Diet	Breeding status	5 / 2y 7m		6 / 3y 4m		7 / 3y 7m		8 / 4y 4m		9 / 4y 7m		All	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Female	Low	Early bred	-24.3	0.23	-24.3	0.16	-24.4	0.42	-24.3	0.23	-24.7	0.33	-24.4	0.30
Female	Low	Unbred	-24.0	0.21	-24.0	0.08	-24.1	0.15	-24.0	0.11	-24.0	0.16	-24.0	0.14
Male	Low		-24.3	0.25	-24.0	0.25	-24.2	0.31	-24.0	0.23	-24.0	0.24	-24.1	0.26
Male	High		-24.2	0.11	-24.1	0.19	-24.5	0.39	-24.3	0.10	-24.3	0.19	-24.3	0.25
$\delta^{15}N$														
Female	Low	Early bred	6.1	0.53	6.5	0.23	6.2	0.18	5.9	0.30	5.8	0.17	6.1	0.38
Female	Low	Unbred	7.0	0.40	7.3	0.57	7.4	0.71	7.2	0.21	7.4	0.36	7.2	0.45
Male	Low		6.4	0.20	5.9	0.32	6.6	0.19	6.1	0.25	6.2	0.28	6.2	0.31
Male	High		6.4	0.31	6.2	0.36	6.7	0.20	6.4	0.40	6.5	0.26	6.4	0.32

Table 6.2. Means and standard deviations of $\delta^{13}C$ and $\delta^{15}N$ in bone collagen from the English Heritage sheep. n=4 per treatment/slaughter group

values 0.2‰ higher ($P<0.05$, 2-tailed) and $\delta^{15}N$ values 0.2‰ lower ($P<0.05$, 2-tailed) than males on the high diet. While these differences are statistically significant they are also small, of the same order as measurement errors. In GLMs with sex and/or breeding status entered, $\delta^{13}C$ values differed significantly with diet, but breeding status was always the most important factor, while $\delta^{15}N$ values did not differ significantly with diet.

1.4.4 Breeding status of ewes

Unbred ewes had had no pregnancies, and early-bred ewes could have had up to 3 pregnancies by the time of slaughter. Slaughter group was not significant in the ewes-only model, so there is no evidence that the number of pregnancies (which would presumably increase with age) had any effect on isotope values. Unbred ewes had $\delta^{13}C$ values 0.35‰ higher ($P<0.001$) and $\delta^{15}N$ values 1.1‰ higher ($P<0.001$) than early-bred ewes. In any GLM that included breeding status it was the most important factor affecting isotope values, and always highly statistically significant.

We can conclude that breeding status was the most important variable affecting isotope values of ewes in this population, and that the effects are likely to noticeably affect measured variability, particularly for $\delta^{15}N$.

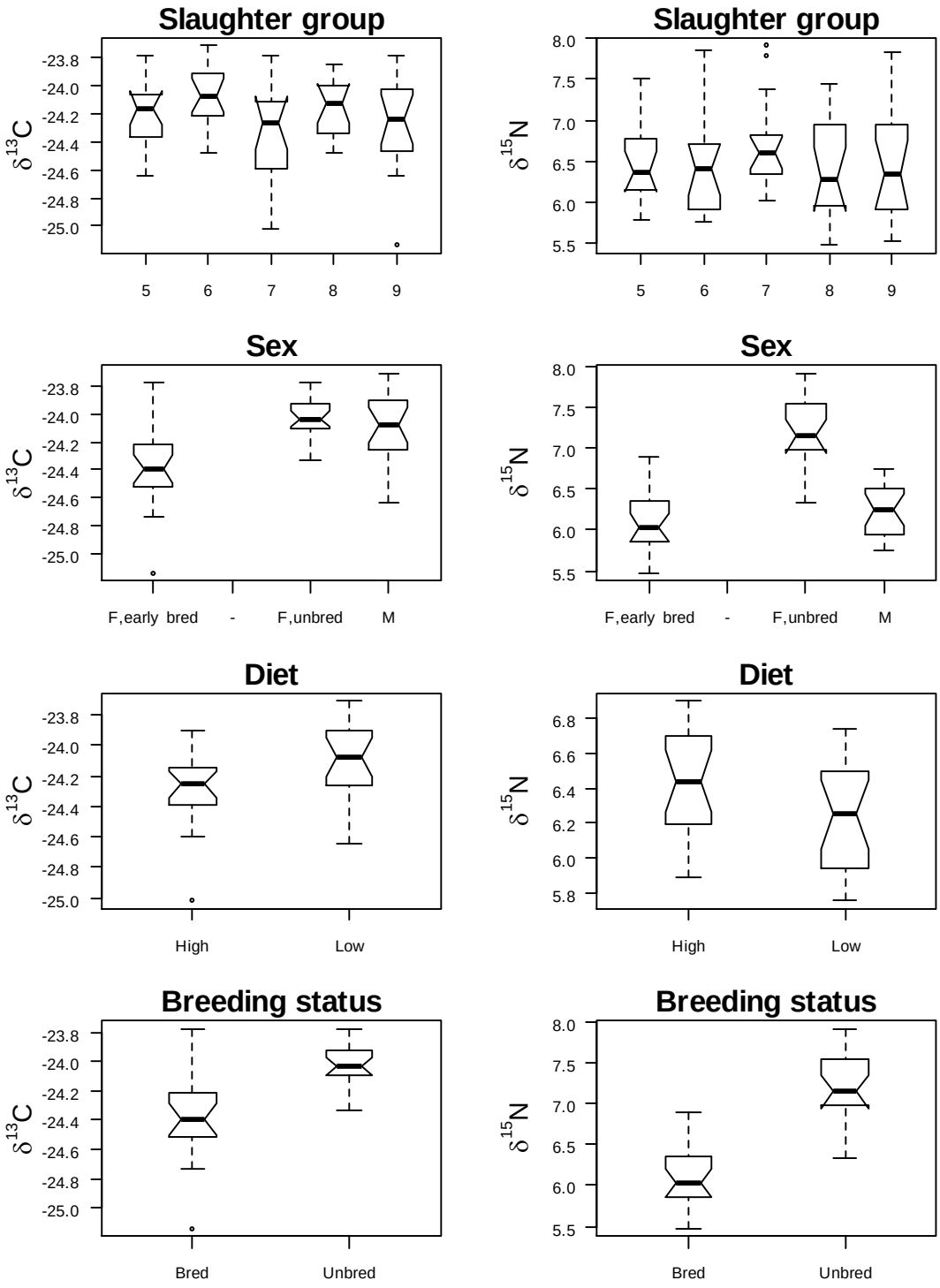


Fig. 6.1 Notched boxplots (median and quartiles) showing results of comparisons between subgroups of the English Heritage sheep. For Sex, only sheep on the low diet are included; for Diet, only males are included; for Breeding status, only females are included. *F* female, *M* male. *Notches* indicate (quasi) 95% confidence intervals for the medians, and if they do not overlap indicate that the groups are significantly different

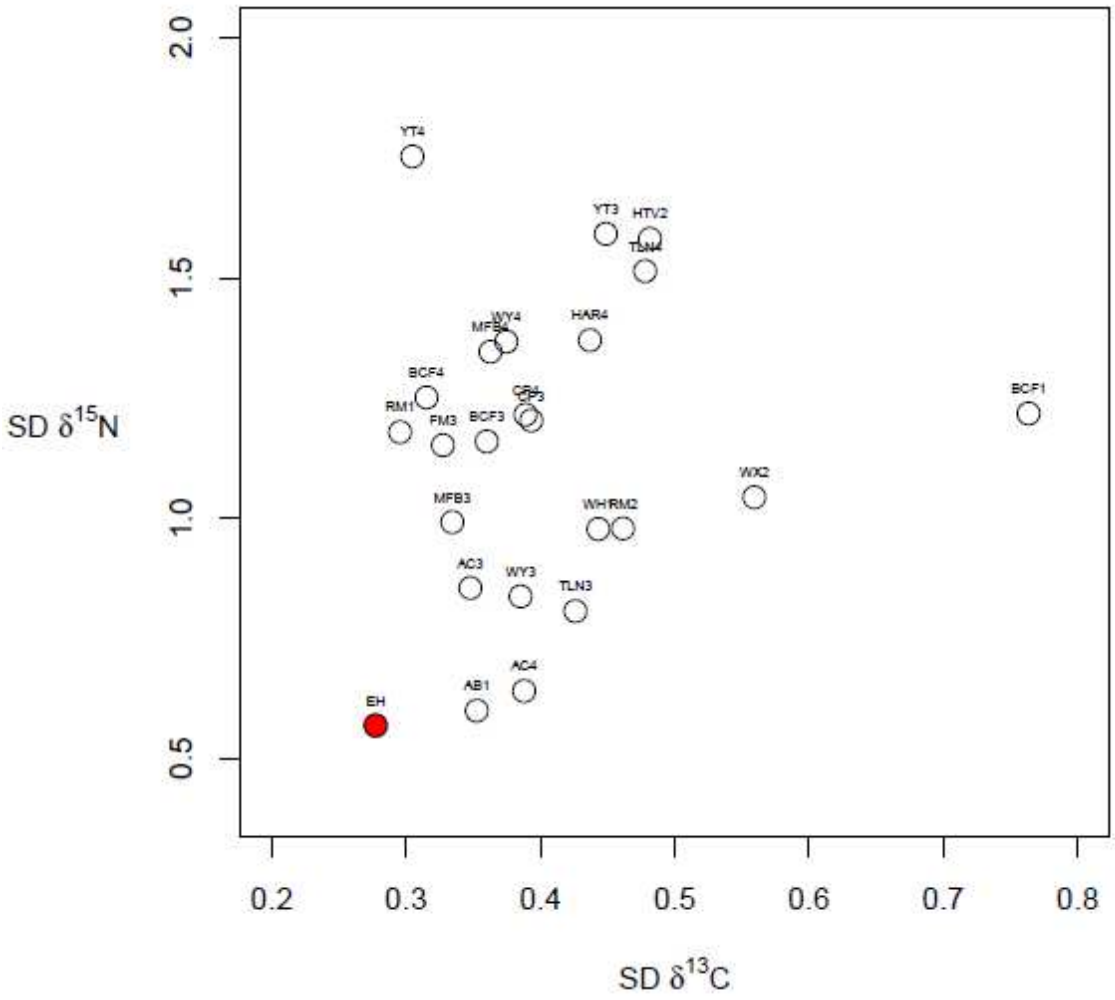


Fig. 6.2 Variation in $\delta^{13}C$ and $\delta^{15}N$ in the English Heritage sheep flock (*red*) and in archaeological sheep samples from Thames Valley sites/periods with n≥10. The *point labels* give the site abbreviation (Table A1.3) followed by a number indicating the period: *1* Neolithic, *2* Bronze Age, *3* Iron Age, *4* Roman.

1.4.5 Variability of a modern population of sheep compared to archaeological "populations"

The English Heritage sheep were compared with the archaeological samples from this project that had n≥10, grouped by site and period (Fig. 6.2). For both $\delta^{13}C$ and $\delta^{15}N$ the standard deviation of the English Heritage sheep is the smallest of all the samples. Since the English Heritage sample includes variation due to age, sex, breeding status and diet, it is likely that there are additional sources of variation in many archaeological samples.

2 Archaeological samples: precision and quality

2.1 Measurement error

Overall analytical precision (Chapter 5, 2.1.2) based on standard deviation of repeated measurement of standards was ±0.15‰ for $\delta^{13}C$ and ±0.30‰ for $\delta^{15}N$ or better. For the archaeological samples, the great majority of values were the mean of only two replicates (in different runs), so standard deviation may not give a good measure of dispersion. The absolute difference between the two replicates ranged from 0 to 1.58 (median 0.08, mean 0.13, SD 0.19, n=965) for $\delta^{13}C$ and 0 to 1.61 (median 0.17, mean 0.24, SD 0.24, n=965) for $\delta^{15}N$. The fact that the mean exceeds the median in each case suggests that the distribution of absolute differences is positively skewed, i.e. that a few large outliers are influencing the mean. For $\delta^{13}C$, 90% of the differences between duplicate runs are <0.3 (±0.15), and for $\delta^{15}N$ 90% of the differences are <0.6 (±0.30). Overall, the precision for the archaeological samples seems similar to analytical precision based on standards.

2.2 Sample quality

Results from samples with collagen yields <1% or molar C/N ratios <3.1 or >3.5 (DeNiro 1985; Ambrose 1990), were considered unreliable and were not included in the analysis (see Table 5.2); a few exceptions listed in the next paragraph). These rejected results are listed along with the accepted results in Appendix 1, Table A1.6. Some samples with acceptable quality indicators were excluded because of a high discrepancy (>0.5‰) between results from different runs (indicating either inhomogeneity or clerical error), and some because the duplicate measurement was lost (included as rejected samples in Table A1.6).

For the archaeological samples, all accepted results came from samples with 11.1 –54.0% carbon, 3.8–19.9% nitrogen, C:N ratio 3.1–3.5, and >1.0% collagen, with the following exceptions:

Three samples (CP146, CP230, MFB133) had C:N ratios 3.55–3.59, but all other indicators were satisfactory.

Seven samples (AB21, HA11, HA19, HO71, MFB14, WY77, YTV194) had 0.7–0.9% collagen, but other indicators were satisfactory and replication was good. It was not possible to calculate %collagen for an additional six samples (RM71, SRF24, SRF25, SRF26, YTV44, YTV67) because of mishaps during sample preparation, but all other indicators were good, and they were included in the analysis.

3 Thames Valley: Between-species variation

There was no correlation between $\delta^{13}C$ and $\delta^{15}N$ (r_p= –0.028, df=1488, P=0.28) for the whole dataset, so $\delta^{13}C$ and $\delta^{15}N$ are treated separately in the following analyses.

3.1 Variation by species and period

There are differences in mean isotope values between the domestic species, but the pattern is not the same in all periods (Fig. 6.3). In the Neolithic and Bronze Age, pig $\delta^{13}C$ is distinctly higher than cattle and sheep $\delta^{13}C$, while in the Iron Age and Roman periods it is not. Pig $\delta^{15}N$ is distinctly higher than cattle and sheep $\delta^{15}N$ in the Iron Age and Roman periods, but is less elevated in the Neolithic and lower in the Bronze Age. Cattle $\delta^{13}C$ is lower than that of sheep in the Neolithic and Bronze Age, but the two herbivores have

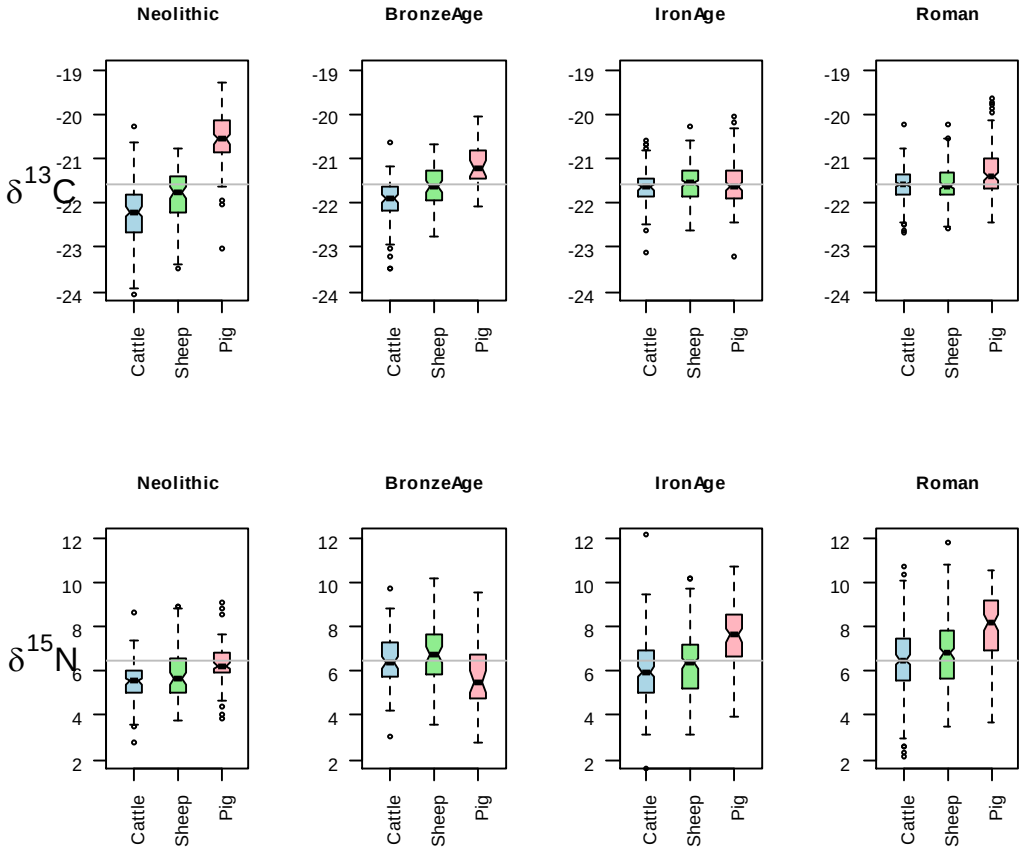


Fig. 6.3 Notched boxplots (median and quartiles) of pooled isotope values for each species by period (n= 589 cattle, 543 sheep, 358 pigs). *Horizontal grey line* indicates grand mean for all species. *Notches* indicate (quasi) 95% confidence intervals for the medians, and if they do not overlap indicate that the groups are significantly different

very similar values in the Iron Age and Roman periods, while their $\delta^{15}N$ values are similar throughout (though sheep $\delta^{15}N$ is always a little higher than cattle $\delta^{15}N$).

Tables A3.1 and A3.2 (Appendix 3) show the (edited) R output from linear models for $\delta^{13}C$ and $\delta^{15}N$, respectively, that include species and period as factors. For both isotopes, species and period have highly significant effects, and their interaction is also significant. Examining the coefficients, we see that the trends noted in the previous paragraph are generally highly significant. While we cannot take the P values at face value because of intra-site correlation (see next paragraph), these ANOVAs are a useful guide to the structure of the data, and, given the strength of the effects, are likely to represent real patterning rather than random noise.

The models shown in Tables A3.1 and A3.2 (a) are ANOVAs, while in (b) linear mixed models are shown, with site as a grouping factor. For both isotopes, including site in this way improves the fit significantly. This means that there is significant intra-site correlation in isotope values, which needs to be taken into account when estimating P values and assessing significance. All subsequent analysis therefore uses the mixed-models approach.

The amount of variance accounted for by site-level factors in these overall models is only 6.5% for $\delta^{13}C$ and 22.5% for $\delta^{15}N$. In both cases the majority of variation is between individuals at sites, and much of this is likely to reflect species differences (Tables A3.1, A3.2). Because the three species have rather different trajectories in time, in the next section they are analysed separately.

3.2 Species trajectories

Species trajectories in time are shown in Fig. 6.4 and the statistics summarised in Table 6.3. $\delta^{15}N$ values are consistently more variable than $\delta^{13}C$ values (e.g. SEs of estimates of coefficients in Table 6.3 are 0.07-0.12 for $\delta^{13}C$ and 0.20-0.29 for $\delta^{15}N$).

3.2.1 Cattle

Cattle $\delta^{13}C$ values are low in the Neolithic, significantly higher in the Bronze Age, and close to the grand mean in the Iron Age and Roman periods, which are significantly different from the earlier periods but not from each other. Cattle $\delta^{15}N$ values are lowest in the Neolithic, significantly higher in the Bronze Age, lower in the Iron Age and higher again in the Roman period. The Bronze Age and Roman periods are significantly different from the Neolithic and Iron Age but not from each other.

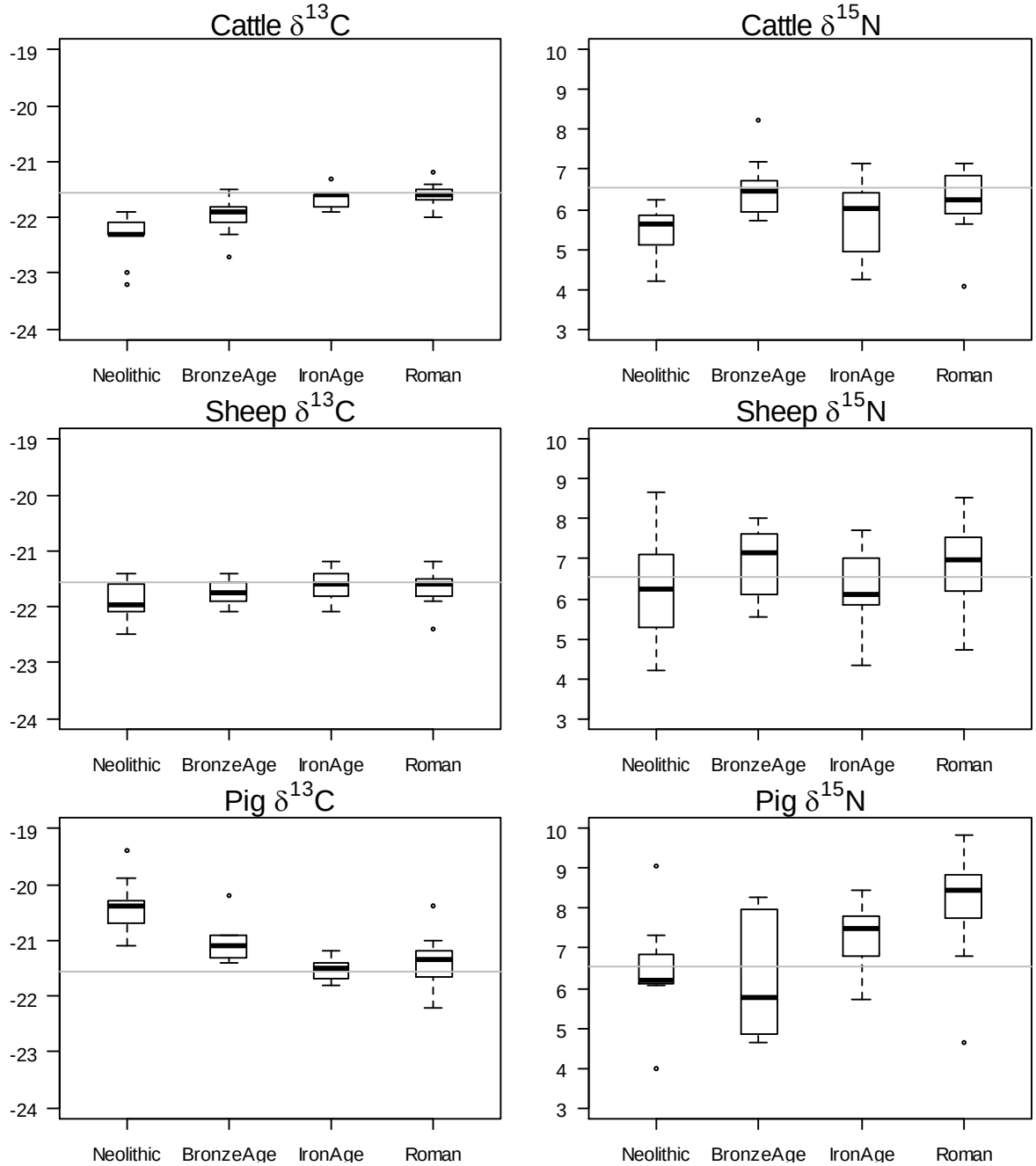


Fig. 6.4 Boxplots (medians and quartiles) of site-mean $\delta^{13}C$ and $\delta^{15}N$ for each species by period. Sample numbers *n* are given in Table A1.8. *Horizontal line* indicates the grand mean of all site means for all species (and see Fig. 6.6 for a plot showing individual site means)

3.2.2 Sheep

Sheep $\delta^{13}C$ values follow a similar trajectory to cattle, but are not as low in the Neolithic and Bronze Age. The Neolithic value is significantly lower than all later periods. Sheep $\delta^{15}N$ values also follow a similar trajectory to cattle, but the differences from the Neolithic are not

significant, reflecting the greater variation in site-mean values. Only the Iron Age and Roman periods differ significantly in $\delta^{15}N$, with higher values in the Roman period.

Species		Estimate	SE	t value	P[1]	%variance at site level
Cattle n=589 n_{site}=23	$\delta^{13}C$					
	Intercept	–22.38	0.07	–320.7	<0.001[a]	20.7
	Bronze Age	0.45	0.08	5.7	<0.001[b]	
	Iron Age	0.78	0.07	10.5	<0.001[c]	
	Roman	0.84	0.07	11.3	<0.001[c]	
Sheep n=543 n_{site}=22	$\delta^{13}C$					
	Intercept	–21.93	0.08	–277.5	<0.001[a]	19.4
	Bronze Age	0.24	0.09	2.5	<0.05[b]	
	Iron Age	0.34	0.08	4.1	<0.001[b]	
	Roman	0.36	0.08	4.4	<0.001[b]	
Pig n=358 n_{site}=21	$\delta^{13}C$					
	Intercept	–20.50	0.08	–245.8	<0.001[a]	10.8
	Bronze Age	–0.61	0.12	–4.9	<0.001[b]	
	Iron Age	–1.07	0.11	–10.1	<0.001[c]	
	Roman	–0.89	0.10	–8.6	<0.001[d]	
Cattle n=589 n_{site}=23	$\delta^{15}N$					
	Intercept	5.50	0.20	27.7	<0.001[a]	19.7
	Bronze Age	0.69	0.23	3.0	<0.01[b]	
	Iron Age	0.28	0.21	1.3	NS[a]	
	Roman	0.64	0.21	3.0	<0.01[b]	
Sheep n=543 n_{site}=22	$\delta^{15}N$					
	Intercept	6.18	0.28	22.4	<0.001	33.1
	Bronze Age	0.22	0.29	0.8	NS	
	Iron Age	0.04	0.27	0.2	NS[b]	
	Roman	0.43	0.26	1.6	NS[c]	
Pig n=358 n_{site}=21	$\delta^{15}N$					
	Intercept	6.36	0.21	30.8	<0.001[a]	17.3
	Bronze Age	–0.60	0.28	–2.1	<0.05[b]	
	Iron Age	1.18	0.25	4.7	<0.001[c]	
	Roman	1.73	0.24	7.1	<0.001[d]	

Table 6.3 Results of linear mixed models for $\delta^{13}C$ and $\delta^{15}N$ for each species. Period was entered as a fixed effect with the Neolithic as the reference (*Intercept*), and site was entered as a grouping factor. In each case models including site fit significantly better. [1] Within each analysis, the P value given is the significance of the difference from the reference value, and coefficients with different *superscript letters* differ significantly from each other. P values, for guidance only, were calculated using the nlme package in R. *P<0.05, **P<0.01, ***P<0.001

3.2.3 Pig

Pig $\delta^{13}C$ values are high in the Neolithic, lower in the Bronze Age, close to the grand mean in the Iron Age, and slightly higher again in the Roman period, and all the differences are significant. Pig $\delta^{15}N$ values are below the grand mean in the Neolithic and Bronze Age, and the Bronze Age value is (just) significantly lower than the Neolithic value, though with very wide variation. In the Iron Age and Roman periods pig $\delta^{15}N$ is above the grand mean, and higher in the Roman period. All the differences between periods are significant.

3.3 Intra-site variation in isotope values

Intra-site variation (measured as the root mean square of standard deviations at sites for each period) in both $\delta^{13}C$ and $\delta^{15}N$ changes significantly over time (Table 6.4). For herbivore $\delta^{13}C$, intra-site variation in $\delta^{13}C$ is greater in the Neolithic and Bronze Age than later, and intra-site variation in $\delta^{15}N$ for all species is considerably lower in the Neolithic than later. The difference between periods was significant for cattle $\delta^{13}C$ and $\delta^{15}N$ and pig $\delta^{15}N$ (Kruskal-Wallis test).

Inter-site variation in pig $\delta^{15}N$ is very high in the Bronze Age (Fig. 6.4), and while intra-site variation is also high, the contrast with intra-site variation at other periods is less strong, suggesting an additional factor is contributing to inter-site variation in this period.

Period	SD per site	Cattle $\delta^{13}C$	Cattle $\delta^{15}N$	Sheep $\delta^{13}C$	Sheep $\delta^{15}N$	Pig $\delta^{13}C$	Pig $\delta^{15}N$	n sites
Neolithic	RMS	0.53	0.75	0.60	0.97	0.45	0.64	8,6,8
	Range SD	0.25-0.83	0.32-0.89	0.30-0.91	0.38-1.22	0.05-0.83	0.09-0.95	
Bronze Age	RMS	0.46	1.02	0.47	1.25	0.81	1.26	8,6,4
	Range SD	0.35-0.61	0.72-1.74	0.13-0.70	0.39-1.86	0.39-1.58	0.96-1.60	
Iron Age	RMS	0.34	1.08	0.39	1.07	0.42	1.18	12,11,7
	Range SD	0.17-0.49	0.62-1.91	0.33-0.44	0.65-1.54	0.26-0.62	0.91-1.36	
Roman	RMS	0.37	1.13	0.36	1.51	0.47	0.98	13,13,10
	Range SD	0.21-0.55	0.63-1.90	0.23-0.48	0.64-2.91	0.19-0.65	0.46-1.53	
P (K-W test)		**0.022**	**0.001**	0.176	0.071	0.417	**0.005**	

Table 6.4 Root mean square (*RMS*) and range (*minimum-maximum*) of standard deviations of site-mean $\delta^{13}C$ and $\delta^{15}N$ values for each period. Site/periods with n<3 are omitted. Number *n* of sites per period is given for each species (*cattle, sheep, pig*).

3.4 The pattern of between-species variation

Cattle, sheep and pig $\delta^{13}C$ and $\delta^{15}N$ values differ significantly, but the pattern of variation is complex and differs across periods. The estimated differences can be substantial – e.g. 1.2‰ between cattle and pig $\delta^{15}N$ (Table A3.2b) – with implications for inferring human diets on the basis of isotopes. For individual species, differences between periods can also be substantial – e.g. 1.1‰ between Neolithic and Iron Age pig $\delta^{13}C$ (Table 6.3). The complexity of the pattern rules out simple universal explanations by physiological differences between species or long-term climatic change, though no doubt these contribute to the overall variation.

For each species a high proportion of variation is intra-site, with only10–20% of variation in $\delta^{13}C$ and 17–33% of variation in $\delta^{15}N$ accounted for by site-level factors such as climate and environment (Table 6.3). These are the factors that can be considered at landscape level, which will be investigated in the next section.

4 Thames Valley: variation between sites

In this section site-level factors are investigated. These include:

1. Abiotic variables such as latitude, longitude, landscape- region (Chapter 3, 3.1), soils and climate. These are not independent, and one focus of the analysis is to investigate their interrelationships, which is useful in deciding which variables to include in linear mixed models.
2. Biotic characteristics of the sites themselves, such as the locally dominant vegetation type, and the spectrum of plant and animal remains found at the site.

Selected variables are then entered into linear mixed models with site as a grouping factor to investigate their relationships with faunal isotope values.

4.1 Geographical variables

Latitude, longitude and elevation had no significant effect on $\delta^{13}C$, and only elevation had a significant effect on $\delta^{15}N$ (Table A3.3). Latitude and longitude were therefore dropped from subsequent models, and elevation from models for $\delta^{13}C$.

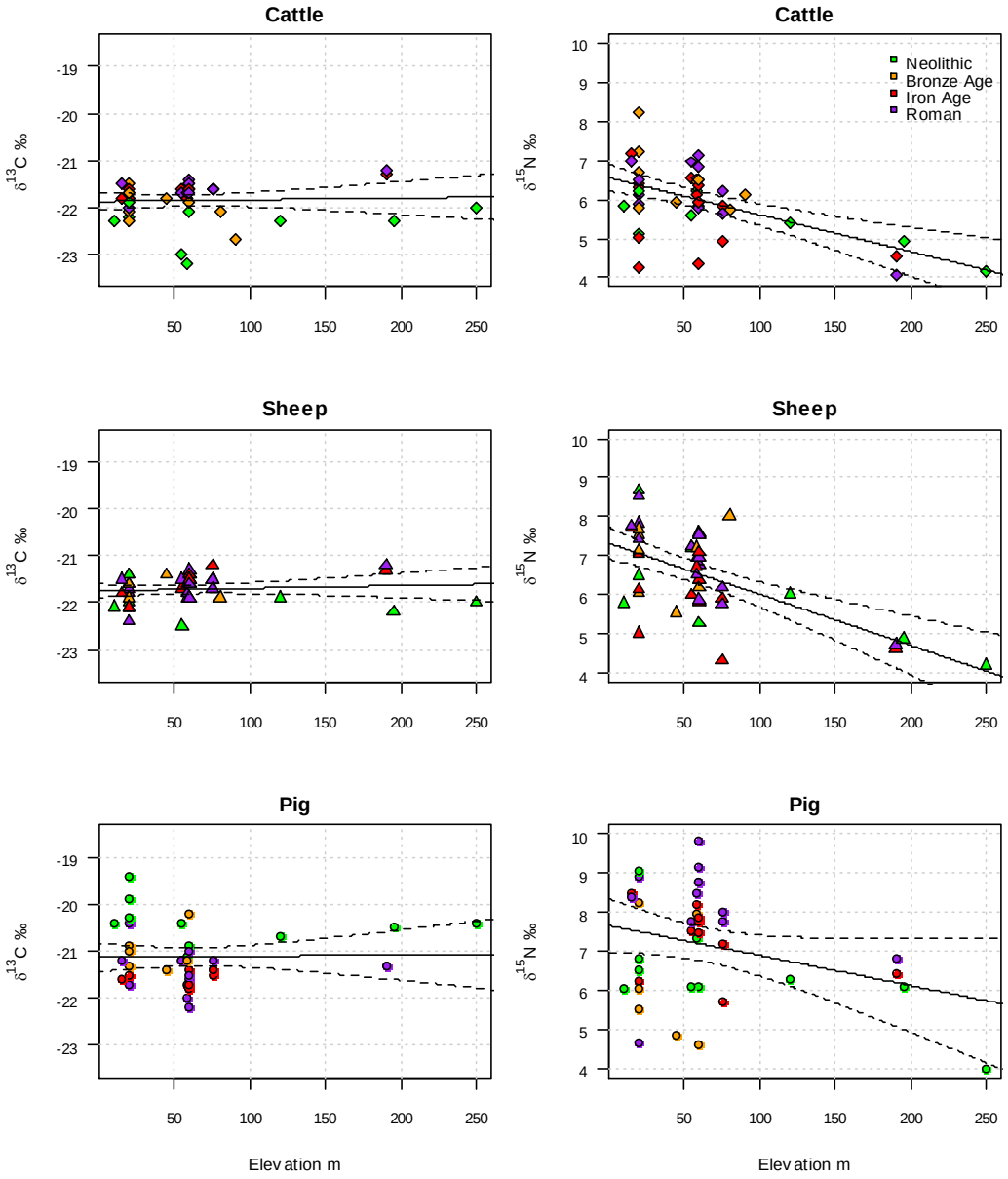


Fig. 6.5 Cattle, sheep and pig site mean $\delta^{13}C$ and $\delta^{15}N$ plotted against elevation (m). The *solid line* is the modelled regression, *dotted lines* are 95% confidence limits

However, Fig. 6.5 suggests that we should interpret the effect of elevation with caution, as only 4 of the 23 sites lie above 100 m (Ascott-under-Wychwood, Hazleton, Windmill Hill, and Alfred's Castle), and there is no clear would be possible to transform the data to correct for the obvious wider variation of the residuals at lower elevations, but it is questionable whether this is worthwhile – it would be much more useful to obtain measurements from a wider range of sites at higher elevations. There is also a possibility of confounding elevation with period - three of the four high-elevation sites are Neolithic, and cattle and especially pigs tend to have lower $\delta^{15}N$ values in the Neolithic.

Using only the Neolithic data (11 sites) elevation remains significant at P<0.01.The effect is small: the coefficient is –0.01‰ per metre of elevation, so about 0.2‰ over the whole range of elevation in this study.

4.2 Regions

On the largest scale, the Upper and Middle parts of the Thames Valley were contrasted to see if there is any systematic difference between them. This contrast had no significant effect and was dropped from further analysis.

The geology of the Middle and Upper Thames is described in Chapter 3 (section 3.1). For analysis, the study area was divided into five geological regions – floodplain, terrace1, terrace 2 (including higher terraces), limestone and chalk – to encompass variation in underlying geology, soil type, topography and hydrology (see Methods).

Individual site means coloured according to region are shown in Fig. 6.6. There is some patterning, varying by species and period.

For cattle and sheep, in the Neolithic and Bronze Age sites on the floodplain and on chalk/limestone have higher $\delta^{13}C$ values. In the Iron Age and Roman periods there is only one site on the chalk, which has high $\delta^{13}C$ values, but one site is not enough to draw conclusions. For pigs, $\delta^{13}C$ values are high on the floodplain in the Neolithic, but not subsequently. In an overall model for $\delta^{13}C$ including species, period and region, the effect of region is significant and $\delta^{13}C$ values are significantly lower on terraces 1 and 2 (reg2 and reg3) than on the floodplain (Table A3.4a).

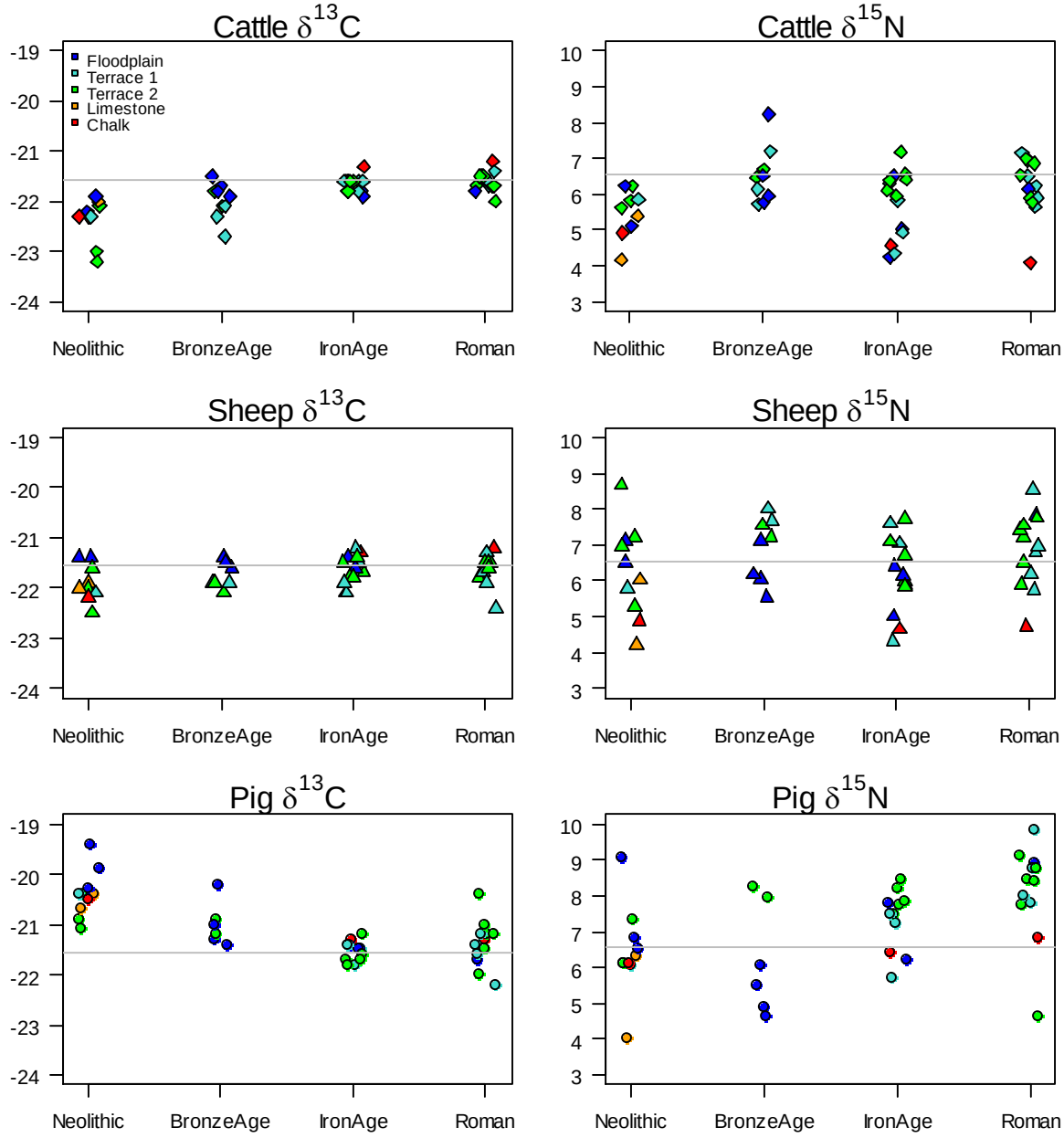


Fig. 6.6 Site-means of $\delta^{13}C$ and $\delta^{15}N$ for each region, plotted by species and period. *Horizontal line* indicates the grand mean of all site means for all species. *Points* have been jittered to improve visibility

$\delta^{15}N$ values on chalk and limestone are consistently among the lowest for each species. This is confirmed by the coefficients (reg4 and reg5) in Table A3.4b, which are both considerably lower than the reference value (floodplain), but not significantly different – instead, the value for terrace 2 (reg3) is significantly higher than the reference.

Because of the different species trajectories in time (above, 3.2) and the contrast in vegetation between the earlier prehistoric period and the Iron Age/Roman period (below, 4.5), the analysis was refined by grouping the Neolithic/Bronze Age and Iron Age/Roman periods and looking at each species separately. The results are shown in Table 6.5.

	$\delta^{13}C$			$\delta^{15}N$		
	Neolithic + Bronze Age					
Region	Cattle	Sheep	Pig	Cattle	Sheep	Pig
Terrace1	–**0.52**	–**0.52***	+0.19	+0.13	+0.89	–0.06
Terrace2	–**0.46**	–**0.53***	–0.28	–0.07	+0.50	+0.83
Limestone	–0.28	–0.47	–0.10	–**1.39***	–0.85	–0.92
Chalk	–0.47	–**0.71***	+0.09	–**1.28**	–1.40	–1.35
	Iron Age + Roman					
Terrace1	+0.13	+0.11	–0.07	+0.41	+0.09	–0.16
Terrace2	+0.05	+0.21	+0.10	**+0.86**	+0.44	–0.12
Limestone	–	–	–	–	–	–
Chalk	**+0.44****	**+0.56**	+0.17	-1.15	**-1.83**	**-1.56**

Table 6.5 Coefficients based on linear mixed models including region, separately for each species and for periods grouped into Neolithic+Bronze Age and Iron Age+Roman. The coefficient is the difference between the region in question and the reference (region 1, floodplain). Neolithic+BA cattle: n=213, n_{sites} = 15; sheep: 144, 15; pig: 135, 13. IA+Roman cattle: 376, 14; sheep: 399, 14; pig: 223, 13. P values, for guidance only, were calculated using the nlme package in R: *P<0.05, **P<0.01. Coefficients in bold type but without asterisks have T>(2×SE), but are borderline significant using nlme with P values 0.05–0.07

There is still significant patterning by region, but some differences between the earlier and later periods. The herbivores have low $\delta^{13}C$ values on the first and second terraces, compared to the floodplain, in the earlier period, but not in the later periods, and higher $\delta^{13}C$ values on the chalk in the later period but not in the earlier period – in fact sheep in the earlier period have lower $\delta^{13}C$ values on the chalk. Pigs show no patterning of $\delta^{13}C$ values with region at any period. All species tend to have low $\delta^{15}N$ values on chalk and limestone, significantly so for cattle in the earlier period and sheep and pig in the later period. Cattle also have significantly higher $\delta^{15}N$ values on the second terrace in the later period; sheep show the same

pattern but the difference from the floodplain is not significant. Pigs show no significant patterning in $\delta^{15}N$ by region except for the low value on chalk in the later period.

Because of the topography of the Thames valley, with limestone and chalk ridges acting as watersheds, there is a clear possibility of confoundment of region and elevation. In a model including both region and elevation as factors, both have significant effects on $\delta^{15}N$ (Table A3.5a); the coefficients for regions 4 and 5 (limestone and chalk) are not unusually low, but region 3 (terrace 2) is 0.7‰ higher than the reference (floodplain). Elevation and region are related, but not confounded. For elevation the same caveats apply as for the model shown in Table A3.3, and when only Neolithic data are used, neither region nor elevation is significant (Table A3.5b).

4.3 Soils

Where possible, soils at the sites were characterised according to type, pH and drainage characteristics, using information from excavation reports (see Methods). Models included species and period, and the subset of sites without missing data for the soil factor or factors being investigated – this meant that not all models could be compared, because numbers of sites and observations differed. A categorical principal components analysis using soil variables and region is shown in Fig. 6.7, to help visualise relationships among the variables. Soil characteristics are related to region, with floodplain and first- and second-terrace soils spreading out along dimension 1 and chalk and limestone soils clustering together. The group of low-pH soils low on dimension 2 are all at sites in the Middle Thames, where soils tend to be more acid (Chapter 3, 3.1).

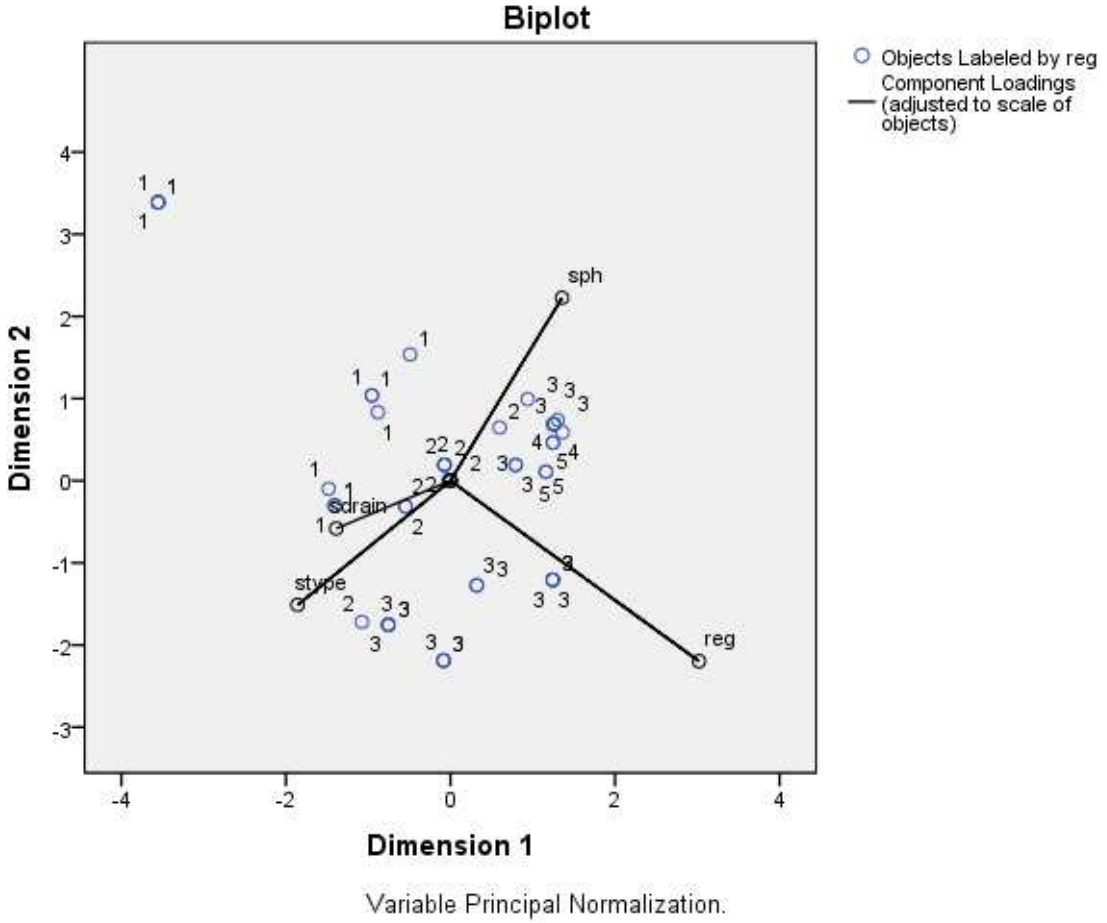


Fig. 6.7 Biplot showing first two dimensions of a Categorical PCA (run in SPSS) using *reg* region and soil categorical variables. *stype* soil type (clay/loam, clay/silt, loam/brown earth, rendzina, sandy loam), *sph* soil pH (acid, alkaline, neutral) and *sdrain* soil drainage (fast-draining, medium-draining). In each case the first variable is the reference variable in the linear mixed models. *Points* represent the position of the sites on these two dimensions; there can be more than one point per site if soil types were different at different periods. Points are labelled by region: *1* floodplain *2* first terrace *3* second terrace *4* limestone *5* chalk

For $\delta^{13}C$, including region in the model with all soil variables, and including soil variables in the model with region, significantly improved the fit in each case (summarised in Table A3.6a). Looking at the soil types entered singly, soil types *clay/silt* and *loam/brown earth* had significantly lower $\delta^{13}C$ values (by about 0.2‰) than the reference, *clay/loam*, while *rendzina* and *sandy loam* did not. *Alkaline* and *neutral* soils were not significantly different from the reference, *acid* soils. Soils with *medium* drainage rates had significantly lower $\delta^{13}C$ values (by about 0.15‰) than *fast*-draining soils. However, in models that also included region, these

differences were no longer significant: instead, there were differences between regions. In the models with soil type or drainage rates, the river terraces had significantly lower $\delta^{13}C$ values than the floodplain (by about 0.3‰), and in the model with soil pH, all regions had significantly lower $\delta^{13}C$ values than the floodplain by (by about 0.3‰).

For $\delta^{15}N$, including region in the model with all soil variables, and including soil variables in the model with region, significantly improved the fit in each case (summarised in Table A3.6b). Looking at the soil characteristics entered singly, no soil types differed significantly from the reference, *clay/loam*. Soils with *medium* drainage rates did not differ significantly from *fast*-draining soils. *Neutral* soils had significantly lower $\delta^{15}N$ values (by 0.7‰) than the reference, *acid* soils. When region was included in this model, soil pH was still significant, and terrace 2 had a significantly higher $\delta^{15}N$ than the reference, floodplain (by 0.9‰). When region was included in the model with soil type, limestone and chalk regions had significantly lower $\delta^{15}N$ values than the reference, floodplain (by 1.9‰ and 2.5‰, respectively). When region was included in the model with drainage rates, neither drainage rate nor region was significant. It is also noteworthy that the soil type *rendzina* showed a strong correlation with chalk and limestone regions, as would be expected.

This is a complex picture, and possibly this type of modelling is not the best way to make sense of it – the dataset is considerably reduced because information on soil types was not available from all sites, and the imbalance of sites across regions is noted above. Soil characteristics explain some of the between-site variance, and are related to geological region (Fig. 6.7) though not in a simple way.

4.4 Climatic variables

The climatic variables used in this analysis are based on geography (Chapter 5, 3.3.2.5) and have not been adjusted for possible variation over time. Many of the climate variables covary (Principal Components (PC) analysis shown in Fig. 6.8). The first three PC axes account for 51%, 29% and 9% of the variance respectively. As discussed in Methods (Chapter 5, 3.3.2.5), single climatic variables were used for linear modelling, for ease of interpretation.

Over the relatively small region of the Thames valley climatic variation is not great. The main points of interest here are (1) whether climatic variables have any effect on faunal $\delta^{13}C$ or $\delta^{15}N$ values and (2) whether climatic variables explain the effects of elevation or region or whether they are additional to them.

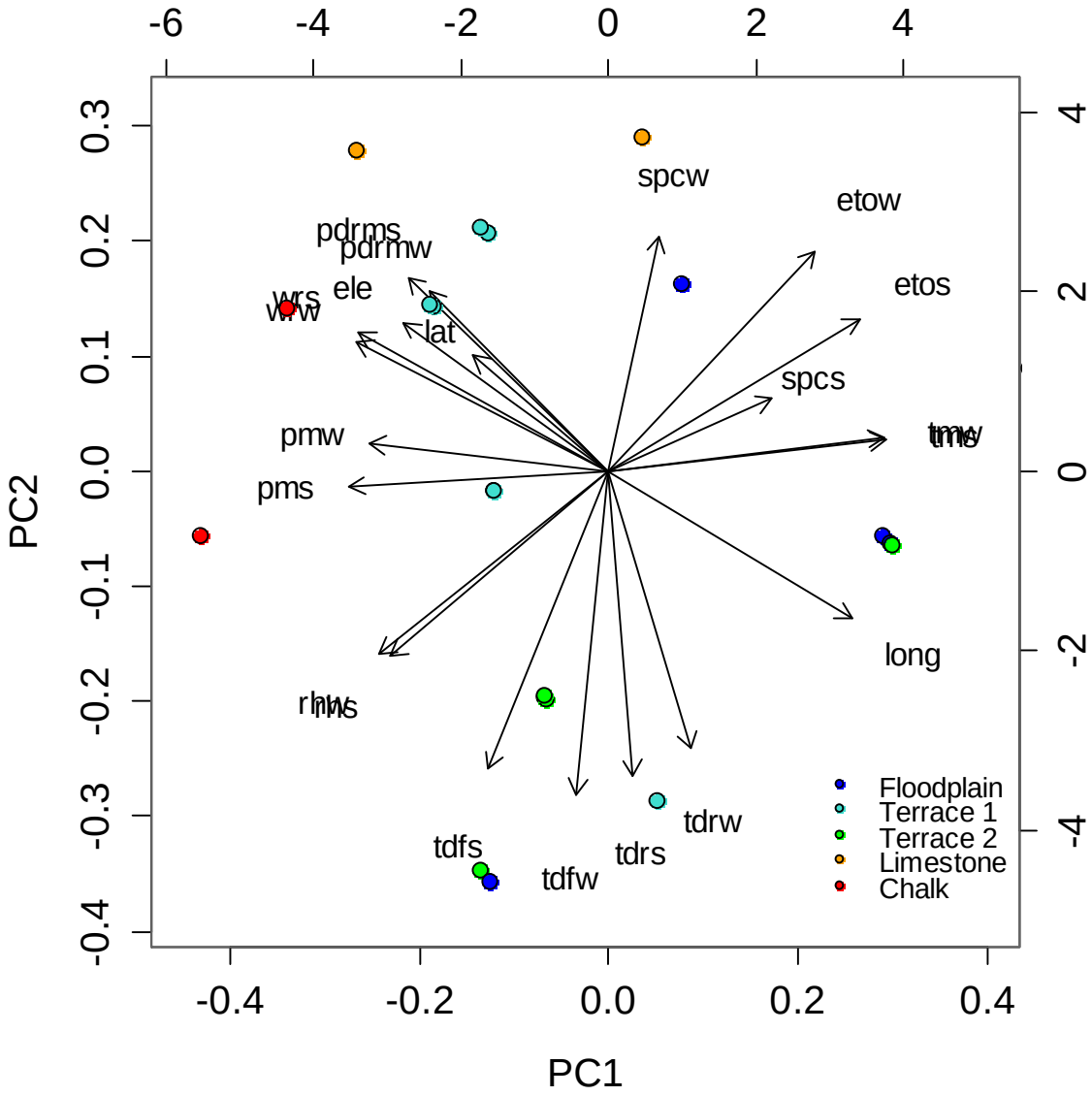


Fig. 6.8 Biplot of first two axes from Principal Components Analysis of climatic variables. Geographical variables *lat* latitude, *long* longitude and *ele* elevation have been included for illustration: they make little difference to the overall pattern of the climatic variables. *Points* represent sites, coloured by region, and have been jittered to improve visibility. PC1 accounts for 51% of the variance and PC2 for 29%.

In models including species and period and one climatic variable, none had a significant effect on $\delta^{13}C$, while several had significant effects on $\delta^{15}N$ (Table 6.6), and were investigated further. The clearest effect is for mean monthly precipitation, followed by mean monthly temperature, in both summer and winter. Temperature range, days with frost and sunshine hours had no significant effect.

Variable	Definition	P
PMS	Mean monthly precipitation summer (mm)	<0.001
PDRMS	Mean number of days with rain per month summer	0.015
TMS	Mean monthly temperature summer (°C)	0.003
TDRS	Mean daily temperature range maximum-minimum summer (°C)	NS
TDFS	Mean number of days with ground frost per month summer	NS
RHS	Mean relative humidity summer (%)	0.040
SPCS	Mean sunshine hours summer (% maximum)	NS
WRS	Mean monthly wind run summer (km/h)	0.012
ETOS	Mean Penman-Monteith reference evapotranspiration summer	0.010
PMW	Mean monthly precipitation winter (mm)	<0.001
PDRMW	Mean number of days with rain per month winter	0.022
TMW	Mean monthly temperature winter (°C)	0.002
TDRW	Mean daily temperature range maximum-minimum winter (°C)	NS
TDFW	Mean number of days with ground frost per month winter	NS
RHW	Mean relative humidity winter (%)	0.028
SPCW	Mean sunshine hours winter (% maximum)	NS
WRW	Mean monthly wind run winter (km/h	0.013
ETOW	Mean Penman-Monteith reference evapotranspiration winter	0.038

Table 6.6 Climate variables and their effect on faunal $\delta^{15}N$ values. Climate variables were added singly to a null model including species and period with site as a grouping factor. The P value shown here is for improvement of fit over the null model.

When elevation was included in models with climate variables, elevation was significant and the climatic variables were not. In contrast, when region was included without elevation, both region and most of the climatic variables (entered singly) were significant (except PDRMS and PDRMW). When both region and elevation were entered, they were both significant, but most of the climatic variables were not (except TDFS, TDFW and ETOW). An example using PMS is shown in Fig. 6.9 and Table A3.7.

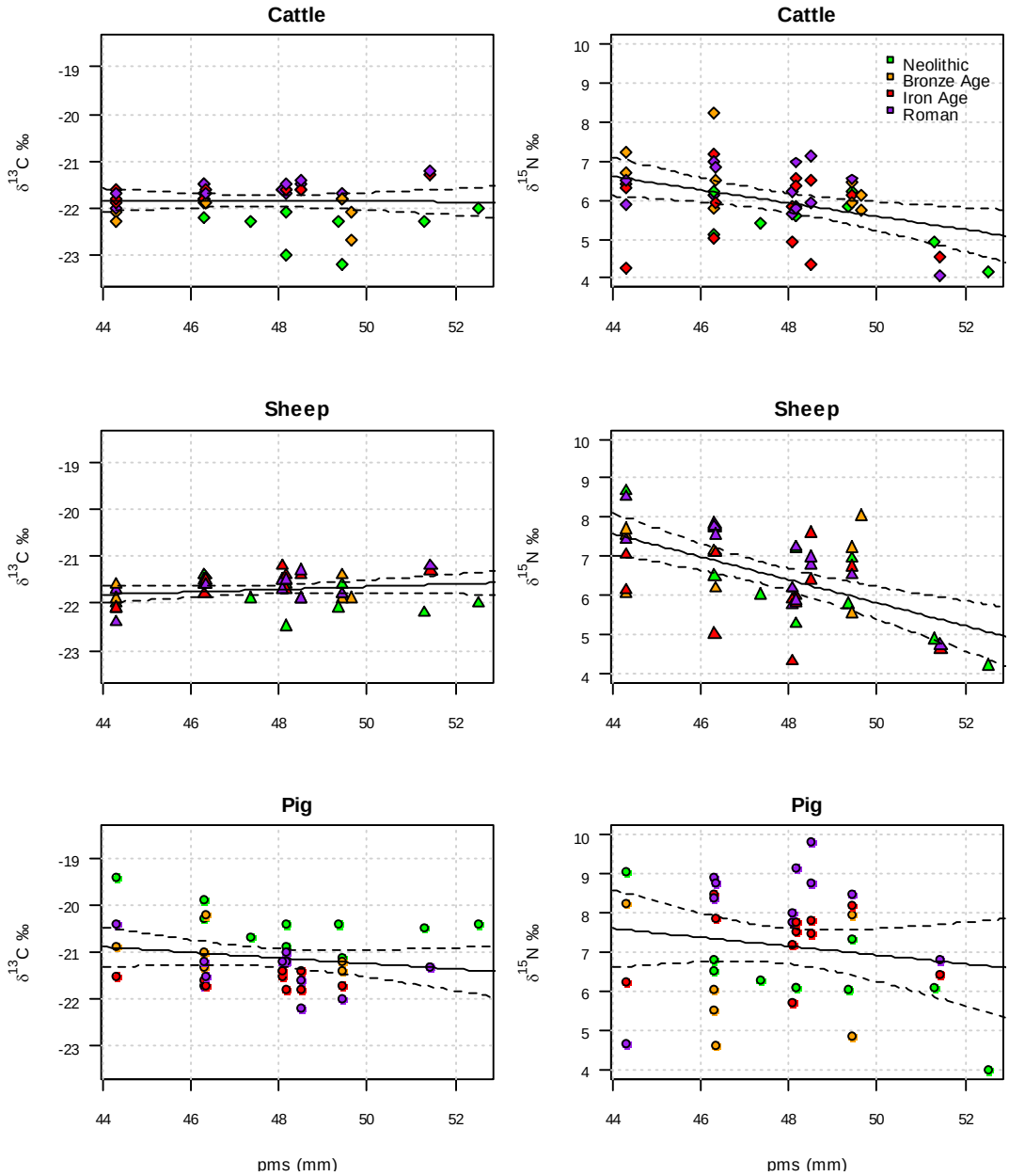


Fig. 6.9 Cattle, sheep and pig site-mean $\delta^{13}C$ and $\delta^{15}N$ plotted against *PMS* summer mean monthly precipitation (mm). The *solid line* is the modelled regression, *dotted lines* are 95% confidence limits

It seems likely, therefore, that the factors "region" and "elevation" are capturing different aspects of environmental variation, and are not confounded. Elevation does seem to be confounded with various climatic variables, however, including mean monthly precipitation (PMS, PMW) which emerged as the most significant climatic variable affecting $\delta^{15}N$ values (see also PCA biplot, Fig. 6.8).

Over the relatively small area of the upper and middle Thames Valley, climatic variation seems to be related to variation in elevation, and there is also another dimension of variation reflecting geology and topography in relation to the river (see above, 4.2). These conclusions are weakened by the lack of measurements from sites at higher elevations (see above, 4.1), and this is not something that can be corrected by manipulating the data. In further modelling, region and PMS are included to account for landscape-scale geographical and climatic variation, where appropriate.

4.5 Vegetation

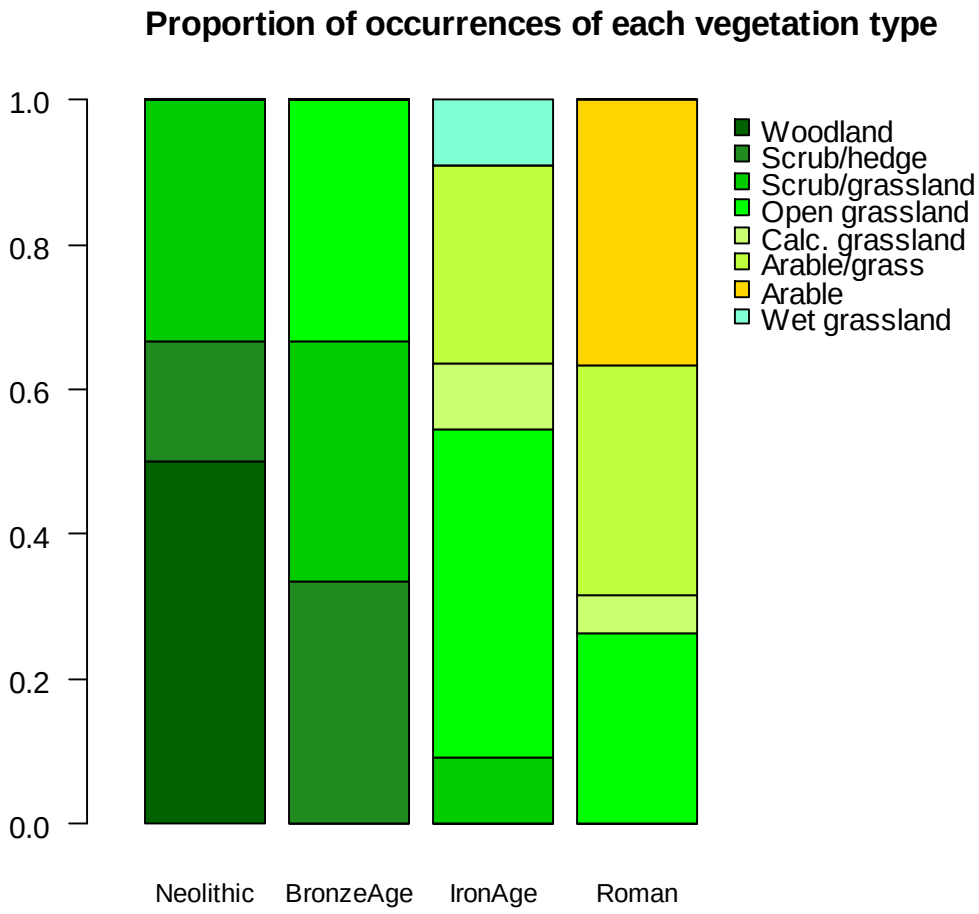


Fig. 6.10 Proportion of occurrences of each vegetation type as the dominant type at a sampled site, by period. One vegetation type was assigned to each site for each period, according to the dominant local vegetation as recorded in the excavation report. Number of sites per period: Neolithic 6, Bronze Age 6, Iron Age 11, Roman 19. Sites lacking information are omitted

As well as the landscape-scale abiotic factors presented above, there is information available from some sites on local vegetation. In many cases variation is strongly related to period, which means that there is little extra explanatory effect of including such factors in models to account for between-site variance. To look at it another way, there is independent evidence of environmental change over time, which may be important in explaining the observed changes in faunal $\delta^{13}C$ and $\delta^{15}N$ values.

Using information from excavation reports where available (Chapter 5, 4.5), vegetation at the sites was characterised according to dominant type (Fig. 6.10). It is clear how the distribution of dominant vegetation types recorded at sampled sites changed over time. The sites are not necessarily a random or even representative sample –accessibility of material and availability of environmental information affected site selection, as well as an attempt to cover a range of regions and periods – but the pattern of vegetation change is in line with the evidence discussed in Chapter 3. The landscape opens up progressively as woodland and scrub disappear, to be replaced by open grassland, and in the Iron Age and Roman periods increasingly by arable.

As well as dominant vegetation type, openness on a 5-point scale and percentage of arboreal pollen were assigned where possible. These three measures were highly correlated in a categorical PCA (Fig. 6.11; omits openness which loads almost identically to vegetation type), and only a 7-point scale of vegetation type (*vt2*) was used in further analysis (not all vegetation types occur in all periods, Fig. 6.10).

The categorical PCA (Fig. 6.11) helps to show how vegetation type is related to the variables considered in the previous sections. Dimension 1 seems to reflect the wetness of local conditions, refracted through soil type and precipitation. While there is some clustering of regions along this dimension (4 and 5, limestone and chalk, towards the low end, 1, floodplain somewhat higher, and 2 and 3, the river terraces, spread out along it) this has little relationship with vegetation type, and may be explained by the association of higher precipitation with the chalk and limestone ridges (section 4.4). Dimension 2 seems to be related to woodland cover, with sites with high percentages of arboreal pollen and/or woodland loading low on this axis. Regions 1 and 2, floodplain and first terrace, tend to be low and 3, the second terrace, higher.

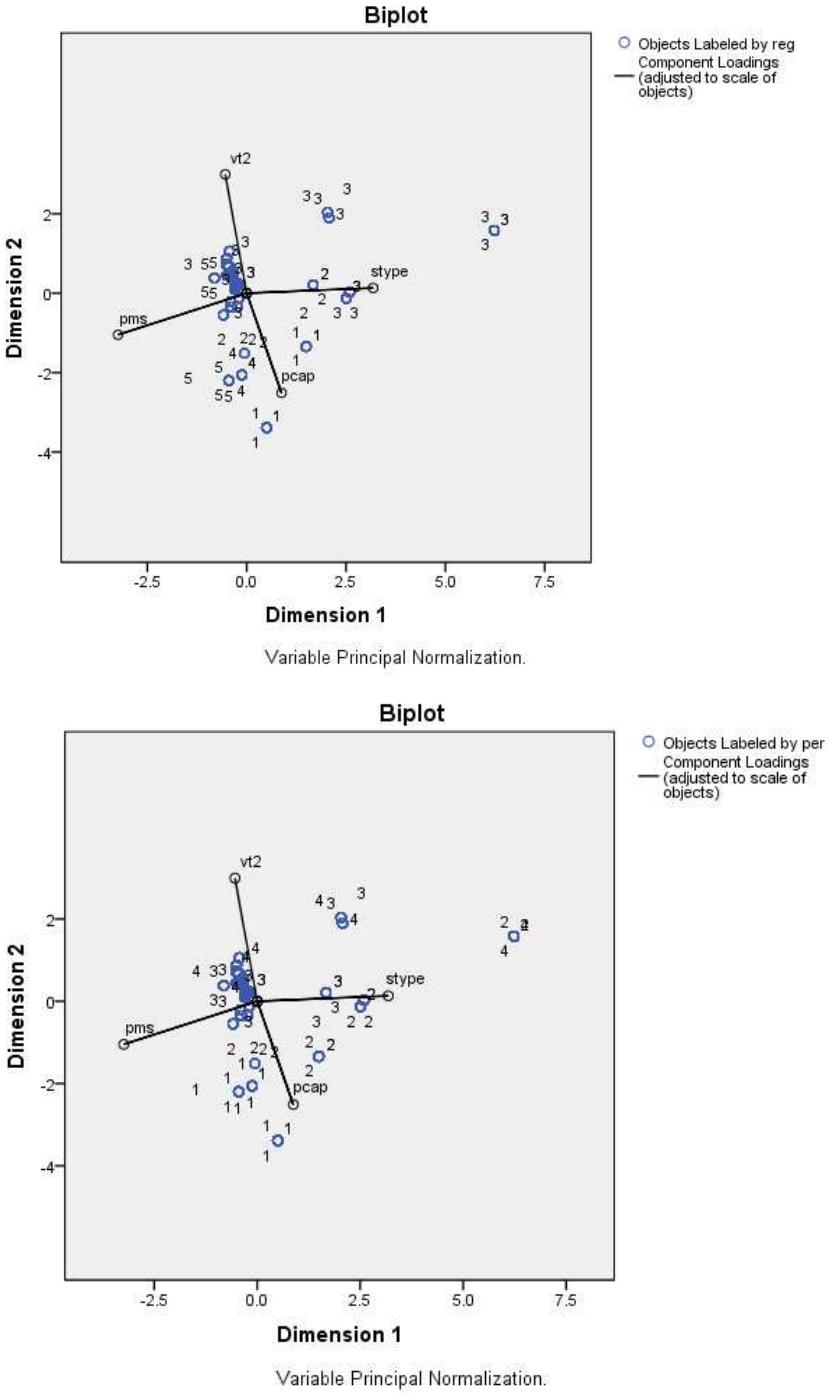


Fig. 6.11 Biplot showing first two dimensions of a Categorical PCA (run in SPSS) using *vt2* vegetation type, *pcap* percentage arboreal pollen, *pms* mean monthly precipitation summer and *stype* soil type. Points represent site/period combinations: in the *upper graph* they are labelled by region *1* floodplain *2* first terrace *3* second terrace *4* limestone *5* chalk, and in the *lower graph* by period *1* Neolithic *2* Bronze Age *3* Iron Age *4* Roman period.

Region 4, limestone, and one group of region 5, chalk, site/periods are also low and one group of chalk sites higher. The reason for this dichotomy is clear in the lower graph where points are labelled by period: all Neolithic and nearly all Bronze Age sites are low on this axis, and nearly all Iron Age and Roman sites are high. The overriding pattern is a progressive reduction in woodland cover in the Neolithic and Bronze Age and continuing openness in the Iron Age and Roman periods.

For modelling, a vegetation type was allotted to each site/period combination for which there was information. The range of vegetation types represented was strongly associated with period (Fig. 6.11), and this led to problems with modelling because of collinearity between these factors. The data set was therefore split into Neolithic+Bronze Age (n=418, 11 sites) and Iron Age+Roman (n=949, 11 sites). It was also not possible to include region within the models presented here, because of collinearity with vegetation type.

Linear mixed models of the effect of vegetation type on $\delta^{13}C$ in the Neolithic and Bronze Age (Table A3.8) show that overall, faunal $\delta^{13}C$ is significantly higher (by 0.2‰) at sites in woodland than in open grassland. This is surprising in view of the pattern of $\delta^{13}C$ values of cattle and sheep rising over time seen in Fig. 5.4 and Fig. 5.6, and the evidence just discussed for a reduction of woodland cover over the same period. When broken down by species, however, the only significant effect is for pigs, with $\delta^{13}C$ significantly higher (by 0.7‰) at sites in woodland than in open grassland.

In the Iron Age and Roman period the woodland and scrub vegetation types are absent, and calcareous grassland, arable/grassland, arable and wet grassland types have appeared (Fig. 6.10). $\delta^{13}C$ values at sites in other vegetation types do not differ significantly from the reference, open grassland (Table A3.9), with one exception. For cattle $\delta^{13}C$ values at calcareous grassland sites are significantly lower than the reference. In fact, this is just one site (in both periods), Alfred's Castle, so it would be unwise to generalise: more data are needed from sites on the chalk and on the limestone.

Results from the same set of models for $\delta^{15}N$ are shown in Tables A3.10 and A3.11. For $\delta^{15}N$ in the Neolithic and Bronze Age, site vegetation type had no significant effect, with one exception: pig $\delta^{15}N$ at woodland sites was significantly higher than for those in open grassland. In the Iron Age and Roman periods all species together and separately had

significantly lower $\delta^{15}N$ at the calcareous grassland site (by –1.6 to –2.1‰), and in addition pigs had significantly higher $\delta^{15}N$ (by 1.0‰) at arable sites.

The progressive opening up of the landscape over time, with an increase in grassland and then arable, is very clear, and forms the background against which changes in faunal isotope values will be interpreted. Linear mixed modelling has shown some variation in faunal values associated with specific vegetation types.

4.6 Plant remains at sites

The spectrum of plant remains at the sites sampled for this project changed over time (Fig.6.12). In the Neolithic emmer was the main cultivated cereal. Spelt appeared in the Bronze Age and was the main cultivated cereal in the Iron Age and Roman periods. Barley occurred throughout, as did bread wheat except for the Bronze Age. Flax and poppy occur from the Bronze Age onwards, and pulses and brassicas from the Iron Age onwards. In the Roman period a wider spectrum of crops was grown, including cultivated fruits and herbs (Van der Veen et al. 2008), and there is evidence of haymaking at some sites. Gathered foods appear throughout, but the proportions decrease steadily from the Neolithic onwards. This is in line with the environmental history (Chapter 3) and general results for the UK.

In linear models including species and period (and region for $\delta^{15}N$) and presence/absence of plant types as variables, none were statistically significant for faunal $\delta^{13}C$ or $\delta^{15}N$ values, using the whole dataset (occurrence of sloe approached significance for $\delta^{13}C$, $t = 1.94$, $P = 0.052$). When the data were split into Neolithic/Bronze Age and Iron Age/Roman periods, the occurrence of bread wheat was significant in the $\delta^{13}C$ model for the earlier periods ($t = -5.24$, $P = <0.01$). Sloe was significant in the $\delta^{15}N$ model for the later periods (Table A3.12b).

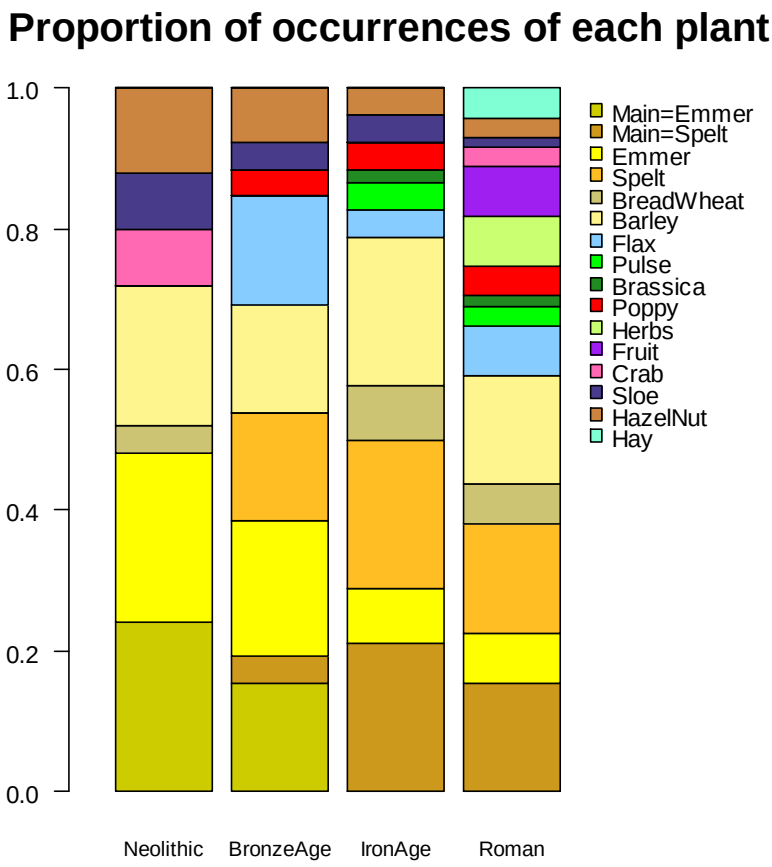


Fig. 6.12 Proportion of occurrences of each plant type at sampled sites, by period. *Main=Emmer* main wheat is emmer, *Main=Spelt* main wheat is spelt, *Emmer* present at site, *Spelt* present at site, *Fruit* cultivated fruits *Crab* apple (may not be distinguished from cultivated apple), *Hay* evidence for haymaking at site. Crab apple, sloe and hazelnut are gathered rather than cultivated. Number of sites per period: Neolithic 6, Bronze Age 5, Iron Age 11, Roman 11. Sites lacking information were omitted

4.7 Animal remains at sites

The spectrum of animal remains at the sites sampled for this project changed over time (Fig. 6.13). Faunal composition (based on number of identified specimens, NISP) in the Neolithic differs from later periods in the high proportion of sites with cattle as the main and pig as the second commonest domesticate, and one (Runnymede) where pig is commoner than cattle. From the Bronze Age onwards the usual faunal composition is cattle as the main and sheep as the second commonest domesticate, with pigs much less important than previously. In the Bronze Age there are 2/7 sites where sheep, followed by pig, are commoner than cattle

(Runnymede and Whitecross Farm). In the Iron Age there are 4/12 sites where sheep are commoner than cattle (Alfred's Castle, Mount Farm Berinsfield, Watkins Farm, Wyndyke Furlong), and in the Roman period 1/12 (Alfred's Castle; at the other 3 sites cattle are now dominant). Fig. 6.14 shows proportions of the three main domesticates as a triangle plot, again making clear the distinctness of faunal composition at the Neolithic sites, and the increasing importance of sheep at the expense of pig after that period. Proportions of cattle at sites seem similar in the Iron Age and Roman periods, with a tail of Iron Age sites with lower cattle and higher sheep, and a tail of Bronze Age sites with higher cattle and lower sheep.

Horse is ubiquitous from the Bronze Age onwards, with donkey only found in the Roman period. Fowl occurs in the Iron Age and Roman periods. While red and roe deer occur throughout, aurochs and wild boar are only found at Neolithic and Bronze Age sites and hare at Iron Age and Roman period sites. Oyster shells occur only in the Roman period, in line with evidence for some consumption of marine resources at this time (Müldner 2013), even though these sites are as far from the sea as is possible in the UK. As pointed out in the previous section, the sampled sites are not necessarily completely representative, but these results are in line with the environmental history (Chapter 3) and general findings for the UK (Albarella et al. 2008; Hambleton 2008; Serjeantson 2011).

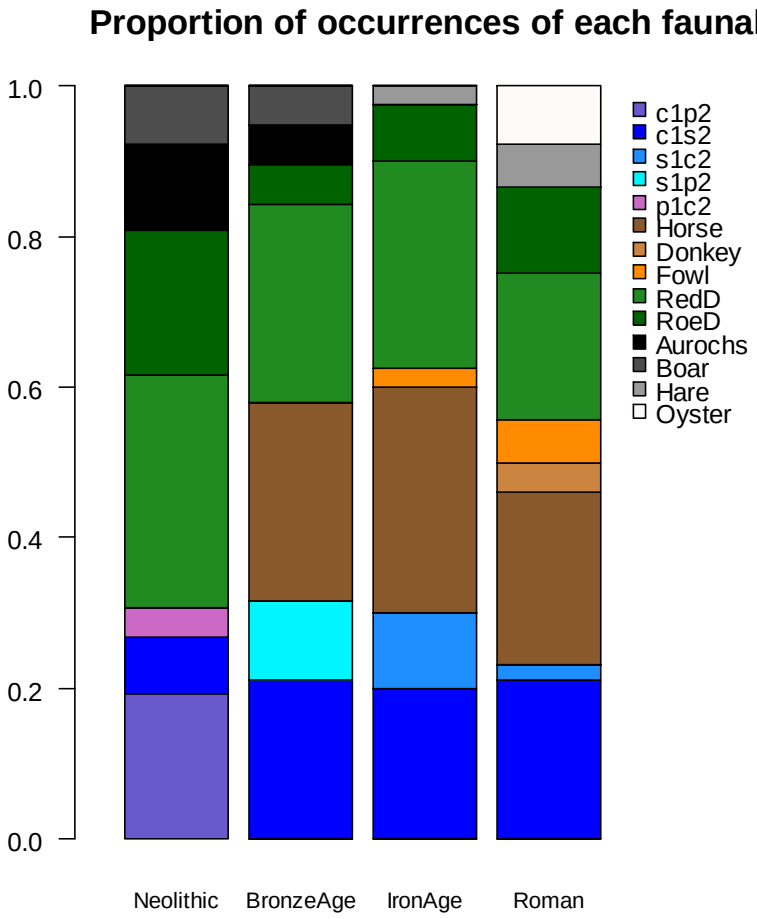


Fig. 6.13 Proportion of occurrences of each faunal type at sampled sites, by period. *c1p2* cattle main domesticate followed by pig, *c1s2* cattle followed by sheep, *s1c2* sheep followed by cattle, *s1p2* sheep followed by pig, *p1c2* pig followed by cattle (based on number of identified specimens, NISP). Number of sites per period: Neolithic 8, Bronze Age 6, Iron Age 12, Roman 12. Sites lacking information or with *NISP*<40 were omitted. Dog is ubiquitous, and isolated occurrences of cat, fox, marten and house mouse, as well as wild birds, were omitted

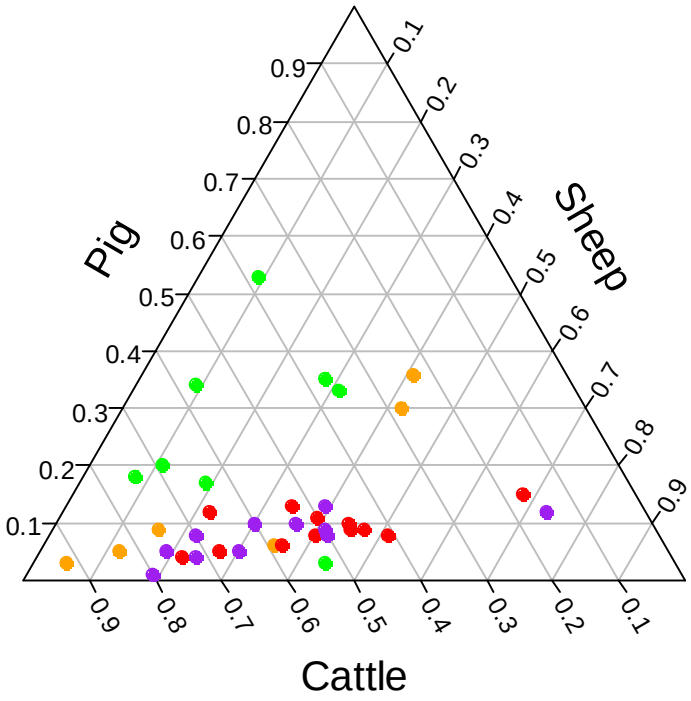


Fig. 6.14 Triplot showing the proportions of the three main domestic species at sites, coloured according to period: *green* Neolithic, *orange* Bronze Age, *red* Iron Age *purple* Roman. *Outlying points:* the Neolithic point with >40% sheep is Horton, the two Bronze Age points with <30% cattle are Runnymede and Whitecross Farm, and the Iron Age and Roman points with <20% cattle are Alfred's Castle. Sites lacking information or with *NISP*<40 were omitted

Most of the Neolithic and many of the Bronze Age sites are not permanently occupied sites, but rather seem to be places where people gathered intermittently. There is a relationship between site type and faunal composition (Table 6.7). The Bronze Age riverside/ midden sites (Runnymede and Whitecross Farm) are both dominated by sheep, followed by pig, while the enclosures/barrows and occupation sites are dominated by cattle, usually followed by pig in the Neolithic and sheep in the Bronze Age (except for the Neolithic settlement at Runnymede, dominated by pig).

	Faunal composition			
Site type	Cattle>pig>sheep	Cattle>sheep>pig	Sheep or pig>cattle	**Total**
Enclosure or barrow	4	2	0	**6**
Riverside midden	0	0	2	**2**
Occupation	1	4	1	**6**
Total	**5**	**6**	**3**	**14**

Table 6.7 Faunal composition at Neolithic and Bronze Age sites. Using a version of the Fisher exact probability test for 3×3 contingency tables (Freeman and Halton 1951), P_A= 0.053 and P_B = 0.040

In linear models including species and period (and region for $\delta^{15}N$) and presence/absence of faunal types as variables, none were statistically significant for $\delta^{13}C$ values, using the whole dataset (though occurrence of c1p2, the usual Neolithic stock pattern, approached significance, t = –1.93, P=0.053). The occurrence of aurochs was statistically significant in a model for $\delta^{15}N$ values (t=2.06, P=0.039; Table A3.13a). When the data were split into Neolithic/Bronze Age and Iron Age/Roman periods, the occurrence of red deer was significant in a $\delta^{15}N$ model for the later periods (t=2.73, P<0.01; Table A 3.13b).

4.8 Summary of factors affecting variation between sites

Most variation in faunal isotope values was within rather than between sites. Depending on species, only 10-20% of variation in $\delta^{13}C$ and 17-33% of variation in $\delta^{15}N$ was accounted for by the site-level factors investigated here.

Latitude and longitude had no significant effect on faunal $\delta^{13}C$ or $\delta^{15}N$ values. Elevation had no significant effect on faunal $\delta^{13}C$ values, but it had a small negative effect on $\delta^{15}N$ values, about 0.2% over the whole range of site elevations (up to 250 m). As very few sites in this sample were over 100 m, this result should be treated with caution.

There was no significant difference in faunal isotope values between Upper and Middle Thames sites. There were significant differences between regions (encompassing variation in geology, topography in relation to the river and hydrology). Fauna from first- and second-terrace sites had significantly lower $\delta^{13}C$ values (by 0.2‰) than from the floodplain, and fauna from second-terrace sites had significantly higher $\delta^{15}N$ values (by 0.7‰). Fauna from the limestone and chalk regions had lower $\delta^{15}N$ values (by 0.7 and 0.9‰ respectively) than those from the floodplain, and the latter approached significance (t= –1.98, P=0.06).

Soil characteristics accounted for some of the between-site variance in faunal $\delta^{15}N$, but not $\delta^{13}C$. When region was included in the models, fauna at sites on neutral soils had significantly

lower $\delta^{15}N$ values (by 0.7‰) than the reference, acid soils, and fauna at sites on terrace 2 had significantly higher $\delta^{15}N$ values (by 0.9‰) than the reference, floodplain. Soil type was confounded with region: in models including region and soil type, fauna in limestone and chalk regions had significantly lower $\delta^{15}N$ values than the reference, floodplain (by 1.9‰ and 2.5‰, respectively) but soil type had no effect. The soil type *rendzina* showed a strong correlation with chalk and limestone regions, as would be expected.

Climatic variables were highly intercorrelated. None had a significant effect on faunal $\delta^{13}C$, and the most important single factors significantly affecting faunal $\delta^{15}N$ values were precipitation (by 1–2‰ over the whole range) and temperature (1–2‰). Climate was confounded with elevation, but not with region. Thus, over the relatively small area of the upper and middle Thames Valley, climatic variation seems to be related to variation in elevation, and there is also another dimension of variation reflecting geology and topography in relation to the river. (These conclusions are weakened by the lack of measurements from sites at higher elevations, and this is not something that can be corrected by manipulating the data.)

The dominant vegetation type at sites changed profoundly over time. The overriding pattern is a progressive opening up of the landscape, with loss of woodland and scrub habitats, and increase in open grassland and then arable. In the Neolithic/Bronze Age faunal $\delta^{13}C$ was significantly higher (by 0.2‰) at sites in woodland habitats than in the reference (open grassland), an unexpected result. When the species were analysed separately, pig $\delta^{13}C$ was significantly higher in woodland (by 0.7‰) but cattle and sheep $\delta^{13}C$ values were not significantly different from open grassland. In the Iron Age/Roman period cattle $\delta^{13}C$ was significantly lower in calcareous grassland (by 0.3‰). In the Neolithic/Bronze Age pig $\delta^{15}N$ was significantly higher (by 0.8‰) at sites in woodland habitats than in the reference (open grassland). In the Iron Age/Roman period faunal $\delta^{15}N$ was significantly lower in calcareous grassland (by 1.8‰). When the species were analysed separately, sheep and cattle $\delta^{15}N$ values were significantly lower in calcareous grassland (by 1.8 and 2.1‰, respectively), while pig $\delta^{15}N$ values were higher at sites in arable habitats (by 1.0‰). It should be noted that in the Iron Age/Roman period calcareous grassland is represented at only one site, Alfred’s Castle.

The spectrum of plant remains at sites also changed considerably over time. Spelt replaced emmer as the main cereal crop, and crop diversity increased, while gathered foods declined.

Evidence of haymaking appeared in the Roman period. In the Neolithic/Bronze Age faunal $\delta^{13}C$ values were significantly lower (by 0.6‰) at sites with bread wheat – in fact, one site (Barton Court Farm) which has unusually low faunal $\delta^{13}C$ values. In the Iron Age/Roman period faunal $\delta^{15}N$ was significantly higher (by 0.6‰) at sites with sloe.

The spectrum of animal remains at sites also changed considerably over time. At most sites cattle is dominant, with sheep increasing at the expense of pig after the Neolithic. Horse appears in the Bronze Age. Red deer and roe deer occur throughout, but aurochs and wild boar occur only in the Neolithic/Bronze Age and hare only in the Iron Age/Roman period. The proportion of wild species is higher in the Neolithic. No single variable affected faunal $\delta^{13}C$ values significantly (though occurrence of the usual Neolithic stock pattern approached significance: P=0.053, $\delta^{13}C$ at sites with cattle>pig>sheep lower by 0.5‰). Faunal $\delta^{15}N$ values were significantly higher (by 0.8‰) at sites with aurochs. When the data were split into periods, faunal $\delta^{15}N$ values were significantly higher (by 0.6‰) at Iron Age/Roman sites with red deer.

In the last two sets of analyses, a large number of variables were tested (16 and 14 respectively in each set of models), and 1 in 20 tests is likely to be significant at the 0.05 level by chance alone, so it would be unwise to over-interpret these results.

5 Pattern of faunal isotope values at sites

Differences in plant and animal species composition at sites over time are likely to be related both to changes in the landscape and changes in animal and crop management in a complex process of interaction. As noted in section 2.2, faunal isotope values also changed over time, and each species had its own trajectory. The pattern of faunal isotope values at sites therefore changes over time. This can be seen in Fig. 6.15, showing the correlations between pairs of species for each isotope.

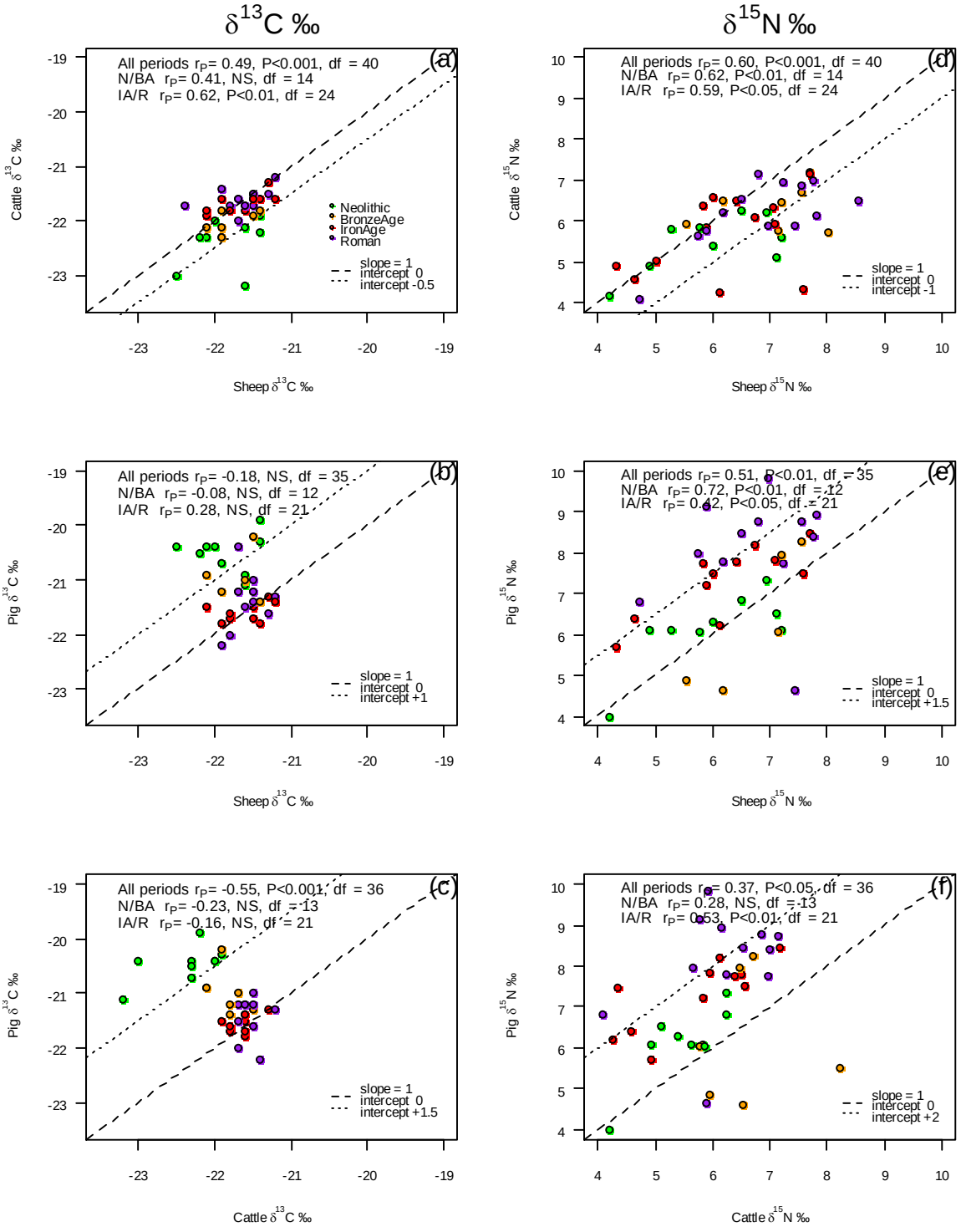


Fig. 6.15 Correlations between pairs of species for (**a-c**) $\delta^{13}C$ and (**d-f**) $\delta^{15}N$. The points represent the mean values of $\delta^{13}C$ or $\delta^{15}N$ for one site/period combination. r_p Pearson product-moment coefficient

Cattle and sheep $\delta^{13}C$ values are significantly correlated overall, but the correlation is much better in the Iron Age/Roman periods than in the Neolithic/Bronze Age – in fact, looking at Fig. 6.15a, it is mainly Neolithic points that are out of line. The tendency for cattle to have lower $\delta^{13}C$ values than sheep is also stronger in the Neolithic and to a lesser extent in the Bronze Age, with the later period points closer to the 1:1 line. Cattle and sheep $\delta^{15}N$ values are consistently significantly correlated, and cattle tend to have lower $\delta^{15}N$ values than sheep – there are more points below the 1:1 line than above it – but it is hard to see any pattern with period.

Pig and sheep $\delta^{13}C$ values are not significantly correlated, and there is strong patterning with period. Pig $\delta^{13}C$ values are higher than those of sheep at Neolithic and most Bronze Age (and one Roman) sites. Pig and sheep $\delta^{15}N$ values, by contrast, are significantly correlated overall. In the Neolithic/Bronze Age the correlation is stronger, and values are closer to the 1:1 line, while pig $\delta^{15}N$ is 1–2‰ higher than that of sheep in the Iron Age and particularly the Roman period, with more scatter.

Pig and cattle $\delta^{13}C$ values are not significantly correlated within the Neolithic/Bronze Age or Iron Age/Roman periods, but overall show a significant negative correlation. From Fig. 6.15c it is clear that this arises from the separate group of Neolithic points, where pigs have $\delta^{13}C$ values around 2‰ higher than cattle, with the Bronze Age intermediate between this and later periods. There is a weak overall correlation between pig and cattle $\delta^{15}N$ values. Pigs tend to have higher $\delta^{15}N$ values in all periods, by around 1‰ in the Neolithic and 2‰ in the Iron Age and particularly Roman periods.

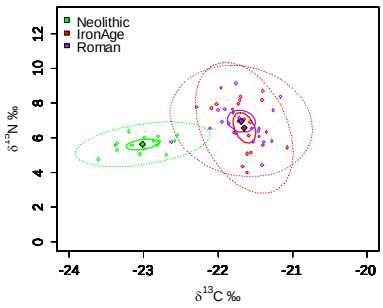
These differences and shifts in the relationships between the species can be interpreted as reflecting changes in their diets, and hence in the use of landscape, as well as changes in the landscape itself.

6 Patterns of change in the Upper Thames valley

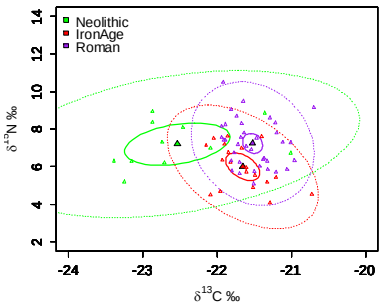
6.1 Changes at individual sites

At some sites it was possible to sample adequate numbers over two or more periods, and sometimes phases within periods. At most sites, differences in $\delta^{13}C$ and $\delta^{15}N$ between

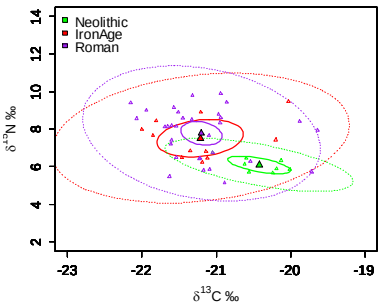
BCF Cattle by period



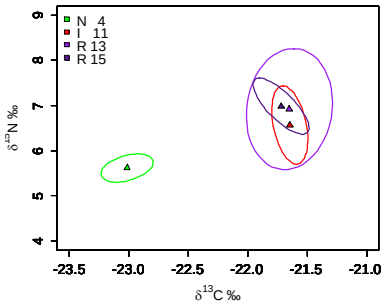
BCF Sheep by period



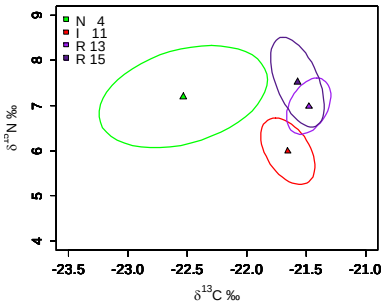
BCF Pig by period



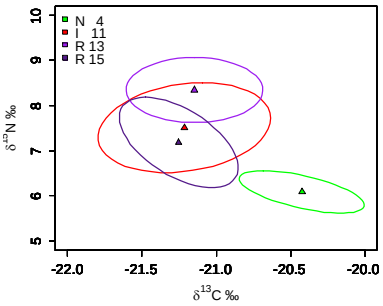
BCF Cattle by phase



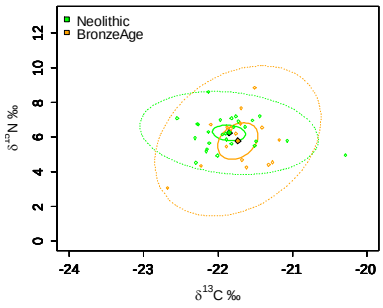
BCF Sheep by phase



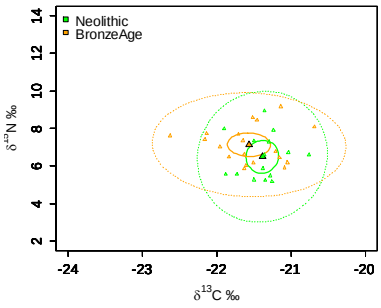
BCF Pig by phase



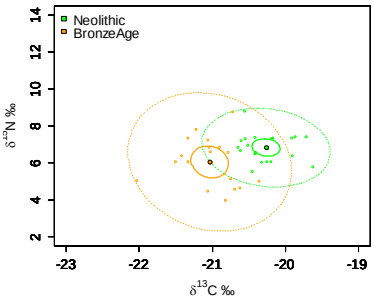
RM Cattle by period



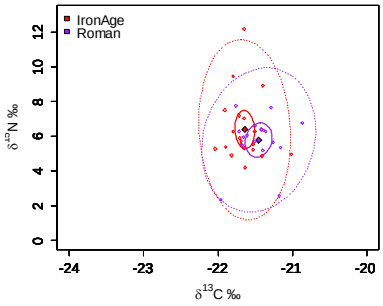
RM Sheep by period



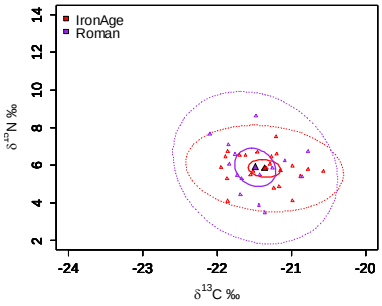
RM Pig by period



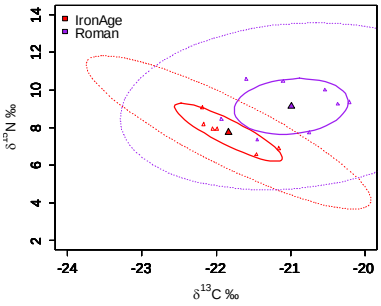
WY Cattle by period



WY Sheep by period



WY Pig by period



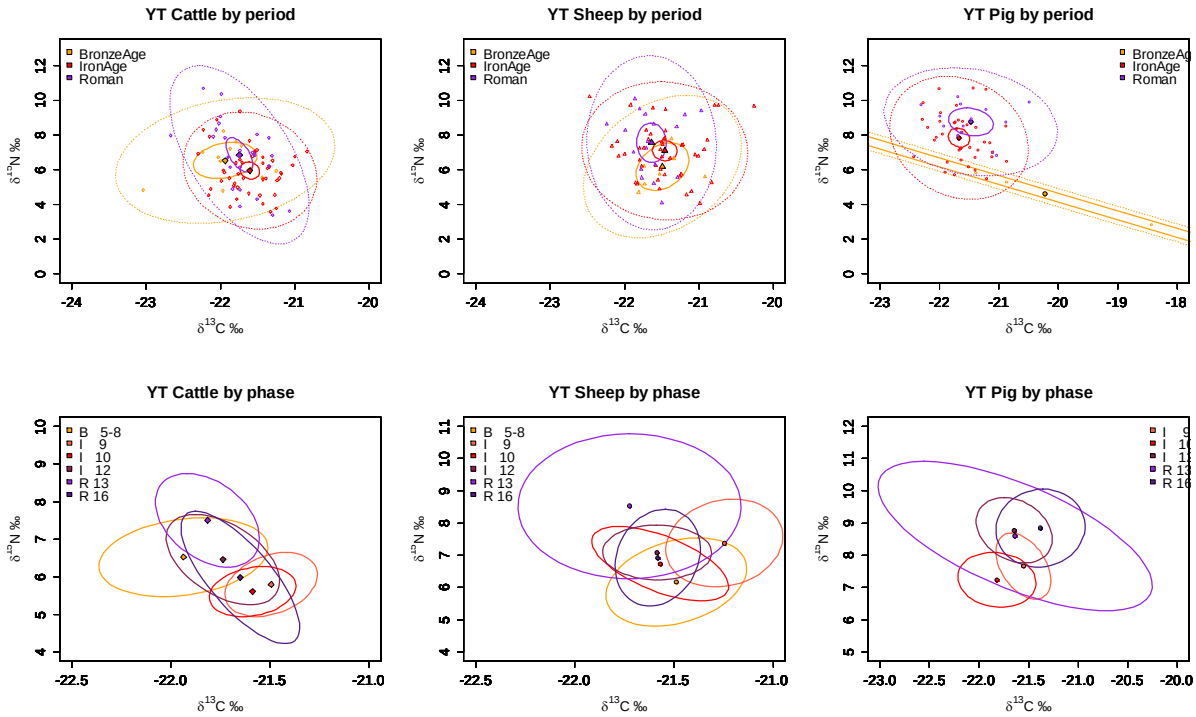


Fig. 6.16 Means, 95% confidence ellipses and prediction ellipses (Grove and Pearson 2014) for selected sites. Where phases are being compared, points and prediction ellipses have been omitted for clarity. $\delta^{13}C$ and $\delta^{15}N$ are compared simultaneously: where 95% confidence ellipses overlap, the means of the two groups are not significantly different (tested by permutation methods). Sites: *BCF* Barton Court Farm, *RM* Runnymede, *WY* Wyndyke Furlong, *YT* Yarnton (the odd shape of the pig ellipse reflects the low number of Bronze Age points)

periods/phases for each species were not significant (Table 6.8). The exceptions are shown in Fig. 6.16 (where 95% confidence ellipses overlap, differences are not significant: Grove and Pearson 2014).

Site	Compared	Cattle n	Sheep n	Pig n	Significantly different?
Alfred's Castle	Iron Age, Roman	26	36	29	NS
Ascott-u-Wychwood	Neolithic 1, Neolithic 2	17	--	15	NS
Barton Court Farm	Neolithic, Iron Age, Roman	59		51	Cattle & Pig: Neol a, IA b, R b
	Neolithic, Iron Age, Roman		67		Sheep: Neolithic a, Iron Age b, Roman c
	Phases: Neol 4, IA 11, R 13, R15	59		51	Cattle and Pig: Neol 4 a, IA-R b
	Phases: Neol 4, IA 11, R 13, R15		67		Sheep: Neol 4 a, IA 11 b, R 13 bc, R15 c
Claydon Pike	Iron Age, Roman	37	50	--	NS
	Phases: IA 10, R 13, R14, R16	37	50	--	NS
Eton Rowing Course	Neolithic, Bronze Age, Iron Age, Roman	19	--	--	NS
Farmoor	Iron Age, Roman	19	17	9	NS
Heathrow T5	Bronze Age, Iron Age, Roman	26	21	--	NS
Mount Farm Berinsfield	Bronze Age, Iron Age, Roman	48	49	--	NS
Runnymede	Neolithic, Bronze Age	44	34		Cattle and Sheep: NS
	Neolithic, Bronze Age			38	Pig: Neol a, BA b
Thornhill Farm	Iron Age, Roman	15	12	--	NS
Thorpe Lea Nurseries	Iron Age, Roman	42	47	20	NS
	Phases: IA 11, R 13, R 15				NS
Wyndyke Furlong	Iron Age, Roman	38	38		Cattle and Sheep: NS
	Iron Age, Roman			14	Pig: IA a, R b
	Phases: I 10, I 11, R 13			--	NS
Yarnton	Bronze Age, Iron Age, Roman	83	71		Cattle and Sheep: NS
	Bronze Age, Iron Age, Roman			58	Pig: BA a, IA b, R b
	Phases: B 5-8, I 9, I 10, I 12, R 13, R 16	83			Cattle: BA abc, IA 9 10 ab, IA 12 R 13 abc, R 16 ac
	Phases: B 5-8, I 9, I 10, I 12, R 13, R 17		71	55	Sheep and Pig: NS (Pig BA omitted)

Previous Page:

Table 6.8 Results of comparisons of $\delta^{13}C$ and $\delta^{15}N$ for each species between periods/phases (using method of Grove and Pearson 2014) at sites with adequate sample numbers. Comparisons followed by *different lowercase letters* are significantly different. Results from sites where significant differences were found are illustrated in Fig. 6.16

At Barton Court Farm, Neolithic $\delta^{13}C$ and $\delta^{15}N$ values for all three species are significantly different from Iron Age and Roman values, and for sheep Iron Age and Roman values also differ. Broken down by phase, sheep values differ between the Iron Age and later Roman phase, but the earlier Roman phase overlaps both. At Runnymede, Neolithic and Bronze Age $\delta^{13}C$ and $\delta^{15}N$ values are not significantly different for cattle and sheep, but are significantly different for pig. At Wyndyke Furlong, Iron Age and Roman $\delta^{13}C$ and $\delta^{15}N$ values are not significantly different for cattle and sheep, but are significantly different for pig. At Yarnton, Bronze Age $\delta^{13}C$ and $\delta^{15}N$ values are not significantly different from Iron Age and Roman values for cattle and sheep, but are significantly different for pig. Broken down by phase, for cattle the earlier Iron Age phases are significantly different from the earlier Roman phase, though all other phase combinations show some overlap. Changes at individual sites will be discussed in Chapter 8

6.2 Dynamics of agricultural change

Lambrick (1992) discussed the dynamics of agricultural change in the later prehistoric period in the Upper Thames valley, using evidence from distributions of settlement types and field systems as well as biological remains. His arguments consider the balance between arable and pasture for varying environmental and social conditions. The present study includes isotope results from seven of the sites mentioned in Lambrick (1992), with one on the floodplain (Farmoor Iron Age) and four each on the first (includes Farmoor Roman) and second terraces. The whole dataset for cattle and sheep is used in a case study relating faunal isotope values to landscape use as inferred from Lambrick (1992) and the extended discussion in Lambrick (2009, pp. 377–391). For this analysis, periods were subdivided into phases that broadly correspond to Lambrick's major chronological divisions (see Methods; different from the phases used in the previous analyses). Analyses were also conducted separately for the Middle and Upper Thames, which had different land use trajectories. The single site on the chalk of the Berkshire Downs, Alfred's Castle, was omitted, as this region was not considered in Lambrick's model.

6.2.1 Bronze Age to Iron Age transition

In the Middle Thames, mean $\delta^{15}N$ in the Iron Age was significantly lower than in the Bronze Age, by -0.9‰, and mean sheep $\delta^{15}N$ was significantly higher than that of cattle, by 0.8‰ (Table A3.14a). In the Upper Thames, mean $\delta^{15}N$ in the Iron Age was not significantly different from that in the Bronze Age, and mean sheep $\delta^{15}N$ was (just) significantly higher than that of cattle, by 0.3‰ (Table A3.14b).

6.2.2 Middle Iron Age to Late Iron Age transition

In the Middle Thames, the mean herbivore $\delta^{15}N$ value in the Late Iron Age was 0.9‰ lower than in the earlier Iron Age, approaching significance (P=0.056; Table A2.15a). When the species were analysed separately, mean cattle $\delta^{15}N$ was significantly lower, by –1.2‰, and sheep values, though also lower, were not significantly different. In the Upper Thames the difference between the phases was small and not significant (Table A3.15a). Sheep $\delta^{15}N$ values were significantly higher than cattle values, and the difference was more marked in the Middle Thames. Regions also had a significant effect on herbivore $\delta^{15}N$ values. In the Middle Thames both cattle and sheep $\delta^{15}N$ values were significantly higher on the 2nd terrace than in the floodplain (Table A3.15; 1.8‰ and 2.5‰, respectively when analysed separately). In the Upper Thames mean cattle $\delta^{15}N$ values were lower by –1.2‰ on the 1st terrace, approaching significance.

6.2.3 Late 1st/2nd century CE

In the Middle Thames, the mean herbivore $\delta^{15}N$ value in the earlier Roman period was 1.6‰ higher than in the later Iron Age (P<0.01), and in the later Roman period it was1.3‰ higher (P<0.05; Table A3.16a). When the species were analysed separately, mean cattle $\delta^{15}N$ was significantly higher, by 1.7‰ in both periods, and sheep values, though also higher, were not significantly different. In the Upper Thames the difference between the phases was small and not significant (Table A3.16b). In the Middle Thames sheep $\delta^{15}N$ values were significantly higher than cattle values, by 1.2‰ (P< 0.001) but in the Upper Thames the difference between the species was small and not significant (Table A3.16b). Regions had no significant effect on herbivore $\delta^{15}N$ values in either area. The results from section 6.2 are discussed in Chapter 8 (section 2).

7 Summary of results

7.1 Variability in faunal samples

In a modern sheep flock, diet had a small but significant effect on both $\delta^{13}C$ and $\delta^{15}N$ values. Isotope values did not vary with age in adult sheep. The largest effect was that of breeding status: ewes that had already lambed had lower $\delta^{13}C$ and $\delta^{15}N$ values than unbred ewes (Fig. 6.1). Variation of sheep isotope values in archaeological assemblages was higher than in the modern flock (Fig. 6.2), reflecting their greater heterogeneity.

7.2 Variation in faunal isotope values by species and period

		Cattle		Sheep		Pigs	
Change over time in:	Period	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$
Mean	Neolithic	Low	Low	Low	Low	High	Low
	Bronze Age	Intermediate	High	Intermediate	High	Lower	Lower, wide range
	Iron Age	High, wider range	Low, wide range	High	Low	Lower	High
	Roman	High, = Iron Age	High	High, = Bronze Age, Iron Age	High	Higher	Higher
Intra-site variance	Neolithic	Higher	Low	(Similar pattern to cattle, but not statistically significant)		(Low)	Low
	Bronze Age	Higher	High			(High)	Highest
	Iron Age	Lower	High			(Low)	High
	Roman	Lower	High			(Low)	High
$\delta^{15}N$ consistently more variable than $\delta^{13}C$							
Sheep $\delta^{15}N$ consistently slightly higher than cattle $\delta^{15}N$							

Table 6.9 Summary of changes over time in site-mean faunal isotope values

Faunal $\delta^{13}C$ and $\delta^{15}N$ values differed between cattle, sheep and pigs according to their different ecophysiological requirements. Each species had its own pattern of change over time (Fig. 6.4, Table 6.9), so that the pattern of isotope values of the three species at individual sites was different in different periods. Differences in diet, feeding environment and management of domestic animals were more important than physiological differences or long-term climatic change in determining isotope values.

7.3 Variations between sites

There were major changes over time in environment and the spectrum of plant and animal remains at sites (Figs. 6.10-6.14, Table 6.10). Sites were characterized according to landscape

regions for analysis, and there was consistent variation in faunal isotope values with both period and landscape region.

Period	**Neolithic**	**Bronze Age**	**Iron Age**	**Roman**
Vegetation	Closed-canopy woodland widespread	More open: less woodland, more scrub and grassland	Open: grassland, grassland/arable, wet grassland	Open: grassland, arable/grassland, arable, wet grassland, hay meadows
Main cereal	Emmer	Emmer	Spelt	Spelt
Plants	Barley, bread wheat Gathered plants common	Barley, flax, spelt	Barley, flax, bread wheat, emmer, beans, brassicas Gathered plants rare	Barley, flax, bread wheat, emmer, beans, brassicas Wide variety including fruits, herbs
Animals	Cattle> pig >sheep	Cattle>sheep>pig, horse	Cattle>sheep>pig, horse	Cattle>sheep>pig, horse
	Early: Neolithic+Bronze Age		**Late: IronAge + Roman**	
Landscape region	**$\delta^{13}C$**			
Floodplain	Reference		Reference	
Terrace1	$\delta^{13}C$ Cattle and sheep low			
Terrace2	$\delta^{13}C$ Cattle and sheep low			
Limestone			–	
Chalk	$\delta^{13}C$ Sheep low		$\delta^{13}C$ Cattle and sheep high	
$\delta^{15}N$				
Floodplain	Reference		Reference	
Terrace1				
Terrace2			$\delta^{15}N$ Cattle high	
Limestone	$\delta^{15}N$ Cattle low		–	
Chalk	$\delta^{15}N$ Cattle (sheep and pig) low		$\delta^{15}N$ (Cattle) sheep and pig low	

Table 6.10 Variation between sites: summary of environmental and agricultural changes over time, and variation in faunal isotopes in different landscape regions in earlier and later periods. In *parentheses* – shows the same trend, but not statistically significant

7.4 Dynamics of agricultural change in the Middle and Upper Thames Valley

In a case study relating cattle and sheep isotope values to landscape use as inferred from Lambrick (1992) and the extended discussion in Lambrick (2009; pp. 377–391), differences in faunal isotope patterns at sites were related to the different proposed trajectories of change in the Middle and Upper Thames. There were significant differences in the pattern of change of faunal isotope values between the Upper and Middle Thames (Table 6.11).

Phase	Middle Thames	Upper Thames
Late Bronze Age	(reference for EIA)	
Earlier Iron Age	Herbivore $\delta^{15}N$ lower than BA Sheep $\delta^{15}N$> cattle	Herbivore $\delta^{15}N$ unchanged from BA Sheep $\delta^{15}N$>cattle
Later Iron Age	Herbivore $\delta^{15}N$ lower than EIA, 2nd terrace $\delta^{15}N$ higher than floodplain Sheep $\delta^{15}N$> cattle	Herbivore $\delta^{15}N$ unchanged from EIA 1st terrace $\delta^{15}N$ lower than floodplain Sheep $\delta^{15}N$>cattle
Earlier Roman	Herbivore $\delta^{15}N$ higher than LIA, Sheep $\delta^{15}N$> cattle	No significant differences from LIA Sheep $\delta^{15}N$=cattle
Later Roman	Herbivore $\delta^{15}N$ higher than LIA, Sheep $\delta^{15}N$> cattle	No significant differences from LIA Sheep $\delta^{15}N$=cattle

Table 6.11 Summary of statistically significant faunal isotope changes in the Middle and Upper Thames Valley. *Phases* are based on Lambrick (1992)

Chapter 7

Discussion of results

In this chapter the results (Chapter 6) are discussed. The results from the English Heritage sheep help identify likely causes of variation in a single flock, and give a basis for comparison with variability in archaeological assemblages. The numbers of samples needed to distinguish groups of interest for different levels of variability are then estimated. Variation between species in the Thames Valley and their different trajectories over time are discussed, and a model developed against which results from individual sites can be compared. The main causes of variation in faunal isotope values between Thames Valley sites are identified.

1 Variation in a modern population: English Heritage sheep

The English Heritage sheep were from one flock kept at one locality, sampled over a few years, with individuals varying in sex, age, diet and breeding status, giving an opportunity to test the effects of these factors which is not available in archaeological faunal samples.

1.1 The effects of age, season, sex, breeding status and diet

There was no significant trend in bone collagen $\delta^{13}C$ or $\delta^{15}N$ values with age in these sheep (adults aged 2.5–5 years), though there was a hint of variation in $\delta^{13}C$ with season – mean values for sheep slaughtered in December were lower than for those slaughtered in September by about 0.1‰. This is within measurement error. Nevertheless, it could reflect seasonal isotopic variation in plants. Schnyder et al. (2006) found that $\delta^{13}C$ in cattle hair reflected variations in $\delta^{13}C$ of C3 plants on which the cattle were grazing, ultimately due to seasonal and other variation in plant-available soil water. The range of variation was about 0.5‰. Turnover of hair keratin is much faster than that of bone collagen, so any seasonal variability would be smoothed in collagen, and would probably not be detected in collagen from older sheep.

Isotope values of early-bred ewes were significantly lower than those of unbred ewes, by about 0.4‰ for $\delta^{13}C$ and 1.0‰ for $\delta^{15}N$, and one or other group differed significantly from rams for each isotope (Chapter 6, 1.4). Depletion of $\delta^{15}N$ during pregnancy is not unexpected (cf. Fuller et al. 2004), though the same study found no effect of pregnancy on $\delta^{13}C$ in humans. Any difference between males and females would depend on the breeding status of

the ewes. In practice the magnitude of any difference between the sexes in an archaeological "population" would depend on sex composition. Flocks are likely to have had a high proportion of females, to maintain the population, but if wool production was important might also include as many wethers (castrated males) as possible (Ryder 1982). A deposit of food waste might consist mainly of young males selected for slaughter if wool was not important. As both (or either) sex and age estimates are rarely available for individual elements, and hence samples, it would be hard to quantify the variability due to sex/breeding status, but it could be large enough to contribute to measured population variability.

Diet had a small but statistically significant effect: rams on the "low" diet had higher $\delta^{13}C$ values and lower $\delta^{15}N$ values (by 0.2‰ in each case) than rams on the "high" diet.

The major known contributor to variation in isotope values in the English Heritage sheep was breeding status of ewes, but the relative effects of factors, with or without interaction, would also depend on the variability of the environment, and the way in which individual sheep were managed. These are unknown for archaeological assemblages, but may well vary more than for the English Heritage sheep. The fact that significant variation due to diet was detected suggests that there is potential for an approach using faunal isotope values as indicators of use of environment or management practices, while bearing in mind that these may not be the only, or the most important, determinants of faunal isotope values.

1.2 Variability of a modern population of sheep compared to archaeological "populations"

For both $\delta^{13}C$ and $\delta^{15}N$ the standard deviation of the English Heritage sheep was the smallest of all the samples (Fig. 6.2: the small standard error reflects the large number of samples analysed). Since the English Heritage sample includes variation due to age (in adults), sex, breeding status and diet, additional sources of variation must operate in the archaeological samples. It is unlikely that samples originate from a single, contemporary flock or biological population in most archaeological assemblages. Archaeological samples, while they include animals that died or at least were disposed of at the same locality, may contain individuals episodically accumulated over an unknown length of time. Animals in archaeological samples may not all have originated locally, or may have moved between pastures that differed much more isotopically than the ones in this experiment. To look at it another way, they are sampling the environment on a wider – though unknown – scale in both space and time compared to a single flock kept in the same locality over a few years.

1.3 How many is enough?

What size samples would we need to detect a statistically significant difference in the means if the variability in isotope values was similar to that of the English Heritage sheep? Using a t-test/2-sample ANOVA, on two groups of equal numbers, with a standard deviation of 0.2 (equivalent to measurement error), and a sample size of 4 in each group, a difference in the means of about 0.4‰ would be significant at P=0.05 (Fig. 7.1; calculated using the power.t.test function in R, with power set at 0.8). With a sample size of 10, a difference of about 0.3‰ would be significant. With a standard deviation of 0.4 – around the maximum for the English Heritage sheep – the corresponding differences in mean values would be around 1.0‰ and 0.5‰. In the Thames Valley archaeological samples standard deviations are higher – typically 0.2–0.6 for $\delta^{13}C$ and 0.6-1.6 for $\delta^{15}N$ (Fig. 6.2).

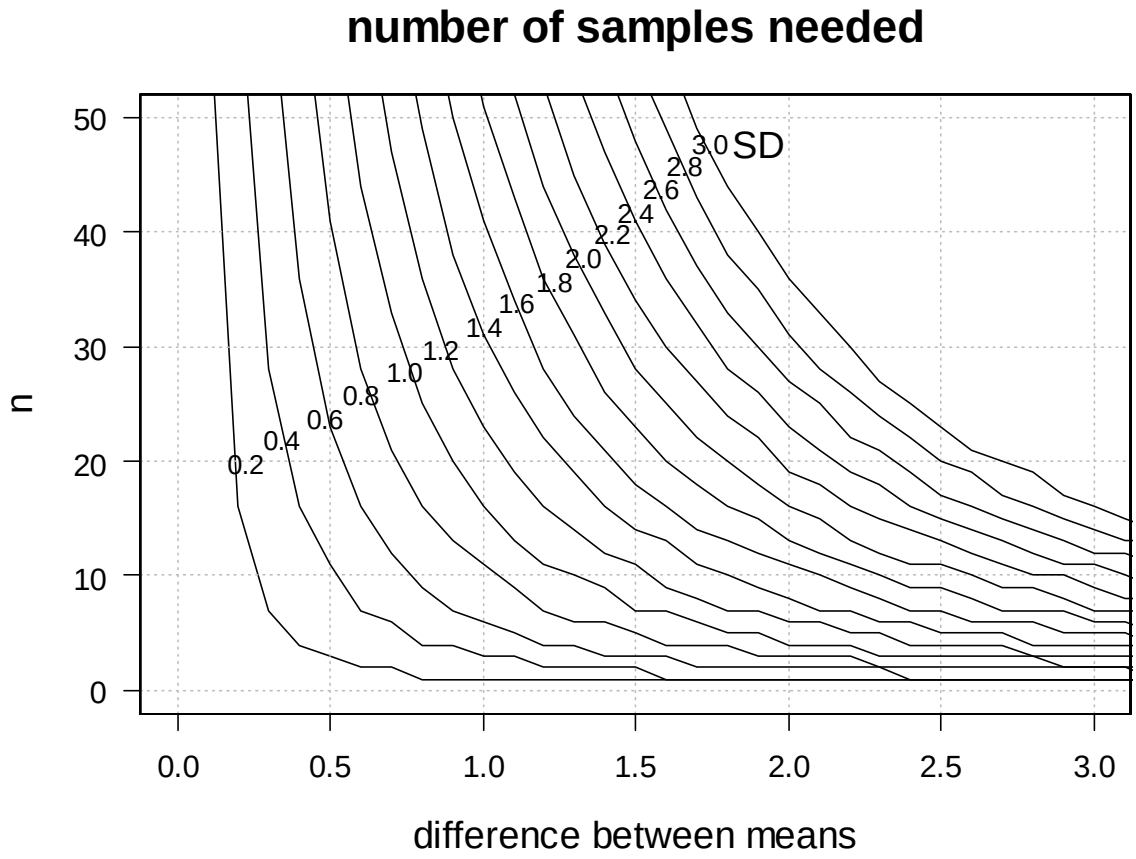


Fig. 7.1 Number of samples needed for a difference in means to be significant at P=0.05, for various values of standard deviation. The lines represent values calculated for a t-test/2-sample ANOVA, on two groups of equal numbers, using the power.t.test function in R, with power set at 0.8. The lines are not smooth at low values of n (the number in each group) because n has been rounded to the next highest integer

In many of these examples sample numbers of 20–30 per group would be needed for a difference in mean isotope values of 0.5-1.0‰ to be significant at P=0.05, in this idealised case (Fig. 7.1).

The linear modelling approach used here deals with some of the problems of unbalanced datasets, as well as that of non-independence of data points from the same site, by effectively giving less weight to data groups with higher variances/lower sample numbers. These calculations should nevertheless give us a sense of perspective in interpreting results (including those presented here) where differences in means, though significant, are small. For planning a sampling strategy, it is clear that the number of samples needed for meaningful results may be higher than commonly assumed. It will also depend on the variation in the sampled "population" which should ideally be assessed in a pilot project or using comparable published data.

Pearson and Grove (2013) used simulation based on a large number of sheep isotope values from Çatalhöyük to address the question of sample size. They showed that beyond a sample size of around 40 there was little effective improvement in accuracy of estimation of the mean, while at sample sizes below 8 each additional measurement had a large effect. The number of samples needed in a particular case would depend on the distribution of values (skewness, kurtosis) as well as the variance.

On this basis, sampling strategies should aim for at least 10–20 samples per group of interest, depending on likely preservation, variability and the differences between means being compared.

The sampling strategy for the Thames Valley project was to obtain at least 15 measurements for each species for each group of interest (site, site/period or site/phase), which seems reasonable in the light of this discussion. The actual numbers of measurements achieved were often lower, mainly because of lack of suitable identifiable and stratified material or lack of good-quality collagen. At some sites (Barton Court Farm, Claydon Pike, Mount Farm Berinsfield, Thorpe Lea Nurseries, Yarnton) large samples were taken with the purpose of investigating change between phases, but in practice sufficient numbers of measurements were rarely achieved. At these sites we can at least be confident that sample numbers for each species are large enough to detect changes at coarser timescales, and to provide a good basis for examining differences across the landscape.

2 Thames Valley: variation in faunal $\delta^{13}C$ and $\delta^{15}N$ values

Within-species variation may be systematically related to differences in age, sex and birth parity, to differential management of different population classes, to seasonal or inter-annual variation in environmental isotope values, or to other, unsystematic variations in dietary isotope values. Such factors contribute to the intra-site variation for each species. Nevertheless, a meaningful proportion of the variation in faunal isotope values reflects differences between sites (Table 6.3).

2.1 Differences between species

The differences in isotope values between species are summarised in Fig. 6.3.

2.1.1 Digestive physiology

The differences between species could have a physiological basis. Cattle and sheep are ruminants with complex digestive systems specialized for herbivory, while pigs are more omnivorous and lack the ruminant foregut adaptations for cellulose breakdown (Chapter 2, 3.3). Because of this, pigs produce less methane than ruminants (Crutzen et al. 1986; Jensen 1996) and would therefore be expected to have lower collagen $\delta^{13}C$ values, other things being equal (as is usually seen in horses, also non-ruminants). This is clearly not the case (Fig. 6.4). In the Neolithic and Bronze Age pig $\delta^{13}C$ values are significantly higher than those of cattle and sheep and in the Iron Age and Roman periods there is no significant difference. If the difference between pigs and ruminants were based solely on digestive physiology, it would be surprising for it to change over time in this way. Similarly, cattle $\delta^{13}C$ values are significantly lower than those of sheep in the Neolithic and Bronze Age but very similar in the later periods. The most likely explanation is that, whether or not there are physiological differences, they are being overwhelmed by factors that vary over time.

For nitrogen, it is not obvious what, if any, difference might be expected between pigs and ruminants based on digestive physiology or water relations (Chapter 2, 3.3.2). Nitrogen metabolism is complex and overall fractionation of amino acids may vary with percentage of protein in the diet, apart from variation of $\delta^{15}N$ values in the diet itself. The observed ^{15}N enrichment of animal tissues compared to diets is generally explained by fractionation during protein metabolism with nitrogen excreted as ^{15}N-depleted urea, although feces also represent a significant output (Sponheimer et al. 2003a,b). Urine may be more concentrated when water availability is low, leading to ^{15}N enrichment of body tissues of drought-tolerant species such as sheep. In the Thames Valley sheep consistently have slightly (but not always significantly) higher $\delta^{15}N$ values than cattle (Fig. 6.15), consistent with a physiological explanation.

However, sheep $\delta^{15}N$ values are not always higher than those of pigs, which, like cattle, require daily access to water. Pig $\delta^{15}N$ values vary over time. They are slightly higher than those of ruminants in the Neolithic, lower (with wide variation) in the Bronze Age, and consistently 1–2‰ higher in the Iron Age and Roman periods. Physiological explanations are inadequate to account for this variation.

Most of the differences between species in isotope values vary over time and are not easily explained by differences in physiology. While interspecific differences in isotope values due to physiology may exist, they are likely to be minor compared to differences that vary over the periods studied here.

2.1.2 Population structure

The study of the English Heritage sheep flock suggested that variation between individuals due to age/sex and birth parity, as well as diet, might be large enough to contribute to differences between flocks (or statistical populations) of different age/sex compositions. In the Thames Valley study samples were taken from adult animals as far as possible, to avoid including juveniles whose $\delta^{15}N$ values were affected by suckling, which should reduce one aspect of inter-individual variation. Could age/sex composition of animal populations have varied enough over time to account for the observed changes?

This question is easiest to resolve for pigs, which show little change in age structure through prehistoric or historic periods (sex structure is usually unknown). Pig assemblages characteristically have large numbers of individuals killed before 3 years old, consistent with management for meat, with a low proportion of old adults (e.g. Hambleton 2008, p. 68; Serjeantson 2011, p. 27). Sometimes a higher proportion of very young pigs is found (e.g. Wetwang Slack, Jay and Richards 2006), but young animals were avoided in the Thames Valley study. Pig population structure does not vary between sites or change consistently over time and cannot explain changes in isotope values.

Both sheep and cattle were exploited for secondary products (milk, wool, traction) as well as for meat. Age profiles of flocks/herds where secondary products were important would include a higher proportion of older animals. Sex structure might also vary with age, with a higher proportion of older breeding females compared to males, especially where meat production was more important than secondary products. There is evidence that age profiles for both species varied over time (Albarella et al. 2008; e.g. Hambleton 2008, p. 68; Serjeantson 2011). Particularly for cattle, the emphasis changed from meat production in the Neolithic towards a higher importance of secondary products in the Iron Age and Roman

periods, though generally age profiles suggest that both were important throughout. However, a very simple model (Excel spreadsheet) comparing the average $\delta^{13}C$ and $\delta^{15}N$ values of herds with extreme "meat production" and "secondary products" age/sex profiles shows that unrealistically large differences in $\delta^{13}C$ and $\delta^{15}N$ values (>5‰) between males and females, would be needed to create a detectable difference, even if the difference increased with age. It seems unlikely, then, that changes in population structure can explain the pattern of change over time for sheep or cattle.

The most likely remaining explanation is that interspecific differences are mainly due to differences in dietary isotope values, and the way they change over time reflects changes in environment and/or management practices.

2.2 Differences over time

2.2.1 Large-scale change over time: climate

Over the period 4000 cal BC to 400 AD the climate of North-Western Europe fluctuated, with a generally downward trend from the Holocene thermal maximum, when mean temperature of the warmest month was about 1.5°C higher than the pre-industrial average and the mean temperature of the coldest month about 1°C lower (Davis et al. 2003; Chapter 3.2). Climatic variation of this magnitude could have a detectable effect on faunal isotope values. On a continental scale, there are consistent trends in $\delta^{13}C$ and $\delta^{15}N$ from north-western to south-eastern Europe (Hedges et al. 2013; Van Klinken et al. 1994). For $\delta^{13}C$ these trends correlate with climatic factors such as temperature and precipitation, though for $\delta^{15}N$ the links with climate are less clear. The implied variation in isotope values would be up to about 0.4‰. However, long-term climatic changes cannot explain the different trajectories of change for the three domestic species, which should vary together if climate were a major explanatory factor.

2.2.2 Large-scale change over time: vegetation

Vegetation cover and composition changed greatly in the Thames Valley area over the same period (Ch.3; Chapter 6, 4.5). The landscape became progressively more open, with loss of woodland and scrub habitats, and increase in open grassland and then arable. Loss of forest cover in the Neolithic and Bronze Age is expected to lead to higher herbivore $\delta^{13}C$ values. This is indeed observed. The increase is greater for cattle (about 0.8‰) than for sheep (about 0.3‰; Table 6.3, Fig. 6.4). These results, and the differences in trends between cattle and sheep fit with their ecological preferences. Cattle are better adapted to closed-canopy environments than sheep and would therefore be more likely to use forest resources, with

lower $\delta^{13}C$ values, when these were available. The effect is smaller than seen in wild herbivores (e.g. Drucker et al. 2008), but domestic herbivores may not use the entire landscape, and are likely to have spent more time in open environments and/or received more fodder derived from agricultural activities, which would take place in clearings or other open environments.

Over the same period $\delta^{15}N$ values fluctuated for both cattle and sheep (Table 6.3, Fig. 6.4; sheep values not significantly different from Neolithic). There does not seem to be a clear-cut explanation for this in terms of environmental variation (but see next section).

The pattern for pigs differs from the herbivores, and the shifts are more complex. Pig $\delta^{13}C$ values are high in the Neolithic, lower in the Bronze Age, close to the grand mean in the Iron Age, and slightly higher again in the Roman period, all significantly different from the Neolithic (Table 6.3, Fig. 6.4). Pig $\delta^{15}N$ values are only slightly higher than herbivore values in the Neolithic, but 1-2‰ higher in the Iron Age and Roman periods. These results are consistent with the earlier more limited data of Hamilton et al. (2009), who argued that the switch in pattern from high $\delta^{13}C$-low $\delta^{15}N$ to low $\delta^{13}C$-high $\delta^{15}N$ reflects the loss of primary forest habitat where pigs could consume large quantities of fungi with relatively higher $\delta^{13}C$ values (Chapter 2, 2.2.6), and belowground plant parts and fruits (mast) which also have higher $\delta^{13}C$ values than leaves (Chapter 2, 2.2.4). The higher $\delta^{15}N$ values in the later periods may reflect a change in management, with pigs having greater access to human waste products under more intensive management in more permanent settlements.

Deforestation had different effects on isotope values of cattle, sheep and pig because of their different ecological requirements, and hence agroecological niche. This is discussed in more detail in the next section.

2.3 Species trajectories

2.3.1 Cattle

The relatively low values of $\delta^{13}C$ for Neolithic cattle, compared to later periods, are best explained as a higher proportion of vegetation from closed-canopy woodland in the diet, compared to later periods. As the amount of woodland decreased, so did the woodland contribution to cattle diet. Bronze Age values are intermediate between Neolithic and Iron Age/Roman values (Table 6.3, Fig. 6.4), corresponding with the opening up of the landscape.

Cattle can graze and browse in woodland, but they are mainly grazers and prefer woodland-edge or open environments (Chapter 2, 3.1). As well as feeding in pastures, cattle might be foddered over the winter. Winter fodder at sites in Switzerland and Austria consisted of leaves and twigs from woodland, understorey and woodland-edge species (Haas et al. 1996; Rasmussen 1993), though there is no direct evidence that I know of for or against winter foddering in England. Grazing may have been managed to provide winter foggage (grass that has been allowed to grow tall by undergrazing in summer, Lambrick 2009, pp. 382-383), which would not have had lower $\delta^{13}C$ values. Both inter- and intra-site variation in cattle $\delta^{13}C$ values is greater in the Neolithic and Bronze Age (Fig. 6.4, Table 6.4), suggesting that in these periods cattle diet included resources from a wider range of habitats, and that the balance between resources from woodland or more open environments might differ at different sites.

Cattle $\delta^{15}N$ is lowest in the Neolithic, and significantly higher in the Bronze Age and Roman period, but not the Iron Age. This pattern is shared with sheep (though for sheep the differences are not significant), so it may reflect environmental processes and not random fluctuation. Plant $\delta^{15}N$ values reflect nitrogen cycling in the soil, a complex process affected by many environmental biotic and abiotic factors, and plant $\delta^{15}N$ values are correspondingly variable. There is some evidence that plant $\delta^{15}N$ values in chalk and perhaps also limestone plant communities are generally lower, either because of tighter nitrogen cycling which reduces nitrogen loss and hence fractionation, or a high proportion of legumes which compete better on nitrogen-poor soils. This is in line with the low herbivore $\delta^{15}N$ values at the few chalk/limestone sites sampled here (Fig. 6.6), but there are not enough such sites to explain the overall low values of herbivore $\delta^{15}N$ in the Iron Age. Manuring increases $\delta^{15}N$ values in soil and hence in crops (Bogaard et al. 2013; Szpak 2014), and soils in and around settlements may have raised nitrogen and $\delta^{15}N$ levels (Commisso and Nelson 2006, 2007, 2010). Domestic animals may be foddered with crop wastes and processing residues (chaff), and though $\delta^{15}N$ values in these may be lower than in the grain consumed by humans (Bogaard et al. 2013) they are still likely to be slightly higher than in plants from unmanured soils. Acting in the opposite direction, nitrogen-fixing legumes tend to have lower $\delta^{15}N$ values than other plants, and in modern farming systems are commonly grown as part of a rotation, restoring fertility (nitrogen) to the soil, or as fodder crops, or encouraged in pasture to increase grazing quality. There is little evidence for legume crops in the Thames Valley before the Iron Age, but grazed grassland communities commonly include legumes such as clovers and vetches. Whether plant communities changed consistently over time or space to include more or fewer

legumes is unknown. In particular, it is not known whether hay, which appeared in the Roman period, had different $\delta^{13}C$ or $\delta^{15}N$ values from other types of grassland.

While there seems no obvious reason why there should be a consistent change over time in $\delta^{15}N$ values of pasture or fodder from wild plants, an increase in $\delta^{15}N$ values might occur on a landscape scale as a greater proportion of land supported arable agriculture, presumably dependent on manuring. Although herbivore $\delta^{15}N$ values are lower in the Neolithic, there is not a steady increase over time as seen for $\delta^{13}C$. The balance between arable and pasture may vary (e.g. Lambrick 1992), and the amount of manuring may also vary, with high levels more difficult to achieve on a large scale or when the ratio of arable to pasture rises. In the Neolithic, the proportion of the landscape under arable would have been lower, though probably intensively manured (Bogaard et al. 2013) and the relative area of pasture higher. Cattle would have derived most of their diet from pasture or wild fodder rather than crop by-products. As human populations grew and the landscape became divided and organised, the proportion available for pasture would fall, and nitrogen and $\delta^{15}N$ levels in intensively used pastures would rise as the density of grazing animals increased. This might explain the rise in cattle $\delta^{15}N$ in the Bronze Age (which is still apparent even if chalk and limestone sites are excluded, Fig. 6.6), or between the Iron Age and Roman periods, but not the apparent dip in the Iron Age. While cattle $\delta^{15}N$ values at most post-Neolithic sites cluster around the grand mean, there is a group in the Iron Age with low values (Fig. 6.6), mostly floodplain and first-terrace sites. Perhaps these represent a system of more extensive, pastoral farming with consequent lower herbivore $\delta^{15}N$ values (further discussed in Chapter 8). In keeping with this explanation, intra-site variation in cattle $\delta^{15}N$ is distinctly lower in the Neolithic than at later periods (Table 6.3), reflecting lower availability of food from arable habitats, but inter-site variation is highest in the Iron Age (Fig. 6.4), suggesting differences in landscape use between sites.

It is possible that changes in the pasture/arable balance and intensification of agriculture affected cattle $\delta^{15}N$ values over time, but to address this question would require close study of $\delta^{15}N$ values at individual sites, including animals and crops, and if possible wild or ruderal plants, as well as of crop weed assemblages which are informative about soil conditions.

2.3.2 Sheep

Sheep isotope values follow similar trends to cattle values, but they are less marked and differences are less often significant. Intra-site variation in sheep $\delta^{13}C$ and $\delta^{15}N$ values is not significantly different between periods (Table 6.4). Sheep are less likely than cattle to thrive

in closed-canopy or wet environments, which would explain why sheep $\delta^{13}C$ values were significantly higher than those of cattle in the Neolithic, though still lower than in later periods. Like cattle, sheep might have been foddered with woodland resources in winter, and this source of ^{13}C-depleted food would decrease over time as dense woodland decreased.

The same arguments as for cattle apply to the time-course of variation in $\delta^{15}N$. As noted above (Chapter 2, 2.4.2.2) there may be a physiological reason that sheep $\delta^{15}N$ values are consistently slightly higher than those of cattle. It is also possible that it reflects a greater proportion of sheep diet coming from manured land, as might happen if they were folded on arable plots or fields as a way of collecting manure. This would be more likely for sheep than cattle as they are smaller, lighter and less destructive of soil structure.

2.3.3 Pig

The results for pig are consistent with and extend the results of Hamilton et al. (2009). There it is suggested that the switch in pig isotope values from high $\delta^{13}C$ compared to herbivores in the Neolithic to high $\delta^{15}N$ in the Iron Age/Roman period reflects a change in management, from extensive feeding in habitats including primary forest to a closer association with human settlement in the Iron Age. Pig $\delta^{13}C$ values in the Bronze Age are intermediate between Neolithic and later values, as would be expected if high values depended on the availability of fungus-rich primary forest habitats. There is no significant difference between the Iron Age and Roman periods in pig $\delta^{13}C$ values. Intra-site variation in pig $\delta^{13}C$ values does not differ significantly between periods (Table 6.4), though it is distinctly higher in the Bronze Age than at other periods. Intra-site variation in pig $\delta^{15}N$ values is lowest in the Neolithic, highest in the Bronze Age and somewhat lower in the Iron Age and Roman periods.

Median site-mean pig $\delta^{15}N$ is lower in the Bronze Age than the Neolithic (Fig. 6.4). This would be expected if fungi contributed a significant amount of protein to pig diets, and had not been replaced by anthropogenic waste. The wide spread of site mean values suggests another possibility: perhaps in the Bronze Age some sites still showed the "Neolithic" management pattern while others had switched to the "Iron Age" pattern. Both inter- and intra-site variation in pig $\delta^{15}N$ values was lowest in the Neolithic and highest in the Bronze Age, suggesting that changes were taking place at both site and landscape level. Fig. 6.6 shows that at floodplain (including eyot) sites $\delta^{15}N$ values decreased from the Neolithic to the Bronze Age, whereas at 2nd-terrace sites they increased. If the higher terraces were favoured for settled farming this might connect the change in pig management with a general change in landscape use. There is only one site with sufficient data from pigs to look at the change at a

single site – Runnymede – where both $\delta^{13}C$ and $\delta^{15}N$ values decrease from Neolithic to Bronze Age, suggesting continued "Neolithic" pig management in a less forested landscape. The numbers of pigs sampled are however very low at all the sites except the midden sites of Runnymede and Whitecross Farm, so this cannot be a firm conclusion.

2.3.4 Pattern of faunal isotope values at sites

Faunal isotope values changed over time, and each species had its own trajectory. The pattern of faunal isotope values at sites therefore changes over time. This can be seen in Fig. 6.15, showing the correlations between pairs of species for each isotope. The obvious differences in the relationship of faunal values to each other at different periods mean that calculating an overall site mean for "fauna" to estimate plant isotope values or to act as a baseline for human diets is a highly dubious exercise. The differences in mean isotope values between species need to be taken into account. Unless this is done, overall site means are not even comparable with each other, and patterns seen at one site cannot be extrapolated to others in different periods or environments. Differences between sites in faunal composition also need to be accounted for. Where faunal isotope values are used to estimate the amount of animal protein in human diets, the different contributions of each species need to be taken into account, and these depend on both the relative proportions of each species and their size.

2.4 Summary and model

Environmental change can account for the differences over time in faunal isotope values. On the landscape scale, changes in vegetation cover provide plausible explanations of the individual species' trajectories of change in isotope values, and hence the pattern of change at sites. Faunal collagen isotope values reflect dietary values, and are affected both by changes of availability of different foods (e.g. woodland resources) and changes in management, which themselves both reflect and affect landscape-scale changes. This is not a closed system, however: management changes may also reflect changes in human society (e.g. the increasing importance of sheep wool, the introduction of new technologies such as wheeled vehicles or horse-riding, changes in the nature of assemblies and feasting, or the development of market systems).

Within-species variation may be related to differences in age, sex and birth parity, to differential management of different population classes, to seasonal or inter-annual variation in environmental isotope values, or to other, unsystematic variations. Such factors contribute

Parameter	Value	Derivation	Notes
$\delta^{13}C_{animal-plant}$	5	Conventional, following Krueger and Sullivan (1984)	Herbivore collagen – plant
$\delta^{13}C_{carnivore-herbivore}$	1	Conventional, following Bocherens and Drucker (2003)	Carnivore (or omnivore) collagen – herbivore collagen
$\delta^{15}N_{animal-plant}$ or $\delta^{15}N_{carnivore-herbivore}$	4	Conventional, following Schoeninger and DeNiro (1984)	Herbivore collagen – plant or carnivore – herbivore collagen
Mean plant $\delta^{13}C$	-26.6	Grand mean sheep $\delta^{13}C$–5	Forage/fodder not affected by canopy effect. Sheep $\delta^{13}C$ least likely to be affected by feeding in woodland
Mean cereal $\delta^{13}C$	-26.6	=Mean plant $\delta^{13}C$	Includes cereal crop residues and other forage
Mean legume $\delta^{13}C$	-26.6	=Mean plant $\delta^{13}C$	Forage/ fodder
Mean "waste" $\delta^{13}C$	-23.6	Mean plant $\delta^{13}C$ + 3	"Waste" includes human food scraps and other items of animal origin (e.g. invertebrates) consumed by pigs, treated as a trophic level higher than plants
Mean woodland $\delta^{13}C$	-29.6	Mean plant $\delta^{13}C$ – 3	Value for canopy effect estimated from (Drucker et al. 2008; Heaton 1999)
Mean fungal $\delta^{13}C$	-21.6	Mean plant $\delta^{13}C$ + 5	As in Hamilton et al. 2009
Mean plant $\delta^{15}N$	2	Grand mean cattle $\delta^{15}N$ – 4	Applies to forage/fodder not affected by manuring. Cattle grand mean was 5.9‰ in Neolithic, 6.1‰ for later periods
Mean cereal $\delta^{15}N$	4.1	Mean plant $\delta^{15}N$ +2.1	Estimated from Fraser et al. (2013b, Table 4). Includes crop residues and other forage growing on manured soils. Local forage at Vaihingen estimated as wild herbivore mean $\delta^{15}N$ – 4 = 2.4‰, and cereals at Vaihingen were 4.5‰, so 2.1‰ enriched over local forage
Mean legume $\delta^{15}N$	0.3	Mean plant $\delta^{15}N$– 1.7	Estimated from Fraser et al. (2013b, Table 4). Legume crops at Vaihingen were 1.7‰ lower than cereal crops
Mean "waste" $\delta^{15}N$	6	Mean plant $\delta^{15}N$ + 4	"Waste" includes items of animal origin (e.g. invertebrates) consumed by pigs, treated as a trophic level higher than plants, and $\delta^{15}N$-enriched items from human waste
Mean woodland $\delta^{15}N$	2	Mean plant $\delta^{15}N$ – 3	Heaton 1999
Mean fungal $\delta^{15}N$	4	Mean plant $\delta^{15}N$ + 2	As in Hamilton et al. 2009
Plant %protein	10%	USDA	Applied to plant, cereal, legume and woodland components
"Waste" %protein	60%	USDA	"Waste" includes human food scraps & other items of animal origin (e.g. invertebrates) consumed by pigs
Fungi %protein	30%	USDA	As in Hamilton et al. 2009
"Routing" to collagen, $\delta^{13}C$ only	0.5	Jim et al. (2004, 2006)	Herbivore collagen – plant

Table 7.1 Parameters used to calculate faunal collagen values for model diets (Fig. 7.2)

to the intra-site variation for each species. but a meaningful proportion is related to variation in dietary isotope values. Variation in dietary values reflects both diet components – e.g. browse, grass, anthropogenic waste – and environmental variation reflected in plant isotope values, such as the lower $\delta^{13}C$ values of dense woodland or the higher $\delta^{15}N$ values of manured crops.

There are differences between the typical $\delta^{13}C$ and $\delta^{15}N$ values of the three major domesticates both at individual sites and in their trajectories over time. Changes in faunal isotope values can plausibly be interpreted as reflecting landscape-scale changes in vegetation and agricultural practices.

Where faunal isotope values are being used in modelling human diets, it is necessary to take account of this variation. Sample numbers for each species need to be large enough to account for intraspecific variation, and it may also be necessary to assess the dietary contribution of each species separately to take account of interspecific variation. It cannot be assumed that faunal isotope values from other sites in different areas, or, perhaps more importantly, from different periods, are applicable.

To act as a point of reference a model (Fig. 7.2) was constructed against which results can be compared. Table 7.1 shows the parameters of the model and how they were arrived at. The R script for the model is given in Appendix 4.

Each of the lines of points has a margin of error because of uncertainties in the estimation of parameters. This is not shown because the uncertainties are difficult to quantify, either because parameters have not been measured (e.g. archaeological forage/fodder baseline values), or the applicability of the values used from other sites (such as Vaihingen) is uncertain, or the appropriate range of variation is not known (e.g. $\Delta_{animal—plant}$ values), or a combination. The values shown allow us to compare measured isotope values with reasonable expectations, but should not be taken as a rigid framework for interpretation. This model will be used to help interpret results from individual sites in Chapter 8.

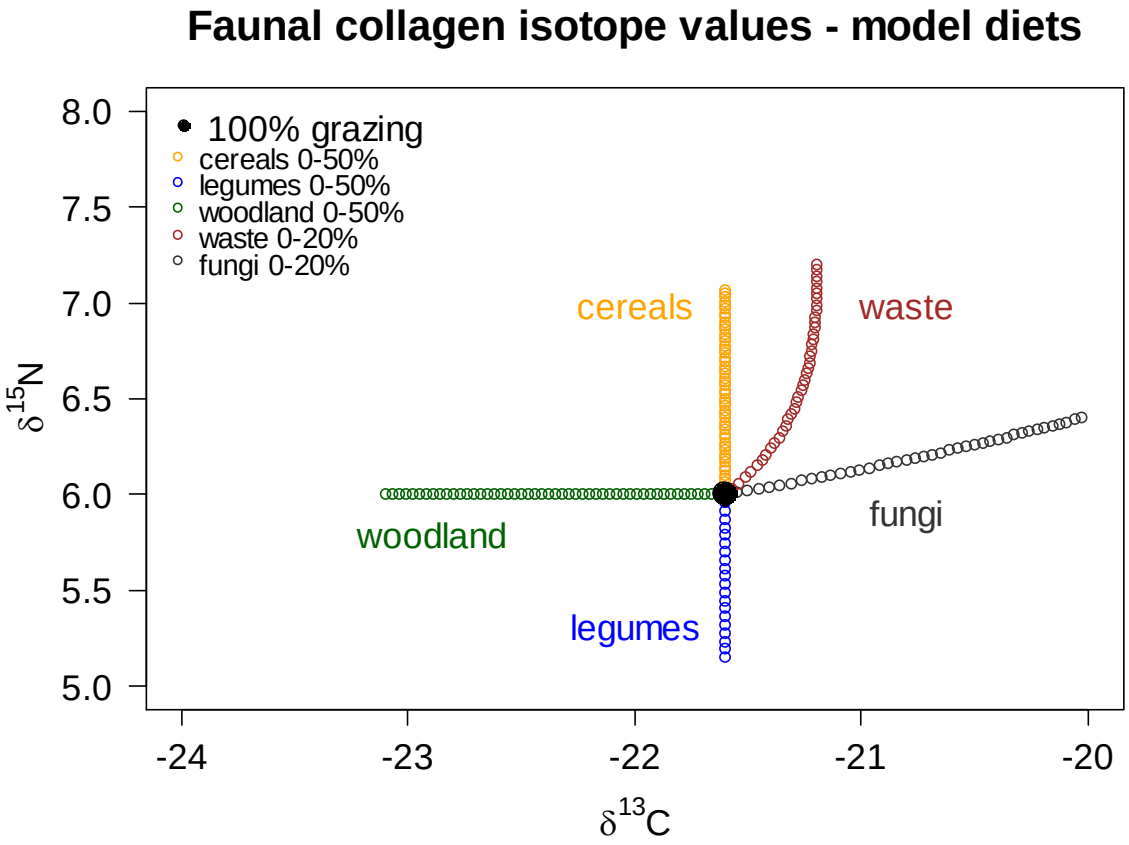


Fig. 7.2 Predicted faunal collagen isotope values from models using parameters given in Table 7.1.

3 Thames Valley: variation between sites

In this section variation between sites will be discussed, to see if there are links between faunal isotope values and environmental factors that vary in space or time.

Most variation in faunal isotope values was within rather than between sites. Depending on species, only 10–20% of variation in $\delta^{13}C$ and 17–33% of variation in $\delta^{15}N$ was accounted for by the site-level factors investigated here (Table 6.3).

3.1 Which environmental variables matter?

The effects of a variety of environmental variables on faunal $\delta^{13}C$ and $\delta^{15}N$ values at sites were investigated (Chapter 5, 3.3.2). As well as accounting for inter-site variation, the intention was to summarise environmental variation in a way that could be used in inter-site comparisons.

The variables were often intercorrelated, complicating interpretation. Five "regions" were defined (Chapter 3, 3.1), combining geology and topography in relation to the river. The highest regions were the limestone and chalk ridges, which therefore differed in geology from the alluvial deposits of the floodplain and river terraces, as well as in elevation. Climate variation was also related to elevation (Chapter 6, 4.4), with higher precipitation and lower temperature at greater elevations. Sites on the chalk and limestone were underrepresented, with only two in the Neolithic and one in the Iron Age/Roman period, so statistics should be interpreted cautiously.

3.1.1 Geographic and climatic variables

Over the relatively small area of the Upper and Middle Thames Valley faunal $\delta^{13}C$ and $\delta^{15}N$ values did not vary significantly with latitude and longitude. This contrasts with results at larger scales (e.g. Hedges et al. 2013) but was in accordance with the design of the study (Chapter 1, 2.3). Climatic variation seemed to be related to variation in elevation, with another dimension of variation reflecting geology and topography in relation to the river (region; Ch.6, 4.2). These conclusions are weakened by the lack of measurements from sites at higher elevations (Ch 6, 4.1), and this is not something that can be corrected by manipulating the data. Site elevation had no significant effect on faunal $\delta^{13}C$ values, but had a small but significant negative effect (0. 15‰) on $\delta^{15}N$ values. This is in the expected direction – lower $\delta^{15}N$ with higher precipitation and lower temperatures – but very small, within measurement error.

3.1.2 Soils

Soil drainage characteristics, linked to soil type, could affect plant $\delta^{13}C$ values via their effect on plant water balance. Fauna at sites on soils with medium drainage rates had slightly but significantly lower $\delta^{13}C$ values (by 0.15‰) than on fast-draining soils, in the expected direction, but within measurement error. When region was included in these models, however, soil characteristics were no longer significant, suggesting that they were confounded with region (see Fig. 6.7).

Faunal $\delta^{15}N$ values should reflect plant values, which should reflect soil values, but the links with soil variables are not obvious. Soil $\delta^{15}N$ values are likely to be related to vegetation types and the use and management of land by people. Soil drainage was not important in accounting for faunal $\delta^{15}N$ values. In models including region, soil type had no effect, but fauna in limestone and chalk regions had significantly lower $\delta^{15}N$ values than the reference, floodplain (by 1.9‰ and 2.5‰, respectively). With soil pH and region included, fauna at 2nd-

terrace sites had significantly higher $\delta^{15}N$ values (by 0.9‰). This could reflect a concentration on arable farming, with associated manured soils, on the second terrace (Chapter 3, 3.3.4). Fauna from sites on neutral, but not alkaline, soils had significantly lower $\delta^{15}N$ values than on acid soils (by 0.7‰) when region was accounted for. This last finding is puzzling. All of the sites with acid soils are in the Middle Thames area, but that does not provide a reason why fauna there should have higher $\delta^{15}N$ values, and there does not seem to be a strong relationship between the broad vegetation categories used in the analysis and soil pH or land use.

The dataset is limited by lack of information on soil types at many sites, and unbalanced with respect to region. Soil characteristics account for some of the between-site variance in $\delta^{13}C$ and $\delta^{15}N$ values, and are related to region (Fig. 6.7), but it is difficult to disentangle clear, inmportant effects.

3.1.3 Region: summarising the abiotic variables

For the purposes of further analysis, "region" provided a reasonable summary of the variation in abiotic factors, such as climate and geology, across the area. Where appropriate (e.g. in models for $\delta^{15}N$) extra variables for climate (precipitation) or soils (pH) could be included, but in practice were not important.

In an overall model for $\delta^{13}C$ including species, period and region, the effect of region was significant and $\delta^{13}C$ values were significantly lower on terraces 1 and 2 than on the floodplain (Table A3.4a, Fig. 6.6). $\delta^{15}N$ values on chalk and limestone were consistently among the lowest for each species (Fig.6.6). This is confirmed by the coefficients (reg4 and reg5) in Table A3.4b, which are both considerably lower than the reference value (floodplain), but not significantly different – instead, the value for terrace 2 is significantly higher than the reference.

Could the lower faunal $\delta^{13}C$ values on the terraces, compared to the floodplain, reflect a more wooded environment, or later clearance, of these areas? Environmental evidence suggests a mosaic of woodland, clearings, scrub and grassland during the earlier periods, with episodes of clearing and regeneration at many sites (Robinson 2011, p. 186), but it is hard to integrate the results from particular sites to see the landscape as a whole, or differentiate environmental history by the regions used here. Breaking the analysis down by species and period (Table 6.5) shows that cattle and sheep had significantly low $\delta^{13}C$ values, by about 0.5‰, at sites on the first and second terraces, compared to the floodplain, in the earlier period, but not in the later period. This is consistent with the idea that it was the presence of dense woodland that

lowered herbivore $\delta^{13}C$ values in the early period, because the landscape in the later period was much more open, with few if any areas of closed-canopy woodland. In fact herbivore $\delta^{13}C$ values were lower than those at sites on the floodplain in all regions in the early period (significantly so for the river terraces, and also for sheep at sites on chalk – though there was only one Neolithic site on chalk, Windmill Hill).

An explanation based on woodland extent for the earlier period would imply that the floodplain was more open and perhaps was cleared earlier than the terraces. This is compatible with the environmental history, suggesting relatively large open areas of summer grazing and perhaps winter foggage on the floodplain – though evidence of alder woodland (found in wet conditions) on the floodplain persists through the earlier period. Grazing pressure on drier areas of the floodplain would reduce woodland regeneration and lead to more open environments. While this is plausible, the same logic implies that the chalk and possibly limestone regions were also more densely wooded than the floodplain (contra Allen and Scaife 2007). To test these ideas would require detailed, well-dated environmental histories from more sites in the different regions.

In contrast, in the later period herbivore $\delta^{13}C$ values were similar at sites on the floodplain and river terraces, as would be expected in a generally open landscape, but significantly higher on the chalk (again, only one Iron Age/Roman site on chalk, Alfred's Castle). Because of the low number of sites on the chalk it would be unwise to generalise, but it is perhaps more likely that herbivore $\delta^{13}C$ values in the later period are related to plant water status – wetter in the river valley, drier on the chalk – than woodland extent. Again, this would be worth further investigation.

Pigs show no patterning of $\delta^{13}C$ values with region at any period (Table 6.5). If herbivore $\delta^{13}C$ values reflect denser woodland cover and hence availability of fungi, pigs would be expected to have higher $\delta^{13}C$ values in regions where the herbivores had lower values in the Neolithic and Bronze Age, and similar values to herbivores in the later period. Pig $\delta^{13}C$ values are similar to those of herbivores in the later period, but the relationship of higher pig $\delta^{13}C$ with dense woodland in the earlier period that is seen when looking at changes over time is not seen. This may be due to inadequate numbers of samples at individual sites, or reflect a different scale of comparison.

All species tend to have low $\delta^{15}N$ values on chalk and limestone, significantly so for cattle in the earlier period and for sheep and pig on chalk in the later period. This may reflect generally

low $\delta^{15}N$ values in chalkland soils and plant communities. The effect is relatively large (0.9-1.8‰) though not always statistically significant. Cattle also have significantly higher $\delta^{15}N$ values on the second terrace in the later period; sheep show the same pattern but the difference from the floodplain is not significant. In the Upper Thames cereal agriculture may have been concentrated on the higher terraces (Robinson and Lambrick 2009, p.265), possibly leading to generally higher plant $\delta^{15}N$ values at these sites via manuring, and/or a greater proportion of herbivore fodder consisting of cereals grown on manured soils. Pigs show no significant patterning in $\delta^{15}N$ by region, except for the low value on chalk in the later period, consistent with the herbivores.

3.1.4 Vegetation

In the linear modelling analysis, there were problems with collinearity of vegetation type with both region and period. To address the latter, the models were run separately for earlier (Neolithic+Bronze Age) and later (Iron Age+Roman) periods, but it was not possible to include region. The effects of region and period on faunal isotope values are largely mediated through the plants that make up the herbivores' and most of the omnivore's diets. The range of plants available is related to the site "vegetation type" variable used here, though inevitably imprecisely. For instance, all the sites considered here had some connection with arable agriculture, and at most of them cereals would have been grown nearby (with the possible exception of some Neolithic gathering sites and later pastoral sites), but it was only in the Roman period that the surroundings of some sites were dominated by arable agriculture.

3.1.4.1 The earlier period

In the Neolithic/Bronze Age faunal $\delta^{13}C$ was significantly higher (by 0.2‰) at sites with "woodland" habitats than in the reference (open grassland), an unexpected result (Table A3.8). Lower $\delta^{13}C$ values would be expected for herbivores at sites with "woodland" vegetation. Based on the coefficients in Table 6.5, cattle $\delta^{13}C$ values would be expected to be around 0.5‰ lower in the Neolithic/Bronze Age than in the later period, sheep $\delta^{13}C$ values not much different, and pig $\delta^{13}C$ values around 0.6‰ higher. This gives a rough estimate of the values we would expect in well-wooded (equivalent to the earlier period) versus open conditions (equivalent to the later period). When the species were analysed separately, pig $\delta^{13}C$ values were significantly higher at sites in woodland by 0.7‰, similar to the expected value, but cattle and sheep $\delta^{13}C$ values were not significantly different from those at sites in open grassland. The effect for pigs is as expected if they were feeding on fungi in woodland, and it is possible that it is large enough to cause the overall positive effect – though this should have been accounted for by including species as a factor in the overall model. The

effect for cattle is in the expected negative direction, but small (0.1‰) and far from statistically significant. Sheep $\delta^{13}C$ values are not as low as cattle values even in the Neolithic so it is not surprising that they are also not significantly different at woodland sites.

Why were herbivore $\delta^{13}C$ values not lower at "woodland" sites?

Modelling It could be argued that the linear modelling is not working well because the dataset has been reduced (numbers are 174 cattle at 11 sites, 130 sheep/10 sites, 114 pigs/9 sites). Inspection of the overall model shows that residuals are satisfactorily normally distributed, and there are no obvious problems with heteroscedasticity or variance, so this does not give a reason to reject the results.

Vegetation type Perhaps the way in which each site has been assigned a single vegetation type to represent the local environment fails to capture the relevant variation between contemporary sites. This is certainly possible. The way vegetation types were assigned was a compromise, retaining as many sites as possible in the analysis on the basis of environmental information obtained by many different, not necessarily compatible, consistent or complementary methods. This reflects the variety of environmental proxies available at different sites, changes in the nature of excavations and methods of analysis over the timespan of excavations included here, the different specialists involved, and different ways of reporting results. While it has been possible to build up a fairly detailed picture of environmental change in the Thames valley on the landscape scale, as demonstrated by Booth et al. (2007), Lambrick et al. (2009), and Hey et al. (2011), it is difficult to reduce this to a useful variable or set of variables at the scale of individual sites. Detailed GIS modelling was beyond the scope of this analysis.

Site type Could the type of site make a difference? If the variance in cattle isotope values was different between different types of site in a way not accounted for in the modelling, this might obscure a difference in $\delta^{13}C$ values between vegetation types. In the overall models, site type was not a significant factor. Most of the sites included in the present analysis are occupation sites, but in the Neolithic 5/8 and in the Bronze Age 2/6 sites are of different types – long barrows, enclosures and riverside middens – where animal bone may mainly have been deposited as a result of activities at communal gatherings. (There is some evidence that faunal composition differs between gathering and occupation sites: Table 6.7). This raises the possibility that animals at non-occupation sites may originate from a wider hinterland and may therefore not represent (only) the local environment of the site. (This could also apply to animals at occupation sites, but it seems reasonable to assume that isotope values of most

animals excavated at occupation sites are representative of the local environment, while recognising that this is an assumption.) Animals at occupation sites should show less variation in C and N isotope values than at sites with animals from a variety of sources. This can be examined using data from this project.

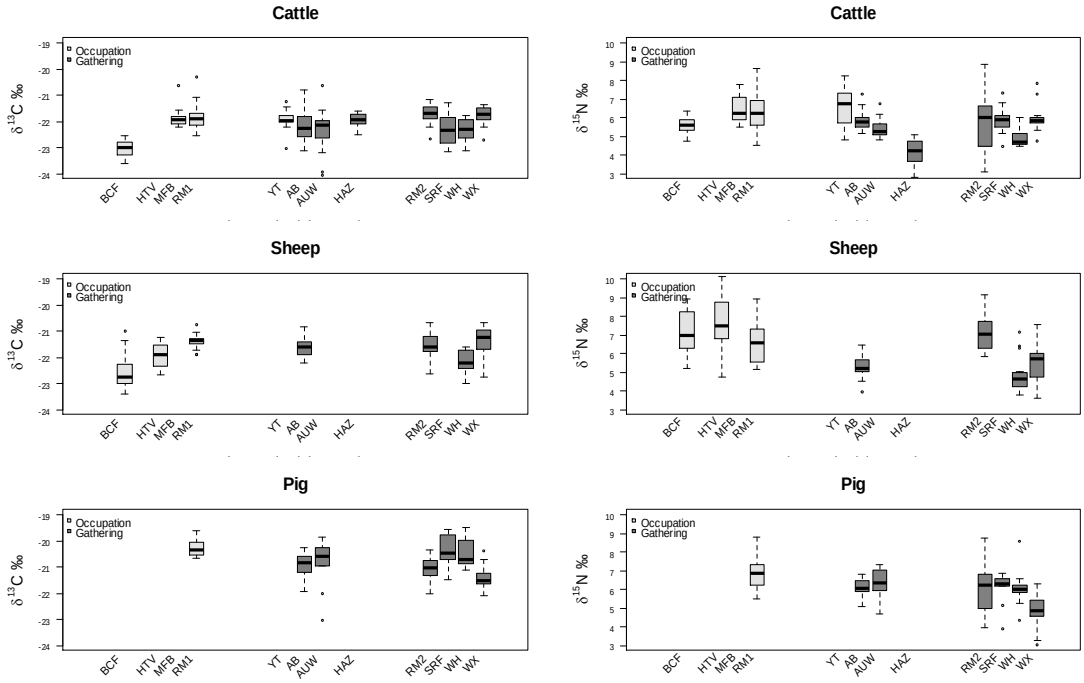


Fig. 7.3 Boxplots (median and quartiles) of $\delta^{13}C$ *(left)* and $\delta^{15}N$ values (*right)* from Neolithic and Bronze Age sites, classified as "occupation" or "gathering" site types. Only data from sites where there were measurements from 10 or more individuals of a given species were included. Both the Levene test and the non-parametric Fligner-Killeen test showed that there were significant differences in variance between sites in $\delta^{13}C$ for cattle ($P<0.05$) but not for sheep or pigs, and in $\delta^{15}N$ for all species ($P<0.001$ for cattle, $P<0.05$ for others). Labels on the horizontal axis are site abbreviations (see Table A1.3)

It is clear that a high proportion of the isotope evidence comes from non-occupation sites in the earlier period, particularly the Neolithic, but there is not much support for the idea that these sites show a higher variance in cattle isotope values that might obscure differences in mean values. Even if that were the case for cattle $\delta^{13}C$, it is difficult to explain why it does not

also apply to cattle $\delta^{15}N$, or pig $\delta^{13}C$. This unexpected result remains unexplained, and suggests that we should be cautious in extrapolating from landscape-scale to site-level effects, or vice versa.

3.1.4.2 The later period

By the Iron Age/Roman period the landscape was largely deforested, so there was not enough dense woodland to affect faunal isotope values via a canopy effect. In the overall model, faunal $\delta^{13}C$ was significantly higher in calcareous grassland (by 0.3‰), and in models for each species singly, only cattle $\delta^{13}C$ was significantly higher in calcareous grassland (by 0.3‰). This might reflect a contrast in water availability (affecting plant $\delta^{13}C$ values) between pasture in damper river floodplain and terrace environments and well-drained calcareous pastures. Sheep showed a greater difference (0.4‰), but also higher variance so it was not significant, and pig diets in this period were likely to include a higher proportion of anthropogenic waste so that pig $\delta^{13}C$ values would be influenced by that as well, obscuring any effect of local plant values. However, since there was only one site with calcareous grassland (Alfred's Castle) it would be unwise to put too much weight on these results: such as they are, they fit plausibly with an explanation based on plant physiology.

In the Neolithic/Bronze Age cattle and sheep $\delta^{15}N$ values did not differ significantly between sites in open grassland and other sites. Pig $\delta^{15}N$ values were significantly higher at "forest" sites (by 0.8‰). This would be expected if pigs were obtaining a significant amount of protein from fungi in dense woodland, as suggested by their elevated $\delta^{13}C$ values.

In the Iron Age/Roman period, faunal $\delta^{15}N$ values were significantly lower at the site in calcareous grassland (by at least 1.5‰, overall and for each species). This may reflect lower plant $\delta^{15}N$ values in this habitat, whether due to tighter nitrogen cycling or a high proportion of legumes in plant communities, as a result of low nitrogen availability. Pigs also had significantly higher $\delta^{15}N$ values (by 1‰) at "arable" sites. This could have several explanations, including feeding more often on manured land (e.g. post-harvest or fallow) or areas with $\delta^{15}N$ values raised by other human activities, or being kept more intensively with more food derived from anthropogenic waste. At other sites, less intensively cultivated, a greater proportion of pig diet could have come from free-range foraging.

In general, the patterning of faunal isotope values with the vegetation types assigned to sites is consistent with suggested variation in environment and animal management. The exception to this is the slightly but significantly higher $\delta^{13}C$ value for cattle at "woodland" sites in the Neolithic/Bronze Age, for which no satisfactory explanation has been found. This suggests that we should be cautious in extrapolating from landscape-scale to site-level effects, or vice versa.

3.2 Site-level variables – plant and animal remains

Site type had no significant effects in the models, and was dropped as a variable. The species/taxon composition of plant and animal remains at sites varied over time, and reflected changes in agriculture as well as the immediate environment, so it was of interest to see if changes in faunal isotopes were associated with any of these.

3.2.1 Plant remains at sites

The spectrum of plant remains at sites also changed considerably over time (Fig. 6.12). Spelt replaced emmer as the main cereal crop, and crop diversity increased, while gathered foods declined. Evidence of haymaking appeared in the Roman period. The results from the sampled sites are in line with the overall environmental history described in Chapter 3.

In linear models including species and period (and region for $\delta^{15}N$) and presence/absence of plant types as variables, none were statistically significant for faunal $\delta^{13}C$ or $\delta^{15}N$ values, using the whole dataset. When the data were split into Neolithic/Bronze Age and Iron Age/Roman periods, the occurrence of bread wheat was significant in the $\delta^{13}C$ model for the earlier periods (Table A3.12a). Bread wheat occurs at only one early site, the Late Neolithic at Barton Court Farm, which has unusually low $\delta^{13}C$ values, so this may be a spurious association (it accounted for only 0.2% of the variance). Sloe was significant in the $\delta^{15}N$ model for the later periods (Table A3.12b). The presence of sloe at a site seems unlikely to be a cause of higher $\delta^{15}N$ values in the stock, so perhaps it reflects an association with an aspect of the landscape (e.g. presence of hedges or scrub). Terrace 2 tends to have high values for $\delta^{15}N$ (though not statistically significant in this model, it is significant in other models e.g. Table A3.7a) so it is possible that sloe is associated with this region, for instance as hedging excluding animals from crops. A large number of variables were tested (16), and 1 in 20 tests is likely to be significant at the 0.05 level by chance alone, so it would be unwise to over-interpret these results.

3.2.2 Animal remains at sites

The spectrum of animal remains at sites also changed considerably over time. At most sites cattle is dominant, with sheep increasing at the expense of pig after the Neolithic. Horse appears in the Bronze Age. Red deer and roe deer occur throughout, but aurochs and wild boar occur only in the Neolithic/Bronze Age and hare only in the Iron Age/Roman period. The proportion of wild species is higher in the Neolithic.

No single variable affected faunal $\delta^{13}C$ values significantly, though occurrence of the usual Neolithic stock pattern approached significance: P=0.053; $\delta^{13}C$ at sites with cattle>pig>sheep was lower by 0.5‰ than at other sites. This shows an association between the distinct faunal composition at Neolithic sites (Fig. 6.13) and the low herbivore $\delta^{13}C$ values seen in that period, but does not suggest a direct causal connection.

In the overall model, faunal $\delta^{15}N$ values were significantly higher (by 0.8‰) at sites with aurochs, and when the data were split into earlier and later periods, faunal $\delta^{15}N$ values were significantly higher (by 0.6‰) at Iron Age/Roman sites with red deer. As in the previous section, a large number of variables were tested in the models (14), so it would be unwise to over-interpret the results. One possibility is that the domestic animals at these sites derived more of their diets from manured areas, e.g. via crop residues, suggesting a greater reliance on arable. If this was linked to greater wealth or status of the sites' inhabitants, this might also express itself via hunting. Such an idea could be tested by compiling the archaeological evidence of the link between wealth or status and the occurrence of hunted species on the one hand, and faunal $\delta^{15}N$ values on the other, though that was beyond the scope of this project.

3.3 Variation between sites – summary and conclusion

Geographical and climatic variables were not very important over the area studied. The greatest contrast between sites was related to period, and also to the dominant vegetation type, which changed profoundly with time (summarised in Table 6.10). The pattern of intra-site interspecific differences in faunal isotope values therefore varied over time (summarised in Table 7.2). Geology/soils and topography/distance from the river were to some extent confounded, and were expressed as the variable "region". There were some consistent differences in faunal site-level isotope values with region (summarised in Table 7.3).

Patterning at the scale of regions within the landscape was consistent with explanations in terms of environmental factors. Such explanations seemed less consistent at the site level, suggesting that we should be cautious in extrapolating from landscape-scale to site-level effects, or vice versa.

This may also be a result of the inclusive approach, with many sites with rather low sample numbers in the dataset, approaching the limits of the statistical techniques.

Next page:

Table 7.2 Summary of variation in faunal isotope values, and interpretations of faunal use of landscape and management. In *parentheses* – shows the same trend, but not statistically significant

		Cattle		Sheep		Pig	
	Period	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$
Site mean	Neolithic	Low	Low	Low	Low	High	Low
	Bronze Age	Higher	Higher	Higher	Higher	Lower	Lower, wide range
	Iron Age	High	Low, wide range	High	Low	Lower	High
	Roman	High	Higher	High	Higher	Higher	Higher
Intra-site variance	Neolithic	Higher	Low	(Like cattle but NS)	(Like cattle but NS)	(Low)	Low
	Bronze Age	Higher	High			(High)	Highest
	Iron Age	Lower	High			(Low)	High
	Roman	Lower	High			(Low)	High
Species compared		Cattle $\delta^{13}C$ < sheep in Neolithic/BA		Sheep $\delta^{15}N$>cattle		Pig $\delta^{13}C$ > herbivores in Neolithic /BA. Pig $\delta^{15}N$> herbivores in IA and Roman	
Manage-ment		Rise in $\delta^{13}C$ values parallels decline in primary, low-$\delta^{13}C$ woodland. Higher intra-site variation in Neolithic/BA reflects availability of woodland habitat, used more by cattle than sheep, as well as forage/fodder from more open habitats. Higher $\delta^{15}N$ values can result from (1) closer association with arable, including feeding on cereal waste or grazing harvested/fallow plots or (2) more intensive use of pasture. The balance between arable and pastoral use of landscape may change as overall production increases, e.g. by extensifying arable (lower cereal $\delta^{15}N$) but intensifying pastoral production (higher plant $\delta^{15}N$). High BA values may reflect increase in arable, lower IA values extensive use of pasture. Wide IA range may reflect variation in cattle management with some sites specialising in pastoral agriculture. Effect of hay (Roman period) uncertain.		Sheep $\delta^{13}C$ higher than cattle reflecting more use of open areas. Lower sheep $\delta^{13}C$ values in Neolithic reflect some use of woodland fodder/forage, but less than cattle. Sheep $\delta^{15}N$ follows similar pattern to cattle, reflecting similar processes at landscape scale. Sheep $\delta^{15}N$ > cattle: may reflect physiology, or sheep may be more strongly associated with arable fields than cattle, e.g. grazing weeds/promoting tillering, folding on arable areas for manuring with less damage to soil texture.		Neolithic: foraging on plants, invertebrates, carrion, including high proportion of fungi (high $\delta^{13}C$) in forest habitats. Iron Age, Roman: loss of primary woodland reduces proportion of fungi in diet, though foraging on uncultivated land still likely; closer association with settlements and arable increases proportion of 15N-enriched foods. BA is intermediate, with variation between sites in management patterns. High $\delta^{15}N$ in Roman period may reflect more intensive pig-keeping.	

Region	Floodplain	Terrace1	Terrace2	Limestone	Chalk	Environments
Early: Neolithic+Bronze Age	Reference	$\delta^{13}C$ Cattle and sheep low	$\delta^{13}C$ Cattle and sheep low	$\delta^{15}N$ Cattle low	$\delta^{13}C$ Sheep low $\delta^{15}N$ Cattle (sheep and pig) low	Low herbivore $\delta^{13}C$ values on 1st and 2nd terraces suggest that floodplain was more open (cleared/grazed) than terraces. Chalk may have been less open than floodplain (low sheep $\delta^{13}C$) Low $\delta^{15}N$ on chalk and limestone ridges could reflect tighter N cycling and/or higher proportion of legumes in N-poor environment
Late: Iron Age + Roman	Reference		$\delta^{15}N$ Cattle (and sheep) high	–	$\delta^{13}C$ Cattle and sheep high $\delta^{15}N$ (Cattle) sheep and pig low	No difference in $\delta^{13}C$ values between floodplain and terraces, by now largely cleared of woodland. High herbivore $\delta^{13}C$ values on chalk could reflect higher plant $\delta^{13}C$ values in open, free-draining environment High cattle $\delta^{15}N$ on 2nd terrace may be related to greater importance of arable in this region Low $\delta^{15}N$ on chalk ridges could reflect tighter N cycling and/or higher proportion of legumes in N-poor environment

Table 7.3 Variation in faunal isotopes in different landscape regions in earlier and later periods. In *parentheses* – shows the same trend, but not statistically significant

Chapter 8

Applications and comparisons

This chapter includes four examples of interpretation using the framework developed in Chapter 7. Firstly, I examine a selection of Thames Valley sites measured for this thesis, comparing the results against the model developed in Chapter 7. Secondly, I compare isotope results from this study with the models of Lambrick (1992, 2009) for the dynamics of agricultural change in the Thames Valley. Thirdly, I compare the Thames Valley results with the UK results reviewed in Chapter 4. Fourthly, I compare the results from the UK Neolithic, including the Thames Valley, with a large body of similar data from the continental European Neolithic.

1 Interpreting patterns of faunal isotope values at individual sites

This section gives some examples of interpretation of faunal isotope values in terms of site environment and management practices. The examples have been chosen because they illuminate particular questions, and because large samples are available (at least 10 of each species per period; exceptions are noted). To provide a common framework, a model of predicted herbivore collagen values for various diet components is used (see Chapter 7, 2.4). While this is based on best estimates of the various parameters, there is a margin of error around each of the series of points, because of uncertainties in the estimation of these parameters. These uncertainties are difficult to quantify, either because parameters have never been measured (e.g. archaeological forage/fodder baseline values), or the applicability of the values used is uncertain (e.g. estimates based on values from Vaihingen), or the appropriate range of variation is not known (e.g. $\Delta_{\text{animal-plant}}$ values), or a combination. The values shown allow comparison of measured isotope values with reasonable expectations, but should not be taken as a rigid framework for interpretation. Two particular concerns are worth mentioning here:

1. The series of points for “fungi” and “waste” only apply to pigs, and because of their different digestive physiology $\delta^{13}C_{\text{pig-diet}}$ values may well be smaller than for the ruminants – this would have the effect of bringing these series of points in towards the centre, and reducing the predicted trophic level effect in $\delta^{13}C$.

2. The model does not fit data from chalk downland well, suggesting that the centre point for the model ("100% grazing") needs to be adjusted to a different baseline. Neither modern nor archaeological data are available to estimate the appropriate adjustment independently. If numbers from Table 6.5 (significantly different coefficients for the chalk region) are used for chalk sites, the modeled centre point falls reassuringly close to the herbivore grazing values – but this is a circular argument, because in both the earlier and later periods there is only one chalk grassland site, from which the numbers are derived. So the baselines have not been adjusted for this part of the discussion. If the model were to be used for data from other areas, the baseline values and parameters should be re-estimated appropriately.

Details of the sites are given in Table A1.3 and Appendix 4, and references are not repeated here.

1.1 Long-term change and farming the second terrace: Barton Court Farm

During the excavation of Iron Age and later settlement remains at Barton Court Farm a scatter of Late Neolithic (Grooved Ware) pits and postholes was found. The pit contents included remains of domestic cattle, sheep and pig, providing an opportunity to look at long-term changes at a single location with adequate sample numbers, as well as changes between the Iron Age (farmstead) and Roman period (substantial farmstead followed by villa).

Fig. 8.1 shows the means and 95% confidence ellipses (Grove and Pearson 2014) for $\delta^{13}C$ and $\delta^{15}N$ values for the three domestic species, superimposed on the values predicted by simple models of diet composition (Fig. 7.2, Table 7.1). The contrast between the Neolithic and later periods is clear, and mean isotope values are significantly different for all three species (Table 6.8). In the Neolithic, both cattle and sheep have $\delta^{13}C$ values well below the modelled "100% grazing" value, which could be adequately explained by the canopy effect. However, in the Neolithic, sites on the first and second terrace have significantly lower $\delta^{13}C$ values (by 0.5‰: Table 6.5), so in a Neolithic version of the model the central point would be shifted to the left. Sheep $\delta^{13}C$ and $\delta^{15}N$ values are higher than those of cattle, as might be expected if their diets included more forage from open and/or manured areas. Pigs have considerably higher $\delta^{13}C$ values than cattle, but only slightly higher $\delta^{15}N$ values. This might be expected if their diets included large amounts of fungi, mast, roots and tubers but was largely vegetarian. Each species was using different aspects of the environment. Cattle and pigs used more forest resources than sheep: forage and fodder for cattle, and these plus fungi, mast and

belowground plant parts for pigs, which were not as commensal as they become in later periods. Sheep derived more of their diet from open areas, and might be more likely than cattle to graze in manured areas, e.g on crop residues, because they are smaller, lighter and cause less damage to soil structure or growing crops. Fodder from crop residues would be ^{15}N-enriched, but there is no clear reason why it would be given preferentially to sheep.

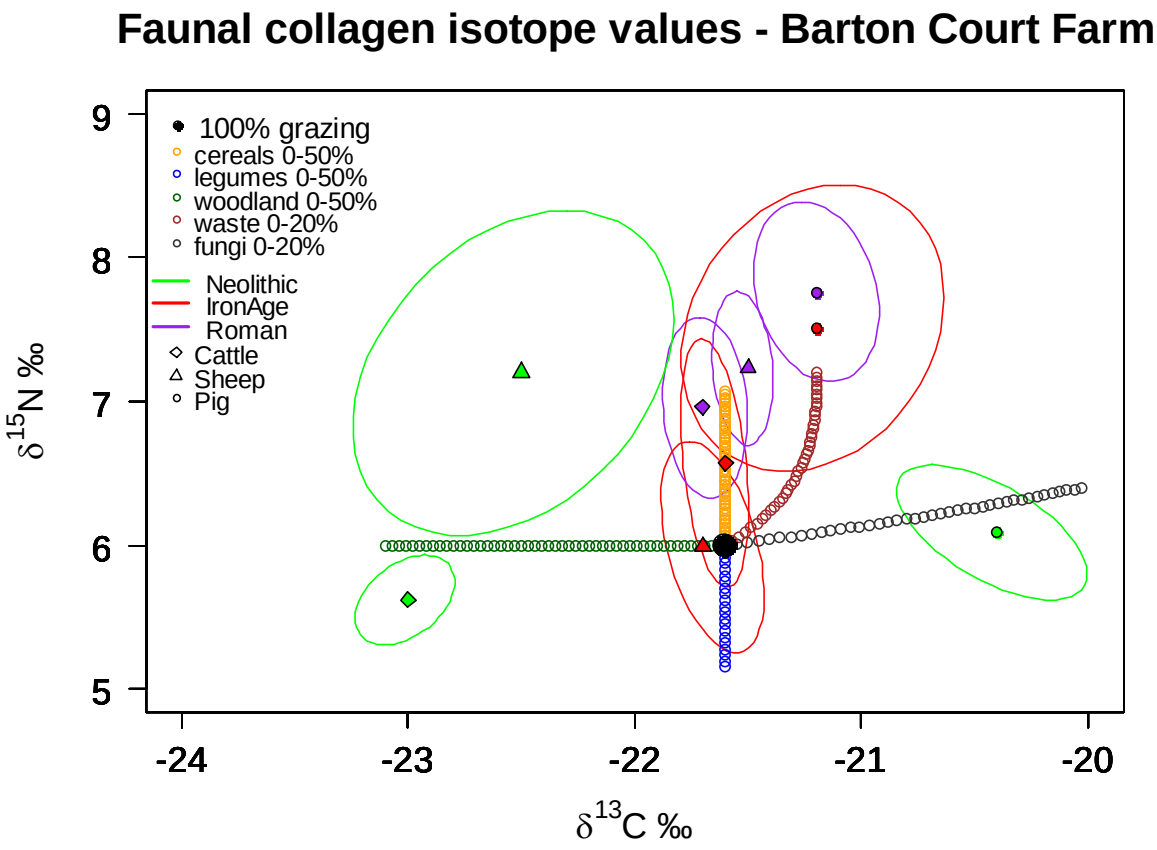


Fig. 8.1 Barton Court Farm: means and 95% confidence ellipses for cattle, sheep and pig in three periods, with modelled points indicating predicted faunal values for different diet combinations. The large black point indicates a diet of 100% grazing, and the series of points show the effect of including 0-50% of pasture/fodder with lower δ^{15}N values (*legumes*), or lower δ^{13}C values (*woodland*), or higher δ^{15}N values (*cereals*); 0-30% anthropogenic waste (*waste*) with higher δ^{15}N and δ^{13}C values; or 0-20% fungi (*fungi*) with considerably higher δ^{13}C and somewhat higher δ^{15}N values (see Table 7.1, Fig.7.2 for details)

In the Iron Age and Roman periods cattle and sheep show similar δ^{13}C values, close to those predicted for open grazing. In the Iron Age sheep have δ^{15}N values close to those predicted for open pasture, and cattle have somewhat higher values (the means are not significantly

different). It is possible that sheep derived more of their diet from low-$\delta^{15}N$ pasture, such as calcareous grassland. This would imply movement about the landscape for sheep if they were feeding on chalk grassland – Barton Court Farm is on the river gravels, at least 10 miles from the Berkshire Downs. Other possibilities include legume-enriched pasture on the river terraces, for which there is no evidence, or fodder/forage from legume crop residues, for which there is no evidence in the Iron Age. The sheep $\delta^{15}N$ value, and range, is close to that of Claydon Pike (below, 1.4) where animals were grazing on the river terraces, but there is no evidence of legume-rich (and hence low-$\delta^{15}N$) or chalkland pasture, so perhaps we should consider this as enrichment in cattle ^{15}N rather than depletion in sheep ^{15}N. This would suggest use of intensively grazed pasture where the soil was enriched in nitrogen and in ^{15}N because of dung, or the inclusion of forage/fodder from manured soils in cattle, but not sheep, diets in the Iron Age.

In the Roman period, cattle have slightly higher $\delta^{15}N$ values, and sheep $\delta^{15}N$ values are higher still, and significantly different from Iron Age sheep $\delta^{15}N$ values. This implies a difference in management of the sheep between the Iron Age and Roman periods. The site report suggests that cattle may have been kept on the floodplain and sheep on the second terrace. Arable farming may have concentrated on the second terrace (Robinson and Lambrick 2009, p. 265), and this region shows elevated faunal $\delta^{15}N$ values (Chapter 6, 4.2), so sheep would be expected to have higher $\delta^{15}N$ values than cattle, as in the Roman period. In the Iron Age sheep $\delta^{15}N$ values at the site suggest that cattle rather than sheep had access to this food source, or possibly that sheep used some other low-$\delta^{15}N$ food source such as chalk grassland. Fig. 6.16 shows the same data broken down by phase, and suggests that the change took place between the Iron Age and the earlier Roman phase, continuing into the later Roman phase with the two Roman phases not differing significantly.

Pig $\delta^{13}C$ and $\delta^{15}N$ values are higher than those of the herbivores in both Iron Age and Roman periods, significantly so for Iron Age pigs versus sheep and Roman pigs versus sheep or cattle. This would be well explained by inclusion of higher-trophic-level residues from human food in pig diets, as well as foraging in areas with elevated soil $\delta^{15}N$, and could imply more intensive management such as sty feeding. The contrast with Neolithic free-ranging pigs in forested environments is strong.

The changes in faunal isotope values over time at this one site echo those seen in the overall analysis. A specific change that may not occur at other sites is the contrast between Iron Age

and Roman sheep $\delta^{15}N$, implying differences in sheep management/use of landscape between these periods.

1.2 Long-term change: Yarnton

The site at Yarnton was occupied from the Neolithic onwards, more or less continuously from the middle Bronze Age onwards. Details of the environment and economy for the Neolithic and Bronze Age periods have not yet been published, and any interpretation of the early Bronze Age remains sampled is highly tentative. The settlement was characterised as a small rural settlement, so of lower status than Barton Court Farm. There was extensive clearance during the Bronze Age. By the Iron Age settlement had shifted from the floodplain to the edge of the second terrace, in line with the rising water table (Chapter 3). The evidence suggests an open mixed agricultural landscape where both arable and pasture of various types were important. There was no evidence for (or against) haymaking.

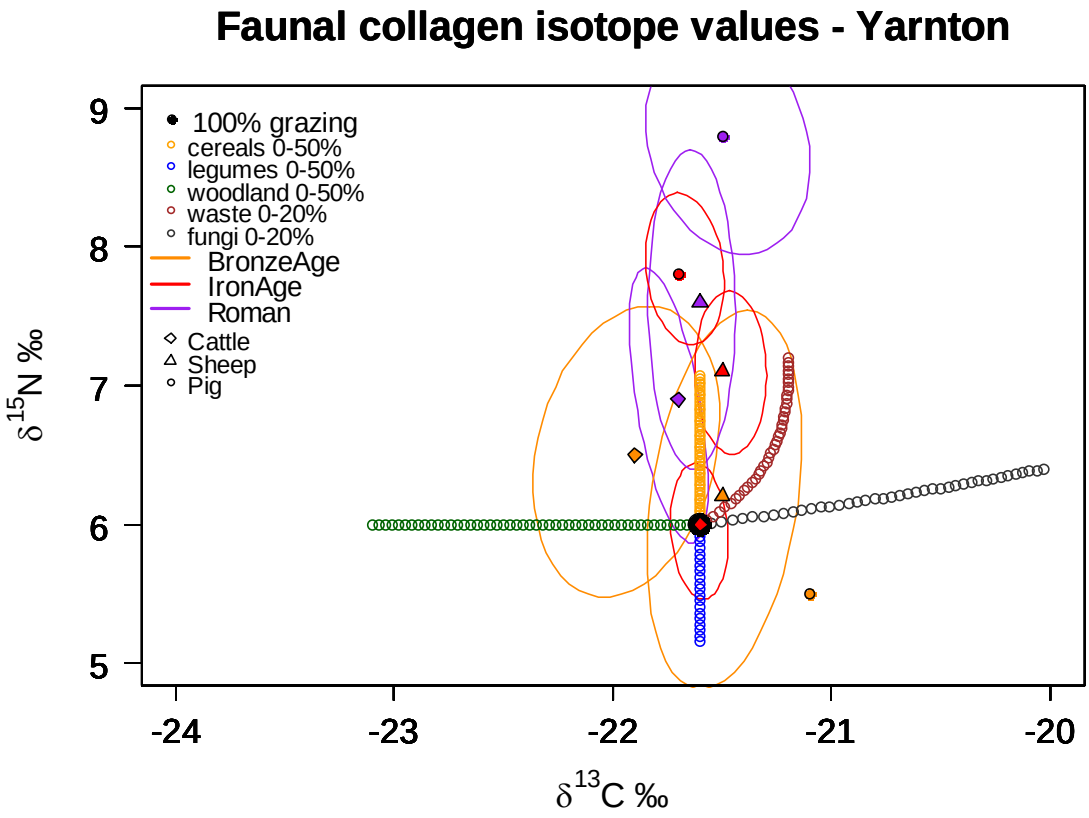


Fig. 8.2 Yarnton: means and 95% confidence ellipses for cattle, sheep and pig in three periods, with modelled points indicating predicted faunal values for different diet combinations (details as in Fig. 8.1). There were only 3 Bronze Age data points for pigs, one of which was anomalous and was omitted, so no ellipse was constructed

The Bronze Age data are included for comparison (Fig. 8.2), though numbers are not high (10 cattle, 8 sheep, and 3 pigs). Bronze Age sheep and cattle values were not far from "100% grazing", with cattle $\delta^{15}N$ values slightly higher and $\delta^{13}C$ values slightly lower than those of sheep. The differences were not statistically significant. Perhaps there is a hint of the "Neolithic pattern" – implying significant use of remaining woodland – in the relative $\delta^{13}C$ values for cattle, sheep and pig, and possibly cattle rather than sheep were fed on crop residues. One of the pigs had highly unusual isotope values ($\delta^{13}C$ –18.4‰, $\delta^{15}N$ 2.8‰): the quality indicators were within acceptable limits, but this value is difficult to explain. The two remaining pig samples show slightly elevated $\delta^{13}C$ values compared to the herbivores, in line with a low proportion of fungi in the diet, but also rather low $\delta^{15}N$ values compared with the herbivores, which is hard to explain. Neither pig nor cattle show strong "forest" signatures, consistent with the environmental evidence for clearance.

In the Iron Age and Roman periods, sheep have distinctly higher $\delta^{15}N$ values than cattle, significantly so in the Iron Age. Iron Age cattle are located close to the 100% grazing point, but Roman cattle have higher $\delta^{15}N$ values, suggesting that they, and sheep in both periods, derive a proportion of their diet from manured land and crop residues. The generally higher $\delta^{15}N$ values in the Roman period may reflect more use of crop residues for feeding stock, and/or the cumulative effect of increasing the area of arable (Lambrick 1992) and hence of manured land, or more intensive use of pasture.

Pigs have the highest $\delta^{15}N$ values. Unlike the pigs at Barton Court Farm, the $\delta^{13}C$ values are very similar to those of the herbivores, so there may have been less higher-trophic-level waste in the diet. In that case, the high $\delta^{15}N$ values could reflect feeding on grain rather than crop residues, or perhaps elevated $\delta^{15}N$ values in invertebrates on manured land. Another possibility is that pig diets included significant amounts of faeces, which have slightly lower $\delta^{13}C$ values but higher ^{15}N values than the diet of the animal that produced them (Sponheimer et al. 2003a).

The patterns of isotope values at the mixed farming settlements of Barton Court Farm and Yarnton are similar, and change over time in line with the overall pattern. The Neolithic at Barton Court Farm is clearly (and statistically) very different from the later periods, and the Bronze Age at Yarnton still shows a hint of this Neolithic pattern. The modelled isotope values (Chapter 7, 2.4) provide a useful framework for interpretation, but in view of the uncertainties involved should not be taken too literally – nevertheless, the fit is plausible.

1.3 Mixed farming in the Middle Thames: Thorpe Lea Nurseries

The site at Thorpe Lea Nurseries was located on a gravel terrace of the Thames, and had occupation remains from the Bronze Age (no faunal samples available), middle/late Iron Age and Roman periods. Occupation seems to have been continuous though the focus of settlement shifted. There were few remains of buildings, but the site was interpreted as a series of small farmsteads, similar to Yarnton. The landscape was open. The economy was based on mixed agriculture, with a shift towards a greater emphasis on rearing animals for meat in the late Roman period, but cereal remains are relatively scanty and the emphasis may have been on pastoral farming throughout.

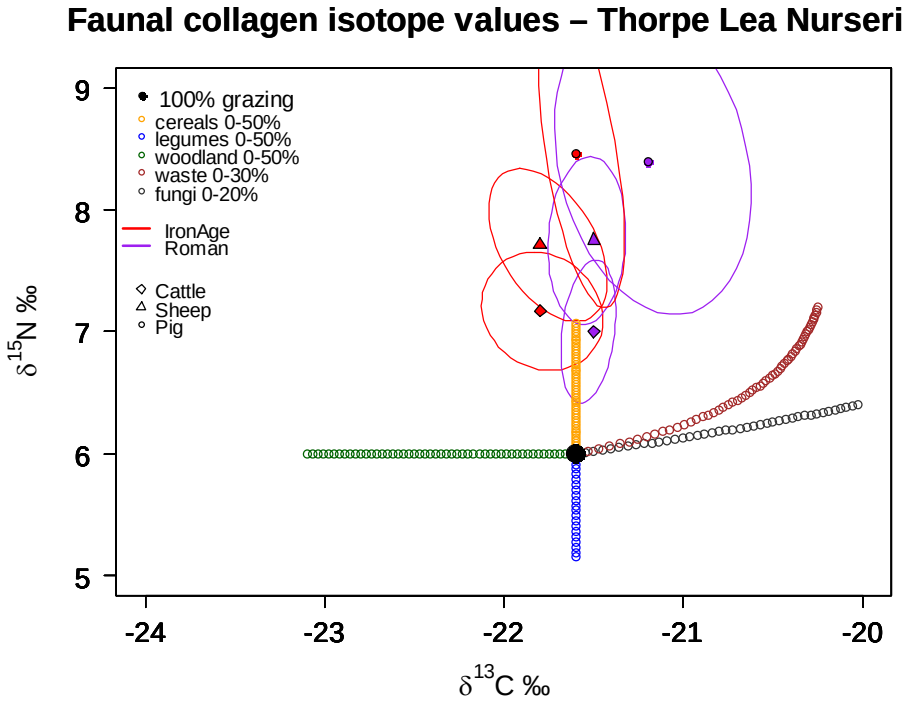


Fig. 8.3 Thorpe Lea Nurseries: means and 95% confidence ellipses for cattle, sheep and pig in two periods, with modelled points indicating predicted faunal values for different diet combinations (details as in Fig.8.1).

Herbivore $\delta^{13}C$ values in both Iron Age and Roman periods are around the predicted value, while herbivore $\delta^{15}N$ values are higher than the model's central 100% grazing point (Fig. 8.3). The means for sheep and cattle in Iron Age and Roman periods are not significantly different and there is considerable overlap between the 95% confidence ellipses, suggesting similar management practices. Compared to Yarnton, a similar site in the Upper Thames Valley, the herbivore $\delta^{15}N$ values do not seem exceptional – the main difference is that at Yarnton Iron

Age cattle had isotope values very close to the 100% grazing point. This seemed to provide a reference value for the other points, which were therefore interpreted as indicating some ^{15}N-enriched components in the diet. If the same interpretation is used at Thorpe Lea, it does not fit well with the excavator's suggestion of a largely pastoral economy, assuming that the ^{15}N-enriched components include fodder/forage from manured arable areas. The evidence of arable farming was certainly greater here than at Claydon Pike, another settlement interpreted as primarily pastoral (1.4 below). Alternatively, the baseline δ^{15}N value here may be higher for some other reason, such as intensive use of pasture leading to elevated soil δ^{15}N values, and the herbivores may in fact be mainly feeding on pasture. In that case, the Iron Age cattle at Yarnton may have had a ^{15}N-depleted food source (such as pasture away from cultivated areas, rich in legumes or in a chalk area) that was not used by the other species / in other periods. Without independent estimates of the isotopic baseline it is not possible to distinguish these alternatives. The human δ^{15}N values at Yarnton have been noted as being unusually high (Lightfoot et al. 2009), but the faunal δ^{15}N values are not unusual in the context of similar Thames Valley sites included in this study. As at Yarnton, sheep in both Iron Age and Roman periods have higher δ^{15}N values than cattle, suggesting a greater proportion of fodder/forage from ^{15}N-enriched sources or more intensive use of pasture.

Pigs at Thorpe Lea Nurseries have higher δ^{15}N values than the herbivores, and slightly higher δ^{13}C values in each period (though the difference between means is not significant), suggesting the inclusion of some anthropogenic waste in their diets, as well as fodder/forage from ^{15}N-enriched environments.

1.4 Pastoral farming: Claydon Pike

Successive settlements at Claydon Pike included a Middle Iron Age farmstead, an enclosure with a Roman-style aisled house, and a villa. In all three phases the emphasis was on pastoral farming, with evidence for haymaking in the earlier Roman phases, though by the time of villa construction the surrounding grassland had reverted to grazed grassland.

The herbivore values in both Iron Age and Roman periods are clustered closely around the modelled "100% grazing" value, with much overlap between the 95% confidence ellipses: the means are not significantly different (Fig. 8.4). At the more or less contemporary Barton Court Farm and Yarnton there is much more evidence of arable farming, and the herbivores there show higher δ^{15}N values in line with this.

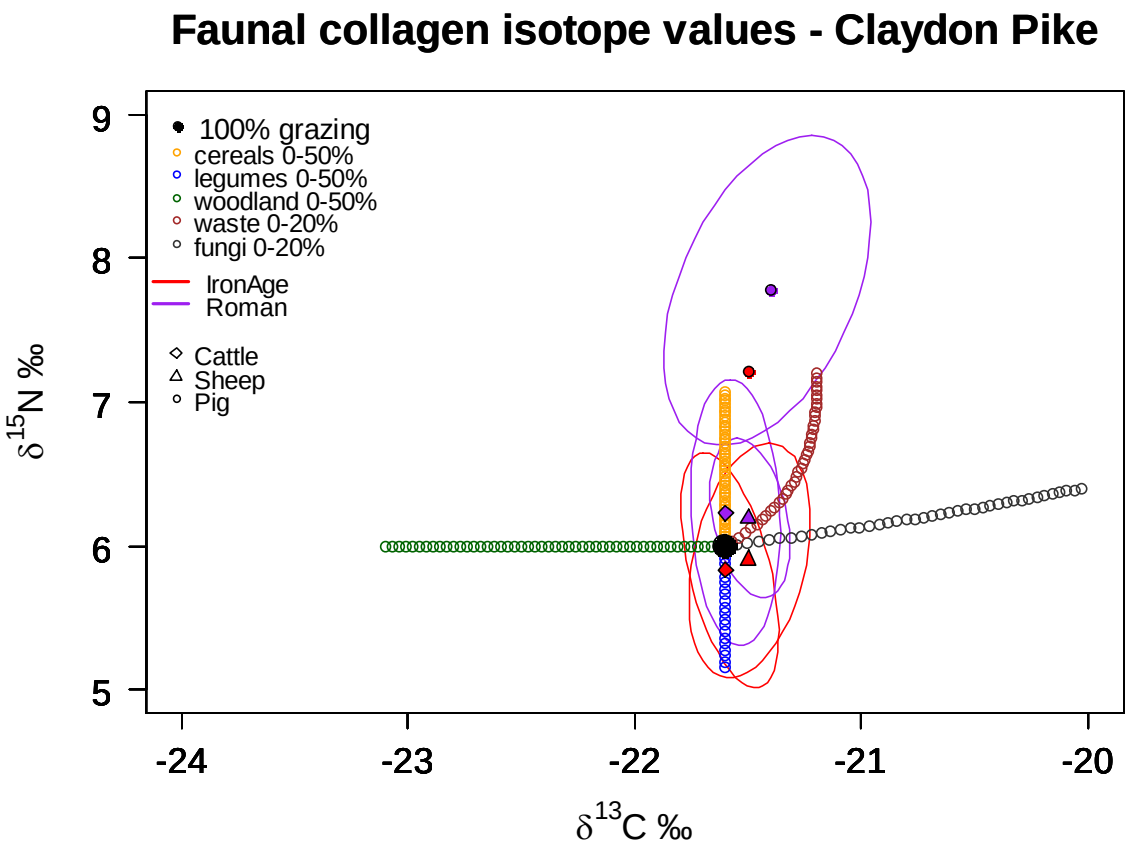


Fig. 8.4 Claydon Pike: means and 95% confidence ellipses for cattle, sheep and pig in two periods, with modelled points indicating predicted faunal values for different diet combinations (details as in Fig. 8.1). There were only 2 Iron Age data points for pigs so no ellipse was constructed

Is there any trace in the herbivore isotope values of the importance of hay? In the earlier Roman period there was a phase when haymaking was important in the economy, coded here as phase 14, while in earlier and later phases the evidence suggests that the surrounding area was mainly permanent pasture.

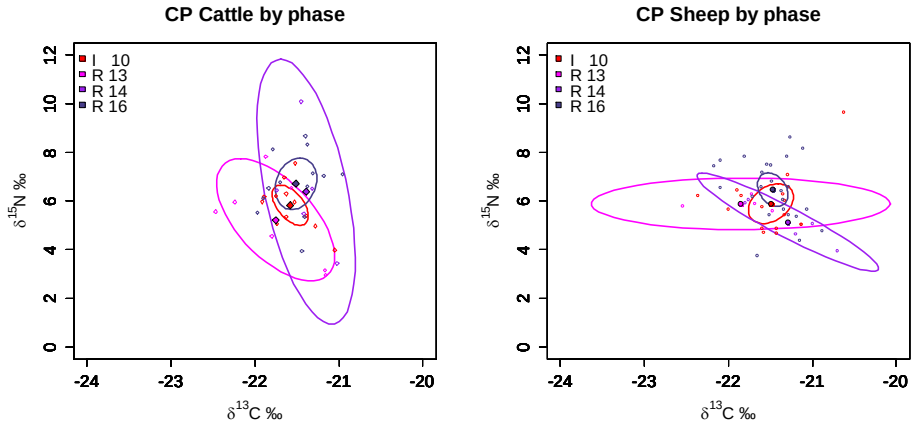


Fig. 8.5 Points, means and 95% confidence ellipses for cattle and sheep isotope values at Claydon Pike, by phase

There are no significant differences between the means for the four phases, and considerable overlap of the 95% confidence ellipses (Fig. 8.5). For cattle the phase-14 mean is close to the later Roman mean and higher in $\delta^{15}N$ than in the earlier phases, while the phase-14 sheep mean $\delta^{15}N$ is lower than that of the other phases. There does not seem to be any consistent pattern here that could distinguish the use of hay as fodder.

The pigs at Claydon Pike have considerably higher $\delta^{15}N$ values than the herbivores (Fig 8.4), though only slightly higher $\delta^{13}C$ values, similarly to Yarnton. This suggests that their diets included a proportion of higher-trophic-level waste, but not enough to significantly raise $\delta^{13}C$ as well as $\delta^{15}N$, and possibly other food sources more enriched in ^{15}N than herbivore diets, such as cereal grain or invertebrates from manured soils.

The absence of ^{15}N-enriched herbivore isotope values at a site that has been archaeologically identified as mainly pastoral suggests that the modelled points are broadly realistic, giving more confidence in the suggested interpretation of the isotope results.

1.5 Chalk downland, Neolithic: Windmill Hill

Windmill Hill was an early Neolithic causewayed enclosure, interpreted as a site for communal feasting at possibly seasonal gatherings. It is therefore uncertain to what extent the animals at the site represent local conditions, or what its catchment area might be. However, it seems likely that most people would have come from not too far away, and that most animals would therefore have been reared on the Downs, where there is evidence of episodes of clearing and regeneration related to settlement and cultivation.

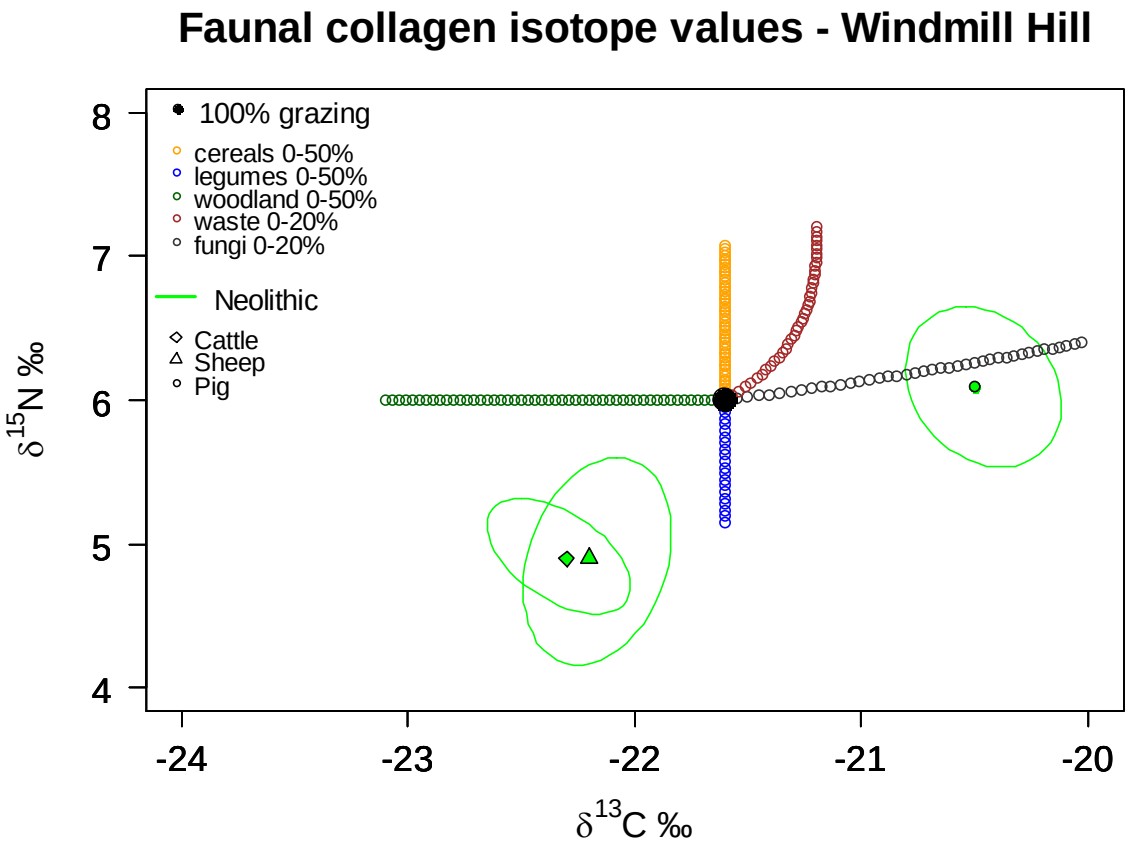


Fig. 8.6 Windmill Hill: means and 95% confidence ellipses for cattle, sheep and pig in the Neolithic, with modelled points indicating predicted faunal values for different diet combinations (details as in Fig. 8.1).

The cattle and sheep mean $\delta^{13}C$ and $\delta^{15}N$ values are strikingly low and close to one another (Fig. 8.6). Low $\delta^{13}C$ values may reflect the generally forested nature of the environment (though Windmill Hill itself was in a clearing). Low $\delta^{15}N$ values are typical of chalk environments (Chapter 2, 2.3.2; Table 6.5), though the reasons are speculative. There is no hint of the difference in $\delta^{15}N$ values between sheep and cattle seen in the Late Neolithic at Barton Court Farm, suggesting that overall they had similar diets and management.

The pigs have considerably higher $\delta^{13}C$ values, typical for the Neolithic, and the mean is close to that expected if they ate considerable amounts of fungi. At first sight the $\delta^{15}N$ value fits well with this – but taking into account the generally lower baseline, it is higher than expected compared with the herbivore values. This suggests a ^{15}N-enriched component to pig diet, which could be fungi (the model uses a value of 2‰ higher $\delta^{15}N$ over plant values, but it could be higher), invertebrates, fodder/forage from ^{15}N-enriched areas such as cultivation

plots, or anthropogenic waste. It would be interesting to see if this pattern of higher pig $\delta^{15}N$ was found at other large gathering sites, suggesting that pigs here might have more access to anthropogenic waste than at other, more small-scale, Neolithic sites. It is not seen at Runnymede, however (1.8).

1.6 Chalk downland, Iron Age: Alfred's Castle

Alfred's Castle was a small enclosed settlement in the Middle Iron Age, on the Berkshire Downs 2.3 miles south of the Ridgeway. A Roman farmhouse was built on the site in the 2nd century CE. In both periods it was a rural farming settlement with an emphasis on sheep farming.

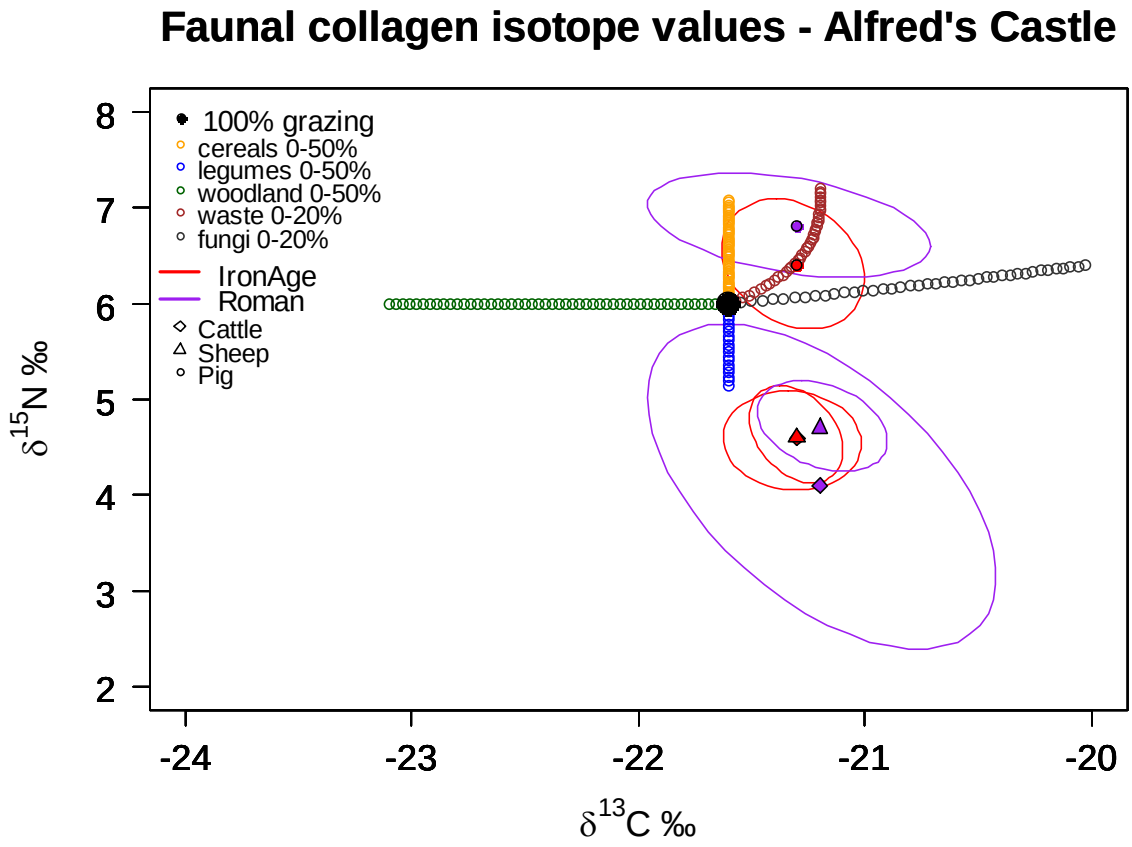


Fig. 8.7 Alfred's Castle: means and 95% confidence ellipses for cattle, sheep and pig in two periods, with modelled points indicating predicted faunal values for different diet combinations (details as in Fig.8.1). Iron Age cattle and sheep points are superimposed

Herbivore $\delta^{15}N$ values are very low, and their $\delta^{13}C$ values higher than expected on the basis of the model (Fig. 8.7). If the "100% grazing" point were shifted by the amounts suggested by

Table 6.5 (+0.4‰ for $\delta^{13}C$, –1.8‰ for $\delta^{15}N$) it would fall close to the herbivore values – but this is a circular argument because Alfred's Castle is the only chalk downland site in these periods. While low $\delta^{15}N$ values seem to be typical of chalk sites both in the Neolithic and later, the high $\delta^{13}C$ values are unexpected, though consistent for all species. They could reflect the more open nature of the downland in the Iron Age compared to the Neolithic: $\delta^{13}C$ values at Windmill Hill are not especially high. The herbivore means are close, with little difference between species or periods. The wide 95% confidence limits for Roman period cattle may reflect their low number (n=7), or greater diversity of food sources, perhaps including habitats other than chalk downland. Because of the uncertainty about the baseline $\delta^{15}N$ value, it is hard to assess to what extent herbivores might have been feeding on ^{15}N-enriched forage or fodder, but the similarity in their means suggests similar management in both periods.

Pigs have considerably higher $\delta^{15}N$ values, higher in the Roman period but with considerable overlap in 95% confidence limits; their $\delta^{13}C$ values are similar to those of the herbivores, so whatever the ^{15}N-enriched diet components were, there may not have been a high proportion of anthropogenic waste.

1.7 The chalk environment

There is clearly a problem with the model baseline isotope values at both chalk downland sites. In both the Neolithic and the later periods faunal $\delta^{15}N$ values are consistently lower in this region, perhaps because of tighter nitrogen cycling in low-nitrogen environments and/or a high proportion of legumes in the flora (Chapter 2, 2.3). In the Neolithic low faunal $\delta^{13}C$ values may simply reflect fodder/forage from extensive woodland areas, but the higher than predicted faunal $\delta^{13}C$ values in later periods are consistent for all the species studied, are not seen in other regions/environments and are not easily explained by dietary differences. They are unlikely to reflect greater openness as by this time dense woodland was rare in all parts of the landscape, but might reflect plant water relations on well-drained chalk soils, in contrast to the wetter soils in the river valley.

For the model to be useful in comparisons, the central point needs to be adjusted appropriately in different areas and environments – though in most cases we do not have independent data to estimate the necessary adjustment.

1.8 Assembly and feasting: Runnymede

The site at Runnymede included two well-separated phases. In the first half of the 4th millennium BC there was a Neolithic settlement on the floodplain by the Thames, with

deposits including in situ and reworked midden material but few structural remains. In the Late Bronze Age (c. 9th century BC) the site was on an eyot, and deposits included large amounts of midden material. The site was interpreted as a riverside midden, representing remains from assembly and feasting, along with evidence of exchange of goods, and the animal remains may therefore not represent only local conditions, but are likely to be drawn from a wider hinterland.

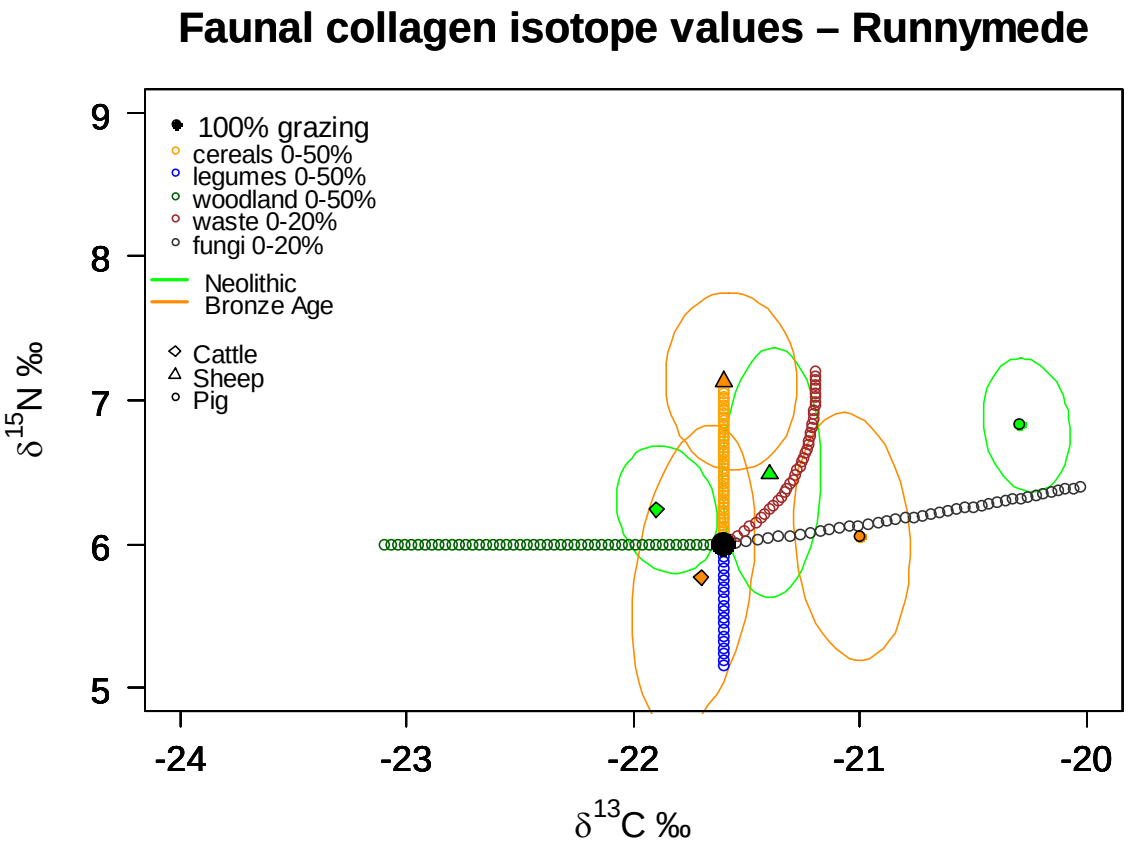


Fig. 8.8 Runnymede: means and 95% confidence ellipses for cattle, sheep and pig in two periods, with modelled points indicating predicted faunal values for different diet combinations (details as in Fig. 8.1).

In the Neolithic, the mean $\delta^{13}C$ values for cattle, sheep and pigs are significantly different (Fig. 8.8), with cattle the lowest and pigs the highest. This is the usual Neolithic pattern, and conforms to the interpretation that cattle diets include more fodder/forage from dense woodland, lowering $\delta^{13}C$ values, while pigs include more fungi from dense woodland, raising their $\delta^{13}C$ values. Sheep $\delta^{13}C$ values are a little higher than predicted by the model, but given the uncertainties in the model this is probably well within the margin of error. The $\delta^{15}N$ values

are not significantly different, but again conform to expectation. Sheep $\delta^{15}N$ values are a little higher than cattle, possibly reflecting a greater proportion of forage/fodder from manured areas. Pig $\delta^{15}N$ values are slightly higher than those of the herbivores, which could be due to higher fungal values and/or more forage/fodder from ^{15}N-enriched areas, but not high enough to suggest a high proportion of anthropogenic waste in pig diets.

The results from this Neolithic occupation are similar to those from other Neolithic sites, even though most of these are not (just) occupation sites.

In the Bronze Age, cattle and sheep $\delta^{13}C$ values are close and not significantly different, while pig $\delta^{13}C$ values are still significantly higher. This is compatible with a continuation of the Neolithic pattern, but in a landscape with far less dense woodland. Sheep $\delta^{15}N$ values are considerably (but again not significantly) higher than those of cattle and pigs, which are lower (but not significantly) than their Neolithic $\delta^{15}N$ values. Looking at the contrast between the herbivores, it is possible that cattle are being extensively grazed while sheep receive more fodder/forage from cultivated and manured areas, and there is no hint that pig diets include either anthropogenic waste or a high input from manured areas. The environmental evidence shows extensive woodland cover in the Neolithic, with a much more open environment, mainly pasture, and a low cover of secondary woodland in the Late Bronze Age, compatible with this interpretation. If the animals deposited at Runnymede were drawn from a wide range of environments, within-species variation in the Bronze Age data should be greater than in the Neolithic. This is not obviously so for $\delta^{13}C$, but cattle and pig $\delta^{15}N$ values are more variable in the Bronze Age (Fig.8.8, Table A1.8). Changes in woodland cover were likely to affect the landscape at a wide scale, so that not much difference would be expected between $\delta^{13}C$ values within each of the three species even if they came from some distance. Without large contemporary faunal samples from other sites it is not clear whether the wider spread in cattle and pig $\delta^{15}N$ values reflects differences between sites or within them.

2 Patterns of change in the Upper and Middle Thames valley

2.1 Dynamics of agricultural change

Lambrick (1992) discussed the dynamics of agricultural change in the later prehistoric period in the Upper Thames valley, using evidence from distributions of settlement types and field systems as well as biological remains. His arguments consider the balance between arable and pasture for varying environmental and social conditions. The discussion is extended in Lambrick (2009, pp. 377–391) drawing on a model of human population change and evidence

of changes in settlement pattern and land use as well as biological and environmental evidence.

Rising populations would require increased production from farming. At first this could be achieved by clearing more land, but at some point it would become necessary to produce more food from the same amount of land ("intensification"). This is most easily achieved by reallocating land from pasture to cereals, which produce 4–5 times more kilocalories per hectare than pastoral farming. Pastoral farming requires relatively large areas of land to maintain viable herd sizes through the winter, so "once a new livestock/cereal ratio was struck, it would have been the need to increase *pastoral* production in a generally expanding mixed farming system that would...put most pressure on limited land resources" (Lambrick 1992, p. 85). While the underlying processes happened gradually, over centuries, at certain points shifts in farming practice and organisation would occur as traditional practice came up against limits. Take-up of new practices could vary considerably in both time and space, leading to a "piecemeal progression" (Jones 1989). Lambrick (1992, p. 83) identifies three periods of discontinuity in the settlement record that might reflect important shifts in farming practice, which will be discussed in turn below.

2.1.1 Bronze Age to Iron Age transition

The first discontinuity is "the recurrent abandonment of Late Bronze Age settlements in the Middle Thames which apparently were not replaced or remodelled in the Early or Middle Iron Age." The causes may have been related to the collapse of the prestige goods economy of the Middle Thames. Having large herds of livestock may have been another aspect of prestige in the Late Bronze Age – many of the known settlements suggest an emphasis on pastoralism – and Robinson (1984) suggested that this may have inhibited expansion of arable agriculture earlier in the Bronze Age. In the Upper Thames, in contrast, while there still seems to have been a strong emphasis on pastoralism and cattle rearing in the Late Bronze Age, by the Early Iron Age there is also much clearer evidence of farming settlements on the higher terraces where crop production played a major role. In this area intensification of agriculture was taking place and can be related to changes in the hydrology of the Thames (Chapter 3). There is also a suggestion (Jones 1984, p. 121) that an increase in leguminous arable weeds might reflect a soil "fertility crisis" in which the expansion of arable had outstripped the availability of good soils. There are other possible interpretations, however, for instance that while the

total area of arable was greater, it was not as intensively manured, because the availability of labour (and possibly of manure) per hectare was lower.

In the Middle Thames, mean herbivore $\delta^{15}N$ values in the Iron Age were substantially and significantly lower than in the Bronze Age, by –0.9‰ , while in the Upper Thames the difference was small and not significant (Table A3.14). Sheep $\delta^{15}N$ values were significantly higher than cattle values, and the difference was much more marked in the Middle Thames. Looking at cattle and sheep separately, the difference between Bronze and Iron Age was only significant for cattle (–1.2‰).

The contrast between the Middle and Upper Thames results fits with some aspects of Lambrick's scenario. Arable expansion was much more marked in the Upper Thames from an earlier stage, and here faunal $\delta^{15}N$ values did not drop markedly in the Early Iron Age. Both forage/foddering on manured land and more intensive use of pasture could keep faunal $\delta^{15}N$ values high, even if not all areas of arable were as intensively manured as before. In the Middle Thames population growth was lower, perhaps because of the collapse of the prestige goods economy (or some other factor), and hence the pressure to turn land over to arable was lower, so that extensive pastoralism was still viable. The greater contrast between cattle and sheep $\delta^{15}N$ values in this area could suggest that sheep were more closely associated with arable cultivation, while cattle were managed in the traditional extensive way.

2.1.2 Middle to Late Iron Age transition

Around the transition from the Middle to the Late Iron Age in the Upper Thames there was commonly a shift of settlement in which the existing settlement area was abandoned for one nearby. During the Middle Iron Age in this area the increase in population and hence arable production continued, and more of the catchment was becoming a fully utilised landscape, so that pressure on grazing land was becoming critical in the most densely settled areas. There is evidence of increasing intensification of pastoral farming on the gravels, and the establishment of specialised pastoral farms on the lower terraces and floodplain. On the higher terraces were mixed farming settlements, and it has been suggested that these were "producer" sites for cereals, while some of the lower, more specialised pastoral farming settlements were "consumer" sites (Robinson and Wilson 1987). This interpretation has since been challenged (discussed in Lambrick et al. 2009, pp. 388–389), but there is evidence of at least different emphases on arable or pastoral farming in different regions. Thus, the Middle Iron Age was characterised by reorganisation of the landscape with a greater area of arable, more intensive pastoral production and some specialisation in farming practices in different topographical

regions, as well as changing hydrology (flooding). By the Late Iron Age/early Roman period, population growth in the Upper Thames may have required another expansion of arable production, and another shift in the arable/pasture balance. The Late Iron Age was one of innovation in arable agriculture, with changing proportions of crops, new ploughing techniques and improvements in crop processing (Jones 1989). Expansion of arable onto valley slopes and clearance of valley sides upriver accelerated alluviation as well as flooding. The shifts in settlement may reflect associated changes. In the Middle Thames, the population may have grown more slowly and the pressure for intensification of both arable and pastoral agriculture may have been less.

In the Middle Thames, the mean herbivore $\delta^{15}N$ value in the Late Iron Age was 0.9‰ lower than in the earlier Iron Age, approaching significance (P=0.056; Table A3.15). When the species were analysed separately, mean cattle $\delta^{15}N$ was significantly lower, by –1.2‰, and sheep values, though also lower, were not significantly different. In the Upper Thames the difference between the phases was small and not significant (Table A3.15.18). Sheep $\delta^{15}N$ values were significantly higher than cattle values, and the difference was more marked in the Middle Thames. Regions also had a significant effect on herbivore $\delta^{15}N$ values. In the Middle Thames both cattle and sheep $\delta^{15}N$ values were substantially (1.8‰ and 2.5‰, respectively) and significantly higher at sites on the 2nd terrace than in the floodplain. In the Upper Thames mean cattle $\delta^{15}N$ values were lower by –1.2‰ at sites on the 1st terrace, approaching significance (P=0.057).

The difference in the trajectories of development in the Middle and Upper Thames areas seems to be reflected in the different patterning of herbivore $\delta^{13}C$ and $\delta^{15}N$ values across the landscape. (It should be noted that site/sample numbers for the Middle Thames are rather small in this analysis). In the Middle Thames herbivore, particularly sheep, $\delta^{15}N$ values are higher on the higher terraces, where arable farming was likely to have concentrated, while cattle values are lower in the Late Iron Age, which could reflect specialised pastoralism on lower terraces/floodplain, developing later than in the Upper Thames. In the Upper Thames there are no significant differences between the earlier and Late Iron Age, perhaps because these developments started earlier than in the Middle Thames, but cattle $\delta^{15}N$ values are lower at sites on the first terrace, which may have specialised in pastoral farming. As previously, the contrast between cattle and sheep $\delta^{15}N$ values is greater in the Middle Thames, suggesting that extensive cattle grazing was more prevalent there.

2.1.3 Late 1st/2nd century CE

In the late 1st/2nd century CE there was major re-planning of some settlements, some cases of settlement shift, and some of more drastic shifts in location or even abandonment of settlement. These patterns of discontinuity are seen by Lambrick (1992) as reflecting "imposed stimuli to change from external political, cultural and economic forces" – i.e. the effects of the Roman conquest – rather than the internal dynamics of expanding population and production, though these too will have played their part. Horticulture became commoner, with the introduction of new crops (van der Veen et al. 2008). The area of arable increased (Fig. 6.10), with further expansion onto the valley sides and consequent alluviation, and by the later Roman period weed floras suggest expansion of arable onto lower-lying, wetter areas. Roman manuring scatters (of pottery) are common, though because Iron Age pottery survives less well it is not possible to show that this represents an increase in intensity of manuring. There is also an increase in leguminous weeds, which on the face of it suggests a decrease in soil fertility, in contradiction to the evidence on manuring. As discussed above (2.1), expansion of the arable area may mean that overall the amount of manure used per hectare falls, because of constraints on labour or manure availability. Intensive manuring may still have been possible for horticultural crops and some arable areas. The likelihood is that the landscape became more diverse in soil nitrogen, and hence $\delta^{15}N$, levels. Haymaking appears in the Roman period, and this would allow at least some stock to be kept over the winter without the need for extensive grazing, representing an intensification of pastoral agriculture and perhaps allowing manure to be collected more easily. Other signs of pastoral intensification are the proliferation of paddocks, enclosures, waterholes and droveways. It is not clear whether hay would have a distinctive isotopic signature compared to pasture, and the limited evidence from Claydon Pike (1.4) suggests that it does not.

The landscape reorganisation seen on the Upper Thames gravels in the late 1st/2nd century CE may reflect the break-up of earlier (Iron Age) structures in the context of "a more capital-intensive system involving a much more complex social, economic and administrative infrastructure" (Lambrick 1992, p. 105). While there was a variety of settlement types and ways of using the landscape, any link with topographical regions (see 2.1.2 above) was not so clear and other factors – such as proximity to roads and markets, military or civilian – may have increased in importance, while technological developments – such as new ploughing tools and techniques, new varieties of crops and domestic animals, or changes in the timing of activities (Campbell and Hamilton 2000) – may have allowed a greater variety of soils and environments to be farmed. The Middle Thames has not received such detailed attention, but

here is assumed to have developed in a similar way to the Upper Thames. The model in Lambrick (2009, p. 378) suggests that arable farming never took up a high proportion of land in the Middle Thames, in line with a lower rate of population growth.

	Isotope patterns	Lambrick model	Management
Phase	**Middle Thames**		
Late Bronze Age	(reference for EIA)	Population growth Field systems common Widespread, low-intensity grazing & arable plots Decreasing area of pasture and arable per person (intensification) Settlement abandonment at LBA/IA transition	Low-intensity grazing Emphasis on pastoralism Cattle herds may reflect prestige Increase in production can still be achieved by clearance
Early/ Middle Iron Age	Cattle $\delta^{15}N$<BA Sheep $\delta^{15}N$> cattle	Slowing population growth Similar proportion of arable Expansion of rough pasture Area of pasture/arable per person does not change	Low-intensity grazing Increase in production can still be achieved by clearance/expansion ?Extensive pasture use, little arable may lower $\delta^{15}N$
Late Iron Age	Herbivore $\delta^{15}N$<EIA, 2nd terrace $\delta^{15}N$>floodplain Sheep $\delta^{15}N$> cattle	Still slow population growth Similar proportion of arable Expansion of rough pasture Area of pasture/arable per person does not change	Low-intensity grazing Increase in production can still be achieved by clearance/expansion ?More intensive arable or grazing on 2nd terrace raising $\delta^{15}N$?Extensive pasture use, little arable may lower $\delta^{15}N$
Earlier Roman	Cattle $\delta^{15}N$>LIA, Sheep $\delta^{15}N$> cattle	Faster population growth Some arable expansion, but not enough to change arable/pasture balance More intensive use of pasture Area of pasture/arable per person does not change	Intensity of grazing increases, raising $\delta^{15}N$
Later Roman	Cattle $\delta^{15}N$>LIA, Sheep $\delta^{15}N$> cattle	Population growth slows as population peaks Some arable expansion, but not enough to change arable/pasture balance More intensive use of of pasture Area of pasture/arable per person does not change	Intensity of grazing increases
All periods	Slower population growth reduces need for landscape reorganisation. Sheep ?less extensively grazed, more closely associated with arable agriculture than cattle, with higher $\delta^{15}N$ values.		

Table 8.1 Faunal isotope values in the Middle Thames valley, in relation to population change and agricultural/land-use changes in the Iron Age and Roman periods (Lambrick 1992, 2009). In the final column faunal isotope values are interpreted in the light of the Lambrick model

In the Middle Thames, the mean herbivore $\delta^{15}N$ value in the earlier Roman period was 1.6‰ higher than in the later Iron Age ($P<0.01$), and in the later Roman period it was1.3‰ higher ($P<0.05$; Table A3.16a). When the species were analysed separately, mean cattle $\delta^{15}N$ was significantly higher in both Roman phases, by 1.7‰, and sheep values, though also higher, were not significantly different. In the Upper Thames the difference between the phases was small and not significant (Table 3.16b). In the Middle Thames sheep $\delta^{15}N$ values were significantly higher than cattle values, by 1.2‰ ($P< 0.001$) but in the Upper Thames the difference between the species was small and not significant (Table A3.16b). Regions had no significant effect on herbivore $\delta^{15}N$ values in either area.

In the Middle Thames the increase in $\delta^{15}N$ values suggests that herbivores, particularly cattle, were obtaining more forage/fodder from manured land or heavily grazed pasture than in the Late Iron Age. Sheep still had significantly higher $\delta^{15}N$ values than cattle, which may suggest closer association of sheep with arable, while pastoral farming was also becoming more intensive. These results could imply a greater proportion of arable in the landscape than the Lambrick model suggests, but should be interpreted with caution because numbers of sites and samples are low. In the Upper Thames, these processes of intensification had a longer history, and there was less contrast in $\delta^{15}N$ values between the Late Iron Age and the Roman period, or between the species.

In both areas, there was no effect of topographical region, in contrast to the Iron Age, and in agreement with the evidence of diversity of settlement type and landscape organisation in the Roman period (Lambrick 1992).

Patterning in the variability of isotope values (e.g. in the models shown in Tables A3.14-A3.16) is clearer in the Middle Thames. For both cattle and sheep, the percentage of variance accounted for by site-level factors decreases from the Bronze Age (about 35 and 25%, respectively) to the Roman period (0), as the intra-site variance increases. That is, by the Roman period herbivores at any given site had as wide a range of $\delta^{15}N$ values in their diet as was available over the whole landscape. This could be either because the landscape (of the Thames gravels) was more heterogeneous at the local scale, or because herbivores at sites were drawn from a much wider area. The former explanation would fit with the Lambrick model of farming development, particularly as the sites considered here were generally “producer” farming settlements rather than “consumer” military or urban sites that might be expected to receive food supplies from a variety of sources. Overall variability (i.e. standard error of estimated coefficients in the models shown in Tables A3.14-A3.16) is a little higher

	Isotope patterns	Lambrick model	Management
Phase	**Upper Thames**		
Late Bronze Age	(reference for EIA)	Population growth Field systems appearing Low-intensity grazing & arable plots	Low-intensity grazing Emphasis on pastoralism Increase in production can still be achieved by clearance/expansion
Early/ Middle Iron Age	Herbivore $\delta^{15}N$=BA Sheep $\delta^{15}N$>cattle	Faster rise in population than MT Some arable expansion especially on higher terraces Decreasing area of pasture and arable per person (intensification) Settlement shift at transition	Intensity of arable agriculture decreasing, lowering $\delta^{15}N$ Intensity of grazing starting to increase, raising $\delta^{15}N$
Late Iron Age	Herbivore $\delta^{15}N$=EIA Cattle 1st terrace $\delta^{15}N$<floodplain Sheep $\delta^{15}N$>cattle	Population growth continues Some arable expansion Decreasing area of pasture and arable per person (intensification) ?Arable/pastoral specialisation in different landscape regions	Intensity of arable agriculture decreasing, lowering $\delta^{15}N$ Intensity of grazing increasing, raising $\delta^{15}N$?Intensive grazing on floodplain as flooding increases, more arable on 2nd terrace
Earlier Roman	Herbivore $\delta^{15}N$=LIA, Sheep $\delta^{15}N$> cattle	Population growth continues Major expansion of arable in some areas, change in arable/pastoral balance Decreasing area of pasture and arable per person (intensification). Hay appears Landscape reorganisation	Intensity of arable agriculture decreasing, lowering $\delta^{15}N$ Horticulture may be more intensive, raising $\delta^{15}N$ Intensity of grazing increasing, raising $\delta^{15}N$
Later Roman	Herbivore $\delta^{15}N$=LIA, Sheep $\delta^{15}N$= cattle	Population growth continues Arable and intensive pasture use increasing, proportion of arable still rising Decreasing area of pasture and arable per person (intensification)	Intensity of arable agriculture decreasing, lowering $\delta^{15}N$ Horticulture may be more intensive, raising $\delta^{15}N$ Intensity of grazing increasing, raising $\delta^{15}N$
All periods	From EIA onwards balance between arable and pastoral land use shifts as population and production increase, arable extensification (lower $\delta^{15}N$) offsetting pastoral intensification (higher $\delta^{15}N$), reducing contrasts in faunal $\delta^{15}N$ values between periods Sheep more closely associated with arable agriculture than cattle, with higher $\delta^{15}N$ values, but lower proportion of grazing land reduces contrast between sheep and cattle compared to Middle Thames		

Table 8.2 Faunal isotope values in the Upper Thames valley, in relation to population change and agricultural/land-use changes in the Iron Age and Roman periods (Lambrick 1992, 2009). In the final column faunal isotope values are interpreted in the light of the Lambrick model

for cattle, but much higher for sheep, in the Iron Age and Roman periods than in the Bronze Age. This could reflect a situation where both species had access to pasture, while sheep were more likely than cattle to also have access to food/fodder from manured land, raising both their mean $\delta^{15}N$ value and variability. In the Upper Thames, the contrast between cattle and

sheep mean $\delta^{15}N$ values is never so great, which could be because grazing practices were less clearly differentiated, or because intensification of pasture use, raising $\delta^{15}N$ values of pasture, occurred earlier in the Upper Thames alongside extension of arable farming, which might reduce $\delta^{15}N$ values in cereal fields, so that the contrast in isotopic values of fodder/forage sources was lower. For cattle, the percentage of variance in $\delta^{15}N$ accounted for by site-level factors is always low (5%), while for sheep it is lower in the Roman period (10%) than in the Bronze or Iron Age (29%, 24%). Also, the variance in sheep $\delta^{15}N$ values is greater in the Iron Age than earlier or later periods. The differences between the Upper and Middle Thames patterns (summarised in Tables 8.1, 8.2) may reflect differences in timing of intensification of pastoral and arable practices that affected cattle and sheep differently, differences in management of the species, and/or differences in organisation of the landscape.

3 Thames Valley in the UK context

Chapter 4 summarises previous work on UK faunal carbon and nitrogen isotopes, and provides a background against which to compare the results of this study.

3.1 Geography

Latitude and longitude had no significant effect on Thames Valley faunal isotopes (Chapter 6, 4.1). This was expected, given the weak evidence for any effect in the wider dataset (Chapter 4, 3.1), and the limited geographical range of this study.

3.2 Geology/environment

The clearest environmental effect (apart from saltmarsh grazing, irrelevant here) in the UK dataset was the tendency towards lower herbivore $\delta^{15}N$ values, and possibly higher $\delta^{13}C$ values, at sites on chalk (but not limestone) in the Iron Age.

The Thames Valley study only included two sites on chalk (Windmill Hill, Neolithic, and Alfred's Castle, Iron Age and Roman) and two on limestone (Ascott-under-Wychwood and Hazleton, both Neolithic). All domestic animals at both chalk and limestone sites had relatively low $\delta^{15}N$ values, and cattle and sheep in the Iron Age and Roman periods had relatively high $\delta^{13}C$ values (Fig. 6.6, Table 6.5). In the larger dataset, the pattern was not clear in the Neolithic (Chapter 4, 3.2). For $\delta^{13}C$ this may reflect local variation in use of landscape – in the Thames Valley the floodplain may have been used for extensive grazing so that it was more open than the chalk downs, but this might not apply everywhere. By the Iron Age the

landscape was much more open everywhere, and $\delta^{13}C$ values reflected water availability rather than variation in use of forest resources (Chapter 7, 3.1.3).

The low $\delta^{15}N$ values are probably related to tight nitrogen cycling in thin, basic, nutrient-poor soils. These can form on both chalk and limestone, and account for the pattern seen in the Thames Valley (Chapter 7, 3.1.3). In the larger dataset, there appears to be no connection between $\delta^{15}N$ and limestone geology, and the connection with chalk is only seen in the Iron Age (Chapter 4, Figs. 4.1–3). Perhaps the "limestone" category is too wide, including more varied soils at coastal and inland sites. The effect may also depend on scale, observable at the level of a region such as the Thames Valley, but obscured by other variables over a wider area. If there had been more chalk or limestone sites included in this study, it would have been possible to look at within- and between-site variation in isotope values on this geology compared with others. For the moment, evidence of the generality of these effects is suggestive rather than conclusive.

3.3 Time

The trends in faunal $\delta^{13}C$ and $\delta^{15}N$ values over time in the Thames Valley are also clear in the larger dataset. Cattle, but not sheep, have lower $\delta^{13}C$ values in the Neolithic, and by the Iron Age both herbivores have similar $\delta^{13}C$ values and similar, widely varying $\delta^{15}N$ values. Pigs, by contrast, have higher $\delta^{13}C$ values than herbivores in the Neolithic, with $\delta^{15}N$ values not much higher than herbivores', but in the Iron Age and Roman periods pigs have similar $\delta^{13}C$ values and higher $\delta^{15}N$ values than herbivores (Ch.4, 2.3, Fig. 4.6; Chapter 6, 3.2, Fig. 6.4).

In the Thames Valley the change in herbivore $\delta^{13}C$ over time has been interpreted as reflecting landscape-scale reduction in forest cover, and the change in herbivore $\delta^{15}N$ over time as reflecting landscape-scale increase in manured arable and heterogeneity in plant $\delta^{15}N$ values. For pigs, the high $\delta^{13}C$ values seen in the Neolithic reflect consumption of fungi, roots and mast in dense woodland, while the higher $\delta^{15}N$ values from the Iron Age reflect changes in pig management (Chapter 7, 2.3). It seems that these trends occur at a larger scale also, and are likely to be seen in other regional studies in the UK.

4 UK Neolithic in the European context

Hedges et al. (2013, pp. 348-365) analysed a large dataset of faunal and human $\delta^{13}C$ and $\delta^{15}N$ values from Linearbandkeramik (LBK) sites in central Europe, with most of the sites belonging to the "developed" phase after 5300 cal BC. The LBK, dating from the later 6th to

the early 5th millennium cal BC, is the first farming culture in this area, and is comparable with the British early Neolithic of the earlier 4th millennium cal BC. Here patterns in Neolithic faunal $\delta^{13}C$ and $\delta^{15}N$ values from the UK are compared with those from the LBK.

The climate would have been warmer in the 6th millennium than in the 4th (Chapter 3, 2) (Marcott et al. 2013), and more continental in the area of the LBK than in the UK. That is, the temperature contrast between winter and summer seasons was stronger, with colder, snowier winters and hot but not dry summers. In the UK the climate was cooler and damper than in the LBK area, but animals could be more easily overwintered. Both areas fall within the deciduous forest biome, and would have had extensive dense woodland cover at the time of arrival of the first farmers. LBK settlements, consisting of groups of longhouses, are correlated with lowland settings, proximity to water and the occurrence of loess soils (Bickle et al. 2013, p. 6). A variety of crops including emmer, einkorn, pea and lentil was intensively cultivated in manured garden plots (Bogaard 2004) and cattle, sheep, pigs and goats were kept, generally dominated by cattle. In contrast, in Britain early Neolithic settlements are much more elusive (though known, e.g. at Yarnton), with most faunal and botanical remains coming from sites of gathering or assembly. The main crops were emmer and barley, but no pulses, probably grown in manured garden plots, and there may have been a greater emphasis on gathered foods such as hazelnuts (Moffett et al. 1989; Robinson 2000). Cattle, sheep, pigs and goats were all present, usually with cattle dominant and sheep rare.

4.1 Cattle

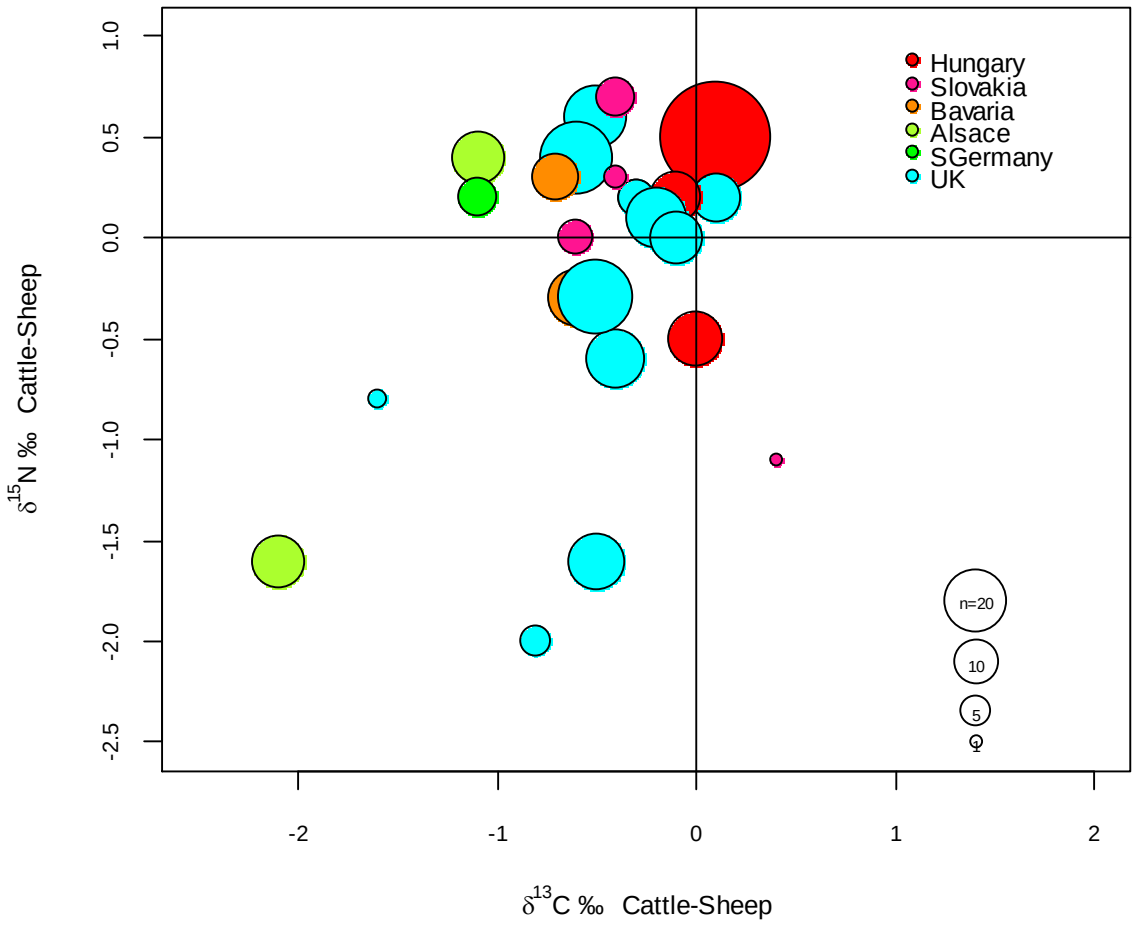


Fig. 8.9 Site mean isotope values for cattle from LBK and UK Neolithic sites. To account for large-scale geographical variation, cattle mean values are given relative to sheep mean values at each site: sites where sheep and cattle means are similar cluster around the 0,0 point. *Point size* indicates the number of data points (*n*) for each site: sites where $n \geq 10$ are likely to give an estimate of the population mean that is not far from the "true" value. Continental regions as in Hedges et al. (2013).

The data are from a wide geographical range, so to remove the variation due to climatic factors associated with latitude and longitude, isotope values were standardised to the sheep mean for each site (assuming that the feeding environment of sheep does not differ greatly or systematically across the geographic range). At the easternmost LBK sites in Hungary, cattle

site mean $\delta^{13}C$ values were similar to those of sheep, but to the west they were lower by 0.5–1.5‰. It is plausible that this reflects a greater proportion of forage or fodder from densely wooded environments in the diets of cattle compared to sheep. While the area around LBK settlements was at least open enough for crop cultivation, woodland

remained the dominant plant cover during the Neolithic (Hedges et al. 2013 p. 346), and cattle are better suited than sheep for forest grazing. The UK sites show a very similar pattern to the LBK sites west of Hungary. At the majority of UK sites, cattle $\delta^{13}C$ values are 0.5–1‰ below those of sheep, reflecting use of forest resources (Chapter 7, 2.3.1). This suggests that cattle played a similar role in human use of the landscape in the early Neolithic in both the UK and central Europe.

The greatest difference between cattle and sheep $\delta^{13}C$ values is seen not in Britain, but at sites in the upper Rhine Valley (Alsace and southern German regions), at the western margin of the early LBK expansion. This may indicate a greater reliance on forest resources in this area. It is suggestive that this is approximately the boundary between the wetter, milder Atlantic climate to the west and the Continental climate to the east, and there are also possible influences from Mesolithic and/or Mediterranean cultural groups (Bickle et al. 2013, pp. 294–296). It would be of great interest if either or both of these could be shown to affect livestock management and people's use of resources in this area, which would require detailed work on the isotopes, as well as the environment and plant and animal management, at more, selected sites.

Cattle $\delta^{15}N$ values are generally within 0.5‰ of sheep $\delta^{15}N$ values. At two sites with adequate samples (Barton Court Farm, n=16 cattle, 11 sheep; Bischoffsheim, n=14 cattle, 6 sheep) cattle $\delta^{15}N$ values are about 1.5‰ lower than those of sheep. Barton Court Farm is the single late Neolithic site in the Thames Valley, but it is not clear whether that is connected to the unusual value. The early Neolithic site of Abingdon causewayed enclosure is within a few hundred metres and there the difference was only 0.6‰, but it is not possible to reconstruct the local environment at the two periods in sufficient detail to see whether that provides an explanation. At Bischoffsheim (and at some other western LBK sites) there was a distinct group of cattle with lower $\delta^{13}C$ values, and some of these also had lower $\delta^{15}N$ values (Bickle et al. 2013, p. 335). This could reflect a greater proportion of feeding in forested environments; the difference is similar to that between domestic cattle and wild red deer. However, at other upper Rhine sites where cattle $\delta^{13}C$ values are low relative to sheep, $\delta^{15}N$ values are not (Fig. 8.9), so perhaps the difference at Bischoffsheim also reflects unusually high sheep $\delta^{15}N$ values. In either case, there seems to be a stronger than usual distinction at

Bischoffsheim and Barton Court Farm between the isotopic feeding niches of cattle and sheep, though for the moment a detailed explanation is lacking.

4.2 Pigs

As for cattle, pig site mean $\delta^{13}C$ and $\delta^{15}N$ values have been standardised using the site mean sheep values, to account for geographical variation (Fig. 8.10). There is a strong contrast between the UK and the LBK data. UK pig $\delta^{13}C$ values are all higher than those of sheep by up to 2‰, and barely overlap with the LBK distribution, where pig $\delta^{13}C$ values are generally 0-0.5‰ lower than those of sheep. UK pig $\delta^{15}N$ values are generally 0–1‰ higher than those of sheep while LBK values are generally 1–2‰ higher. There is some scatter in both cases, mostly sites with n<10. Early Neolithic pigs were clearly being managed in different ways in Britain and Central Europe.

The high $\delta^{13}C$ – low $\delta^{15}N$ value pattern is interpreted as reflecting consumption of fungi, mast and belowground plant parts in dense unmanaged woodland, with a low proportion of the diet coming from environments with high $\delta^{15}N$ values due to manure or anthropogenic waste (Chapter 2, 4.2), and clearly applies to British Neolithic pigs. It may be relevant that the UK site with the lowest pig $\delta^{13}C$ value is Etton causewayed enclosure, which was constructed in an environment that was open and largely treeless (French and Pryor 2005; Pryor 1998), and presumably low in fungi. The LBK pigs conform better to the "village pig" model (Chapter 2, 4.2), with a greater proportion of the diet coming from the vicinity of the settlement and enriched in ^{15}N. This may be related to the fact that LBK settlements are generally more substantial and less ephemeral than seen in the UK Neolithic. The somewhat lower pig $\delta^{13}C$ compared to sheep at the LBK sites could indicate some use of forest resources other than fungi (though it is difficult to see how this could have been managed if pigs were herded in the forest), but it could also be because pigs are non-ruminants (Chapter 2, 2.4.2.1) – it is of about the right magnitude. There may be some geographical structure in the LBK data, with a tendency for the pig-sheep difference in $\delta^{13}C$ to rise towards the west, and the two Alsace sites showing a slight positive value (along with two other more easterly sites), but the sample numbers are generally too small to make much of this. It could, however, if confirmed, suggest a tendency towards more extensive pig management and greater use of forest resources, perhaps in tandem with changes in cattle management.

There is likely to have been a genetic difference between the UK pigs and the LBK pigs sampled by Hedges et al. (2013). The domestic pigs accompanying the LBK spread across central Europe carried a near Eastern mitochondrial DNA haplotype, but by 4000 BCE a high

proportion of domestic pigs in western Europe carried a haplotype typical of local wild boar (Larson et al. 2007; Ottoni et al. 2013), which subsequently spread eastward as well as westward and replaced

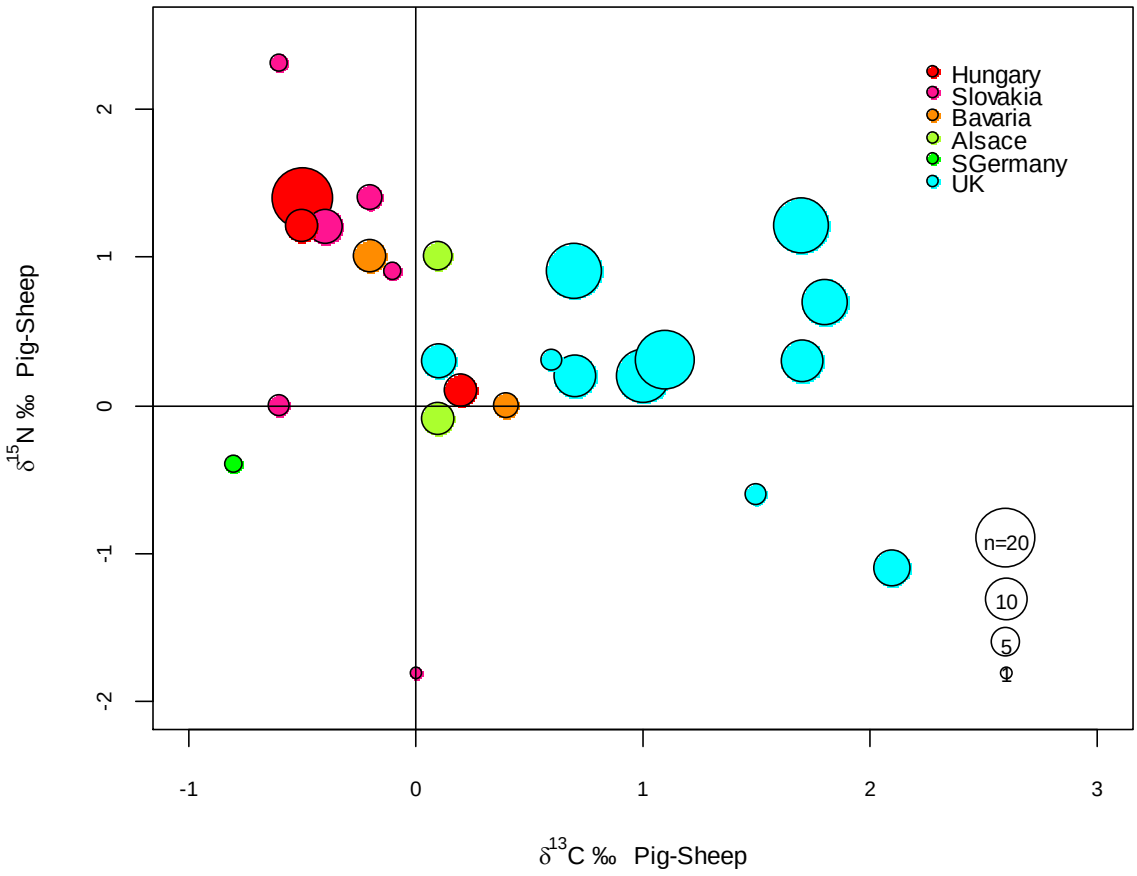


Fig. 8.10 Site mean isotope values for pigs from LBK and UK Neolithic sites. To account for large-scale geographical variation, cattle mean values are given relative to sheep mean values at each site: sites where sheep and cattle means are similar cluster around the 0,0 point. *Point size* indicates the number of data points (*n*) for each site: sites where $n \geq 10$ are likely to give an estimate of the population mean that is not far from the "true" value. Continental regions as in Hedges et al. (2013).

the Near Eastern haplotype over the whole range. This indicates interbreeding between local wild boar and introduced domestic pigs in western Europe, and possibly also local domestication. Contact between the wild and domesticated populations is more likely where domestic pigs range freely away from human settlement. A degree of human agency is suggested by the fact that these are mitochondrial haplotypes, inherited maternally, so female wild boar must have been incorporated into domestic herds – introgression between wild boar and domestic pigs was not solely the result of opportunistic mating by male wild boar. The isotopic evidence suggests greater use of forest by cattle as the LBK expanded westward (above, 4.1), and possibly also by pig. It is tempting to see a connection with the genetic evidence also – a suggestion that could be tested by looking at pig aDNA and isotopes together at sites over the LBK range, and at other early Neolithic sites e.g. in France. It implies a change in attitude of people towards use of forest resources, and hence in their relationship with the landscape.

5 Conclusions

These examples show that measurements of faunal isotope values at sites can aid interpretation at a variety of scales.

At the level of individual sites, differences in isotope values between the species suggest differences in their management and in the use of the landscape, and how these can change at one location over time. Sometimes this is as clear as the switch in pig management after the Neolithic, seen for instance at Barton Court Farm and Runnymede. Sometimes it is more subtle, such as the change in cattle isotope values relative to sheep between Iron Age and Roman periods at Barton Court Farm, which is hard to interpret without comparison with other sites. If we are correct in seeing the more or less contemporary herbivore isotope values at Claydon Pike as the expected values for a pastoral site with little or no arable, the higher Iron Age cattle values at Barton Court Farm may indicate intensification of pasture use. If suitable environmental evidence is available, e.g. from weed floras or coleopteran faunas, such hypotheses can be checked, and related to agricultural and cultural change at local or regional levels. Working in the other direction, the use of hay as fodder in the earlier Roman phase at Claydon Pike was deduced from archaeological and environmental evidence, but does not appear to have a distinct isotopic signature.

At a regional or landscape level, differences between the Middle and Upper Thames Valley in the timing and extent of agricultural intensification have been postulated based on

archaeological evidence. Differences in the pattern and trajectory of cattle and sheep isotope values between the regions are marked, and fit with the suggested scenario. The differences in pattern between the two areas make it unlikely that the difference between cattle and sheep could be explained by physiology; if there is any physiological difference it is small compared to effects of diet and/or management. In this example it would have been hard to arrive at an interpretation based on the isotope values alone: the strength of the method is in the links and interplay between the archaeological and environmental evidence at various scales (site, region, landscape).

At a wider scale, the trajectories of change in faunal isotope values in the Thames Valley appear similar to those seen at other (mainly southern) British sites, reflecting profound changes in the environment as well as agricultural practices. At sites with large samples and detailed environmental evidence, faunal isotope values can be studied in relation to environment, and where there are widespread similarities in patterning, similar processes may be implied. One general pattern is the low $\delta^{15}N$ values in herbivores from chalkland areas. The reasons for this are not known, but could be investigated in modern contexts. Meanwhile, caution is required when comparing isotope values from sites on different geologies.

Comparing early Neolithic faunal isotope values from Britain and continental Europe, it is apparent that there are both similarities and differences in the use of landscape and in animal management. In both areas, cattle dominate the faunal assemblages and appear to make more use of woodland resources than sheep. Pigs, however, are managed very differently in the two areas, with a strong connection to settlements in the LBK, and with an emphasis on free-range forest feeding in Britain. The possible connection with genetic change in domesticated pig populations would repay further detailed research at suitable sites, to illuminate the processes involved in adaptation and change in farming systems as they spread westwards across Europe.

Chapter 9

Conclusions

In this chapter the results for the Thames Valley are summarised, and considered in the light of broader issues. The extent to which research questions were answered is then evaluated, and further work suggested.

1 Introduction

The aim of this research was to investigate the application of carbon and nitrogen stable isotope values of domestic animals to the archaeology of agroecosystems at scales from site to landscape.

This work was based on extensive sampling of the three major domestic animals – cattle, sheep and pigs – from a coherent geographical area, at archaeological sites dating from the Neolithic to the Roman period. Variation in $\delta^{13}C$ and $\delta^{15}N$ values was also measured in a modern flock of sheep varying in nutritional, sex and breeding status, for comparison with archaeological bone assemblages. Statistical analysis using linear mixed models accounted for spatial autocorrelation. Variation in $\delta^{13}C$ and $\delta^{15}N$ values within and between species, sites and periods could be examined in unprecedented detail, and linked to variation in environmental and archaeological factors. The results allowed investigation of farming practice and the interactions between people, their animals and their environment at site and landscape scales.

2 Summary of findings

2.1 Variability in faunal samples

In the modern sheep flock, there was no significant change in isotope values with age, and diet had a significant but small effect on both $\delta^{13}C$ and $\delta^{15}N$. The largest effect was that of breeding status: ewes that had already lambed had lower $\delta^{13}C$ and $\delta^{15}N$ values than unbred ewes (Fig. 6.1). Variation of sheep isotope values in archaeological assemblages was higher than in the modern flock (Fig. 6.2), reflecting their greater heterogeneity. On this basis, adequate sample sizes for future work can be suggested.

2.2 Effect of climatic cooling

Long-term climatic change (cooling following the Holocene thermal maximum) does not satisfactorily explain the results presented here. Other things being equal, herbivore $\delta^{13}C$ values would be expected to fall by ≤ 0.5‰ in response to long-term climate cooling (Chapter 3, 4.1). In fact, the opposite was observed (Chapter 6, 3.2), and the three species followed different trajectories of change. Any effect of long-term climate change was overwhelmed by environmental effects at shorter timescales. It is possible that some of these environmental changes were connected to climatic variation, but that could not be tested in this study. Shorter-term climatic changes are even less likely to be detectable in faunal isotopes.

2.3 Variations between species

Faunal $\delta^{13}C$ and $\delta^{15}N$ values differed between cattle, sheep and pigs in ways that reflected their different ecophysiological requirements. Each species had its own pattern of change over time, so that the relationship between the isotope values of each species at individual sites changed consistently from the Neolithic onwards. Physiological differences (e.g. in digestion or water relations) could lead to small but consistent differences in isotope values between species (Chapter 2, 4), but the observed patterning suggested that any physiological differences were much less important than differences in diet, feeding environment and management.

Each species had its own trajectory in time (Fig. 6.4). Cattle $\delta^{13}C$ values were lower than those of sheep in the Neolithic, but rose as the amount of dense woodland in the landscape declined, and by the Iron Age herbivore $\delta^{13}C$ values no longer differed. Sheep $\delta^{13}C$ values also tended to be lower in the Neolithic than later, but not as low as those of cattle. This pattern reflects greater use, particularly by cattle, of forest plant resources with low $\delta^{13}C$ values due to the canopy effect. Pig $\delta^{13}C$ values, in contrast, were higher than those of cattle and sheep in the Neolithic and declined as dense woodland disappeared from the landscape. This pattern is attributed to loss of the high biomass of fungi, and perhaps also underground plant parts and mast, characteristic of primary, unmanaged forest, which was exploited by omnivorous pigs while still available. The different trajectories of change for the three species could be explained by environmental change, but were not consistent with predicted responses to long-term climatic change.

Variation in faunal $\delta^{15}N$ values was greater than that in $\delta^{13}C$ values. The $\delta^{15}N$ values of cattle and sheep followed similar trajectories, increasing from the Neolithic to the Bronze Age,

decreasing from the Bronze Age to the Iron Age, and increasing from the Iron Age to the Roman period. Increasing $\delta^{15}N$ values may reflect intensification in arable agriculture or in use of pasture, or both, as well as increasing association of animals with arable areas including feeding on crop wastes. Sheep $\delta^{15}N$ values were consistently slightly higher than those of cattle, possibly reflecting a physiological difference, or a stronger association of sheep with arable. Pig $\delta^{15}N$ values followed a different pattern, being low in the Neolithic, low and very variable in the Bronze Age, high in the Iron Age and higher in the Roman period. It is suggested that this pattern implies a major change in pig management during the Bronze Age, from mainly free-range feeding on plants, fungi and invertebrates and some scavenging, to a much closer association with settlements and agricultural land and a greater contribution of anthropogenic waste to the diet. The high values in the Roman period may reflect more intensive pig-keeping.

Changes in faunal isotope values over time were related both to landscape-scale environmental changes, and changes in agricultural and pastoral management by people.

2.4 Variations between sites

Most variation in faunal isotope values was within, rather than between, sites, with no more than a third accounted for by environmental factors (Table 6.3). Faunal isotope values were not related to latitude or longitude, not surprisingly within the relatively small area studied. $\delta^{15}N$, but not $\delta^{13}C$, values at sites were slightly affected by elevation, most likely because of differences in geology and soils, and/or possibly small differences in climatic factors. Soils had a complex relationship with topography and geology, and were related to faunal $\delta^{13}C$ and $\delta^{15}N$ values at sites, but not in consistently patterned ways. Because of the relationship between geology and topography (high-elevation chalk or limestone ridges contrasted with lower river terrace deposits), the main abiotic environmental variable used in the analysis was the “region”, comprising floodplain, first and second terraces, and chalk or limestone ridges.

Because of the profound changes in vegetation cover at the landscape scale, and in pastoral and cultivation practices, the earlier (Neolithic and Bronze Age) and later (Iron Age and Roman) periods were analysed separately.

There was significant patterning of faunal isotope values by region (Table 6.5). In the Neolithic/Bronze Age, cattle and sheep had lower $\delta^{13}C$ values on the river terraces than on the

floodplain, and sheep also had lower $\delta^{13}C$ values on the chalk. This suggests that the floodplain was the most open environment at the time, with denser woodland on the river terraces and the ridges. In the Iron Age/Roman period, there was no difference in faunal $\delta^{13}C$ values between floodplain and terraces, but sheep and cattle $\delta^{13}C$ values were higher on the chalk. This could reflect higher plant $\delta^{13}C$ values in an open, free-draining environment. In the Neolithic/Bronze Age, there was no difference in faunal $\delta^{15}N$ values between floodplain and terraces, but cattle $\delta^{15}N$ values were lower on chalk and limestone. Sheep and pig showed the same pattern, but it was not statistically significant. This may reflect lower plant $\delta^{15}N$ values on chalk due to tighter nitrogen cycling and possibly a higher proportion of legumes in chalk grassland pasture. In the Iron Age/Roman period, faunal $\delta^{15}N$ values were lower on the chalk, significantly so for sheep and pigs, probably for the same reason. Cattle $\delta^{15}N$ values were significantly higher on the second terrace than on the floodplain, and sheep showed a similar, non-significant, tendency. Higher $\delta^{15}N$ values could reflect more intensive use of pasture, a greater proportion of diet derived from crop residues, and/or closer association with cultivated areas. The finding is particularly interesting in the light of the suggestion that arable farming was concentrated on the second terrace in the Iron Age (Lambrick 1992, 2009 p. 265).

The major vegetation type at each site varied greatly over time (Fig. 6.10). The overriding pattern is a progressive reduction in woodland cover in the Neolithic and Bronze Age and continuing openness and increase in arable in the Iron Age and Roman periods. There were progressive changes in the proportions of crops at sites (Fig. 6.12). Emmer was replaced by spelt as the main cereal crop by the Iron Age, and new crops such as pulses and brassicas appeared in the Iron Age, with an even greater variety in the Roman period, while the use of gathered resources declined. At the site level, faunal isotope values were not convincingly related to changes in plant remains from sites.

The pattern of faunal occurrences at sites also changed over time (Fig. 6.13). The main contrast is between a Neolithic pattern with cattle dominant, followed by pig, and sheep only in low numbers, and the pattern seen from the Bronze Age onwards where sheep outnumber pigs, with cattle dominant except on the chalk (Fig. 6.14). Horses were present from the Bronze Age onwards, and the number of sites with the remains of hunted animals declined progressively. At the site level, faunal isotope values were not convincingly related to changes in animal remains from sites.

2.5 Applications and comparisons

A model of expected faunal isotope values was set up, against which the values found at particular sites/periods could be compared (Table 7.1, Fig. 7.2). This exercise suggested that faunal isotope values could be useful in interpreting environmental information and farming and animal management practices at individual sites (Chapter 8, 1), taking into account the local context.

In a case study relating cattle and sheep isotope values to landscape use as inferred from Lambrick (1992) and the extended discussion in Lambrick (2009; pp. 377–391), differences in faunal isotope patterns at sites were related to the different proposed trajectories of change in the Upper and Middle Thames (Chapter 8, 2). There were significant differences in the pattern of change of faunal isotope values between the Upper and Middle Thames. The pattern was consistent with the evidence for higher rates of human population growth, a greater emphasis on arable agriculture, and more intensive pastoralism in the Upper Thames from the Iron Age onwards, and more extensive pastoralism continuing for longer in the Middle Thames (Lambrick 2009).

Patterns and changes in faunal isotope values from the Thames Valley were similar to those seen in southern Britain in general over the same period (Chapter 8, 3). There were differences, however, between Neolithic isotope values from Britain and central Europe that suggested differences in animal management (Chapter 8, 4).

3 Assessment of this research

3.1 Methodology

The acquisition of a large dataset of faunal isotope values from a limited area, obtained from sites with extensive archaeological and environmental information, has allowed a thorough characterisation of variability in domestic faunal isotope values, within and between species, sites, archaeological periods, and landscape regions. This provides a firm foundation for further work, including the development of sampling strategies, and a basis for comparison with other datasets.

The statistical analysis focused on finding significant differences in faunal isotope values and linking these to archaeological and environmental variables. The method chosen, linear mixed modelling, was able to handle the data, in spite of the problems that are inevitable in

archaeological datasets. These include incompleteness and lack of balance, because adequate numbers of suitable samples may not be available and/or collagen preservation is unpredictable. This method is also able to cope with spatial autocorrelation, so that variance within and between sites (and areas, if appropriate) can be separated. In this study much of the variance in faunal isotopes occurred within sites, reflecting both intrapopulation variation and heterogeneity of faunal assemblages, but the remaining variation between sites could be linked to archaeological and environmental variables, as hoped.

One of the original objectives was to develop a suite of archaeological and environmental variables that summarised possible sources of variation in faunal isotope values and could be consistently applied across sites. This was only partially successful. Geographical and climatic variables were the easiest to characterise. Chronology was harder, partly because excavations had taken place over several decades, during which dating methods developed considerably, and partly because of inherent problems of stratigraphy and dating at some sites, particularly on the gravels. The four archaeological periods used to divide the 4.5 millennia covered were reasonably consistent across sites, but matching phase divisions within periods was more difficult. Summarising environmental variables using multivariate methods proved less effective than hoped, though this might still be a worthwhile approach with a carefully selected group of sites. Environmental information was eventually broadly summarised by assigning sites to geological/topographical regions.

The analysis was successful in demonstrating patterns of variation and change that could be interpreted consistently, and in answering some of the questions raised. This was possible because each site could be interpreted in the context of a variety of other sites within the same general area.

3.2 Research questions

It was possible to answer some of the research questions clearly, especially at the landscape scale. Long-term climatic change did not have any clear effect over the area and period studied. Trends in faunal $\delta^{13}C$ values over time reflected both habitat change and changes in animal management, and varied between species in ways that reflected their different requirements and functions within the agroecosystem. The results for $\delta^{15}N$ values were less clear, partly because of greater variability but mainly because of the complexities of the processes underlying the distribution of nitrogen isotopes in ecosystems. $\delta^{15}N$ values could be used to interpret faunal isotopes in terms of association with cultivated areas, intensity of manuring, and intensity of pasture use, and association with different areas of the landscape.

However, in the absence of relevant data from well-characterised modern experimental or traditional systems, or fodder/forage plant data from archaeological sites, such interpretations should be treated with caution.

In some cases large differences in model coefficients were not statistically significant because of the scatter in the data, or differences were very small, within measurement error, even though they were statistically significant. Given the high variability in faunal isotope ratios, it would be inadvisable to over-interpret differences between means for species or periods at a single site. Rather, consistent patterning over many sites is desirable for details of interpretation. Studies such as this one, with adequate samples from a number of sites, can, and should, provide local contexts for interpretation of faunal isotope ratios.

Bearing these caveats in mind, it was possible to interpret faunal isotope values consistently at individual sites, over landscape regions, and over time in terms of changes in people's use of landscape. To do this, the context provided by isotope results from a large number of sites within a limited area, and by detailed information on environment and agriculture at sites, was essential.

This study has demonstrated that domestic faunal $\delta^{13}C$ and $\delta^{15}N$ values are patterned in relation to species and to environment, at site, regional and landscape scales. They can contribute to interpretation of site environments, of the ways in which people interact with their environments, and of details of farming practices that integrate the management of plants and animals (Bogaard et al. 2013). In combination with other lines of evidence, faunal isotope values could be extremely useful in describing the ecodynamics of agricultural systems.

4 Further work

Given the constraints of time, accessibility of collections, availability of contextual information and the need to cover the four periods adequately, sampling was as thorough as possible, but not ideal. There was also a tension between the need to define variables so that they could be used consistently across sites, and the type of information and level of detail available for individual sites. Some specific suggestions for improvement are given here.

The sites sampled were concentrated on the river gravels, with much lower coverage of the chalk and limestone ridges, and none of the clay vale or the Corallian ridge. The later Neolithic and earlier Bronze Age were not well represented, because sites of these periods with large faunal assemblages are rare. To improve coverage, and to test the findings of this

work, analysis of adequate samples from sites in underrepresented periods and landscape regions would be useful.

The timeframe used was constrained. Consistent internal site phasing was generally possible, though at some sites (e.g. Mount Farm Berinsfield) there could be problems of residuality which made detailed phasing problematic. It was possible to group sites at the fairly coarse-grained level of periods. However it was not always easy to assign consistent phases within periods that could be used across sites, particularly when these were in different areas and/or excavated many years apart. This is essentially a problem of archaeological stratigraphy and dating applied across an area. As applied to changes in faunal isotope values and their relationship with ecological and agricultural changes at or between sites, it is important to formulate questions that can be answered by analysing the available material, with planned and adequate sampling.

In the absence of detailed reconstruction of past climatic conditions at sites, a current-day model of climate was used to assign climatic variables. While this model is likely to be applicable on a broad geographical scale, it may not be suitable at the smaller scales considered here. As detailed GIS-based climatic modelling becomes more sophisticated, it might be possible to back-project current climate models to achieve a better level of detail.

The type and amount of environmental evidence differed between sites. Even where there was detailed, comparable environmental evidence (such as beetle faunas or macrophytes) from a number of sites, it proved difficult to construct consistent classifications of environmental variables for use in the overall analysis, as originally intended. One approach to this problem would be to choose groups of sites with comparable information (e.g. beetle faunas, Booth et al. 2007, pp. 21-23) for comparison with isotope results. GIS-based modelling of site environments (Spikins 2000), as has been done using pollen (e.g. Fyfe 2006), is another possibility. This would require use of environmental proxies other than pollen, since pollen data are not necessarily easily available for sites with good bone preservation.

There are also more general problems which would repay further investigation, and provide a better basis for inference in archaeological isotope studies.

Carbon and nitrogen isotope ratios typical of different plant communities, modern or archaeological, are largely unknown. There is an increasing amount of information for archaeological crops, but very little for non-crop plants; herbivore forage isotope ratios are still generally inferred from herbivore values (e.g. Fraser et al. 2013, Table 5). Measurements

of isotope ratios from current vegetation types (Rodwell 1991a,b, 1992, 1995, 2000), such as chalk grassland, hay meadow, or pasture under different grazing regimes, in conjunction with measurements on herbivores, are essential to avoid circular argument in interpretation of herbivore isotope ratios. Anthropogenic changes in atmospheric CO_2 concentration and isotope ratio, and in nitrogen cycling leading to eutrophication, both need to be taken into account, so measurements on non-crop plants from ancient ecosystems would also be useful (if achievable), both to validate the use of modern values and to indicate baseline values for ancient herbivores.

Isotope studies of animals in modern contexts could help to clarify the relationships between archaeological fauna and their environments. For archaeological purposes, studies using isotope ratios in collagen (e.g. Rodière et al. 1996; Stevens et al. 2006) would be useful as well as studies using hair. While it is easier to track seasonal effects or other changes in hair, the longer turnover time of collagen means that results from hair cannot be uncritically applied.

The interpretation of pig isotope ratios also needs testing. In the absence of a good analogue for the primeval forest (though see Bocherens and Drucker 2003), feeding studies would be needed to test the hypothesis that in Britain, Neolithic pig $\delta^{13}C$ values reflect a high dietary contribution of fungi and/or ^{13}C-enriched plant parts, and the reasons for the higher $\delta^{15}N$ ratios in pigs associated with settlements.

It would be of great interest to further investigate pig isotopes in western Europe, between the early spread of the LBK and the early Neolithic in Britain, to see when and where the changes in isotope patterns happen and whether they coincide with genetic, environmental or management changes.

This study was also limited by considering only carbon and nitrogen isotopes in bone collagen. Inclusion of other isotopes (oxygen, hydrogen, sulphur) would enhance results by looking at other aspects of ecology, and strontium and oxygen isotopes in tooth dentine and enamel would help to clarify animal origins and movements, on local and greater scales.

5 Archaeological implications

Characterising the variation in faunal isotope values has shown that there needs to be more consideration of the way they are used in interpreting human diets.

Because of the high variability in each species' isotope ratios, faunal material needs to be sampled intensively to provide adequate data for estimating means and errors. Means of faunal values are often used for estimating isotopic baselines in the study of human diets, but their errors need to be considered too, particularly when trying to distinguish food sources isotopically. The precise number of measurements needed per species and grouping of interest (e.g. context type, phase or period) will depend on the variation in that particular sample, but is likely to be around 10-20.

There may be consistent differences between isotope ratios measured in different domestic animal species, reflecting differences in physiology as well as diet and use of the environment. The patterning is not the same in all places and periods, and needs to be established for each site. This has two consequences. Firstly, it is not valid simply to use a combined mean faunal value to estimate baselines for human diets: the differences between species and their contributions to diet need to be taken into account. Secondly, it is not valid to use isotope values from other sites uncritically to provide baselines where local data are not available – there can be considerable differences in faunal values between sites or areas and periods. This is a particular problem where faunal and human remains are not directly associated, for instance where people are buried in cemeteries but faunal remains are only found in settlements.

There is also a positive side to variation in animal isotope ratios. Since some of the variation in domestic animal isotope ratios is linked to variation in use of the local environment, there is great potential for use of faunal isotope values, in combination with information on environmental conditions and plant and animal husbandry, to aid interpretation of interactions between people and their environments at various scales, from site to landscape.

To quote Bowen et al. (2010, p.426):

"The unifying concept of isotopes-based research is a natural extension of the basic recognition of spatiotemporal variation in environmental isotope systems to the principle that this variation is mechanistic *and* predictable. *These two properties underlie the power of isoscapes. That the spatiotemporal variation is mechanistic implies that, with adequate understanding, observed patterns of isotopic variation can be 'inverted' to reveal aspects of the underlying Earth systems processes."*

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Appendix 1: Data Tables

Table A1.1 UK sites with published faunal isotope data

Site	Site code	Latitude	Longitude	Period(s)	Reference
Abingdon	AB	51.68	-1.26	Neolithic	Hamilton and Hedges 2011
Ascott-u-Wychwood	AUW	51.86	-1.56	Neolithic	Hedges et al. 2006
BabrahamRd	BAB	52.16	0.17	Neolithic	Lynch et al. 2008
Bainbridge	BAI	54.30	-2.10	Neolithic	Lynch et al. 2008
Birstall	BIR	52.67	-1.12	Neolithic	Lynch et al. 2008
Bornais	BOR	57.24	-7.41	Late Iron Age[2]	Mulville et al. 2009
BoscombeDown	BOS	51.13	-1.67	Neolithic	Lynch et al. 2008
BreanDown	BD	51.33	-3.03	Bronze Age	Britton et al. 2008
BrimblePitSwallet	BPS	51.25	-2.70	Neolithic	Lynch et al. 2008
Broxmouth	BRX	55.99	-2.48	Iron Age	Jay and Richards 2007
BuryHill	BH	51.19	-1.50	Iron Age	Stevens et al. 2013
Catterick Bainesse	CAT	54.37	-1.63	Roman	Chenery et al. 2011
Chalk Hill	CH	51.33	1.39	Neolithic	Hamilton and Hedges 2011
Cladh Hallan	CLH	57.17	-7.41	Bronze Age	Mulville et al. 2009
Corhampton	COR	50.98	-1.13	Neolithic	Lynch et al. 2008
DaneburyHillfort	DBH	51.14	-1.54	Iron Age	Stevens et al. 2010a
DorsetCombined	DOR	50.70	-2.43	Iron Age, Roman	Redfern et al. 2010
DryburnWood	DBW	55.97	-2.44	Iron Age	Jay and Richards 2007
DurringtonWalls	DW	51.19	-1.78	Neolithic	Lynch et al. 2008
EtonRowingCourse	ERC	51.49	-0.66	Neolithic,Bronze Age,Iron Age,Roman	Stevens et al. 2012
Etton	ET	52.64	-0.32	Neolithic	Hamilton and Hedges 2012
Fengate	FEN	52.57	-0.22	Neolithic	Lynch et al. 2008
Gayhurst	GAY	52.10	-0.75	Bronze Age	Towers et al. 2011
GlastonburyLakeVillage	GS	51.16	-2.72	Iron Age	Jay 2008
Gloucester	GLR	51.86	-2.24	Roman	Chenery et al. 2009
Hambledon	HAM	50.91	-2.22	Neolithic	Richards 2014
HarlynBay	HBA	50.54	-5.00	Iron Age	Jay and Richards 2007
Hazleton[1]	HZ	51.87	-1.90	Neolithic	Hedges et al. 2008, Lynch et al. 2008
HoughtonDown	HD	51.12	-1.51	Iron Age	Stevens et al. 2012
Irthlingborough	IRTH	52.34	-0.59	Bronze Age	Towers et al. 2011
JubileeCave	JC	54.09	-2.25	Neolithic	Lynch et al. 2008

Lismore	LIS	56.52	-5.50	Late Iron Age[2]	Mulville et al. 2009 citing O'Connell and Kimball 2006
Llanmaes	LLM	51.41	-3.47	Iron Age	Madgwick et al. 2012
MicheldeverWood	MW	51.13	-1.24	Iron Age	Jay and Richards 2007
MountPleasant	MP	50.71	-2.41	Neolithic	Lynch et al. 2008
NettlebankCopse	NC	51.15	-1.49	Iron Age	Stevens et al. 2013
NewBuildings	NB	51.13	-1.51	Iron Age	Stevens et al. 2013
NorthEndPot	NEP	54.15	-2.47	Neolithic	Lynch et al. 2008
Peterstone	BD	51.52	-3.06	Bronze Age	Britton et al. 2008
Porlock	POR	51.21	-3.59	Neolithic	Lynch et al. 2008
PortSeton	PSE	55.95	-2.95	Iron Age	Jay and Richards 2007
Potterne	Pot	51.33	-2.02	Bronze Age	Madgwick et al. 2012
Redwick	BD	51.57	-2.66	Bronze Age	Britton et al. 2008
Sparsholt	SPA	51.58	-1.50	Neolithic	Lynch et al. 2008
SuddernFarm	SF	51.14	-1.60	Iron Age	Stevens et al. 2012
TrevelgueHead	TREV	50.43	-5.06	Iron Age	Jay and Richards 2007
Wetwang	WW	54.03	-0.56	Iron Age	Jay and Richards 2006
WhiteHorseStone	WHS	51.31	0.52	Neolithic	Lynch et al. 2008
WindmillHill	WH	51.44	-1.88	Neolithic	Hamilton and Hedges 2011
WinnallDown	WD	51.07	-1.30	Iron Age	Jay and Richards 2007
Yarnton	YT	51.78	-1.32	Iron Age, Roman	Lightfoot et al. 2009
York	YOR	53.95	1.08	Roman	Muldner and Richards 2007

N Neolithic, *BA* Bronze Age, *IA* Iron Age, *R* Roman

[1]Sheep/goat were not distinguished from pig at Hazleton, except for one specimen of each: only these were included in the dataset

[2]Although the results from Lismore and Bornais are from a period called the Late Iron Age, it is chronologically equivalent to the Romano-British period further south and has been included with Roman. The results from Newark Bay, Orkney (Richards et al. 2006) have been omitted because the dating of the faunal specimens is vague and most if not all of them are probably later

Table A1.2 Faunal $\delta^{13}C$ and $\delta^{15}N$ values from UK sites, means and standard deviations.

			Cattle					Sheep/goat					Pig				
Site	**Environment**	**Period**	**$\delta^{13}C$**	**SD**	**$\delta^{15}N$**	**SD**	**n**	**$\delta^{13}C$**	**SD**	**$\delta^{15}N$**	**SD**	**n**	**$\delta^{13}C$**	**SD**	**$\delta^{15}N$**	**SD**	**n**
Abingdon*	River/Fen	Neolithic	-22.1	0.5	5.8	0.5	19	-21.6	0.4	5.2	0.6	20	-21.0	0.4	6.1	0.3	18
Ascott-u-Wychwood*	Limestone	Neolithic	-22.3	0.5	5.4	0.7	17	-21.9	1.1	6.0	0.6	9	-20.8	1.0	6.1	0.9	16
Babraham Road	Chalk	Neolithic	-22.6	1.0	6.2	0.4	8	–	–	–	–	–	–	–	–	–	–
Bornais	Other	Roman	-21.1	0.4	4.3	0.5	15	-21.3	0.3	4.4	0.6	12	-20.6	0.4	6.9	0.8	9
Boscombe Down	Chalk	Bronze Age	-22.0	0.6	4.3	1.6	2	–	–	–	–	–	–	–	–	–	–
Brean Down	Saltmarsh	Bronze Age	-20.7	0.4	8.2	0.6	8	-21.3	0.8	7.9	1.2	11	–	–	–	–	–
Brimble Pit Swallet	Limestone	Neolithic	-22.6	0.1	5.2	0.4	6	–	–	–	–	–	–	–	–	–	–
Broxmouth	Limestone	Iron Age	-21.9	0.2	6.1	0.7	5	-21.6	0.2	6.4	1.4	7	-21.8	0.4	7.7	0.7	6
Catterick Bainesse	Other	Roman	-21.6	0.1	5.1	0.6	7	-21.7	0.2	6.2	1.0	9	-21.2	0.4	8.0	2.1	5
Chalk Hill	Chalk	Neolithic	-21.8	0.5	5.4	0.5	16	-21.5	0.5	6.1	0.6	13	-21.0	0.6	6.8	0.5	3
Cladh Hallan	Other	Bronze Age	-21.7	0.5	5.0	0.6	12	-20.1	0.4	5.9	0.6	2	–	–	–	–	–
Danebury Hillfort	Chalk	Iron Age	-21.6	0.3	4.3	1.2	39	-21.2	0.4	4.2	0.8	57	-21.4	0.4	6.4	1.1	30
Dorset Combined	Chalk	Iron Age	-21.3	–	4.4	–	1	-21.8	0.8	6.1	2.1	2	-21.2	0.4	6.8	0.6	3
Dorset Combined	Chalk	Roman	-21.4	–	6.2	–	1	-20.3	–	4.9	–	1	-20.3	–	9.9	–	1
Dryburn Bridge	Limestone	Iron Age	-21.8	0.1	5.6	1.1	4	-21.8	–	6.3	–	1	-21.3	–	6.8	–	1
Durrington Walls	Chalk	Neolithic	-22.9	0.1	5.6	0.2	2	–	–	–	–	–	–	–	–	–	–
Eton Rowing Course*	River/Fen	Neolithic	-22.2	0.6	5.1	0.3	5	-21.4		7.1		1	-19.9	0.5	6.5	0.9	3
Eton Rowing Course*	River/Fen	Bronze Age	-21.6	0.4	8.2	0.7	3	–	–	–	–	–	-21.3	–	5.5	–	1
Eton Rowing Course*	River/Fen	Iron Age	-21.8	0.5	5.0	1.0	6	-21.6	–	5.0	–	1	–	–	–	–	–
Eton Rowing Course*	River/Fen	Roman	-21.8	0.2	6.1	1.5	5	-21.8	0.4	7.8	1.1	5	-21.7	0.3	8.9	0.9	4
Etton	River/Fen	Neolithic	-21.9	0.3	5.7	0.9	7	-21.6	0.6	5.5	0.8	4	-21.5	0.3	5.8	0.7	7
Fengate	River/Fen	Neolithic	-22.9	–	5.4	–	1	–	–	–	–	–	–	–	–	–	–
Gayhurst	River/Fen	Bronze Age	-23.1	0.3	6.0	0.3	12	–	–	–	–	–	–	–	–	–	–
Glastonbury Lake Village	River/Fen	Iron Age	-22.1	0.2	6.8	0.9	6	-22.0	0.3	6.8	0.6	6	-22.1	0.5	6.7	0.4	4

			Cattle					Sheep/goat					Pig				
Site	**Environment**	**Period**	**$\delta^{13}C$**	**SD**	**$\delta^{15}N$**	**SD**	**n**	**$\delta^{13}C$**	**SD**	**$\delta^{15}N$**	**SD**	**n**	**$\delta^{13}C$**	**SD**	**$\delta^{15}N$**	**SD**	**n**
Gloucester	Other	Roman	-21.7	0.3	6.6	0.4	4	-21.4	–	5.5	–	1	-21.4	–	5.5	–	1
Hambledon	Chalk	Neolithic	-21.5	0.6	5.1	0.1	26	-20.9	0.3	4.7	0.2	3	-20.2	0.6	4.9	0.3	10
Harlyn Bay	Other	Iron Age	-21.9	0.1	5.8	0.0	2	–	–	–	–	–	-22.4	–	5.7	–	1
Hazleton*	Limestone	Neolithic	-22.0	0.3	4.4	0.8	16	-22.0	–	4.2	–	1	-20.4	–	4.0	–	1
Houghton Down	Chalk	Iron Age	-21.5	0.4	3.9	0.9	18	-21.0	0.2	4.5	0.5	18	-21.2	0.3	6.8	0.7	8
Irthlingborough	River/Fen	Bronze Age	-22.9	2.3	6.0	0.4	10	–	–	–	–	–	–	–	–	–	–
Lismore	Other	Roman	-22.4	0.5	4.6	0.6	5	-22.7	0.4	6.0	0.9	10	-21.9	0.7	6.0	0.8	4
Llanmaes	Limestone	Iron Age	-22.1	0.3	5.5	0.9	12	-21.8	0.4	6.3	1.0	12	-21.5	0.4	6.6	1.2	60
Micheldever Wood	Chalk	Iron Age	–	–	–	–	–	–	–	–	–	–	-21.3	0.5	6.1	0.2	5
Nettlebank Copse	Chalk	Iron Age	-21.3	0.4	3.9	1.1	35	-21.1	0.5	4.1	0.8	34	-21.1	0.5	6.6	0.9	35
New Buildings	Chalk	Iron Age	-21.7	0.5	4.7	1.2	17	-21.3	0.3	4.8	0.8	19	-21.2	0.4	6.4	1.1	5
North End Pot	Limestone	Neolithic	-22.3	0.4	4.9	0.7	6	–	–	–	–	–	–	–	–	–	–
Peterstone	Saltmarsh	Bronze Age	-20.8	–	8.2	–	1	–	–	–	–	–	–	–	–	–	–
Port Seton	Limestone	Iron Age	-21.6	0.4	5.3	1.4	3	-21.8	0.3	7.4	0.4	3	-21.6		9.2		1
Potterne	Chalk	Bronze Age	-21.9	0.3	5.5	0.7	9	-21.6	0.5	5.3	1.3	10	-21.2	0.5	5.8	1.2	36
Redwick	Saltmarsh	Bronze Age	-20.9	–	8.2	–	1	–	–	–	–	–	–	–	–	–	–
Sparsholt	Chalk	Neolithic	-22.4	–	5.3	–	1	–	–	–	–	–	–	–	–	–	–
Suddern Farm	Chalk	Iron Age	-21.4	0.3	3.7	1.4	39	-21.2	0.4	4.1	0.7	32	-21.2	0.3	6.0	0.7	8
Trevelgue Head	Other	Iron Age	-22.0	0.4	5.5	0.7	6	-21.8	0.3	5.6	0.5	7	-21.4	0.3	7.0	1.4	7
Wetwang	Chalk	Iron Age	-21.5	0.4	4.6	1.1	10	-21.7	0.5	5.0	1.0	15	-21.8	0.6	6.4	1.4	11
Windmill Hill*	Chalk	Neolithic	-22.3	0.4	4.9	0.5	17	-22.2	0.4	4.9	1.0	15	-20.5	0.5	6.1	0.8	17
WinnallDown	Chalk	Iron Age	-21.8	0.4	4.4	1.1	11	-21.5	0.4	4.1	0.8	8	-21.4	0.6	5.7	1.0	4
Yarnton	River/Fen	Iron Age	-21.6	0.3	6.9	1.4	12	-21.5	0.2	6.6	1.3	12	-21.7	0.4	8.1	0.8	12
Yarnton	River/Fen	Roman	-21.5	0.4	6.7	2.1	10	-21.4	0.3	7.6	1.9	9	-21.6	0.4	8.8	1.2	8
York	Other	Roman	-22.4	0.5	4.6	0.6	5	-21.6	0.4	5.9	1.5	5	-22.1	0.5	6.9	1.4	12

*Sites marked with an asterisk are included in the Thames Valley dataset

Table A1.3 Geographical details and references for sites analysed in this project

Site	Site code	Site number	Town	County	Upper/Middle Thames	Latitude	Longitude	Elevation (m)	References
Abingdon	AB	8	Radley	Oxon	Upper	51.681	-1.262	60	Case & Whittle 1982; Whittle et al. 2011
Alfred's Castle	AC	15	Ashbury	Oxon	Middle	51.536	-1.612	190	Gosden & Lock 2013
Ascott-under-Wychwood	AUW	2	Ascott-under-Wychwood	Oxon	Upper	51.856	-1.566	120	Benson & Whittle 2007
Barton Court Farm	BCF	10	Abingdon	Oxon	Upper	51.676	-1.264	55	Miles 1986; Barclay & Halpin 1988
Claydon Pike	CP	7	Fairford	Glos	Upper	51.695	-1.725	75	Miles et al. 2007
Eton Rowing Course	ERC	16	Dorney	Bucks	Middle	51.493	-0.666	20	Stevens et al. 2012; Allen et al. 2013; Parker et al. 2008
Farmoor	FM	4	Farmoor	Oxon	Upper	51.742	-1.364	60	Lambrick & Robinson 1979
Harlington	HAR	18	Harlington	Berks	Middle	51.491	-0.446	20	Powell et al. forthcoming
Hazleton North	HAZ	1	Hazleton	Glos	Upper	51.869	-1.895	250	Saville 1990; Hedges et al. 2008; Meadows et al. 2007
Horton	HOR	17	Horton	Berks	Middle	51.491	-0.46	20	Barclay et al. in prep
Heathrow Terminal 5	HTV	19	Heathrow	London	Middle	51.473	-0.49	20	Framework Archaeology 2006, 2010
Latton Lands	LL	12	Fairford	Wilts	Upper	51.664	-1.879	80	Stansbie & Laws 2004

Site	Site code	Site number	Town	County	Upper/Middle Thames	Latitude	Longitude	Elevation (m)	References
Mount Farm Berinsfield	MFB	11	Berinsfield	Oxon	Upper	51.669	-1.161	58	Lambrick 2010
Runnymede	RM	21	Egham	Surrey	Middle	51.429	-0.549	20	Needham 1991, 2000; Needham & Spence 1996
Shorncote Quarry	SQ	13	Cirencester	Glos	Upper	51.663	-1.958	90	Hearne & Adam 1999
Staines Road Farm	SRF	23	Shepperton	Surrey	Middle	51.404	-0.453	10	Jones et al. 2008
Thornhill Farm	TF	6	Fairford	Glos	Upper	51.702	-1.738	75	Jennings et al. 2004; Stansbie et al. 2007
Thorpe Lea Nurseries	TLN	22	Egham	Surrey	Middle	51.419	-0.537	15	Hayman et al. 2012
Watkins Farm	WF	5	Northmoor	Oxon	Upper	51.729	-1.385	60	Allen 1990
Windmill Hill	WH	20	Avebury	Wilts	Middle	51.442	-1.876	195	Whittle et al. 1999, 2011
Whitecross Farm	WX	14	Wallingford	Oxon	Upper	51.589	-1.125	45	Cromarty et al. 2006
Wyndyke Furlong	WY	9	Abingdon	Oxon	Upper	51.676	-1.304	60	Muir & Roberts 1999; Parrington 1978
Yarnton	YT	3	Yarnton	Oxon	Upper	51.796	-1.334	60	Hey & Timby 2011; Hey et al. in prep

Table A1.4 Climate variables for each site

Site	PMS	PDRMS	TMS	TDRS	TDFS	RHS	SPCS	WRS	ETOS	PMW	PDRMW	TMW	TDRW	TDFW	RHW	SPCW	WRW	ETOW
Abingdon	48.1	12.9	13.2	9.7	3.9	79.5	37.8	3.9	2.5	52.5	15.4	5.7	6.6	14.8	88.8	24.7	4.4	0.6
Alfred's Castle	51.4	14.8	12.9	9.7	3.7	80.3	38.0	4.1	2.5	63.6	17.6	5.5	6.6	14.1	89.5	24.5	4.8	0.6
Ascott-u-Wychwood	47.3	14.0	13.3	9.4	3.1	77.7	38.3	4.0	2.6	50.2	16.6	5.8	6.5	13.4	87.5	25.5	4.6	0.7
Barton Court Farm	48.1	12.9	13.2	9.7	3.9	79.5	37.8	3.9	2.5	52.5	15.4	5.7	6.6	14.8	88.8	24.7	4.4	0.6
Claydon Pike	48.1	14.8	13.1	9.4	3.3	79.0	38.2	4.1	2.5	55.3	17.5	5.6	6.5	13.7	88.5	24.7	4.7	0.6
Eton Rowing Course	46.3	12.9	13.8	9.7	3.2	78.5	38.8	3.6	2.6	51.1	15.8	6.2	6.8	14.0	87.8	24.7	4.0	0.7
Farmoor	48.5	13.8	13.1	9.7	3.5	79.0	37.8	4.0	2.5	54.9	16.4	5.7	6.6	13.9	88.7	24.7	4.6	0.6
Harlington	44.3	12.5	14.1	9.4	3.1	77.5	39.2	3.6	2.7	47.6	15.2	6.4	6.5	13.8	87.5	25.0	4.0	0.7
Hazleton North	52.5	14.1	13.2	9.0	3.1	78.7	37.8	4.1	2.6	58.9	16.6	5.6	6.2	13.7	88.3	24.8	4.6	0.6
Horton	44.3	12.5	14.1	9.4	3.1	77.5	39.2	3.6	2.7	47.6	15.2	6.4	6.5	13.8	87.5	25.0	4.0	0.7
Heathrow Terminal 5	44.3	12.5	14.1	9.4	3.1	77.5	39.2	3.6	2.7	47.6	15.2	6.4	6.5	13.8	87.5	25.0	4.0	0.7
Latton Lands	49.6	13.9	13.3	9.1	3.1	79.2	38.5	4.1	2.6	56.1	16.4	5.8	6.3	13.6	88.5	25.2	4.7	0.7
Mount Farm	49.4	12.7	13.2	9.8	3.9	80.2	37.7	3.8	2.5	51.9	15.2	5.7	6.7	14.9	89.5	24.2	4.3	0.6
Runnymede	46.3	12.9	13.8	9.7	3.2	78.5	38.8	3.6	2.6	51.1	15.8	6.2	6.8	14.0	87.8	24.7	4.0	0.7
Shorncote Quarry	49.6	13.9	13.3	9.1	3.1	79.2	38.5	4.1	2.6	56.1	16.4	5.8	6.3	13.6	88.5	25.2	4.7	0.7
Staines Road Farm	49.3	12.8	13.3	9.8	3.8	80.0	39.7	3.6	2.5	56.7	15.9	5.7	6.8	15.2	88.8	25.2	4.1	0.6
Thornhill Farm	48.1	14.8	13.1	9.4	3.3	79.0	38.2	4.1	2.5	55.3	17.5	5.6	6.5	13.7	88.5	24.7	4.7	0.6
Thorpe Lea Nurseries	46.3	12.9	13.8	9.7	3.2	78.5	38.8	3.6	2.6	51.1	15.8	6.2	6.8	14.0	87.8	24.7	4.0	0.7
Watkin's Farm	48.5	13.8	13.1	9.7	3.5	79.0	37.8	4.0	2.5	54.9	16.4	5.7	6.6	13.9	88.7	24.7	4.6	0.6

Site	PMS	PDRMS	TMS	TDRS	TDFS	RHS	SPCS	WRS	ETOS	PMW	PDRMW	TMW	TDRW	TDFW	RHW	SPCW	WRW	ETOW
Windmill Hill	51.3	14.0	12.9	9.1	3.3	80.5	39.3	4.2	2.5	61.7	16.7	5.5	6.3	13.8	89.3	25.3	4.8	0.6
Whitecross Farm	49.4	12.7	13.2	9.8	3.9	80.2	37.7	3.8	2.5	51.9	15.2	5.7	6.7	14.9	89.5	24.2	4.3	0.6
Wyndyke Furlong	48.1	12.9	13.2	9.7	3.9	79.5	37.8	3.9	2.5	52.5	15.4	5.7	6.6	14.8	88.8	24.7	4.4	0.6
Yarnton	46.3	13.6	13.5	9.4	3.1	78.3	38.2	4.0	2.6	48.6	16.1	5.9	6.5	13.8	88.0	25.2	4.5	0.7

PMS Mean monthly precipitation summer (mm), *PDRMS* Mean number of days with rain per month summer, *TMS* Mean monthly temperature summer (°C), *TDRS* Mean daily temperature range maximum–minimum summer (°C), *TDFS* Mean number of days with ground frost per month summer, *RHS* Mean relative humidity summer (%), *SPCS* Mean sunshine hours summer (% maximum), *WRS* Mean monthly wind run summer (km/h), *ETOS* Mean Penman-Monteith reference evapotranspiration summer, *PMW* Mean monthly precipitation winter (mm), *PDRMW* Mean number of days with rain per month winter, *TMW* Mean monthly temperature winter (°C), *TDRW* Mean daily temperature range maximum–minimum winter (°C), *TDFW* Mean number of days with ground frost per month winter, *RHW* Mean relative humidity winter (%), *SPCW* Mean sunshine hours winter (% maximum), *WRW* Mean monthly wind run winter (km/h), *ETOW* Mean Penman-Monteith reference evapotranspiration winter

Table A1.5 Environmental variables for each site.

Site	Period	Geology	Soil type	Soil pH	Soil Drainage	Openness	Vegetation Type	Main Wheat	Faunal composition
Abingdon	1	Terrace2	Sandy loam	Neutral	Fast	4	Scrub/ grass	Emmer	1
Alfred's Castle	3,4	Chalk	–	Alkaline	Fast	5	Calcareous grassland	Spelt	3
Ascott-u-Wychwood	1	Limestone	Rendzina	Alkaline	Fast	2	Woodland	–	1
Barton Court Farm	1	Terrace2	Loam	Neutral	Fast	4	Scrub/ grass	Emmer	1
	3,4	Terrace2	Loam	Neutral	Fast	5	Arable/ grass	Spelt	2
Claydon Pike	3,4	Terrace1	Clay loam	Alkaline	Medium	5	Grassland/ wet pasture	Spelt	2
Eton Rowing Course	1,2,3,4	Floodplain/ Terrace1	–	–	–	–	–	–	–
Farmoor	3	Floodplain	Clay/loam	Acid/neutral	Medium	5	Grassland/ pasture/ meadow	Spelt	2
	4	Terrace1	Loam	Neutral/ alkaline	Fast	5	Grassland/ meadow/ pasture	Spelt	2
Harlington	1	Terrace3	Silty clay	Acid	Medium	–	–	–	–
	2	Terrace3	Silty clay	Acid	Medium	–	–	–	1
	3,4	Terrace3	Silty clay	Acid	Medium	–	–	–	2
Hazleton	1	Limestone	Brown earth	Neutral	Fast	2	Clearing/ scrub	Emmer	1

Site	Period	Geology	Soil type	Soil pH	Soil Drainage	Openness	Vegetation Type	Main Wheat	Faunal composition
Horton	1, 2, 3	Floodplain	Brickearth over gravels	Acid	Fast	–	–	–	2
Heathrow Terminal 5	2	Terrace3	–	Acid	–	4	Grassland/ scrub/ arable	Emmer	2
	3,4	Terrace3	–	Acid	–	5	Grassland/ arable	Spelt	2
Latton Lands	2	Terrace1	–	–	–	–	–	–	2
Mount Farm Berinsfield	1	Terrace2	–	–	–	–	–	Emmer	–
	2	Terrace2	–	–	–	4	Grassland/ scrub	Emmer	2
	3	Terrace2	–	–	–	5	Grassland	Spelt	2
	4	Terrace2	–	–	–	5	Grassland/ arable/ disturbed	Spelt	2
Runnymede	1	Eyot	Alluvial gleyic brown	Alkaline	Medium	2	Clearing/ woodland	Emmer	1
	2	Eyot	Alluvial gleyic rendzina	Neutral?	Medium	4	Grassland	Spelt	3
Shorncote Quarry	2	Terrace1	–	Alkaline	Fast	4	Grassland/ scrub/ hedge	–	–
Staines Rd Farm	1	Terrace2	Brickearth over gravels...	Acid	–	–	–	–	1

Site	Period	Geology	Soil type	Soil pH	Soil Drainage	Openness	Vegetation Type	Main Wheat	Faunal composition
Thornhill Farm	3, 4	Terrace1	Clay/loam	Alkaline	Medium	5	Grassland/ pasture	Spelt	2
Thorpe Lea Nurseries	3,4	Terrace2	–	Acid	Fast	5	"open"	Spelt	2
Watkins Farm	3	Terrace1	Silty clay	Neutral	Medium	4	Grassland/ pasture	Spelt	3
	4	Terrace1	Silty clay	Neutral	Medium	5	Grassland/ pasture	Spelt	2
Windmill Hill	1	Chalk	Rendzina	Alkaline	Fast	2	Woodland/ clearing	Emmer	2
Whitecross Farm	2	Eyot	Clay/silt	Neutral	Fast	4	Grassland lightly grazed	Emmer	3
Wyndyke Furlong	3	Terrace2	Clay/loam	Alkaline	Fast	4	Grassland/ scrub/ hedge	Spelt	3
	4	Terrace2	Clay/loam	Alkaline	Fast	5	Open/ dry arable	Spelt	2
Yarnton	2	Floodplain	Loam/brown earth	Neutral	Medium	4	Grassland	Emmer	–
	3	Terrace2	Loam/brown earth	Neutral	Fast	4	Grassland/ arable	Spelt	2
	4	Terrace2	Loam/brown earth	Neutral	Fast	5	Grassland/ arable	Spelt	2

Period: *1* Neolithic, *2* Bronze Age, *3* Iron Age, *4* Roman. Openness: 5-point scale from 1 (closed canopy) to 5 (no tree cover). Faunal composition: *1* cattle>pig>sheep, *2* cattle>sheep>pig, *3* sheep or pig>cattle (NISP)

Table A1.6 $\delta^{13}C$ and $\delta^{15}N$ values measured at each site

Sample	Period	Phase	Taxon	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C	%N	%Collagen	C:N
Alfred's Castle									
AC1	Iron Age	10	Pig	-21.5	5.8	18.4	6.3	1.6	3.39
AC2	Iron Age	10	Pig	-20.8	6.3	25.4	9.0	3.2	3.30
AC3	Iron Age	10	Pig	-21.4	7.9	39.0	14.2	2.7	3.21
AC4	Iron Age	10	Cattle	-21.1	3.8	26.5	9.4	3.6	3.29
AC5	Iron Age	10	Sheep	-21.5	4.3	19.6	6.7	2.0	3.41
AC6	Iron Age	10	Sheep	-21.8	4.7	28.1	10.1	3.5	3.24
AC7	Iron Age	10	Sheep	-21.6	6.1	29.0	10.5	4.1	3.23
AC8	Iron Age	10	Sheep	-22.0	5.1	27.7	10.1	3.6	3.21
AC9	Iron Age	10	Sheep	-21.1	3.8	33.9	12.5	6.1	3.15
AC10	Iron Age	10	Cattle	-21.3	3.8	30.8	11.1	5.2	3.22
AC11	Iron Age	10	Pig	-20.3	6.2	21.4	7.4	2.4	3.39
AC13	Iron Age	10	Pig	-20.7	6.4	31.3	11.2	4.6	3.25
AC14	Iron Age	10	Sheep	-20.8	3.7	43.2	16.3	17.3	3.09
AC15	Iron Age	10	Sheep	-21.5	4.9	25.3	9.0	3.3	3.27
AC16	Iron Age	10	Sheep	-21.4	4.0	39.2	14.1	4.3	3.24
AC17	Iron Age	10	Sheep	-21.7	4.4	31.7	11.5	4.7	3.22
AC18	Iron Age	10	Sheep	-21.6	4.3	23.2	8.2	2.9	3.29
AC19	Iron Age	10	Sheep	-21.0	4.4	28.2	10.2	3.6	3.23
AC20	Iron Age	10	Sheep	-21.0	4.3	41.6	15.7	14.6	3.09
AC21	Iron Age	10	Sheep	-21.4	3.6	27.0	9.6	3.1	3.27
AC22	Iron Age	10	Sheep	-21.5	6.4	25.8	9.3	2.9	3.24
AC23	Iron Age	10	Sheep	-21.4	6.9	43.4	16.2	18.0	3.12
AC24	Iron Age	10	Cattle	-21.5	4.6	39.7	14.8	14.5	3.12
AC25	Iron Age	10	Pig	-22.0	7.1	22.0	7.8	2.8	3.31
AC26	Iron Age	10	Pig	-21.8	8.2	40.7	15.2	15.7	3.13
AC27	Iron Age	10	Sheep	-20.7	4.6	40.7	15.1	11.6	3.15
AC28	Iron Age	10	Sheep	-20.9	4.3	44.0	16.6	14.0	3.09
AC29	Iron Age	10	Cattle	-21.7	4.4	23.6	8.4	2.9	3.27
AC30	Iron Age	10	Pig	-20.7	5.7	43.8	16.1	14.6	3.18
AC31	Iron Age	10	Sheep	-21.2	4.8	36.3	13.1	5.4	3.24
AC32	Iron Age	10	Cattle	-21.8	6.0	34.2	12.5	5.0	3.19
AC33	Iron Age	10	Sheep	-21.2	4.1	43.2	16.0	10.5	3.14
AC34	Iron Age	10	Sheep	-20.9	4.3	39.5	14.7	8.6	3.14
AC35	Iron Age	10	Pig	-21.2	7.2	45.1	16.3	4.6	3.23
AC36	Iron Age	10	Cattle	-21.2	4.4	28.9	10.2	3.4	3.29
AC37	Iron Age	10	Pig	-21.4	5.7	29.5	10.5	3.1	3.28
AC38	Roman	13	Pig	-22.0	6.3	39.4	14.3	4.4	3.22
AC39	Iron Age	10	Cattle	-20.7	5.4	36.2	13.2	6.1	3.21
AC40	Iron Age	10	Pig	-21.4	5.5	30.0	10.8	2.6	3.23
AC41	Iron Age	10	Cattle	-20.8	5.0	31.6	11.3	4.0	3.27
AC42	Iron Age	10	Cattle	-20.7	5.2	32.5	11.6	4.7	3.26
AC43	Iron Age	10	Cattle	-20.8	4.2	27.2	9.8	3.2	3.23
AC46	Iron Age	10	Cattle	-20.6	4.6	28.4	10.1	3.8	3.27
AC47	Iron Age	10	Pig	-21.6	6.7	26.6	9.5	3.8	3.25
AC48	Iron Age	10	Cattle	-20.9	4.0	26.7	9.6	3.7	3.25
AC49	Iron Age	10	Pig	-21.7	4.0	25.4	9.1	2.9	3.27

Sample	Period	Phase	Taxon	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C	%N	%Collagen	C:N
AC50	Iron Age	10	Cattle	-22.0	3.4	27.2	9.6	3.4	3.30
AC51	Iron Age	10	Pig	-21.6	7.6	28.3	10.0	4.0	3.30
AC52	Iron Age	10	Pig	-21.9	7.4	26.1	9.2	3.2	3.29
AC53	Iron Age	10	Cattle	-21.9	5.3	25.9	9.2	3.2	3.29
AC54	Iron Age	10	Cattle	-21.8	4.5	21.2	7.4	2.4	3.32
AC55	Iron Age	10	Cattle	-21.3	3.1	29.4	10.7	4.2	3.19
AC56	Iron Age	10	Cattle	-21.8	4.7	24.1	8.5	2.9	3.29
AC57	Roman	15	Cattle	-20.2	2.1	30.1	10.6	2.1	3.30
AC58	Roman	15	Cattle	-21.6	3.4	26.0	9.3	3.1	3.25
AC59	Iron Age	10	Sheep	-21.4	4.3	26.5	9.6	2.7	3.24
AC60	Iron Age	10	Pig	-21.7	6.3	25.3	9.0	2.7	3.29
AC61	Iron Age	10	Pig	-20.5	5.4	23.7	8.3	2.1	3.30
AC62	Iron Age	10	Cattle	-21.6	4.2	32.4	11.8	3.6	3.20
AC63	Iron Age	10	Cattle	-21.8	6.2	20.9	7.3	1.7	3.36
AC64	Roman	15	Pig	-21.4	7.8	32.4	11.8	3.1	3.20
AC65	Roman	16	Sheep	-21.4	4.9	36.0	12.9	3.6	3.26
AC66	Roman	16	Sheep	-20.8	4.4	43.7	16.2	15.5	3.15
AC67	Roman	16	Sheep	-20.5	4.6	43.8	16.2	16.2	3.15
AC68	Roman	16	Sheep	-20.7	5.1	39.8	14.6	9.5	3.17
AC69	Roman	16	Pig	-21.8	7.2	35.2	12.7	4.4	3.25
AC70	Roman	16	Cattle	-21.6	4.1	24.6	8.7	2.8	3.31
AC71	Roman	16	Cattle	-21.6	6.1	26.8	9.5	5.1	3.27
AC72	Roman	16	Sheep	-20.9	4.7	26.1	9.2	2.3	3.32
*AC73**	*Roman*	*16*	*Sheep*	*-22.5*	*4.5*	*27.0*	*7.9*	*1.8*	*4.00*
AC95	Roman	13	Cattle	-20.8	4.2	31.8	11.3	4.6	3.30
AC96	Roman	13	Cattle	-20.9	4.6	43.7	15.6	6.8	3.28
AC97	Roman	13	Cattle	-21.5	4.0	27.4	9.5	1.8	3.35
AC98	Roman	13	Sheep	-21.1	5.1	35.0	12.3	4.1	3.32
AC99	Roman	15	Sheep	-21.2	4.1	34.9	12.6	4.1	3.23
AC100	Roman	15	Sheep	-21.6	5.1	24.1	8.5	1.9	3.32
AC101	Roman	15	Sheep	-21.5	3.9	26.5	9.3	2.0	3.31
AC102	Roman	15	Sheep	-21.5	5.6	28.6	10.2	1.9	3.28
AC103	Roman	15	Sheep	-20.8	3.5	27.0	9.5	2.1	3.31
AC104	Roman	15	Sheep	-21.4	5.0	28.3	9.9	1.5	3.35
AC105	Roman	15	Sheep	-21.2	5.5	30.5	11.0	2.2	3.25
AC106	Roman	13	Sheep	-21.3	3.9	38.8	14.1	6.0	3.20
AC107	Roman	13	Sheep	-21.9	5.3	23.5	8.3	2.0	3.31
AC108	Roman	13	Pig	-21.1	6.8	38.0	13.7	6.4	3.23
AC109	Iron Age	10	Pig	-21.2	7.3	23.6	8.2	1.6	3.35
AC110	Iron Age	10	Pig	-21.7	5.2	29.7	10.6	2.2	3.28
AC111	Roman	15	Pig	-21.2	7.0	25.0	8.6	1.1	3.38
AC112	Roman	15	Pig	-21.0	5.9	34.2	12.3	2.1	3.25
AC113	Roman	15	Pig	-21.1	7.0	31.6	11.1	2.2	3.32
AC115	Roman	15	Pig	-19.9	6.3	32.9	11.8	2.4	3.25
AC116	Roman	13	Pig	-22.1	7.1	21.9	7.5	1.8	3.40
AC117	Roman	13	Pig	-21.6	6.8	28.0	9.9	2.6	3.28
Barton Court Farm									
BCF1	Roman	15	Sheep	-21.8	9.0	32.7	11.3	5.3	3.38
BCF2	Roman	15	Sheep	-21.5	5.1	22.3	7.6	2.9	3.42

Sample	Period	Phase	Taxon	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C	%N	%Collagen	C:N
*BCF3**	*Roman*	*15*	*Sheep*	*-21.7*	*7.8*	*19.7*	*6.4*	*2.1*	*3.61*
BCF4	Roman	15	Sheep	-21.9	10.5	27.8	9.3	4.2	3.48
BCF5	Roman	15	Sheep	-21.7	7.2	27.1	9.1	2.5	3.48
*BCF6**	*Roman*	*15*	*Sheep*	*-21.3*	*6.8*	*20.6*	*6.9*	*2.8*	*3.48*
BCF7	Roman	15	Sheep	-21.2	8.3	24.2	8.1	2.0	3.50
BCF8	Roman	15	Sheep	-21.6	9.5	36.3	13.6	8.9	3.12
BCF9	Roman	13	Pig	-22.1	8.6	26.7	9.2	4.2	3.40
BCF10	Roman	15	Pig	-21.6	8.1	33.8	12.1	7.2	3.26
BCF11	Roman	15	Pig	-19.7	5.7	33.7	11.8	8.6	3.33
BCF12	Roman	15	Pig	-21.2	6.4	33.9	11.8	8.1	3.35
BCF14	Roman	15	Cattle	-21.8	7.6	25.5	8.7	2.3	3.41
BCF15	Roman	15	Cattle	-21.6	6.5	29.7	10.4	6.0	3.32
BCF16	Roman	15	Cattle	-21.7	7.2	25.8	8.8	2.3	3.42
BCF17	Roman	15	Cattle	-22.3	7.8	37.2	13.7	6.5	3.16
BCF18	Roman	15	Cattle	-21.9	6.8	18.7	6.4	2.0	3.43
*BCF19**	*Roman*	*15*	*Cattle*	*-22.0*	*3.9*	*19.1*	*6.2*	*2.2*	*3.60*
BCF20	Roman	15	Cattle	-21.4	5.8	23.5	8.0	3.1	3.40
BCF21	Roman	15	Cattle	-21.9	6.9	21.8	7.5	3.6	3.38
*BCF22**	*Roman*	*15*	*Cattle*	*-21.8*	*9.6*	*18.4*	*6.2*	*2.5*	*3.48*
BCF23	Roman	15	Cattle	-21.9	7.6	20.2	6.9	3.3	3.41
BCF24	Roman	15	Cattle	-21.5	6.4	21.4	7.3	3.4	3.41
*BCF25**	*Roman*	*15*	*Cattle*	*-21.8*	*8.1*	*18.2*	*6.2*	*2.7*	*3.47*
BCF26	Roman	15	Cattle	-21.4	6.5	18.6	6.3	2.9	3.43
BCF27	Roman	15	Pig	-21.5	8.9	32.7	11.4	5.1	3.34
BCF28	Roman	15	Pig	-22.1	9.4	20.8	7.1	2.6	3.39
BCF29	Roman	15	Sheep	-21.4	6.0	28.1	9.8	6.6	3.35
BCF31	Roman	15	Cattle	-22.0	7.6	23.6	8.1	5.2	3.41
BCF32	Roman	15	Sheep	-21.9	8.2	29.1	10.0	4.7	3.41
BCF33	Roman	15	Sheep	-21.0	6.3	28.5	9.8	4.6	3.39
BCF34	Roman	15	Pig	-21.5	8.2	35.1	12.1	4.7	3.39
BCF35	Roman	15	Pig	-20.5	6.3	37.0	13.2	10.0	3.26
*BCF36**	*Roman*	*15*	*Pig*	*-21.9*	*7.5*	*24.1*	*8.0*	*2.7*	*3.51*
BCF37	Roman	15	Cattle	-21.3	5.8	33.6	11.6	3.1	3.38
BCF38	Roman	15	Cattle	-21.7	8.2	30.6	10.7	7.1	3.34
BCF39	Roman	15	Pig	-20.9	8.6	31.0	10.7	6.5	3.39
BCF40	Roman	15	Sheep	-21.2	5.7	37.4	12.9	2.0	3.40
BCF41	Roman	15	Sheep	-21.9	7.6	30.2	10.5	6.1	3.35
*BCF43**	*Roman*	*15*	*Sheep*	*-21.6*	*6.1*	*22.5*	*7.2*	*2.6*	*3.66*
BCF44	Roman	15	Sheep	-21.3	5.8	30.9	10.8	6.1	3.35
BCF45	Roman	15	Sheep	-21.7	8.7	22.9	7.8	4.0	3.42
BCF46	Roman	15	Sheep	-21.6	7.1	29.1	10.1	2.5	3.36
*BCF47**	*Roman*	*15*	*Cattle*	*-21.6*	*8.4*	*16.9*	*5.5*	*2.4*	*3.56*
BCF49	Roman	15	Pig	-21.2	6.5	19.5	6.6	3.0	3.47
BCF50	Roman	15	Sheep	-21.9	7.4	36.9	13.3	8.5	3.25
*BCF51**	*Roman*	*15*	*Cattle*	*-21.8*	*6.3*	*17.8*	*5.5*	*2.5*	*3.74*
BCF53	Iron Age	11	Sheep	-21.9	7.2	23.2	7.8	3.9	3.47
*BCF54**	*Roman*	*15*	*Cattle*	*-21.4*	*7.0*	*15.0*	*5.0*	*2.0*	*3.47*
BCF55	Roman	15	Pig	-21.6	9.1	30.7	10.8	6.2	3.33
BCF56	Roman	15	Pig	-20.9	5.1	31.8	10.9	7.3	3.39

Sample	Period	Phase	Taxon	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C	%N	%Collagen	C:N
BCF57	Roman	15	Sheep	-21.0	7.3	37.8	13.7	13.9	3.23
BCF58	Roman	15	Sheep	-21.9	8.2	37.7	13.5	15.3	3.26
*BCF59**	*Iron Age*	*11*	*Sheep*	*-22.6*	*7.3*	*13.9*	*4.7*	*1.9*	*3.49*
*BCF60**	*Roman*	*15*	*Cattle*	*-22.2*	*8.5*	*15.4*	*5.2*	*2.2*	*3.46*
BCF61	Roman	13	Cattle	-21.2	8.4	25.1	8.8	5.3	3.31
*BCF62**	*Iron Age*	*11*	*Cattle*	*-22.2*	*3.7*	*18.9*	*6.5*	*3.0*	*3.39*
BCF63	Iron Age	11	Cattle	-21.4	6.3	33.0	11.5	11.7	3.35
BCF64	Iron Age	11	Cattle	-21.6	6.9	31.9	11.2	9.4	3.31
*BCF65**	*Iron Age*	*11*	*Cattle*	*-21.8*	*6.3*	*18.5*	*6.3*	*3.4*	*3.46*
BCF66	Roman	13	Sheep	-21.1	5.8	23.7	8.2	5.7	3.37
BCF67	Roman	15	Pig	-21.1	6.7	23.9	8.2	5.1	3.41
*BCF68**	*Roman*	*15*	*Pig*	*-21.9*	*8.8*	*15.8*	*5.3*	*2.8*	*3.47*
*BCF69**	*Roman*	*15*	*Pig*	*-21.1*	*4.2*	*17.8*	*5.9*	*3.1*	*3.54*
BCF70	Roman	15	Pig	-21.7	8.1	22.7	7.7	5.9	3.44
*BCF71**	*Roman*	*15*	*Pig*	*-21.3*	*7.8*	*14.5*	*4.9*	*2.4*	*3.48*
BCF73	Iron Age	11	Cattle	-21.6	6.1	31.9	11.2	10.7	3.34
BCF76	Iron Age	11	Cattle	-21.7	7.0	27.3	9.4	6.9	3.38
BCF77	Iron Age	11	Cattle	-21.6	5.1	26.1	8.9	7.0	3.42
BCF78	Iron Age	11	Sheep	-21.3	4.1	22.9	8.0	2.9	3.34
BCF79	Iron Age	11	Sheep	-20.7	4.5	33.3	12.2	13.5	3.17
*BCF80**	*Iron Age*	*11*	*Sheep*	*-22.3*	*8.8*	*16.8*	*5.6*	*2.8*	*3.50*
*BCF81**	*Iron Age*	*11*	*Sheep*	*-21.9*	*4.9*	*17.0*	*5.7*	*2.9*	*3.47*
BCF82	Iron Age	11	Sheep	-22.0	7.5	23.1	7.7	5.2	3.50
BCF83	Iron Age	11	Sheep	-22.1	7.1	29.7	10.1	6.7	3.44
BCF84	Iron Age	11	Sheep	-21.5	5.5	32.1	11.8	10.0	3.18
BCF85	Iron Age	11	Cattle	-21.6	5.2	25.0	8.8	6.0	3.32
BCF86	Iron Age	11	Pig	-21.4	6.8	23.9	8.2	6.1	3.38
BCF87	Iron Age	11	Sheep	-21.6	5.7	20.6	6.9	3.5	3.48
BCF88	Iron Age	11	Sheep	-22.1	4.5	19.1	6.5	3.3	3.46
*BCF89**	*Iron Age*	*11*	*Sheep*	*-21.7*	*5.8*	*14.0*	*4.8*	*2.0*	*3.42*
BCF90	Iron Age	11	Sheep	-21.6	5.9	34.0	12.0	12.1	3.30
BCF92	Iron Age	11	Pig	-22.0	8.0	24.8	8.4	3.4	3.44
BCF93	Iron Age	11	Cattle	-21.7	4.3	28.6	9.9	6.4	3.35
BCF94	Iron Age	11	Sheep	-21.7	7.0	25.8	8.7	3.2	3.45
BCF95	Iron Age	11	Cattle	-21.1	5.4	25.3	8.5	4.9	3.45
BCF96	Iron Age	11	Cattle	-21.8	6.3	30.5	10.7	8.8	3.33
*BCF98**	*Iron Age*	*11*	*Pig*	*-22.3*	*7.4*	*24.4*	*8.3*	*3.1*	*3.44*
BCF99	Iron Age	11	Pig	-21.8	8.4	30.3	10.4	6.0	3.40
*BCF100**	*Iron Age*	*11*	*Pig*	*-21.9*	*7.3*	*26.8*	*9.1*	*3.3*	*3.45*
BCF101	Iron Age	11	Pig	-21.5	6.5	23.9	8.0	4.3	3.49
BCF102	Iron Age	11	Pig	-21.1	6.5	30.6	10.4	6.6	3.42
BCF103	Iron Age	11	Pig	-21.8	7.7	28.2	9.8	5.5	3.37
*BCF104**	*Iron Age*	*11*	*Pig*	*-21.6*	*6.8*	*17.9*	*6.1*	*2.2*	*3.44*
BCF105	Iron Age	11	Pig	-21.1	6.8	29.6	10.5	5.2	3.29
BCF106	Iron Age	11	Pig	-21.2	8.9	28.0	9.5	5.1	3.45
BCF107	Iron Age	11	Pig	-20.2	7.4	21.9	7.5	3.4	3.40
*BCF108**	*Iron Age*	*11*	*Sheep*	*-21.7*	*5.2*	*21.3*	*7.2*	*2.5*	*3.46*
BCF109	Iron Age	11	Sheep	-21.4	7.6	26.8	9.2	4.1	3.42
BCF110	Iron Age	11	Sheep	-21.9	6.3	29.2	10.1	5.8	3.36

Sample	Period	Phase	Taxon	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C	%N	%Collagen	C:N
BCF111	Iron Age	11	Cattle	-21.6	4.0	24.4	8.3	3.4	3.42
BCF112	Iron Age	11	Sheep	-21.9	6.8	38.4	13.9	6.6	3.23
BCF113	Iron Age	11	Pig	-21.2	6.2	31.1	11.0	7.0	3.29
BCF114	Iron Age	11	Cattle	-21.8	7.5	26.8	9.1	2.9	3.44
BCF115	Iron Age	11	Cattle	-22.1	7.7	22.2	7.5	2.9	3.43
*BCF116**	*Iron Age*	*11*	*Sheep*	*-21.8*	*5.4*	*19.4*	*6.6*	*2.2*	*3.43*
BCF117	Iron Age	11	Sheep	-21.5	4.9	27.1	9.3	3.9	3.42
*BCF118**	*Iron Age*	*11*	*Sheep*	*-21.5*	*6.7*	*19.6*	*6.7*	*2.5*	*3.40*
*BCF119**	*Iron Age*	*11*	*Pig*	*-22.2*	*8.3*	*22.1*	*7.5*	*3.2*	*3.43*
BCF120	Iron Age	11	Sheep	-21.2	5.4	27.4	9.3	4.0	3.43
BCF121	Iron Age	11	Sheep	-21.3	5.2	27.1	9.6	3.3	3.29
BCF122	Iron Age	11	Sheep	-22.0	4.7	37.7	13.5	9.2	3.27
BCF123	Iron Age	11	Sheep	-21.8	6.2	37.1	13.3	6.5	3.25
BCF124	Iron Age	11	Pig	-20.0	9.5	37.9	13.5	7.6	3.28
BCF125	Iron Age	11	Cattle	-22.0	7.9	26.3	9.4	3.7	3.27
BCF126	Iron Age	11	Cattle	-21.7	8.4	28.1	9.9	6.2	3.32
BCF127	Iron Age	11	Sheep	-21.9	7.6	23.8	8.3	2.3	3.36
BCF128	Iron Age	11	Cattle	-21.4	8.2	26.0	9.2	3.7	3.29
BCF129	Iron Age	11	Cattle	-21.6	7.1	23.3	8.2	2.6	3.31
BCF130	Iron Age	11	Cattle	-21.7	8.0	25.7	9.1	3.4	3.29
BCF131	Iron Age	11	Cattle	-21.7	7.0	32.6	11.7	6.2	3.26
BCF132	Roman	13	Sheep	-21.3	8.6	43.8	16.0	19.3	3.19
BCF133	Roman	13	Sheep	-21.7	8.3	32.6	11.6	12.2	3.27
BCF134	Roman	13	Sheep	-21.8	5.8	32.7	11.8	9.6	3.24
BCF135	Roman	13	Sheep	-20.7	9.1	18.5	6.5	2.1	3.31
BCF136	Roman	13	Sheep	-21.7	5.6	22.6	8.0	2.6	3.29
BCF137	Roman	13	Cattle	-21.4	8.7	32.5	11.6	4.7	3.28
BCF138	Roman	13	Cattle	-21.3	7.6	25.9	9.2	3.3	3.30
BCF139	Roman	13	Cattle	-21.8	9.1	29.2	10.4	4.3	3.28
BCF144	Roman	13	Pig	-21.1	5.8	25.4	9.0	2.3	3.31
BCF145	Roman	13	Pig	-21.1	7.7	37.1	13.1	6.7	3.30
BCF146	Roman	13	Sheep	-21.7	6.2	20.0	7.0	1.9	3.33
BCF147	Roman	13	Sheep	-21.7	7.6	27.1	9.6	2.5	3.31
BCF148	Roman	13	Cattle	-21.4	4.4	32.4	11.5	5.0	3.27
BCF149	Roman	13	Cattle	-21.8	6.3	22.5	7.9	1.5	3.32
BCF150	Roman	13	Cattle	-21.4	5.6	35.4	12.7	7.3	3.24
BCF152	Roman	13	Pig	-20.9	9.4	31.7	11.4	5.7	3.25
BCF153	Roman	13	Pig	-21.0	8.8	33.0	11.7	5.0	3.28
BCF154	Roman	13	Pig	-21.3	8.5	26.6	9.4	3.1	3.32
BCF155	Roman	13	Pig	-20.9	9.9	34.4	12.3	4.2	3.27
BCF156	Roman	13	Pig	-20.9	8.3	30.3	10.7	2.5	3.29
BCF157	Roman	13	Pig	-21.9	9.0	30.4	10.7	3.4	3.32
BCF158	Roman	13	Pig	-21.3	9.8	41.5	15.0	8.2	3.24
BCF159	Roman	15	Pig	-21.5	6.5	27.3	9.6	2.9	3.31
BCF160	Roman	15	Pig	-21.2	5.8	33.3	11.9	5.1	3.27
BCF161	Roman	15	Pig	-21.6	5.5	33.4	11.7	3.8	3.34
BCF164	Roman	13	Cattle	-22.6	5.8	18.2	6.3	2.5	3.37
BCF165	Roman	13	Cattle	-22.1	6.5	32.2	11.5	4.0	3.25
BCF167	Roman	13	Sheep	-21.4	6.5	38.2	13.8	8.6	3.23

Sample	Period	Phase	Taxon	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C	%N	%Collagen	C:N
BCF168	Roman	13	Sheep	-21.8	6.3	37.7	13.4	7.0	3.28
BCF169	Roman	13	Sheep	-21.5	7.5	22.6	8.0	2.0	3.32
BCF170	Roman	13	Sheep	-21.8	6.7	24.9	8.8	2.6	3.31
BCF171	Roman	13	Sheep	-21.4	6.4	40.9	14.7	10.2	3.24
BCF172	Roman	13	Sheep	-21.9	7.4	36.9	13.2	6.9	3.25
BCF177	Roman	13	Cattle	-22.0	8.9	17.7	6.3	1.4	3.30
BCF178	Roman	13	Cattle	-21.4	6.1	32.3	11.5	3.1	3.28
BCF179	Roman	13	Cattle	-21.5	5.8	18.2	6.4	1.5	3.33
BCF180	Roman	13	Sheep	-21.5	6.9	29.9	10.7	3.0	3.26
BCF181	Neolithic	4	Cattle	-23.0	5.4	28.7	10.2	1.8	3.29
BCF182	Neolithic	4	Cattle	-23.4	5.7	21.3	7.5	2.0	3.33
BCF183	Neolithic	4	Cattle	-22.6	5.8	28.9	10.3	2.7	3.29
BCF184	Neolithic	4	Cattle	-22.8	6.1	34.5	12.4	3.7	3.26
BCF185	Neolithic	4	Cattle	-22.8	5.6	22.5	7.8	1.3	3.36
BCF186	Neolithic	4	Cattle	-23.4	5.3	39.6	14.2	3.4	3.26
BCF187	Neolithic	4	Pig	-20.6	5.7	27.7	9.8	2.4	3.30
BCF188	Neolithic	4	Sheep	-22.1	7.0	34.8	12.4	2.2	3.28
BCF189	Neolithic	4	Sheep	-23.2	5.2	34.7	12.3	1.0	3.28
BCF190	Neolithic	4	Sheep	-22.5	8.1	30.2	10.6	2.4	3.34
BCF191	Neolithic	4	Pig	-20.2	5.7	31.7	11.2	1.9	3.30
BCF192	Neolithic	4	Pig	-20.1	6.3	30.1	10.7	3.6	3.29
BCF193	Neolithic	4	Cattle	-23.4	5.6	24.8	8.6	1.6	3.36
BCF194	Neolithic	4	Cattle	-23.2	6.4	37.0	13.3	3.5	3.25
BCF195	Neolithic	4	Sheep	-23.1	6.3	29.8	10.5	2.2	3.32
BCF196	Neolithic	4	Sheep	-23.4	6.3	37.2	13.0	3.2	3.34
BCF197	Neolithic	4	Cattle	-23.0	5.1	22.1	7.7	2.4	3.34
BCF198	Neolithic	4	Cattle	-23.0	6.0	22.1	7.7	2.2	3.36
BCF199	Neolithic	4	Cattle	-23.6	4.7	30.6	10.7	2.5	3.35
BCF201	Neolithic	4	Cattle	-22.9	5.8	26.6	8.9	1.0	3.48
BCF202	Neolithic	4	Sheep	-22.7	7.3	34.6	11.9	1.8	3.39
BCF203	Neolithic	4	Pig	-21.1	6.7	39.6	13.9	3.8	3.32
BCF204	Neolithic	4	Cattle	-22.6	6.1	41.3	15.1	11.7	3.20
BCF206	Neolithic	4	Sheep	-22.7	6.2	22.9	7.9	1.1	3.39
BCF207	Neolithic	4	Sheep	-21.0	6.7	42.0	15.3	8.9	3.21
BCF208	Neolithic	4	Sheep	-21.4	8.8	41.1	14.6	8.9	3.28
BCF209	Roman	13	Sheep	-21.5	5.7	30.3	10.8	2.8	3.26
BCF210	Roman	13	Pig	-21.4	8.6	34.4	12.4	5.8	3.25
BCF211	Roman	13	Pig	-21.6	8.2	37.4	13.1	4.1	3.33
BCF212	Roman	13	Pig	-19.9	8.4	43.6	15.5	9.8	3.28
BCF213	Roman	13	Pig	-21.6	7.2	26.7	9.2	3.4	3.37
BCF214	Roman	13	Pig	-19.6	7.9	42.2	15.2	10.3	3.25
BCF215	Roman	13	Pig	-21.6	7.4	41.5	14.4	4.3	3.35
BCF216	Roman	13	Sheep	-21.1	7.3	31.8	11.4	4.4	3.27
BCF217	Roman	13	Sheep	-21.3	6.3	31.1	11.0	3.1	3.31
BCF218	Roman	13	Sheep	-21.2	7.8	38.3	13.6	5.6	3.29
BCF219	Roman	13	Sheep	-21.6	7.8	42.1	15.1	6.0	3.25
BCF220	Neolithic	4	Cattle	-22.7	5.0	35.4	12.7	3.6	3.26
BCF221	Neolithic	4	Cattle	-22.8	5.8	33.7	11.9	2.8	3.31
BCF223	Neolithic	4	Pig	-20.2	5.9	40.1	14.3	4.2	3.29

Sample	Period	Phase	Taxon	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C	%N	%Collagen	C:N
BCF224	Neolithic	4	Sheep	-22.9	8.4	33.9	12.1	3.1	3.28
BCF225	Neolithic	4	Sheep	-22.9	8.9	35.6	12.5	3.1	3.32
BCF226	Neolithic	4	Pig	-20.0	5.9	40.6	14.5	4.6	3.27
BCF227	Neolithic	4	Pig	-20.6	6.1	32.0	11.2	2.8	3.32
BCF228	Neolithic	4	Pig	-20.6	6.5	32.4	11.4	2.6	3.31
BCF229	Neolithic	4	Cattle	-23.2	5.6	39.5	14.4	8.8	3.21
Claydon Pike									
CP3	Roman	16	Sheep	-21.3	5.4	29.9	10.5	2.6	3.33
CP4	Roman	16	Sheep	-21.8	7.8	33.5	12.0	3.6	3.26
CP5	Roman	16	Cattle	-21.8	6.5	37.3	13.4	4.1	3.24
*CP6**	*Roman*	*16*	*Cattle*	*-22.3*	*5.3*	*15.0*	*4.5*	*0.8*	*3.87*
*CP9**	*Roman*	*16*	*Sheep*	*-22.7*	*7.3*	*21.9*	*7.0*	*1.5*	*3.65*
CP12	Roman	16	Cattle	-21.3	7.1	31.6	11.1	2.9	3.32
CP14	Roman	16	Pig	-22.1	6.9	24.6	8.2	1.6	3.49
CP17	Roman	16	Cattle	-21.4	5.4	27.2	9.5	2.5	3.34
CP18	Roman	16	Pig	-22.2	6.2	27.0	9.1	1.3	3.44
CP25	Roman	14	Sheep	-20.7	3.9	40.1	14.5	7.8	3.23
CP31	Roman	14	Cattle	-21.3	6.5	39.9	14.4	6.8	3.24
CP33	Roman	14	Pig	-21.4	9.2	35.3	12.4	3.9	3.33
CP35	Roman	14	Cattle	-21.4	5.5	35.5	12.7	3.1	3.28
CP37	Roman	14	Pig	-20.1	9.6	39.7	14.5	7.7	3.21
*CP38**	*Roman*	*14*	*Cattle*	*-24.9*	*5.2*	*4.4*	*0.9*	*1.0*	*5.43*
CP39	Roman	14	Cattle	-21.4	10.1	31.5	11.2	3.6	3.28
CP40	Roman	14	Cattle	-21.0	3.4	27.6	9.3	2.4	3.28
CP42	Roman	14	Cattle	-21.7	6.4	27.6	9.3	1.7	3.45
CP43	Roman	14	Sheep	-21.0	5.1	30.2	10.5	1.8	3.36
CP45	Roman	14	Sheep	-21.2	4.6	29.5	10.2	2.0	3.36
CP51	Roman	14	Sheep	-21.8	6.1	22.3	7.4	1.0	3.48
CP52	Roman	14	Sheep	-21.8	5.9	28.6	9.7	1.9	3.44
*CP56**	*Roman*	*14*	*Sheep*	*-22.0*	*6.7*	*15.0*	*4.9*	*0.7*	*3.60*
*CP59**	*Roman*	*14*	*Sheep*	*-27.4*	*1.5*	*5.0*	*0.4*	*0.2*	*12.96*
CP73	Roman	13	Cattle	-21.6	6.6	42.3	15.4	7.3	3.20
CP75	Roman	13	Sheep	-21.7	6.3	32.8	11.7	2.8	3.27
*CP76**	*Roman*	*13*	*Cattle*	*-22.5*	*5.6*	*18.5*	*5.9*	*1.0*	*3.67*
CP78	Roman	16	Cattle	-21.4	3.9	32.1	11.4	2.9	3.29
CP79	Roman	16	Sheep	-21.7	3.7	36.3	12.9	3.6	3.29
CP80	Roman	16	Sheep	-21.6	7.2	36.6	13.1	4.1	3.26
CP84	Roman	13	Sheep	-21.7	5.9	35.2	12.5	2.8	3.29
CP85	Roman	13	Pig	-22.0	8.5	22.4	7.6	1.2	3.44
CP91	Roman	16	Cattle	-21.8	8.1	31.4	11.2	2.7	3.26
CP92	Roman	16	Sheep	-21.2	4.4	27.3	9.7	1.8	3.29
CP93	Roman	16	Cattle	-21.9	6.1	30.2	10.7	1.4	3.28
CP94	Roman	16	Sheep	-20.9	4.8	34.7	12.5	3.0	3.23
CP95	Roman	16	Pig	-20.2	9.3	36.7	13.3	3.6	3.22
CP98	Roman	16	Cattle	-21.4	8.7	41.5	15.2	10.7	3.18
CP114	Roman	16	Sheep	-21.5	7.5	35.8	12.8	2.9	3.25
CP115	Roman	16	Sheep	-22.1	7.7	32.9	11.9	2.4	3.22
CP116	Roman	16	Sheep	-21.7	6.2	23.2	7.7	1.1	3.53
CP117	Roman	16	Cattle	-21.0	7.1	38.3	14.2	10.4	3.16

Sample	Period	Phase	Taxon	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C	%N	%Collagen	C:N
CP120	Roman	16	Cattle	-21.4	8.3	38.8	14.0	5.3	3.24
*CP122**	*Roman*	*16*	*Pig*	*-27.9*	*4.9*	*5.8*	*0.5*	*0.3*	*13.23*
CP127	Roman	16	Cattle	-21.4	6.6	30.0	10.7	2.3	3.28
CP128	Roman	16	Cattle	-21.7	6.8	28.4	10.0	1.9	3.31
CP131	Roman	13	Cattle	-21.2	3.2	43.4	16.2	13.9	3.13
CP132	Roman	13	Cattle	-21.9	7.8	29.0	10.2	1.5	3.31
CP133	Roman	13	Pig	-21.8	8.6	22.3	7.4	1.1	3.53
CP134	Roman	13	Cattle	-21.2	3.0	42.1	15.6	12.4	3.16
CP135	Roman	13	Sheep	-21.5	5.6	39.0	14.5	10.5	3.15
CP146	Roman	13	Sheep	-22.5	5.8	23.1	7.6	1.3	3.55
CP153	Roman	13	Cattle	-22.5	5.6	42.0	15.6	13.4	3.13
CP159	Roman	13	Cattle	-21.8	4.6	29.5	10.4	1.4	3.31
CP164	Roman	13	Pig	-21.5	6.5	24.5	8.5	1.5	3.37
CP166	Roman	13	Cattle	-22.2	6.0	26.8	9.2	1.9	3.39
*CP168**	*Roman*	*13*	*Pig*	*-22.7*	*7.8*	*17.2*	*5.1*	*0.8*	*3.92*
CP171	Roman	16	Pig	-22.4	5.3	31.5	11.1	2.3	3.31
CP172	Roman	16	Pig	-21.2	5.9	35.5	12.7	3.4	3.28
CP175	Roman	16	Sheep	-22.1	6.5	32.4	11.5	3.4	3.27
CP178	Roman	16	Pig	-21.1	6.7	42.7	15.9	11.7	3.12
CP179	Roman	16	Sheep	-22.2	7.4	18.9	6.6	1.0	3.37
CP180	Roman	16	Sheep	-21.3	7.8	39.1	14.4	7.9	3.17
CP182	Roman	16	Sheep	-21.3	5.7	37.0	13.6	4.8	3.18
CP183	Roman	16	Sheep	-21.5	5.4	38.4	13.9	5.2	3.23
CP184	Roman	16	Pig	-21.4	7.6	36.7	13.5	3.9	3.17
CP185	Roman	16	Cattle	-21.2	7.0	37.2	13.6	4.9	3.19
CP186	Roman	16	Sheep	-21.3	8.6	36.3	13.3	7.2	3.18
CP187	Roman	16	Sheep	-21.5	7.5	32.7	11.7	2.4	3.26
CP189	Roman	16	Cattle	-22.0	5.5	39.9	14.8	8.0	3.14
CP190	Roman	16	Sheep	-21.4	6.4	36.2	13.1	4.1	3.23
CP192	Roman	16	Pig	-21.3	7.0	47.0	17.3	10.3	3.17
CP193	Roman	16	Sheep	-21.6	6.6	37.5	13.6	4.0	3.22
CP194	Roman	16	Sheep	-21.3	6.6	38.0	14.0	6.0	3.16
CP195	Roman	16	Sheep	-21.1	5.7	41.0	15.3	8.1	3.12
CP196	Roman	16	Pig	-20.8	7.2	39.3	14.5	5.5	3.17
CP197	Roman	16	Sheep	-21.1	8.2	28.9	10.5	1.9	3.21
CP198	Roman	16	Sheep	-21.2	5.4	38.9	14.4	5.5	3.15
CP199	Roman	16	Sheep	-21.3	6.1	38.0	13.9	3.7	3.19
CP200	Roman	16	Sheep	-21.5	6.8	33.6	12.0	2.4	3.25
CP201	Roman	16	Pig	-21.6	10.2	42.1	15.6	8.2	3.14
CP202	Roman	16	Pig	-21.4	9.7	38.4	14.2	6.5	3.15
CP208	Iron Age	10	Cattle	-21.9	6.0	35.0	12.6	2.2	3.24
CP210	Iron Age	10	Sheep	-21.3	5.4	39.6	14.6	10.9	3.16
CP211	Iron Age	10	Sheep	-21.1	5.0	42.5	15.9	11.4	3.13
CP212	Iron Age	10	Sheep	-21.8	6.2	29.2	10.2	2.2	3.34
CP213	Iron Age	10	Cattle	-21.3	5.0	42.0	15.4	12.4	3.17
*CP215**	*Iron Age*	*10*	*Cattle*	*-23.0*	*5.0*	*22.8*	*7.2*	*1.1*	*3.68*
CP218	Iron Age	10	Sheep	-21.3	6.0	42.9	15.8	14.3	3.16
CP219	Iron Age	10	Sheep	-22.4	6.2	30.4	10.9	1.7	3.25
CP220	Iron Age	10	Sheep	-21.4	6.3	41.6	15.3	11.2	3.17

Sample	Period	Phase	Taxon	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C	%N	%Collagen	C:N
CP224	Iron Age	10	Cattle	-21.9	6.2	30.4	10.7	1.6	3.30
CP226	Iron Age	10	Cattle	-21.7	5.1	27.8	9.8	1.2	3.32
CP230	Iron Age	10	Pig	-22.2	6.9	26.0	8.5	1.0	3.58
CP231	Iron Age	10	Cattle	-21.8	6.2	37.2	13.5	4.0	3.20
CP234	Iron Age	10	Cattle	-21.6	7.0	42.0	15.6	12.2	3.13
CP235	Iron Age	10	Cattle	-21.6	6.3	37.9	13.9	4.7	3.19
CP236	Iron Age	10	Cattle	-21.1	4.0	40.3	15.0	12.7	3.13
CP237	Iron Age	10	Cattle	-21.5	6.0	42.1	15.7	10.4	3.14
CP238	Iron Age	10	Sheep	-21.9	6.4	37.9	13.8	7.2	3.21
CP239	Iron Age	10	Sheep	-21.6	4.9	42.5	15.9	14.2	3.12
CP240	Iron Age	10	Sheep	-22.0	5.7	44.9	16.3	15.0	3.22
CP241	Iron Age	10	Sheep	-20.6	9.6	43.7	16.2	15.5	3.15
CP242	Iron Age	10	Pig	-20.8	7.5	39.9	14.4	7.5	3.22
*CP243**	*Iron Age*	*10*	*Pig*	*-22.6*	*6.9*	*21.0*	*6.8*	*1.2*	*3.62*
CP244	Iron Age	10	Cattle	-21.4	5.4	41.4	14.8	9.8	3.26
CP245	Iron Age	10	Sheep	-21.4	4.9	43.7	16.0	11.8	3.18
CP246	Iron Age	10	Sheep	-21.6	4.7	42.5	15.5	12.5	3.20
CP248	Iron Age	10	Sheep	-21.4	4.7	41.4	15.3	13.5	3.16
CP249	Iron Age	10	Sheep	-21.3	7.1	41.1	15.3	13.0	3.14
CP250	Iron Age	10	Cattle	-21.6	5.4	42.3	15.4	15.1	3.20
CP251	Iron Age	10	Sheep	-21.1	5.0	41.3	15.0	13.0	3.21
CP252	Iron Age	10	Sheep	-21.6	5.8	42.1	15.4	14.0	3.20
CP253	Iron Age	10	Sheep	-21.5	6.4	41.9	15.4	15.2	3.17
CP254	Iron Age	10	Cattle	-21.5	7.6	39.7	14.2	5.1	3.26
Farmoor									
FM1	Roman	15	Cattle	-21.3	8.5	41.6	15.5	8.2	3.13
FM2	Roman	15	Cattle	-21.5	5.8	25.3	9.0	1.0	3.28
FM3	Roman	15	Pig	-21.5	8.1	31.1	11.2	2.5	3.23
FM5	Roman	15	Sheep	-21.2	8.6	42.9	16.0	8.3	3.13
FM6	Roman	15	Sheep	-21.3	6.3	39.6	14.6	10.4	3.16
FM7	Roman	15	Pig	-21.2	9.7	40.5	15.1	10.6	3.13
FM10	Roman	13	Cattle	-21.2	6.9	42.7	15.9	13.8	3.13
FM11	Roman	15	Cattle	-21.7	6.5	25.5	9.1	3.5	3.27
FM12	Roman	15	Cattle	-21.7	5.5	40.1	14.9	10.9	3.14
FM13	Roman	15	Cattle	-21.5	5.9	39.8	14.7	10.2	3.16
FM14	Roman	15	Pig	-22.2	8.4	37.3	13.6	6.0	3.20
FM15	Roman	15	Sheep	-20.7	3.7	41.1	15.3	10.1	3.14
FM16	Roman	15	Sheep	-21.4	6.0	37.6	13.7	6.0	3.20
FM17	Roman	15	Sheep	-21.1	7.3	40.2	14.9	8.6	3.15
FM20	Roman	15	Cattle	-21.2	8.8	32.3	11.7	1.9	3.22
FM21	Roman	15	Cattle	-21.9	9.2	44.1	16.4	14.3	3.13
FM23	Roman	13	Sheep	-21.9	7.9	33.1	12.0	2.1	3.24
FM25	Roman	15	Sheep	-21.3	7.6	39.2	14.4	4.0	3.19
FM27	Iron Age	10	Sheep	-21.5	8.0	33.5	12.1	2.3	3.22
FM30	Iron Age	10	Cattle	-21.7	5.1	40.9	15.0	7.4	3.19
FM36	Iron Age	10	Sheep	-21.9	4.6	39.8	14.2	3.9	3.27
FM41	Iron Age	10	Cattle	-21.3	7.2	43.2	16.2	12.7	3.13
FM42	Iron Age	10	Cattle	-22.1	8.2	42.0	15.7	12.2	3.12
FM44	Iron Age	10	Pig	-21.7	9.7	37.0	13.6	6.2	3.18

Sample	Period	Phase	Taxon	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C	%N	%Collagen	C:N
FM45	Iron Age	10	Sheep	-21.0	6.2	42.1	15.7	13.1	3.12
FM46	Iron Age	10	Sheep	-21.3	5.4	42.3	15.9	13.3	3.11
FM47	Iron Age	10	Sheep	-21.0	4.9	42.9	16.0	13.5	3.13
FM48	Iron Age	10	Sheep	-21.2	7.2	44.3	16.5	14.0	3.14
FM49	Iron Age	10	Sheep	-21.6	7.7	41.4	15.4	10.2	3.15
FM56	Iron Age	10	Sheep	-21.9	7.0	38.5	13.9	5.3	3.24
FM58	Iron Age	10	Sheep	-21.5	6.5	34.4	12.3	4.3	3.27
FM59	Iron Age	10	Sheep	-21.6	6.4	44.6	16.7	14.8	3.11
FM61	Iron Age	10	Cattle	-21.4	5.7	44.6	16.8	11.5	3.11
FM62	Iron Age	10	Cattle	-21.2	5.0	41.3	15.4	14.6	3.13
FM63	Iron Age	9	Cattle	-21.6	5.1	19.7	6.8	2.6	3.41
FM64	Iron Age	10	Cattle	-21.2	6.1	42.4	15.8	15.9	3.12
FM65	Iron Age	10	Cattle	-21.5	7.0	43.3	16.2	18.3	3.13
FM68	Iron Age	10	Pig	-21.1	6.8	44.3	16.6	15.3	3.13
FM70	Iron Age	9	Pig	-21.1	7.2	27.8	10.0	3.8	3.23
FM71	Iron Age	9	Pig	-21.4	6.9	39.7	14.7	24.5	3.15
FM72	Iron Age	10	Pig	-21.2	7.3	39.1	14.5	8.9	3.15
FM73	Iron Age	10	Pig	-21.8	8.9	41.6	15.4	14.0	3.15
FM74	Iron Age	10	Cattle	-22.0	7.6	24.3	8.4	1.9	3.36
FM75	Iron Age	10	Cattle	-21.9	6.5	30.6	11.0	1.3	3.26
FM76	Iron Age	10	Cattle	-21.8	7.9	41.8	15.6	15.4	3.13
Harlington									
HA1	Roman	16	Cattle	-21.6	6.4	41.6	15.3	19.2	3.17
HA2	Roman	16	Cattle	-22.5	4.9	47.6	17.4	18.9	3.19
*HA3**	*Roman*	*14*	*Cattle*	*-22.9*	*5.8*	*10.0*	*2.9*	*0.4*	*4.59*
*HA4**	*Roman*	*13*	*Cattle*	*-24.4*	*13.4*	*2.5*	*0.5*	*0.1*	*7.00*
*HA5**	*Roman*	*14*	*Cattle*	*-23.0*	*6.1*	*9.2*	*2.8*	*0.4*	*4.30*
*HA6**	*Roman*	*14*	*Cattle*	*-22.7*	*7.6*	*6.5*	*2.0*	*0.5*	*4.24*
HA8	Bronze Age	8	Cattle	-22.2	7.0	21.0	7.2	1.0	3.40
HA10	Bronze Age	8	Cattle	-21.9	7.5	30.3	10.8	1.9	3.27
HA11	Bronze Age	8	Cattle	-22.6	6.2	17.2	5.7	0.7	3.51
HA14	Bronze Age	8	Cattle	-22.3	6.6	30.0	10.9	2.0	3.22
HA17	Roman	14	Cattle	-22.4	5.3	20.3	7.0	1.1	3.40
HA19	Roman	14	Cattle	-22.4	5.8	25.3	9.0	0.9	3.28
HA20	Roman	16	Cattle	-21.1	5.8	37.3	13.6	8.1	3.20
HA21	Roman	16	Sheep	-21.7	6.9	40.9	14.9	14.0	3.20
HA22	Bronze Age	8	Cattle	-21.9	8.1	40.6	15.0	12.4	3.17
HA23	Bronze Age	8	Sheep	-22.2	7.2	37.0	13.1	6.4	3.29
*HA26**	*Roman*	*14*	*Sheep*	*-23.0*	*9.0*	*14.6*	*5.1*	*0.8*	*3.35*
*HA28**	*Iron Age*	*10*	*Cattle*	*-22.0*	*8.3*	*21.7*	*7.9*	*1.1*	*3.18*
HA29	Roman	14	Sheep	-22.1	7.4	36.5	13.2	3.9	3.23
HA30	Roman	14	Sheep	-22.3	9.3	39.8	14.2	3.8	3.27
HA31	Iron Age	10	Cattle	-21.4	6.7	35.3	13.0	3.8	3.19
HA32	Iron Age	10	Cattle	-21.9	6.1	21.5	7.6	1.4	3.31
*HA34**	*Iron Age*	*10*	*Cattle*	*-23.3*	*3.6*	*7.4*	*2.4*	*0.3*	*3.51*
HA35	Roman	13	Cattle	-22.0	6.7	22.9	8.0	1.5	3.32
HA36	Roman	13	Cattle	-21.7	6.3	25.6	9.2	1.4	3.24
HA37	Roman	13	Sheep	-21.3	5.8	36.8	13.6	3.9	3.16
HA38	Roman	13	Sheep	-22.2	8.5	37.6	13.8	5.0	3.19

Sample	Period	Phase	Taxon	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C	%N	%Collagen	C:N
*HA41**	*Iron Age*	*10*	*Sheep*	*-23.9*	*3.8*	*9.3*	*3.2*	*0.5*	*3.44*
HA48	Bronze Age	8	Sheep	-22.0	7.8	35.2	12.3	5.9	3.33
HA52	Roman	14	Sheep	-22.1	7.6	32.6	11.7	2.3	3.24
*HA53**	*Neolithic*	*3*	*Cattle*	*0.0*	*-2.6*	*0.0*	*0.9*	*0.0*	*0.00*
HA54	Neolithic	3	Sheep	-22.0	8.7	25.8	8.9	1.6	3.37
HA55	Bronze Age	7	Cattle	-22.1	6.9	41.6	14.6	2.4	3.31
HA58	Bronze Age	8	Cattle	-21.6	5.3	31.5	11.5	3.7	3.20
HA59	Bronze Age	8	Cattle	-21.6	6.5	19.7	7.1	2.1	3.22
HA60	Bronze Age	8	Cattle	-22.5	6.3	38.4	14.0	5.0	3.19
HA61	Bronze Age	8	Pig	-21.4	7.8	35.4	13.0	4.0	3.19
HA62	Bronze Age	8	Pig	-21.4	7.4	33.0	12.1	5.4	3.18
HA63	Bronze Age	8	Pig	-20.1	9.6	34.1	12.2	2.8	3.27
HA64	Roman	14	Pig	-19.8	3.7	35.1	12.7	3.5	3.22
HA65	Roman	14	Pig	-21.0	5.6	41.7	15.1	7.1	3.21
HA67	Roman	14	Sheep	-21.1	8.6	39.9	14.4	5.2	3.25
HA68	Roman	14	Sheep	-21.1	8.5	38.5	14.2	9.1	3.18
HA71	Roman	14	Sheep	-21.3	4.6	40.1	14.7	8.0	3.20
HA72	Roman	14	Sheep	-21.6	7.7	37.7	13.6	5.3	3.23
HA73	Roman	14	Sheep	-22.0	6.7	39.4	14.5	5.5	3.17
Horton Kingsmead Quarry									
*HO8**	*Neolithic*	*1*	*Sheep*	*-22.6*	*7.3*	*13.5*	*4.4*	*0.6*	*3.60*
*HO18**	*Neolithic*	*1*	*Sheep*	*-22.9*	*6.3*	*13.5*	*4.5*	*0.6*	*3.52*
*HO19**	*Neolithic*	*1*	*Sheep*	*-26.0*	*2.1*	*3.0*	*0.4*	*0.1*	*7.59*
*HO20**	*Neolithic*	*1*	*Sheep*	*-23.1*	*5.9*	*9.1*	*2.4*	*0.4*	*4.42*
HO22	Neolithic	1	Pig	-19.3	9.1	33.6	11.8	4.9	3.32
HO40	Bronze Age	7	Sheep	-21.6	6.0	35.1	12.7	6.6	3.24
*HO62**	*Iron Age*	*12*	*Cattle*	*-22.3*	*5.3*	*17.9*	*6.3*	*1.2*	*3.34*
*HO63**	*Iron Age*	*12*	*Sheep*	*-21.8*	*5.8*	*16.6*	*5.7*	*0.8*	*3.39*
HO58	Iron Age	12	Sheep	-22.4	6.5	21.8	7.8	1.4	3.27
HO64	Iron Age	12	Cattle	-21.8	3.8	23.8	8.5	2.2	3.26
HO66	Iron Age	12	Cattle	-22.0	4.7	24.9	9.0	2.1	3.21
HO65	Iron Age	12	Sheep	-22.4	7.1	21.1	7.3	1.5	3.36
*HO67**	*Iron Age*	*12*	*Sheep*	*-22.9*	*3.6*	*9.3*	*3.4*	*0.5*	*3.19*
*HO68**	*Iron Age*	*12*	*Sheep*	*-22.0*	*4.4*	*22.1*	*7.9*	*1.6*	*3.29*
*HO69**	*Iron Age*	*12*	*Sheep*	*-22.8*	*6.2*	*13.5*	*4.3*	*0.6*	*3.68*
HO70	Iron Age	12	Sheep	-21.5	5.3	26.7	9.5	2.3	3.27
HO71	Iron Age	12	Sheep	-22.0	5.6	16.9	5.9	0.8	3.33
*HO72**	*Iron Age*	*12*	*Sheep*	*-22.8*	*8.1*	*13.7*	*4.5*	*0.6*	*3.56*
*HO73**	*Iron Age*	*12*	*Cattle*	*-24.0*	*-4.1*	*7.7*	*2.5*	*0.4*	*6.75*
*HO75**	*Iron Age*	*12*	*Pig*	*-22.7*	*9.2*	*15.3*	*5.3*	*0.8*	*3.39*
*HO76**	*Iron Age*	*12*	*Cattle*	*-23.7*	*5.5*	*6.5*	*1.8*	*0.3*	*4.09*
*HO79**	*Iron Age*	*12*	*Cattle*	*-23.1*	*5.9*	*7.3*	*2.3*	*0.3*	*3.81*
Heathrow Terminal 5									
HTV1	Roman	14	Sheep	-22.5	8.3	41.2	14.8	15.8	3.25
HTV2	Roman	14	Sheep	-22.6	10.8	37.9	13.6	11.8	3.27
*HTV3**	*Bronze Age*	*8*	*Cattle*	*-22.1*	*5.8*	*16.7*	*5.7*	*0.9*	*3.44*
HTV6	Iron Age	11	Cattle	-21.8	7.6	37.7	13.8	12.8	3.20
HTV7	Iron Age	12	Cattle	-22.0	6.7	35.7	12.8	9.3	3.27
*HTV8**	*Iron Age*	*11*	*Cattle*	*-26.8*	*-18.7*	*2.0*	*0.2*	*0.1*	*10.59*

Sample	Period	Phase	Taxon	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C	%N	%Collagen	C:N
*HTV9**	*Iron Age*	*11*	*Cattle*	*-28.3*	*-11.1*	*3.0*	*0.2*	*0.2*	*14.58*
HTV10	Iron Age	11	Cattle	-21.6	4.6	33.5	12.2	8.3	3.23
*HTV11**	*Iron Age*	*11*	*Cattle*	*-22.3*	*6.9*	*22.3*	*7.9*	*2.7*	*3.33*
HTV14	Bronze Age	7	Sheep	-21.5	8.2	40.8	14.9	14.9	3.20
HTV15	Bronze Age	7	Cattle	-22.2	7.3	35.3	12.6	6.5	3.28
HTV16	Bronze Age	7	Cattle	-22.5	4.4	31.3	11.0	5.6	3.33
HTV17	Bronze Age	7	Cattle	-23.5	4.9	37.7	13.4	11.7	3.28
HTV21	Iron Age	10	Sheep	-22.5	7.1	37.7	13.3	17.3	3.31
*HTV22**	*Bronze Age*	*7*	*Cattle*	*-26.2*	*-12.5*	*1.9*	*0.3*	*0.2*	*7.43*
*HTV24**	*Roman*	*14*	*Cattle*	*-24.8*	*-6.8*	*2.7*	*0.5*	*0.2*	*5.82*
HTV26	Roman	14	Cattle	-22.1	5.7	38.7	14.0	19.9	3.24
HTV27	Roman	14	Cattle	-21.2	6.9	36.6	13.3	13.2	3.20
HTV28	Roman	14	Cattle	-22.0	6.0	33.1	12.1	10.8	3.20
HTV30	Iron Age	11	Cattle	-21.5	6.9	39.4	14.4	15.0	3.19
HTV31	Iron Age	11	Cattle	-21.9	8.0	36.8	13.3	10.7	3.21
HTV32	Iron Age	11	Cattle	-21.6	6.5	36.6	13.4	12.9	3.18
HTV33	Iron Age	11	Sheep	-22.2	6.3	35.1	12.8	9.8	3.20
HTV34	Iron Age	11	Pig	-21.5	6.2	37.0	13.5	15.8	3.20
HTV35	Bronze Age	8	Sheep	-21.8	8.4	40.2	14.0	13.9	3.35
HTV36	Iron Age	10	Sheep	-21.5	6.8	33.0	12.0	10.7	3.20
HTV38	Iron Age	10	Sheep	-22.3	7.9	36.4	13.2	10.2	3.24
HTV39	Iron Age	10	Cattle	-22.6	6.8	37.7	13.8	18.3	3.18
HTV40	Iron Age	10	Cattle	-21.9	7.1	34.8	12.6	13.5	3.21
HTV41	Iron Age	12	Cattle	-21.3	4.9	35.4	12.9	14.5	3.20
HTV42	Iron Age	12	Cattle	-22.3	4.5	30.5	10.9	8.7	3.27
HTV43	Roman	14	Sheep	-22.4	7.6	38.5	13.8	17.5	3.26
HTV44	Roman	14	Sheep	-21.9	7.4	35.6	13.0	15.5	3.20
HTV45	Roman	14	Cattle	-21.3	6.3	40.5	14.6	17.5	3.24
HTV46	Roman	14	Cattle	-21.7	6.9	35.2	12.9	15.6	3.18
HTV47	Roman	14	Cattle	-21.8	7.3	44.4	16.2	24.2	3.21
HTV48	Iron Age	11	Cattle	-21.6	6.0	29.3	10.4	14.8	3.27
HTV49	Bronze Age	7	Sheep	-21.3	6.1	32.4	11.6	13.5	3.27
HTV50	Bronze Age	7	Sheep	-21.2	4.8	35.3	12.8	16.4	3.21
HTV51	Bronze Age	7	Sheep	-22.1	6.1	28.9	10.1	9.0	3.33
HTV52	Bronze Age	7	Sheep	-22.3	9.8	33.1	12.0	14.4	3.23
HTV53	Bronze Age	7	Sheep	-21.8	6.8	36.1	13.0	16.2	3.24
HTV54	Bronze Age	7	Sheep	-22.5	10.1	32.6	11.6	15.9	3.27
HTV55	Bronze Age	7	Sheep	-22.7	8.8	35.9	12.8	14.8	3.27
HTV56	Bronze Age	7	Sheep	-22.6	9.3	32.6	11.8	15.4	3.24
HTV57	Bronze Age	7	Sheep	-21.9	7.1	29.7	10.7	12.4	3.26
HTV58	Bronze Age	7	Cattle	-21.6	8.7	27.9	10.1	8.5	3.21
HTV59	Bronze Age	7	Cattle	-21.5	8.3	28.5	10.3	8.6	3.23
HTV60	Bronze Age	7	Cattle	-22.5	7.7	30.0	10.8	12.8	3.25
HTV61	Bronze Age	7	Cattle	-22.1	7.4	24.0	8.7	5.5	3.20
HTV62	Bronze Age	7	Cattle	-22.0	6.4	34.9	12.8	13.4	3.19
HTV63	Bronze Age	7	Cattle	-22.5	9.7	17.8	6.3	2.5	3.29
HTV64	Bronze Age	7	Sheep	-21.4	7.1	34.1	12.3	11.8	3.25
HTV65	Bronze Age	7	Sheep	-21.9	7.5	37.0	13.4	17.4	3.23
*HTV66**	*Roman*	*14*	*Cattle*	*-25.8*	*4.3*	*1.8*	*0.3*	*0.2*	*8.27*

Sample	Period	Phase	Taxon	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C	%N	%Collagen	C:N
Latton Lands									
LL43	Bronze Age	7	Cattle	-22.0	5.7	41.7	15.3	10.3	3.18
LL48	Bronze Age	7	Sheep	-21.1	8.3	30.2	10.9	1.3	3.23
LL52	Bronze Age	7	Sheep	-22.2	7.6	41.1	15.1	9.5	3.19
LL53	Bronze Age	7	Sheep	-22.4	8.2	40.0	14.6	10.4	3.20
Mount Farm Berinsfield									
MFB1	Bronze Age	7	Cattle	-20.6	7.3	33.5	12.2	2.0	3.19
MFB2	Bronze Age	7	Cattle	-21.9	6.1	36.8	13.4	3.8	3.21
MFB3	Bronze Age	7	Cattle	-22.1	7.0	19.7	6.9	1.9	3.32
MFB4	Bronze Age	7	Cattle	-21.8	7.1	29.3	10.5	2.8	3.25
MFB5	Bronze Age	7	Cattle	-21.6	6.4	34.3	12.4	2.5	3.23
MFB6	Bronze Age	7	Cattle	-22.1	6.0	39.1	14.4	5.7	3.18
MFB7	Bronze Age	7	Cattle	-22.1	5.9	31.8	11.6	2.9	3.21
MFB8	Bronze Age	7	Pig	-21.2	8.0	39.4	14.4	5.3	3.19
MFB9	Bronze Age	7	Sheep	-21.9	7.6	36.8	13.5	3.5	3.19
MFB10	Bronze Age	7	Cattle	-22.2	5.7	23.5	8.3	1.6	3.32
MFB11	Bronze Age	7	Cattle	-21.8	7.8	26.9	9.6	2.3	3.26
MFB12	Bronze Age	7	Cattle	-21.8	5.5	27.4	9.8	1.9	3.27
MFB13	Bronze Age	7	Cattle	-22.1	6.9	34.8	12.7	2.8	3.21
MFB14	Bronze Age	7	Cattle	-22.1	5.8	22.4	7.6	0.9	3.46
MFB15	Bronze Age	7	Sheep	-22.0	9.4	34.2	12.4	2.6	3.22
MFB16	Bronze Age	7	Sheep	-21.7	4.9	27.4	9.8	1.7	3.29
MFB17	Bronze Age	7	Sheep	-21.9	6.8	26.7	9.5	1.1	3.28
MFB18	Neolithic	3	Sheep	-21.4	6.6	39.6	14.8	10.1	3.13
MFB19	Neolithic	3	Sheep	-21.7	7.3	28.4	9.8	1.0	3.38
MFB20	Neolithic	3	Pig	-21.0	7.2	29.6	10.4	1.2	3.31
MFB21	Neolithic	3	Pig	-21.1	7.4	30.1	10.6	1.5	3.31
MFB22	Neolithic	3	Pig	-21.0	7.4	32.0	11.4	1.7	3.28
MFB23	Neolithic	3	Cattle	-23.1	6.3	35.8	12.8	3.1	3.26
MFB24	Neolithic	3	Cattle	-23.2	6.2	33.7	12.2	2.3	3.23
MFB25	Iron Age	9	Sheep	-21.8	6.7	17.9	6.3	1.8	3.32
MFB26	Iron Age	9	Sheep	-21.5	7.6	22.1	7.8	2.0	3.29
MFB27	Iron Age	9	Sheep	-21.5	7.3	24.7	8.8	2.1	3.27
MFB28	Iron Age	9	Pig	-21.7	8.9	31.3	11.4	3.2	3.20
MFB29	Iron Age	9	Cattle	-21.6	5.8	27.3	9.9	3.3	3.23
MFB30	Iron Age	9	Cattle	-21.9	5.5	25.8	9.2	2.9	3.27
*MFB31**	*Iron Age*	*9*	*Cattle*	*-22.2*	*3.9*	*26.9*	*9.7*	*2.8*	*3.24*
MFB32	Iron Age	9	Cattle	-22.3	5.6	19.2	6.8	1.7	3.28
MFB33	Iron Age	9	Cattle	-21.5	6.4	26.7	9.6	4.1	3.23
MFB34	Iron Age	9	Cattle	-22.0	6.0	38.2	13.9	6.1	3.23
MFB36	Iron Age	9	Sheep	-22.0	6.9	27.7	9.9	1.2	3.27
MFB37	Iron Age	9	Sheep	-22.4	10.2	43.4	15.7	9.5	3.23
MFB39	Iron Age	9	Pig	-22.0	7.3	32.9	11.9	2.9	3.24
MFB41	Iron Age	9	Pig	-22.1	7.8	30.5	10.9	1.9	3.26
MFB42	Iron Age	9	Pig	-21.4	10.7	32.5	11.8	4.1	3.23
MFB43	Iron Age	9	Pig	-21.9	7.7	33.7	12.2	8.3	3.22
MFB44	Iron Age	9	Pig	-22.1	7.9	37.0	13.5	9.5	3.19
*MFB45**	*Iron Age*	*9*	*Sheep*	*-22.4*	*6.4*	*21.8*	*7.8*	*1.7*	*3.24*
MFB46	Iron Age	9	Sheep	-21.5	5.1	38.0	13.9	13.5	3.19

Sample	Period	Phase	Taxon	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C	%N	%Collagen	C:N
MFB47	Iron Age	9	Sheep	-22.2	7.0	39.0	14.2	6.5	3.21
MFB48	Iron Age	9	Sheep	-22.1	7.3	48.3	17.7	7.8	3.19
MFB49	Iron Age	9	Sheep	-21.9	6.3	39.5	14.4	11.8	3.20
MFB51	Iron Age	9	Sheep	-22.0	7.6	38.5	14.0	10.9	3.20
MFB54	Iron Age	12	Cattle	-22.0	5.6	33.6	12.1	3.0	3.24
MFB56	Iron Age	12	Cattle	-21.9	5.0	24.2	8.7	2.8	3.25
MFB57	Iron Age	12	Cattle	-22.0	4.0	25.4	9.1	3.1	3.25
MFB58	Iron Age	12	Sheep	-21.8	6.3	26.4	9.5	2.9	3.25
MFB59	Iron Age	12	Sheep	-21.3	5.3	32.4	11.8	3.4	3.22
MFB60	Iron Age	12	Sheep	-21.8	6.8	48.1	17.6	4.5	3.21
MFB61	Iron Age	12	Sheep	-22.1	6.9	37.3	13.5	6.2	3.21
MFB62	Iron Age	12	Sheep	-21.7	4.0	31.5	11.4	4.4	3.25
MFB64	Iron Age	12	Cattle	-22.2	7.8	34.6	12.5	4.9	3.23
MFB65	Iron Age	12	Cattle	-21.6	6.3	29.1	10.5	2.8	3.26
MFB66	Iron Age	12	Sheep	-21.2	4.9	30.2	10.9	4.1	3.24
MFB67	Iron Age	12	Sheep	-21.6	7.1	34.3	12.5	4.1	3.22
MFB68	Iron Age	12	Pig	-21.9	6.6	36.3	13.2	3.4	3.20
MFB70	Iron Age	12	Pig	-21.6	8.8	34.4	12.4	3.0	3.23
MFB71	Iron Age	12	Cattle	-22.0	7.0	23.3	8.3	1.7	3.27
MFB72	Iron Age	12	Cattle	-21.9	7.3	41.5	15.3	10.8	3.17
MFB73	Iron Age	12	Sheep	-22.1	6.6	45.0	16.5	7.6	3.19
MFB74	Iron Age	12	Pig	-21.2	10.5	41.6	15.2	8.4	3.19
MFB76	Iron Age	12	Cattle	-22.0	6.9	38.4	14.0	6.6	3.22
MFB78	Iron Age	12	Sheep	-22.1	7.2	42.0	15.3	7.9	3.21
MFB79	Iron Age	12	Pig	-22.0	9.1	38.1	13.6	5.1	3.26
MFB81	Iron Age	12	Cattle	-21.9	8.6	30.5	10.9	2.3	3.28
MFB83	Iron Age	12	Cattle	-21.9	5.5	20.8	7.5	1.6	3.25
MFB84	Iron Age	12	Cattle	-22.2	5.3	26.9	9.8	3.2	3.22
MFB86	Iron Age	12	Pig	-21.3	8.1	21.7	7.8	2.0	3.26
MFB87	Iron Age	12	Pig	-21.7	6.6	38.1	13.9	6.5	3.20
*MFB88**	*Iron Age*	*12*	*Sheep*	*-23.0*	*4.5*	*29.3*	*11.0*	*2.2*	*3.19*
MFB89	Iron Age	12	Sheep	-21.6	5.6	31.0	11.0	1.9	3.30
MFB90	Iron Age	12	Sheep	-22.0	7.2	33.9	12.3	5.2	3.20
MFB91	Iron Age	12	Sheep	-21.7	7.2	40.3	14.5	8.3	3.24
MFB92	Iron Age	12	Sheep	-22.1	7.0	27.6	9.9	4.2	3.25
MFB93	Iron Age	12	Sheep	-22.1	7.2	34.0	12.3	5.0	3.24
MFB94	Iron Age	12	Cattle	-21.0	3.8	35.1	12.8	4.2	3.19
MFB95	Iron Age	12	Cattle	-21.5	4.7	32.2	11.8	4.1	3.20
MFB96	Iron Age	12	Pig	-21.9	6.5	38.3	14.0	11.1	3.19
MFB97	Iron Age	12	Pig	-22.0	8.1	32.4	11.5	3.5	3.29
MFB98	Roman	14	Cattle	-21.5	5.5	38.0	13.9	5.9	3.20
MFB99	Roman	14	Cattle	-21.3	5.1	39.7	14.5	7.6	3.20
MFB100	Roman	14	Sheep	-21.8	5.9	38.6	14.0	8.5	3.22
MFB101	Roman	14	Sheep	-21.9	6.8	41.0	15.1	11.7	3.18
MFB102	Roman	14	Sheep	-21.3	4.6	43.1	15.9	10.0	3.17
MFB103	Roman	14	Cattle	-21.4	6.3	30.8	11.3	3.9	3.20
MFB105	Roman	14	Cattle	-22.1	7.2	15.5	5.4	1.0	3.36
MFB106	Roman	14	Cattle	-21.7	8.0	28.5	10.3	4.4	3.23
MFB107	Roman	14	Cattle	-22.2	5.9	27.9	9.7	2.5	3.35

Sample	Period	Phase	Taxon	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C	%N	%Collagen	C:N
MFB108	Roman	14	Cattle	-22.2	5.4	26.8	9.4	2.0	3.34
MFB109	Roman	14	Sheep	-21.8	5.6	36.3	13.2	6.8	3.21
MFB110	Roman	14	Sheep	-21.7	5.5	22.9	8.2	2.4	3.28
MFB111	Roman	14	Sheep	-21.3	4.6	31.1	11.3	2.9	3.21
MFB112	Roman	14	Sheep	-21.6	4.3	20.6	7.3	2.1	3.26
MFB113	Roman	14	Sheep	-21.4	7.7	28.3	10.2	4.5	3.25
MFB114	Roman	14	Sheep	-22.0	6.9	33.1	11.7	2.2	3.31
MFB115	Roman	14	Pig	-21.8	7.8	35.8	13.0	7.3	3.21
MFB118	Roman	14	Cattle	-21.4	6.5	33.5	12.2	4.2	3.20
MFB119	Roman	14	Cattle	-21.4	8.0	40.7	15.0	9.6	3.17
MFB120	Roman	14	Pig	-22.0	8.3	24.4	8.8	1.5	3.26
MFB121	Roman	14	Cattle	-21.8	6.3	39.6	14.5	9.0	3.19
MFB122	Roman	14	Sheep	-21.6	7.4	38.7	14.2	8.1	3.18
MFB123	Iron Age	9	Cattle	-21.8	7.7	17.7	6.3	2.0	3.28
MFB124	Iron Age	9	Cattle	-22.0	6.5	23.6	8.4	2.3	3.28
MFB125	Iron Age	9	Sheep	-20.9	6.1	29.7	10.5	1.5	3.31
MFB126	Iron Age	9	Sheep	-22.6	6.3	27.5	9.4	3.4	3.42
MFB127	Iron Age	9	Cattle	-21.8	5.0	23.7	8.4	2.3	3.29
MFB128	Iron Age	9	Cattle	-21.9	7.5	22.9	8.2	2.5	3.27
MFB129	Iron Age	9	Cattle	-21.8	6.9	35.3	12.8	7.7	3.21
MFB131	Iron Age	9	Cattle	-21.5	6.0	26.5	9.5	2.8	3.23
MFB132	Iron Age	9	Sheep	-21.6	5.7	24.2	8.7	1.9	3.27
MFB133	Iron Age	9	Sheep	-22.0	7.5	39.5	12.9	3.0	3.59
MFB134	Iron Age	9	Pig	-22.1	8.2	21.3	7.6	1.8	3.29
MFB135	Iron Age	9	Pig	-22.0	7.2	28.0	10.1	2.2	3.25
MFB136	Iron Age	9	Pig	-20.8	9.5	42.9	15.3	7.3	3.27
MFB137	Iron Age	9	Sheep	-21.6	6.8	27.3	9.8	2.6	3.26
MFB138	Iron Age	9	Sheep	-21.7	7.7	28.7	10.4	2.9	3.24
MFB139	Roman	14	Sheep	-22.4	7.3	19.6	7.0	2.0	3.27
MFB140	Roman	14	Sheep	-22.0	8.4	39.7	14.5	6.8	3.19
MFB141	Roman	14	Sheep	-22.4	7.8	17.8	6.3	1.6	3.31
MFB142	Roman	14	Sheep	-22.2	8.1	23.5	8.4	1.4	3.27
MFB143	Roman	14	Sheep	-21.5	6.8	26.7	9.5	2.4	3.27
MFB144	Roman	14	Cattle	-21.7	6.3	21.3	7.6	3.8	3.26
MFB145	Roman	14	Pig	-22.2	9.3	28.4	10.3	3.6	3.23
MFB146	Roman	14	Cattle	-21.4	8.0	25.4	9.1	2.5	3.27
Runnymede									
RM1	Neolithic	2	Pig	-20.3	6.1	15.4	5.5	1.7	3.29
*RM2**	*Neolithic*	*2*	*Pig*	*-21.5*	*6.6*	*4.2*	*1.2*	*0.4*	*3.99*
*RM3**	*Neolithic*	*2*	*Pig*	*-22.2*	*7.4*	*3.4*	*0.9*	*0.3*	*4.31*
RM4	Neolithic	2	Cattle	-21.5	7.0	14.1	5.0	1.9	3.29
*RM5**	*Neolithic*	*2*	*Cattle*	*-20.0*	*7.0*	*14.7*	*5.3*	*2.1*	*3.24*
RM6	Neolithic	2	Cattle	-21.9	5.9	18.0	6.6	2.4	3.19
*RM7**	*Neolithic*	*2*	*Pig*	*-20.4*	*7.0*	*10.3*	*3.5*	*1.2*	*3.43*
*RM8**	*Neolithic*	*2*	*Cattle*	*-22.1*	*8.3*	*6.0*	*2.0*	*0.6*	*3.61*
*RM9**	*Neolithic*	*2*	*Cattle*	*-21.8*	*8.2*	*11.2*	*3.9*	*1.5*	*3.34*
RM10	Neolithic	2	Pig	-20.6	8.8	11.8	4.1	2.1	3.39
*RM11**	*Neolithic*	*2*	*Pig*	*-21.0*	*8.3*	*6.7*	*2.2*	*0.5*	*3.49*
RM12	Neolithic	2	Sheep	-21.2	7.9	13.5	4.6	1.6	3.40

Sample	Period	Phase	Taxon	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C	%N	%Collagen	C:N
RM13	Neolithic	2	Pig	-19.9	7.4	12.0	4.2	1.2	3.31
*RM14**	*Neolithic*	*2*	*Pig*	*-20.3*	*8.0*	*9.8*	*3.3*	*1.2*	*3.45*
RM15	Neolithic	2	Pig	-20.2	7.3	14.7	5.2	1.6	3.30
RM16	Neolithic	2	Cattle	-21.8	7.1	15.4	5.5	2.1	3.26
*RM17**	*Neolithic*	*2*	*Sheep*	*-21.9*	*7.0*	*11.1*	*3.6*	*0.8*	*3.59*
RM18	Neolithic	2	Pig	-20.2	7.3	15.5	5.6	1.6	3.25
RM19	Neolithic	2	Pig	-20.6	6.6	11.2	3.8	1.2	3.39
RM20	Neolithic	2	Pig	-19.9	6.4	14.0	4.9	1.6	3.32
*RM21**	*Neolithic*	*2*	*Sheep*	*-21.8*	*9.0*	*9.0*	*3.0*	*0.9*	*3.53*
RM22	Neolithic	2	Sheep	-21.9	8.0	17.6	6.2	2.5	3.32
RM23	Neolithic	2	Pig	-20.4	7.4	15.6	5.5	2.0	3.30
RM24	Neolithic	2	Cattle	-22.3	6.7	19.5	7.1	2.2	3.20
RM25	Neolithic	2	Cattle	-21.5	5.5	21.9	7.9	2.9	3.22
*RM26**	*Neolithic*	*2*	*Pig*	*-20.7*	*7.6*	*9.2*	*3.1*	*1.0*	*3.48*
RM27	Neolithic	2	Pig	-20.4	6.5	18.3	6.6	1.9	3.22
*RM28**	*Neolithic*	*2*	*Sheep*	*-22.6*	*7.4*	*11.2*	*3.4*	*1.3*	*3.81*
RM29	Neolithic	2	Sheep	-21.0	6.7	20.1	7.4	2.8	3.17
RM30	Neolithic	2	Cattle	-21.1	5.8	19.2	6.9	1.3	3.26
RM31	Neolithic	2	Cattle	-22.0	7.0	14.9	5.2	1.9	3.36
RM32	Neolithic	2	Pig	-19.9	7.3	15.9	5.7	2.1	3.25
*RM33**	*Neolithic*	*2*	*Pig*	*-20.4*	*7.9*	*8.7*	*3.0*	*0.8*	*3.45*
*RM34**	*Neolithic*	*2*	*Sheep*	*-21.7*	*7.5*	*13.6*	*4.5*	*1.7*	*3.52*
*RM35**	*Neolithic*	*2*	*Sheep*	*-21.3*	*12.3*	*9.2*	*2.8*	*1.1*	*3.83*
RM36	Neolithic	2	Sheep	-21.3	5.2	16.8	6.1	2.0	3.23
RM37	Neolithic	2	Sheep	-21.4	8.9	14.2	5.0	1.9	3.27
RM38	Neolithic	2	Sheep	-21.5	5.3	18.6	6.7	2.7	3.27
RM39	Neolithic	2	Cattle	-21.9	6.2	18.2	6.5	3.3	3.28
RM40	Neolithic	2	Cattle	-21.5	5.8	18.5	6.6	2.2	3.26
RM41	Neolithic	2	Cattle	-21.9	6.3	20.0	7.1	2.6	3.30
RM42	Neolithic	2	Cattle	-21.7	6.9	16.3	5.8	2.0	3.30
RM43	Neolithic	2	Cattle	-21.4	7.2	17.0	6.1	1.9	3.23
RM44	Neolithic	2	Pig	-20.6	7.2	17.4	6.2	2.2	3.28
RM45	Neolithic	2	Sheep	-21.5	7.3	18.7	6.6	2.2	3.31
RM46	Neolithic	2	Pig	-20.7	6.8	15.9	5.7	1.9	3.25
RM47	Neolithic	2	Cattle	-22.2	5.3	22.5	8.2	2.3	3.21
RM48	Neolithic	2	Cattle	-22.3	4.5	15.6	5.5	1.0	3.29
RM49	Neolithic	2	Cattle	-22.3	5.9	18.0	6.3	1.8	3.33
RM50	Neolithic	2	Pig	-20.2	6.0	23.3	8.4	2.4	3.23
RM51	Neolithic	2	Sheep	-20.8	6.6	19.6	7.0	2.0	3.27
RM52	Neolithic	2	Cattle	-21.9	6.1	20.7	7.4	2.4	3.27
RM53	Neolithic	2	Cattle	-21.6	6.6	17.7	6.3	2.5	3.28
RM54	Bronze Age	8	Pig	-20.8	5.1	34.1	12.5	8.4	3.18
RM55	Bronze Age	8	Cattle	-21.9	5.4	30.9	11.4	2.6	3.18
RM56	Bronze Age	8	Cattle	-21.6	4.2	38.0	14.0	9.2	3.18
RM57	Bronze Age	8	Cattle	-21.4	6.6	19.5	7.0	2.2	3.25
RM58	Bronze Age	8	Sheep	-21.5	8.4	28.4	10.4	5.2	3.19
RM59	Bronze Age	8	Sheep	-21.6	5.9	25.5	9.3	2.5	3.20
RM60	Bronze Age	8	Pig	-21.0	6.8	35.9	13.2	13.3	3.17
RM61	Bronze Age	8	Cattle	-21.3	4.4	33.3	12.3	9.1	3.16

Sample	Period	Phase	Taxon	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C	%N	%Collagen	C:N
RM62	Bronze Age	8	Sheep	-21.1	6.2	31.0	11.5	7.2	3.16
RM63	Bronze Age	8	Pig	-20.7	8.7	18.8	6.7	2.2	3.26
RM64	Bronze Age	8	Pig	-21.2	7.8	31.0	11.4	5.5	3.18
RM65	Bronze Age	8	Pig	-20.9	6.8	30.3	11.1	6.3	3.20
RM66	Bronze Age	8	Sheep	-21.5	8.6	26.6	9.8	3.2	3.18
RM67	Bronze Age	8	Pig	-20.6	4.6	28.8	10.5	5.1	3.21
RM68	Bronze Age	8	Pig	-20.7	4.6	25.2	9.0	4.5	3.26
RM69	Bronze Age	8	Cattle	-22.2	4.3	25.1	9.1	6.3	3.23
*RM70**	*Bronze Age*	*8*	*Cattle*	*-21.9*	*7.8*	*13.9*	*4.8*	*1.8*	*3.36*
RM71	Bronze Age	8	Sheep	-22.1	7.7	22.3	8.1	0.0	3.21
RM72	Bronze Age	8	Sheep	-21.1	9.2	27.9	10.1	5.5	3.22
RM73	Bronze Age	8	Pig	-20.4	5.0	27.7	10.1	6.6	3.22
RM74	Bronze Age	8	Cattle	-21.3	4.5	27.7	10.1	5.7	3.21
RM75	Bronze Age	8	Sheep	-22.0	7.0	25.9	9.3	6.2	3.26
RM76	Bronze Age	8	Sheep	-21.7	7.7	31.0	11.4	9.1	3.18
RM77	Bronze Age	8	Pig	-21.1	4.5	35.3	12.9	7.0	3.20
RM78	Bronze Age	8	Sheep	-21.6	7.3	29.9	10.8	5.5	3.23
RM79	Bronze Age	8	Sheep	-21.2	6.8	31.1	11.3	7.0	3.22
*RM80**	*Bronze Age*	*8*	*Sheep*	*-21.5*	*6.9*	*16.0*	*5.3*	*2.0*	*3.50*
RM81	Bronze Age	8	Sheep	-20.7	8.1	22.5	8.0	4.8	3.29
RM82	Bronze Age	8	Pig	-20.8	6.5	30.6	11.1	9.2	3.23
RM83	Bronze Age	8	Cattle	-21.7	4.7	31.6	11.5	5.9	3.22
RM84	Bronze Age	8	Pig	-20.8	4.0	33.9	12.2	8.0	3.24
RM85	Bronze Age	8	Sheep	-22.6	7.6	33.3	12.2	7.0	3.19
*RM86**	*Bronze Age*	*8*	*Pig*	*-20.6*	*4.5*	*29.3*	*10.6*	*6.4*	*3.23*
*RM87**	*Bronze Age*	*8*	*Cattle*	*-22.2*	*6.2*	*16.1*	*5.8*	*1.5*	*3.26*
*RM88**	*Bronze Age*	*8*	*Pig*	*-20.7*	*4.1*	*37.4*	*13.5*	*5.9*	*3.22*
RM89	Bronze Age	8	Pig	-21.3	7.3	27.6	9.7	3.4	3.32
RM90	Bronze Age	8	Cattle	-21.7	7.7	28.5	10.1	3.4	3.29
RM91	Bronze Age	8	Cattle	-22.7	3.1	17.4	6.0	1.7	3.40
RM92	Bronze Age	8	Pig	-21.1	7.2	31.7	11.3	4.2	3.27
*RM93**	*Bronze Age*	*8*	*Cattle*	*-21.9*	*6.2*	*12.6*	*4.1*	*2.2*	*3.60*
RM94	Bronze Age	8	Cattle	-21.8	6.5	28.2	10.0	4.7	3.31
RM95	Bronze Age	8	Sheep	-21.8	6.5	26.3	9.2	3.8	3.34
RM96	Bronze Age	8	Sheep	-21.2	6.4	27.4	9.6	4.3	3.31
RM97	Bronze Age	8	Pig	-21.0	6.6	35.5	12.7	7.3	3.26
RM98	Bronze Age	8	Sheep	-21.1	5.9	31.0	10.8	4.5	3.36
*RM99**	*Bronze Age*	*8*	*Cattle*	*-22.0*	*6.1*	*22.0*	*7.6*	*4.3*	*3.39*
RM100	Bronze Age	8	Cattle	-21.2	5.8	32.6	11.6	7.2	3.28
RM101	Bronze Age	8	Pig	-21.3	6.1	30.0	10.4	4.0	3.37
RM102	Bronze Age	8	Sheep	-21.6	6.0	20.7	7.1	3.3	3.42
RM103	Bronze Age	8	Sheep	-22.2	7.4	27.9	9.9	7.2	3.30
RM104	Bronze Age	8	Pig	-22.0	5.0	26.7	9.4	4.6	3.30
RM105	Bronze Age	8	Cattle	-21.7	6.8	25.2	9.0	5.2	3.27
RM106	Bronze Age	8	Cattle	-22.1	6.7	34.3	12.3	5.0	3.27
RM107	Bronze Age	8	Pig	-21.5	6.0	20.5	7.1	2.7	3.37
RM108	Bronze Age	8	Sheep	-21.6	6.6	30.2	10.6	4.7	3.34
RM109	Bronze Age	8	Sheep	-21.5	6.2	30.2	10.8	6.2	3.27
RM110	Bronze Age	8	Pig	-21.4	6.4	22.7	7.9	3.2	3.35

Sample	Period	Phase	Taxon	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C	%N	%Collagen	C:N
RM111	Bronze Age	8	Cattle	-21.8	6.2	24.7	8.7	4.1	3.32
RM112	Bronze Age	8	Cattle	-21.5	8.8	33.6	12.1	10.3	3.24
RM113	Bronze Age	8	Cattle	-21.9	6.6	21.4	7.5	2.5	3.32
RM114	Neolithic	2	Cattle	-21.8	6.6	37.5	13.6	17.6	3.23
RM115	Neolithic	2	Cattle	-21.8	5.6	37.7	13.6	15.7	3.24
RM116	Neolithic	2	Cattle	-22.0	4.9	36.6	13.3	15.5	3.23
RM117	Neolithic	2	Cattle	-22.5	7.1	38.7	13.6	13.7	3.32
RM118	Neolithic	2	Pig	-20.6	7.3	32.2	11.5	9.1	3.28
RM119	Neolithic	2	Pig	-20.5	5.5	36.6	12.4	8.9	3.43
RM120	Neolithic	2	Cattle	-20.3	5.0	37.6	13.2	15.2	3.33
RM121	Neolithic	2	Sheep	-21.3	5.2	36.4	12.9	13.8	3.29
RM122	Neolithic	2	Pig	-19.6	5.8	37.9	13.4	17.9	3.30
RM123	Neolithic	2	Cattle	-22.2	5.2	35.8	12.9	11.4	3.24
RM124	Neolithic	2	Cattle	-21.8	7.2	37.8	13.5	16.4	3.26
RM125	Neolithic	2	Cattle	-22.1	5.6	36.6	13.2	16.2	3.24
*RM126**	*Neolithic*	*2*	*Pig*	*-20.6*	*6.3*	*34.8*	*12.5*	*17.5*	*3.27*
*RM127**	*Neolithic*	*2*	*Pig*	*-21.2*	*5.9*	*38.1*	*13.3*	*13.0*	*3.35*
*RM128**	*Neolithic*	*2*	*Pig*	*-20.7*	*6.8*	*38.8*	*13.7*	*16.4*	*3.31*
RM129	Neolithic	2	Sheep	-21.4	5.9	33.9	11.9	8.6	3.32
RM130	Neolithic	2	Cattle	-22.1	8.6	38.5	13.6	17.9	3.30
RM131	Neolithic	2	Pig	-19.7	7.4	36.9	13.1	13.1	3.28
RM132	Neolithic	2	Pig	-20.5	6.9	31.6	11.0	5.6	3.35
RM133	Neolithic	2	Pig	-20.4	6.5	34.4	12.0	8.5	3.35
RM134	Neolithic	2	Cattle	-22.3	6.8	35.1	12.5	10.4	3.27
RM135	Neolithic	2	Cattle	-22.1	6.3	39.9	14.4	14.2	3.23
RM136	Neolithic	2	Sheep	-21.9	5.6	35.0	11.9	9.5	3.43
RM137	Neolithic	2	Pig	-20.3	6.0	32.4	11.2	8.4	3.38
*RM138**	*Neolithic*	*2*	*Sheep*	*-22.7*	*4.4*	*26.2*	*7.7*	*4.1*	*3.98*
RM139	Neolithic	2	Sheep	-21.3	5.5	37.3	13.2	13.4	3.30
RM140	Neolithic	2	Sheep	-21.3	7.3	41.8	14.8	15.4	3.29
*RM141**	*Neolithic*	*2*	*Sheep*	*-24.3*	*5.8*	*13.4*	*3.2*	*1.8*	*4.87*
RM142	Neolithic	2	Sheep	-21.7	5.6	37.7	13.3	11.8	3.32
RM143	Neolithic	2	Sheep	-21.4	6.6	37.5	13.3	12.5	3.28
*RM144**	*Neolithic*	*2*	*Sheep*	*-21.4*	*6.5*	*33.3*	*11.5*	*7.3*	*3.38*
Shorncote Quarry									
SQ1	Bronze Age	8	Cattle	-22.3	7.8	43.7	14.6	3.5	3.49
SQ2	Bronze Age	8	Cattle	-23.2	6.5	42.3	14.1	6.6	3.49
SQ3	Bronze Age	8	Cattle	-21.8	5.6	30.8	11.0	3.2	3.26
SQ4	Bronze Age	8	Cattle	-22.9	6.0	32.4	11.7	2.6	3.23
SQ5	Bronze Age	8	Cattle	-22.6	4.7	33.3	12.1	3.6	3.21
SQ6	Bronze Age	8	Cattle	-23.5	6.4	36.6	12.3	4.6	3.49
Staines Road Farm									
SRF1	Neolithic	2	Pig	-19.8	3.9	23.2	8.5	4.4	3.18
SRF2	Neolithic	2	Sheep	-21.4	5.7	31.7	11.4	5.8	3.22
*SRF3**	*Neolithic*	*2*	*Cattle*	*-22.3*	*4.5*	*3.9*	*1.0*	*0.3*	*4.32*
SRF4	Neolithic	2	Pig	-20.5	6.3	28.2	10.2	3.6	3.24
SRF5	Neolithic	2	Cattle	-21.3	5.9	30.6	11.1	4.1	3.21
SRF6	Neolithic	2	Cattle	-22.3	5.5	26.6	10.0	5.4	3.09
SRF7	Neolithic	2	Cattle	-22.4	6.1	27.6	10.3	5.0	3.11

Sample	Period	Phase	Taxon	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C	%N	%Collagen	C:N
SRF8	Neolithic	2	Pig	-21.5	6.8	33.9	12.2	5.1	3.23
SRF9	Neolithic	2	Pig	-20.9	6.2	20.5	7.5	2.7	3.19
SRF10	Neolithic	2	Pig	-20.7	6.6	23.5	8.6	2.2	3.18
SRF11	Neolithic	2	Cattle	-21.9	5.8	17.7	6.5	2.6	3.17
SRF12	Neolithic	2	Cattle	-22.9	5.4	25.6	9.5	4.9	3.15
SRF13	Neolithic	2	Cattle	-21.8	6.4	25.7	9.6	4.7	3.13
SRF14	Neolithic	2	Cattle	-22.3	5.2	21.4	8.1	2.9	3.08
SRF15	Neolithic	2	Pig	-20.5	6.1	21.6	8.0	3.2	3.15
SRF16	Neolithic	2	Cattle	-21.5	5.2	20.2	7.5	2.5	3.14
SRF17	Neolithic	2	Sheep	-23.5	5.4	27.8	10.1	5.3	3.21
SRF18	Neolithic	2	Cattle	-23.2	5.9	21.7	7.9	2.2	3.21
SRF19	Neolithic	2	Cattle	-22.7	6.2	27.2	9.8	3.1	3.22
SRF20	Neolithic	2	Pig	-20.1	6.2	23.9	8.7	3.0	3.20
SRF22	Neolithic	2	Cattle	-21.4	5.9	19.9	7.4	2.6	3.14
SRF23	Neolithic	2	Cattle	-23.1	5.8	17.9	6.5	1.7	3.18
SRF24	Neolithic	2	Cattle	-21.8	5.4	24.0	9.0	-	3.12
SRF25	Neolithic	2	Cattle	-22.7	6.0	16.1	5.9	-	3.19
SRF26	Neolithic	2	Cattle	-22.8	7.3	16.9	6.1	-	3.19
SRF27	Neolithic	2	Cattle	-23.0	6.8	21.5	8.0	1.8	3.15
SRF28	Neolithic	2	Cattle	-22.0	4.5	26.4	9.7	4.9	3.19
SRF29	Neolithic	2	Pig	-20.5	6.6	20.3	7.6	3.1	3.10
SRF30	Neolithic	2	Cattle	-22.9	5.7	21.3	8.1	2.8	3.11
SRF31	Neolithic	2	Pig	-19.7	5.1	36.2	13.3	9.3	3.19
SRF32	Neolithic	2	Sheep	-21.8	5.7	20.8	7.9	1.9	3.06
SRF33	Neolithic	2	Sheep	-21.8	6.3	17.8	6.8	1.9	3.07
SRF34	Neolithic	2	Cattle	-22.2	6.4	26.3	9.7	2.8	3.13
SRF35	Neolithic	2	Pig	-19.6	6.6	25.7	9.3	3.4	3.20
Thornhill Farm									
TF9	Iron Age	10	Cattle	-21.4	5.6	37.4	13.5	8.1	3.23
TF10	Iron Age	10	Sheep	-21.1	3.2	36.6	12.9	3.6	3.30
TF11	Roman	13	Pig	-21.0	7.8	38.0	13.4	4.0	3.31
TF18	Iron Age	10	Pig	-21.4	5.7	41.6	15.0	9.4	3.24
TF19	Iron Age	10	Sheep	-20.7	3.3	43.0	15.5	12.4	3.23
TF30	Iron Age	10	Cattle	-21.8	1.6	31.2	10.5	1.9	3.46
TF42	Roman	13	Sheep	-21.4	5.2	36.9	12.7	3.7	3.40
TF43	Roman	13	Cattle	-21.8	7.2	34.6	12.4	3.8	3.27
TF47	Roman	13	Cattle	-21.7	2.6	39.3	13.8	4.1	3.32
TF52	Roman	13	Cattle	-21.8	6.9	42.3	15.3	13.0	3.23
TF59	Iron Age	10	Sheep	-21.4	5.8	39.5	14.2	10.9	3.24
TF61	Iron Age	10	Cattle	-21.7	5.3	42.6	15.7	16.8	3.17
TF62	Iron Age	10	Cattle	-21.7	6.4	40.5	14.7	13.8	3.21
TF63	Roman	13	Cattle	-21.4	5.6	39.6	14.4	12.0	3.21
TF64	Roman	13	Sheep	-21.6	4.8	42.7	15.6	16.6	3.20
TF65	Roman	13	Sheep	-21.5	5.6	39.6	14.4	11.5	3.21
TF66	Roman	13	Sheep	-21.6	5.2	41.6	15.1	14.0	3.21
TF67	Roman	13	Cattle	-21.6	6.1	41.8	14.9	11.5	3.26
TF68	Roman	13	Cattle	-21.4	5.8	37.9	13.5	3.7	3.27
TF69	Roman	13	Cattle	-21.2	5.5	44.8	16.5	14.8	3.17
TF70	Roman	13	Sheep	-21.8	5.8	43.2	15.7	14.1	3.21

Sample	Period	Phase	Taxon	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C	%N	%Collagen	C:N
TF71	Roman	13	Pig	-21.4	7.7	32.3	11.7	10.4	3.23
TF72	Roman	13	Sheep	-21.6	7.1	48.2	17.7	15.0	3.18
TF73	Roman	13	Sheep	-22.2	6.2	41.8	15.2	14.5	3.20
TF75	Roman	13	Sheep	-21.8	6.2	41.7	15.0	13.8	3.25
TF79	Roman	13	Cattle	-21.3	4.4	36.2	13.0	7.6	3.25
TF80	Roman	13	Cattle	-21.8	7.0	38.1	13.9	11.4	3.20
TF81	Roman	13	Cattle	-21.8	5.5	37.2	13.6	10.2	3.20
TF84	Roman	13	Pig	-21.1	8.5	42.0	15.3	12.4	3.20
TF89	Iron Age	10	Cattle	-21.4	5.8	38.5	14.2	13.1	3.16
TF91	Iron Age	11	Sheep	-21.7	5.0	34.7	12.5	11.5	3.25
Thorpe Lea Nurseries									
TLN1	Iron Age	11	Cattle	-21.7	6.9	41.3	14.9	14.3	3.24
TLN2	Iron Age	11	Cattle	-21.6	6.0	29.9	10.9	4.0	3.22
TLN3	Iron Age	11	Cattle	-21.5	8.1	18.2	6.4	3.0	3.31
TLN4	Iron Age	11	Cattle	-21.6	8.1	34.3	12.3	7.7	3.25
TLN5	Iron Age	11	Cattle	-22.0	7.8	14.8	5.2	1.9	3.33
TLN6	Iron Age	11	Sheep	-21.9	8.4	25.1	9.0	2.5	3.26
TLN7	Iron Age	11	Sheep	-21.5	6.9	34.6	12.7	8.2	3.19
TLN9	Roman	15	Pig	-21.3	7.9	26.0	9.3	4.0	3.26
TLN10	Roman	15	Cattle	-21.6	7.9	15.3	5.5	2.8	3.26
TLN11	Roman	13	Cattle	-21.5	7.9	20.5	7.2	1.9	3.32
TLN12	Iron Age	11	Pig	-21.7	8.5	38.9	13.9	14.4	3.27
TLN13	Iron Age	11	Sheep	-22.3	7.7	30.0	10.8	6.7	3.23
TLN14	Iron Age	11	Pig	-21.4	8.9	39.7	14.0	9.6	3.30
TLN15	Iron Age	11	Pig	-21.9	9.0	33.3	11.9	3.7	3.27
TLN17	Iron Age	11	Pig	-21.4	7.9	30.0	10.7	5.3	3.26
TLN18	Iron Age	11	Cattle	-21.7	7.0	19.8	7.0	2.7	3.29
TLN19	Roman	15	Cattle	-21.8	8.1	30.1	10.8	6.5	3.26
TLN20	Roman	15	Sheep	-21.8	8.2	24.7	8.9	2.4	3.25
TLN21	Roman	15	Cattle	-21.6	7.6	22.4	8.0	3.2	3.26
TLN22	Roman	15	Cattle	-21.4	7.5	21.1	7.6	2.6	3.24
TLN23	Roman	13	Cattle	-21.7	7.1	14.5	5.2	2.6	3.22
TLN24	Roman	13	Sheep	-22.2	10.0	26.3	9.6	7.5	3.21
TLN25	Roman	13	Sheep	-21.1	6.0	29.4	10.7	7.0	3.20
TLN26	Roman	13	Sheep	-22.1	10.2	26.9	9.9	6.0	3.18
TLN28	Roman	15	Cattle	-21.7	6.4	18.1	6.6	3.0	3.20
TLN29	Roman	15	Cattle	-22.1	4.0	18.5	6.5	2.5	3.34
TLN30	Iron Age	11	Sheep	-21.9	7.7	31.8	11.4	7.5	3.25
*TLN31**	*Roman*	*13*	*Cattle*	*-21.0*	*4.3*	*13.2*	*4.8*	*0.9*	*3.21*
TLN32	Roman	13	Cattle	-21.3	7.6	27.7	10.2	6.5	3.18
TLN33	Iron Age	11	Cattle	-21.4	6.6	27.6	9.9	4.3	3.24
TLN34	Iron Age	11	Sheep	-22.0	7.9	28.8	10.3	4.0	3.27
TLN35	Iron Age	11	Pig	-21.8	8.2	15.8	5.6	2.9	3.32
TLN36	Roman	13	Sheep	-21.6	7.2	31.4	10.9	2.9	3.35
TLN37	Roman	13	Sheep	-21.5	7.7	19.7	7.0	5.1	3.31
*TLN38**	*Roman*	*13*	*Cattle*	*-22.2*	*7.4*	*16.2*	*5.4*	*2.1*	*3.47*
TLN39	Roman	13	Cattle	-20.9	7.3	18.1	6.5	4.6	3.23
TLN40	Iron Age	11	Pig	-21.9	8.8	27.3	10.0	5.9	3.20
TLN42	Iron Age	11	Sheep	-20.7	6.6	13.2	4.7	2.0	3.31

Sample	Period	Phase	Taxon	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C	%N	%Collagen	C:N
TLN43	Iron Age	11	Cattle	-21.6	6.7	33.7	12.3	13.3	3.20
TLN45	Roman	15	Sheep	-22.0	7.0	41.6	14.8	14.0	3.29
TLN46	Roman	13	Cattle	-21.9	5.0	14.6	4.9	2.2	3.49
*TLN48**	*Roman*	*15*	*Pig*	*-22.3*	*8.2*	*9.4*	*3.0*	*1.3*	*3.62*
TLN49	Roman	15	Sheep	-21.3	7.1	40.4	14.6	18.2	3.24
TLN50	Roman	15	Sheep	-21.9	8.9	31.6	11.3	6.4	3.26
TLN51	Roman	15	Cattle	-21.8	7.6	22.2	7.8	3.4	3.30
TLN52	Iron Age	11	Pig	-21.4	7.8	33.0	11.9	9.7	3.22
TLN53	Iron Age	11	Pig	-21.1	5.0	25.2	9.1	3.7	3.25
TLN54	Roman	15	Sheep	-21.7	6.9	33.8	12.3	12.7	3.22
TLN56	Roman	13	Pig	-21.9	8.7	36.9	13.3	15.2	3.23
TLN57	Roman	13	Cattle	-21.7	7.0	38.3	13.8	7.6	3.25
TLN58	Roman	13	Cattle	-21.2	6.6	24.0	8.9	5.1	3.17
TLN59	Roman	13	Cattle	-21.5	8.2	19.9	7.0	2.7	3.29
TLN60	Roman	13	Pig	-20.5	9.4	35.1	12.7	9.5	3.22
TLN61	Roman	13	Sheep	-21.7	6.7	31.7	11.5	8.6	3.21
TLN62	Iron Age	11	Sheep	-21.2	6.7	31.3	11.2	6.3	3.26
TLN63	Iron Age	11	Cattle	-21.7	7.0	42.0	15.2	12.2	3.22
TLN64	Iron Age	11	Sheep	-21.6	8.3	39.5	14.4	11.4	3.21
*TLN65**	*Roman*	*15*	*Cattle*	*-21.4*	*5.6*	*14.4*	*5.0*	*2.4*	*3.39*
*TLN66**	*Roman*	*13*	*Cattle*	*-23.5*	*7.4*	*3.6*	*0.8*	*0.5*	*5.36*
*TLN67**	*Roman*	*13*	*Pig*	*-22.0*	*5.5*	*5.6*	*1.7*	*0.3*	*3.82*
*TLN68**	*Roman*	*13*	*Sheep*	*-23.1*	*7.2*	*2.3*	*0.5*	*0.2*	*5.09*
TLN70	Roman	15	Cattle	-21.3	5.9	29.8	10.5	6.4	3.32
TLN71	Roman	15	Sheep	-21.5	6.9	32.9	11.9	14.5	3.24
TLN72	Roman	15	Sheep	-20.5	8.2	35.2	12.6	16.1	3.27
*TLN73**	*Roman*	*15*	*Cattle*	*-22.3*	*8.2*	*17.3*	*5.8*	*4.4*	*3.52*
TLN74	Roman	15	Sheep	-21.8	6.5	36.9	13.1	4.8	3.27
TLN75	Roman	15	Sheep	-21.3	6.2	34.8	12.4	8.5	3.29
*TLN76**	*Roman*	*15*	*Cattle*	*-22.1*	*3.4*	*16.9*	*5.6*	*3.3*	*3.53*
TLN77	Roman	15	Cattle	-21.6	5.6	25.0	8.7	3.5	3.35
TLN78	Roman	15	Pig	-21.1	7.9	34.3	12.1	11.3	3.30
TLN79	Roman	15	Sheep	-21.0	8.7	21.5	7.4	4.5	3.37
TLN81	Roman	13	Sheep	-21.3	8.9	22.4	8.0	4.5	3.28
TLN82	Roman	13	Cattle	-21.3	7.4	32.7	11.8	8.1	3.24
TLN83	Roman	13	Cattle	-20.9	7.4	17.0	6.0	3.5	3.33
*TLN85**	*Roman*	*13*	*Cattle*	*-25.6*	*-3.9*	*1.3*	*0.1*	*0.1*	*10.50*
TLN86	Roman	15	Pig	-21.0	8.7	38.6	13.6	8.9	3.32
*TLN87**	*Roman*	*15*	*Sheep*	*-22.5*	*3.5*	*2.9*	*0.8*	*0.3*	*4.34*
TLN89	Roman	15	Sheep	-21.6	8.6	27.1	9.7	5.5	3.25
TLN90	Roman	15	Sheep	-21.4	7.6	29.8	10.6	5.8	3.27
TLN91	Roman	15	Sheep	-21.5	8.9	35.4	12.6	9.6	3.28
TLN92	Roman	15	Pig	-21.2	9.5	29.6	10.6	5.6	3.27
TLN93	Roman	15	Cattle	-21.4	8.9	26.3	9.1	1.2	3.38
TLN94	Roman	15	Cattle	-21.3	9.1	28.8	10.3	6.9	3.29
TLN951	Roman	15	Sheep	-21.5	8.8	35.0	12.6	9.2	3.24
TLN952	Roman	15	Cattle	-21.3	6.6	22.2	8.0	3.0	3.24
*TLN96**	*Roman*	*15*	*Cattle*	*-21.5*	*6.9*	*15.0*	*5.6*	*1.6*	*3.15*
TLN97	Roman	15	Sheep	-20.8	9.4	44.4	16.0	16.4	3.24

Sample	Period	Phase	Taxon	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C	%N	%Collagen	C:N
TLN98	Roman	15	Sheep	-21.6	8.0	43.4	15.8	19.0	3.21
TLN99	Roman	15	Pig	-21.6	9.9	24.2	8.5	4.4	3.33
TLN100	Roman	15	Sheep	-22.1	5.7	32.5	11.9	7.4	3.19
TLN101	Roman	15	Sheep	-20.7	4.0	28.2	10.2	3.3	3.22
TLN102	Roman	15	Sheep	-21.7	6.6	54.0	19.8	19.7	3.18
TLN103	Roman	15	Cattle	-21.6	7.8	34.5	12.5	9.2	3.22
TLN104	Roman	15	Cattle	-21.2	5.1	32.8	12.0	6.8	3.19
*TLN105**	*Roman*	*15*	*Cattle*	*-22.7*	*0.5*	*3.2*	*1.0*	*0.3*	*3.88*
*TLN106**	*Roman*	*15*	*Cattle*	*-23.8*	*6.7*	*3.1*	*0.8*	*0.2*	*4.30*
*TLN108**	*Roman*	*15*	*Cattle*	*-24.8*	*4.2*	*1.9*	*0.3*	*0.1*	*7.01*
*TLN109**	*Roman*	*15*	*Cattle*	*-24.9*	*5.6*	*2.5*	*0.5*	*0.2*	*5.41*
*TLN110**	*Roman*	*15*	*Sheep*	*-21.9*	*8.1*	*28.4*	*10.3*	*5.4*	*3.22*
TLN112	Roman	13	Cattle	-21.9	6.3	33.2	12.2	11.1	3.18
TLN113	Roman	13	Cattle	-21.7	6.2	22.4	8.1	3.2	3.23
TLN115	Roman	13	Cattle	-22.1	7.5	21.3	7.8	3.4	3.17
TLN117	Iron Age	11	Sheep	-22.0	8.9	30.0	11.1	7.8	3.14
*TLN118**	*Iron Age*	*11*	*Pig*	*-22.5*	*10.0*	*17.5*	*6.2*	*1.5*	*3.33*
*TLN119**	*Iron Age*	*11*	*Pig*	*-21.9*	*8.3*	*11.6*	*3.8*	*1.5*	*3.53*
TLN120	Iron Age	11	Pig	-21.9	9.2	28.4	10.5	8.0	3.15
TLN122	Roman	13	Pig	-20.4	6.5	25.9	9.2	4.7	3.27
TLN123	Roman	13	Sheep	-20.2	11.8	31.8	11.6	8.5	3.19
*TLN124**	*Iron Age*	*11*	*Pig*	*-21.8*	*9.4*	*27.0*	*9.7*	*5.1*	*3.25*
TLN125	Roman	13	Sheep	-21.6	7.4	28.0	10.1	4.4	3.23
*TLN126**	*Roman*	*13*	*Cattle*	*-21.6*	*6.3*	*11.1*	*3.9*	*0.9*	*3.32*
*TLN127**	*Roman*	*13*	*Cattle*	*-20.3*	*7.5*	*13.8*	*5.0*	*2.2*	*3.25*
TLN128	Roman	13	Cattle	-21.7	6.5	39.2	14.4	18.4	3.18
TLN129	Iron Age	11	Sheep	-22.0	8.2	42.7	15.5	15.8	3.21
TLN130	Roman	13	Sheep	-21.6	6.4	42.0	15.1	11.3	3.25
TLN131	Roman	13	Sheep	-22.2	9.4	16.2	5.7	3.2	3.29
TLN132	Iron Age	11	Sheep	-22.2	8.2	38.0	13.5	3.3	3.28
*TLN133**	*Iron Age*	*11*	*Cattle*	*-21.8*	*7.2*	*33.6*	*12.2*	*6.0*	*3.20*
TLN134	Iron Age	11	Cattle	-21.9	6.4	33.4	12.3	7.0	3.18
TLN135	Iron Age	11	Cattle	-22.1	7.3	33.7	12.3	5.5	3.21
TLN136	Iron Age	11	Cattle	-23.1	7.5	19.4	6.5	1.3	3.50
TLN137	Iron Age	11	Cattle	-21.4	7.6	31.2	11.6	8.5	3.14
TLN138	Iron Age	11	Sheep	-22.0	6.2	41.4	15.3	16.4	3.16
TLN139	Iron Age	11	Pig	-21.4	9.0	25.4	9.4	4.4	3.18
TLN140	Iron Age	11	Cattle	-21.6	7.4	25.1	9.1	2.9	3.20
TLN141	Iron Age	11	Pig	-21.5	10.5	27.5	10.0	6.1	3.20
TLN142	Iron Age	11	Sheep	-21.7	8.1	36.8	13.6	10.1	3.17
TLN143	Iron Age	11	Sheep	-21.5	8.2	32.5	12.0	9.6	3.15
TLN144	Roman	13	Sheep	-21.9	7.6	40.8	14.9	12.7	3.20
TLN145	Roman	13	Sheep	-22.2	6.7	36.3	13.2	6.0	3.21
TLN146	Roman	15	Sheep	-21.8	7.3	36.8	13.2	5.5	3.26
TLN147	Roman	15	Pig	-21.6	7.1	34.1	12.5	11.9	3.20
Watkins Farm									
WF1	Iron Age	10	Cattle	-21.7	3.7	39.3	14.1	18.9	3.26
WF2	Iron Age	10	Pig	-21.6	7.6	38.1	13.5	17.1	3.30
WF3	Iron Age	10	Cattle	-21.4	4.4	39.9	14.1	12.2	3.30

Sample	Period	Phase	Taxon	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C	%N	%Collagen	C:N
WF5	Iron Age	10	Cattle	-21.9	5.2	40.4	14.2	9.5	3.31
WF6	Iron Age	10	Cattle	-21.6	4.1	39.7	13.9	26.1	3.33
WF8	Iron Age	10	Sheep	-21.9	7.6	41.2	14.8	14.8	3.25
WF9	Roman	13	Sheep	-21.7	3.8	42.2	14.8	9.0	3.32
WF10	Roman	13	Cattle	-22.0	7.0	43.9	15.5	16.1	3.29
WF11	Roman	13	Cattle	-21.1	4.4	34.5	12.4	10.1	3.26
WF12	Roman	13	Sheep	-22.0	6.9	42.7	15.2	13.9	3.29
*WF15**	*Roman*	*13*	*Cattle*	*-22.2*	*4.8*	*7.0*	*2.1*	*0.5*	*3.91*
*WF16**	*Roman*	*13*	*Sheep*	*-26.6*	*4.7*	*4.1*	*0.4*	*0.3*	*11.05*
WF19	Roman	13	Sheep	-21.7	4.3	35.9	12.8	13.8	3.27
*WF20**	*Roman*	*13*	*Pig*	*-22.3*	*11.4*	*15.9*	*4.9*	*2.9*	*3.83*
*WF21**	*Iron Age*	*10*	*Pig*	*-27.2*	*-2.2*	*2.7*	*0.3*	*0.2*	*11.26*
*WF22**	*Roman*	*13*	*Pig*	*-26.5*	*7.8*	*3.8*	*0.5*	*0.3*	*9.51*
*WF23**	*Roman*	*13*	*Cattle*	*-23.1*	*7.7*	*12.6*	*4.0*	*0.9*	*3.71*
*WF25**	*Roman*	*13*	*Cattle*	*-28.0*	*10.5*	*1.5*	*0.1*	*0.1*	*11.92*
WF27	Roman	13	Sheep	-22.4	9.4	24.7	8.3	4.5	3.45
*WF31**	*Iron Age*	*10*	*Sheep*	*-26.6*	*5.3*	*2.9*	*0.3*	*0.1*	*12.04*
*WF33**	*Iron Age*	*10*	*Pig*	*-27.0*	*5.0*	*3.9*	*0.4*	*0.1*	*11.24*
*WF34**	*Iron Age*	*10*	*Pig*	*-25.5*	*6.5*	*3.4*	*0.5*	*0.2*	*7.84*
*WF35**	*Iron Age*	*10*	*Sheep*	*-26.5*	*4.4*	*3.6*	*0.4*	*0.2*	*11.37*
*WF36**	*Iron Age*	*10*	*Cattle*	*-26.7*	*4.2*	*5.4*	*0.6*	*0.4*	*10.65*
*WF37**	*Iron Age*	*10*	*Cattle*	*-25.3*	*11.2*	*5.3*	*0.9*	*0.4*	*7.05*
*WF38**	*Iron Age*	*10*	*Sheep*	*-27.9*	*7.9*	*2.3*	*0.3*	*0.1*	*9.74*
*WF39**	*Iron Age*	*10*	*Sheep*	*-27.0*	*5.4*	*3.2*	*0.3*	*0.2*	*11.25*
*WF41**	*Iron Age*	*10*	*Cattle*	*-27.6*	*4.3*	*2.8*	*0.3*	*0.2*	*12.80*
WF42	Roman	13	Cattle	-21.5	7.3	24.5	8.5	5.5	3.39
WF43	Roman	13	Cattle	-20.8	5.1	30.0	10.2	4.5	3.44
WF44	Roman	13	Sheep	-22.0	10.4	25.8	8.9	3.3	3.36
WF45	Roman	13	Pig	-22.3	9.7	28.9	10.0	4.5	3.38
*WF46**	*Iron Age*	*10*	*Pig*	*-26.3*	*4.8*	*2.9*	*0.3*	*0.1*	*9.32*
*WF47**	*Iron Age*	*10*	*Sheep*	*-26.2*	*13.0*	*3.6*	*0.4*	*0.3*	*9.65*
*WF48**	*Iron Age*	*10*	*Cattle*	*-26.4*	*5.2*	*4.0*	*0.6*	*0.2*	*8.33*
*WF49**	*Iron Age*	*10*	*Cattle*	*-25.1*	*9.1*	*4.5*	*1.0*	*0.2*	*5.41*
*WF50**	*Iron Age*	*10*	*Cattle*	*-26.6*	*8.7*	*3.6*	*0.5*	*0.2*	*8.25*
*WF51**	*Iron Age*	*10*	*Sheep*	*-24.7*	*6.4*	*6.8*	*1.6*	*0.3*	*5.11*
*WF53**	*Iron Age*	*10*	*Sheep*	*-26.6*	*6.3*	*3.9*	*0.5*	*0.2*	*8.26*
*WF54**	*Roman*	*13*	*Pig*	*-23.9*	*7.6*	*7.6*	*2.0*	*0.5*	*4.35*
*WF55**	*Roman*	*13*	*Sheep*	*-27.8*	*3.8*	*2.2*	*0.2*	*0.2*	*15.70*
*WF56**	*Roman*	*13*	*Cattle*	*-26.8*	*3.0*	*3.2*	*0.4*	*0.2*	*8.95*
*WF58**	*Roman*	*13*	*Sheep*	*-27.6*	*3.1*	*1.7*	*0.2*	*0.2*	*11.90*
*WF59**	*Roman*	*13*	*Cattle*	*-26.8*	*18.6*	*1.0*	*0.1*	*0.1*	*12.31*
WF61	Roman	13	Pig	-22.1	9.9	33.0	11.5	7.2	3.34
*WF62**	*Roman*	*13*	*Sheep*	*-27.3*	*11.8*	*2.2*	*0.2*	*0.2*	*11.69*
*WF64**	*Roman*	*13*	*Cattle*	*-25.3*	*4.0*	*2.5*	*0.4*	*0.2*	*6.46*
*WF66**	*Roman*	*13*	*Cattle*	*-27.2*	*6.5*	*1.6*	*0.2*	*0.1*	*8.78*
*WF67**	*Roman*	*13*	*Pig*	*-23.7*	*7.8*	*5.8*	*1.4*	*0.3*	*4.78*
*WF68**	*Roman*	*13*	*Sheep*	*-28.1*	*8.4*	*6.7*	*0.6*	*0.4*	*12.48*
WF69	Roman	13	Cattle	-21.5	5.8	30.2	10.6	2.9	3.33
*WF70**	*Roman*	*13*	*Sheep*	*-27.7*	*3.4*	*2.8*	*0.3*	*0.1*	*12.61*

Sample	Period	Phase	Taxon	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C	%N	%Collagen	C:N
*WF71**	*Roman*	*13*	*Pig*	*-25.2*	*9.6*	*8.7*	*1.5*	*0.7*	*6.90*
*WF72**	*Roman*	*13*	*Sheep*	*-26.2*	*3.7*	*5.0*	*0.7*	*0.2*	*7.96*
*WF73**	*Roman*	*13*	*Cattle*	*-25.8*	*10.5*	*3.1*	*0.5*	*0.2*	*7.22*
*WF78**	*Iron Age*	*10*	*Sheep*	*-26.2*	*10.0*	*2.6*	*0.3*	*0.1*	*8.39*
*WF79**	*Iron Age*	*10*	*Cattle*	*-27.0*	*4.9*	*2.5*	*0.3*	*0.1*	*10.29*
*WF80**	*Iron Age*	*10*	*Cattle*	*-27.4*	*2.2*	*4.4*	*0.4*	*0.3*	*12.98*
*WF83**	*Iron Age*	*10*	*Sheep*	*-26.1*	*3.9*	*5.5*	*0.7*	*0.3*	*9.14*
*WF84**	*Iron Age*	*10*	*Cattle*	*-26.9*	*5.0*	*4.1*	*0.5*	*0.3*	*9.02*
*WF87**	*Iron Age*	*10*	*Sheep*	*-27.6*	*8.3*	*6.1*	*0.6*	*0.4*	*11.93*
*WF88**	*Iron Age*	*10*	*Cattle*	*-27.4*	*6.5*	*4.7*	*0.3*	*0.3*	*16.07*
*WF89**	*Iron Age*	*10*	*Cattle*	*-27.7*	*5.3*	*3.5*	*0.3*	*0.2*	*13.05*
WF90	Iron Age	10	Pig	-22.0	7.3	30.4	10.6	5.3	3.36
*WF91**	*Iron Age*	*10*	*Pig*	*-26.7*	*5.5*	*5.6*	*0.6*	*0.2*	*10.25*
*WF92**	*Roman*	*13*	*Pig*	*-25.3*	*10.7*	*7.5*	*1.2*	*0.5*	*7.04*
*WF94**	*Roman*	*13*	*Pig*	*-23.7*	*5.6*	*8.1*	*2.1*	*0.5*	*4.58*
*WF96**	*Iron Age*	*10*	*Cattle*	*-27.7*	*5.0*	*4.6*	*0.3*	*0.3*	*19.54*
*WF106**	*Iron Age*	*10*	*Pig*	*-22.7*	*8.1*	*13.4*	*4.0*	*1.3*	*3.92*
*WF116**	*Roman*	*13*	*Cattle*	*-22.6*	*6.8*	*20.8*	*6.4*	*1.5*	*3.78*
Whitecross Farm									
WX1*	*Bronze Age*	*8*	*Pig*	*-21.9*	*7.1*	*16.7*	*5.6*	*0.9*	*3.49*
WX2	Bronze Age	8	Pig	-21.5	5.3	36.0	13.1	5.3	3.20
WX3	Bronze Age	8	Pig	-21.4	4.9	38.8	14.2	7.8	3.19
WX4	Bronze Age	8	Pig	-21.2	4.6	38.8	14.1	5.8	3.20
WX6	Bronze Age	8	Sheep	-22.8	7.5	35.9	12.9	4.2	3.25
*WX7**	*Bronze Age*	*8*	*Sheep*	*-21.4*	*3.1*	*13.9*	*4.5*	*0.7*	*3.62*
*WX8**	*Bronze Age*	*8*	*Sheep*	*-21.8*	*3.9*	*21.9*	*7.5*	*1.3*	*3.44*
WX9	Bronze Age	8	Sheep	-21.6	5.4	37.5	13.6	7.2	3.22
WX10	Bronze Age	8	Sheep	-20.9	5.8	37.6	13.7	6.2	3.21
WX11	Bronze Age	8	Sheep	-21.8	6.1	28.8	10.3	2.3	3.27
WX13	Bronze Age	8	Cattle	-21.6	5.7	32.7	11.7	3.1	3.25
WX15	Bronze Age	8	Cattle	-22.1	7.8	24.6	8.5	1.6	3.39
WX16	Bronze Age	8	Cattle	-21.9	4.8	41.2	15.1	9.4	3.19
WX17	Bronze Age	8	Sheep	-22.0	4.5	37.3	13.4	5.1	3.24
WX19	Bronze Age	8	Sheep	-21.1	4.7	31.3	11.2	2.2	3.28
WX20	Bronze Age	8	Sheep	-20.8	6.7	40.2	14.7	9.5	3.19
WX21	Bronze Age	8	Sheep	-20.9	7.0	40.1	14.6	9.5	3.20
WX22	Bronze Age	8	Sheep	-20.9	5.1	39.2	14.2	6.9	3.22
WX23	Bronze Age	8	Sheep	-20.7	5.7	37.1	13.6	6.8	3.19
WX24	Bronze Age	8	Pig	-20.7	5.5	35.1	12.3	2.8	3.33
WX25	Bronze Age	8	Cattle	-21.4	7.3	34.0	12.3	2.7	3.22
WX27	Bronze Age	8	Sheep	-21.4	5.8	33.4	12.0	3.4	3.24
WX29	Bronze Age	8	Cattle	-21.8	5.9	35.7	12.9	3.7	3.24
WX30	Bronze Age	8	Pig	-21.0	5.6	33.6	12.0	3.0	3.25
WX31	Bronze Age	8	Pig	-20.4	5.1	35.5	12.8	3.8	3.24
*WX32**	*Bronze Age*	*8*	*Sheep*	*-23.1*	*5.9*	*20.7*	*6.8*	*1.2*	*3.55*
WX33	Bronze Age	8	Sheep	-21.1	5.9	33.7	12.1	3.4	3.26
WX37	Bronze Age	8	Cattle	-21.8	6.1	33.3	12.0	3.3	3.24
WX40	Bronze Age	8	Pig	-21.5	6.3	38.5	14.0	6.3	3.20
WX41	Bronze Age	8	Pig	-21.7	4.2	39.5	14.2	4.3	3.25

Sample	Period	Phase	Taxon	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C	%N	%Collagen	C:N
WX43	Bronze Age	8	Sheep	-21.9	3.6	30.2	10.7	2.3	3.31
WX44	Bronze Age	8	Sheep	-21.4	4.5	32.6	11.6	3.5	3.27
WX46	Bronze Age	8	Pig	-22.1	4.8	24.5	8.3	1.4	3.43
WX47	Bronze Age	8	Cattle	-22.0	5.9	21.5	7.2	1.2	3.46
WX49	Bronze Age	8	Sheep	-21.3	4.8	42.0	15.4	13.0	3.18
WX50	Bronze Age	8	Pig	-22.0	3.3	36.8	13.3	7.0	3.24
WX51	Bronze Age	8	Cattle	-22.7	6.0	41.2	15.0	6.7	3.19
WX52	Bronze Age	8	Pig	-22.0	3.0	42.7	15.7	9.5	3.18
WX53	Bronze Age	8	Cattle	-21.5	5.7	45.3	16.7	14.2	3.17
WX54	Bronze Age	8	Cattle	-21.5	5.4	42.2	15.5	10.8	3.18
WX55	Bronze Age	8	Pig	-21.5	6.1	32.8	11.5	2.7	3.33
WX56	Bronze Age	8	Cattle	-21.6	5.8	40.4	14.9	10.8	3.17
WX57	Bronze Age	8	Cattle	-22.2	5.9	24.3	8.3	1.7	3.45
WX58	Bronze Age	8	Pig	-21.5	4.8	32.8	11.6	3.4	3.29
WX59	Bronze Age	8	Cattle	-21.4	5.3	38.6	14.1	6.4	3.19
WX60	Bronze Age	8	Cattle	-21.5	5.7	38.0	13.8	5.9	3.20
Wyndyke Furlong									
WY1	Roman	13	Cattle	-21.2	2.6	20.0	7.0	1.9	3.35
WY2	Roman	13	Cattle	-21.7	5.5	18.3	6.3	2.4	3.38
WY3	Roman	13	Cattle	-21.7	6.3	21.3	7.4	1.5	3.36
WY5	Iron Age	10	Sheep	-20.8	5.8	36.4	12.9	2.8	3.29
WY6	Iron Age	10	Sheep	-21.5	5.5	19.4	6.7	1.9	3.38
WY7	Iron Age	10	Sheep	-21.9	6.7	23.1	8.0	2.4	3.35
WY8	Iron Age	10	Cattle	-21.5	6.3	24.7	9.0	3.5	3.19
WY9	Iron Age	10	Pig	-22.2	8.2	18.1	6.0	1.9	3.50
WY10	Iron Age	10	Pig	-21.5	6.5	23.0	8.3	2.7	3.25
WY11	Iron Age	10	Cattle	-22.0	5.3	21.1	7.2	2.2	3.42
WY12	Iron Age	10	Sheep	-21.2	6.6	32.4	11.8	4.4	3.20
WY13	Iron Age	10	Cattle	-21.5	5.5	16.8	5.8	2.0	3.40
WY14	Iron Age	10	Cattle	-21.7	12.2	20.6	7.2	2.9	3.33
WY15	Iron Age	10	Cattle	-21.4	4.9	28.4	10.2	4.4	3.25
WY16	Iron Age	10	Sheep	-21.9	6.4	18.7	6.5	1.4	3.37
WY17	Iron Age	10	Sheep	-21.3	6.1	26.1	9.2	3.5	3.29
WY18	Iron Age	10	Pig	-21.2	6.9	26.0	9.1	2.7	3.32
WY20	Roman	13	Sheep	-21.8	6.6	31.2	11.3	2.4	3.22
WY21	Roman	13	Sheep	-21.8	6.1	33.8	12.2	3.8	3.22
WY22	Roman	13	Sheep	-22.1	7.6	32.5	11.6	6.5	3.26
WY23	Roman	13	Cattle	-21.5	6.6	35.3	12.7	3.5	3.24
WY25	Iron Age	10	Cattle	-21.4	8.9	18.7	6.5	1.6	3.36
WY26	Iron Age	10	Cattle	-21.8	6.3	31.5	11.4	2.1	3.22
WY27	Iron Age	10	Cattle	-21.7	5.9	27.3	9.7	3.3	3.28
WY28	Iron Age	10	Cattle	-21.4	6.4	14.9	5.1	1.6	3.41
WY29	Iron Age	10	Sheep	-21.2	4.8	24.9	8.8	2.5	3.31
WY30	Iron Age	10	Pig	-22.0	7.9	39.8	14.6	13.3	3.18
WY31	Iron Age	10	Pig	-22.2	9.1	17.7	6.1	1.2	3.41
WY33	Iron Age	10	Sheep	-21.2	5.7	23.7	8.3	2.5	3.31
WY34	Iron Age	10	Sheep	-21.0	4.1	39.1	14.1	10.2	3.22
WY35	Iron Age	10	Sheep	-21.3	6.4	15.7	5.4	1.5	3.39
WY36	Iron Age	10	Sheep	-21.5	5.7	31.2	11.5	4.0	3.17

Sample	Period	Phase	Taxon	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C	%N	%Collagen	C:N
WY37	Roman	13	Sheep	-20.9	5.4	26.8	9.5	2.9	3.30
WY38	Roman	13	Cattle	-21.4	6.3	27.4	9.7	1.5	3.31
WY41	Roman	13	Cattle	-21.4	6.4	23.6	8.3	2.5	3.30
WY42	Roman	13	Sheep	-21.4	3.5	30.6	11.2	3.4	3.20
WY43	Roman	13	Sheep	-21.1	6.2	32.1	11.6	4.5	3.22
WY44	Roman	13	Sheep	-21.4	3.9	25.8	9.1	1.6	3.29
WY45	Roman	13	Pig	-20.5	10.0	37.0	13.2	6.3	3.26
WY46	Roman	13	Cattle	-21.5	5.7	19.0	6.7	2.0	3.32
WY47	Roman	13	Cattle	-20.9	6.8	30.8	10.9	3.1	3.28
WY48	Roman	13	Cattle	-21.4	5.2	27.9	9.9	3.3	3.29
WY49	Roman	13	Cattle	-21.3	7.6	22.9	7.9	2.2	3.37
WY51	Roman	13	Pig	-20.8	7.7	29.3	10.4	1.8	3.31
WY53	Roman	13	Sheep	-20.8	6.7	31.2	11.3	3.5	3.23
WY54	Roman	13	Sheep	-21.4	5.5	26.0	9.1	4.0	3.32
WY55	Roman	13	Sheep	-21.9	7.1	28.1	10.1	3.7	3.25
WY56	Roman	13	Sheep	-21.7	4.4	21.5	7.5	2.2	3.33
WY57	Roman	13	Cattle	-22.0	2.3	22.9	8.1	3.0	3.30
WY58	Roman	13	Cattle	-21.4	6.3	24.8	8.6	3.8	3.34
WY60	Roman	13	Cattle	-21.6	6.1	14.7	5.0	1.6	3.42
WY61	Roman	13	Pig	-20.4	9.2	34.2	12.3	3.5	3.24
WY62	Roman	13	Cattle	-21.3	5.7	29.4	10.6	4.7	3.24
WY63	Roman	13	Cattle	-21.8	7.7	20.4	7.1	2.2	3.36
WY64	Roman	13	Sheep	-21.5	8.6	27.5	9.6	1.9	3.33
WY65	Roman	13	Sheep	-21.7	5.5	35.2	13.2	8.1	3.11
WY67	Roman	13	Pig	-21.6	10.5	25.6	9.0	2.6	3.32
WY68	Iron Age	10	Sheep	-20.9	5.4	34.3	12.5	6.3	3.19
WY69	Iron Age	10	Cattle	-21.9	5.4	30.7	11.0	4.1	3.25
WY70	Iron Age	10	Cattle	-21.5	5.2	37.6	13.9	15.7	3.16
WY71	Iron Age	10	Sheep	-21.3	5.8	26.1	9.2	3.2	3.30
WY72	Iron Age	10	Sheep	-21.6	6.5	24.2	8.5	2.7	3.33
WY73	Iron Age	10	Sheep	-21.9	4.1	32.5	11.5	3.9	3.30
WY74	Iron Age	11	Sheep	-21.0	5.9	38.6	14.1	6.2	3.20
WY76	Iron Age	11	Cattle	-21.8	4.9	27.1	9.4	1.1	3.36
WY77	Iron Age	11	Sheep	-21.9	5.3	24.6	8.5	0.8	3.40
WY79	Iron Age	11	Sheep	-20.6	5.7	35.8	12.8	4.7	3.25
WY81	Iron Age	11	Pig	-22.1	7.9	35.5	12.7	2.6	3.25
*WY82**	*Iron Age*	*11*	*Cattle*	*-22.9*	*7.1*	*24.8*	*8.6*	*1.4*	*3.34*
WY83	Iron Age	11	Cattle	-21.7	5.7	29.2	10.6	1.7	3.22
WY85	Iron Age	11	Cattle	-21.6	4.2	32.8	11.7	2.3	3.27
WY86	Roman	13	Pig	-21.9	8.4	25.1	8.7	2.8	3.35
WY87	Roman	13	Cattle	-21.2	5.3	40.7	15.2	12.3	3.13
WY88	Roman	13	Cattle	-21.7	6.0	26.0	9.2	2.2	3.31
WY89	Roman	13	Sheep	-21.3	5.8	22.6	7.8	1.7	3.39
WY90	Roman	13	Sheep	-21.7	5.3	30.5	10.8	3.6	3.28
WY91	Iron Age	10	Cattle	-21.7	7.0	29.2	10.3	3.8	3.30
WY92	Iron Age	10	Sheep	-21.9	5.9	21.6	7.4	1.9	3.42
WY93	Iron Age	10	Cattle	-21.8	9.5	31.3	11.3	2.5	3.24
WY94	Iron Age	10	Cattle	-21.7	5.6	17.8	6.0	1.7	3.47
WY95	Iron Age	10	Sheep	-21.7	6.5	33.0	11.7	2.8	3.29

Sample	Period	Phase	Taxon	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C	%N	%Collagen	C:N
WY96	Iron Age	10	Sheep	-21.5	6.7	40.3	14.5	7.9	3.24
WY97	Iron Age	10	Cattle	-21.9	7.5	31.3	11.2	2.8	3.25
WY98	Iron Age	10	Sheep	-21.2	7.5	37.0	13.2	12.3	3.27
WY99	Roman	13	Pig	-20.2	9.3	25.8	8.8	2.4	3.42
WY100	Roman	13	Pig	-21.1	10.4	30.5	10.7	4.7	3.32
WY101	Roman	13	Pig	-21.4	7.3	25.5	8.8	2.6	3.38
WY102	Iron Age	10	Sheep	-21.2	4.9	27.4	9.6	2.8	3.33
WY103	Iron Age	10	Cattle	-21.7	7.2	27.0	9.3	2.2	3.38
WY104	Iron Age	10	Cattle	-21.0	4.9	40.4	14.8	12.0	3.19
WY106	Iron Age	10	Cattle	-21.7	5.3	22.3	7.6	2.4	3.41
Yarnton									
YTV1	Iron Age	9	Sheep	-21.1	6.8	24.3	8.8	2.8	3.22
YTV2	Iron Age	9	Sheep	-20.8	9.7	35.2	12.5	4.1	3.29
YTV3	Iron Age	9	Sheep	-21.4	6.7	27.9	10.0	3.0	3.23
YTV4	Iron Age	9	Sheep	-20.7	9.7	36.3	13.0	3.8	3.27
YTV5	Iron Age	9	Sheep	-21.2	5.7	41.6	14.6	3.0	3.31
YTV6	Iron Age	9	Sheep	-20.3	9.7	46.0	16.4	18.4	3.28
YTV7	Iron Age	9	Cattle	-21.8	6.4	21.5	7.7	2.5	3.25
YTV8	Iron Age	9	Cattle	-21.4	6.7	23.7	8.7	2.5	3.16
YTV9	Iron Age	9	Cattle	-22.2	4.5	37.8	13.9	15.3	3.16
YTV10	Iron Age	9	Cattle	-21.5	7.1	21.0	7.8	2.2	3.14
YTV13	Iron Age	9	Cattle	-21.2	5.8	19.4	7.2	3.5	3.17
YTV14	Iron Age	9	Cattle	-21.3	4.5	26.3	9.7	4.6	3.16
YTV15	Iron Age	9	Cattle	-21.3	3.6	20.8	7.7	3.1	3.16
YTV16	Iron Age	9	Cattle	-21.0	6.3	36.8	13.1	4.6	3.28
YTV17	Iron Age	9	Cattle	-20.8	7.1	23.2	8.6	4.1	3.16
YTV18	Iron Age	9	Cattle	-21.4	5.5	21.1	7.8	4.3	3.17
YTV19	Iron Age	9	Sheep	-21.5	7.6	20.1	7.3	2.5	3.20
YTV20	Iron Age	9	Pig	-21.7	9.7	21.6	7.9	1.6	3.19
YTV21	Iron Age	9	Sheep	-21.0	4.1	27.1	10.0	2.9	3.17
YTV22	Iron Age	9	Cattle	-21.7	5.5	34.9	12.6	2.3	3.23
YTV23	Iron Age	9	Cattle	-21.5	7.1	16.1	6.0	1.6	3.12
YTV24	Iron Age	9	Sheep	-21.1	4.7	44.7	16.1	17.9	3.24
YTV25	Iron Age	10	Cattle	-21.2	5.8	35.6	13.0	3.8	3.19
YTV26	Iron Age	10	Sheep	-21.5	5.7	32.6	11.8	4.1	3.23
YTV27	Iron Age	10	Cattle	-21.8	4.3	32.6	11.7	3.2	3.26
YTV28	Iron Age	10	Cattle	-21.4	4.0	27.1	9.9	4.1	3.17
YTV30	Iron Age	9	Cattle	-21.9	3.9	42.9	15.4	5.9	3.26
YTV32	Iron Age	9	Sheep	-21.2	7.4	36.8	13.2	2.3	3.27
YTV33	Iron Age	9	Cattle	-21.6	6.8	30.4	11.2	4.1	3.17
YTV37	Iron Age	9	Cattle	-21.5	7.0	29.5	10.9	5.6	3.17
YTV38	Iron Age	9	Sheep	-21.9	9.7	17.5	6.5	2.4	3.16
YTV39	Iron Age	9	Sheep	-21.5	7.4	19.2	7.0	2.3	3.17
YTV40	Iron Age	10	Sheep	-21.0	6.8	23.6	8.6	2.9	3.19
YTV41	Iron Age	10	Sheep	-20.8	5.3	28.3	10.2	4.3	3.24
YTV42	Iron Age	10	Cattle	-21.2	5.5	18.3	6.9	1.7	3.08
YTV43	Iron Age	10	Cattle	-21.2	5.4	23.9	8.9	1.2	3.14
YTV44	Iron Age	10	Pig	-21.5	8.6	29.0	10.7		3.17
YTV45	Iron Age	10	Cattle	-21.8	5.1	32.2	11.9	3.8	3.17

Sample	Period	Phase	Taxon	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C	%N	%Collagen	C:N
YTV46	Iron Age	10	Cattle	-21.7	6.4	18.6	6.9	1.7	3.14
YTV47	Iron Age	10	Cattle	-22.0	5.4	17.9	6.5	2.3	3.19
YTV48	Iron Age	10	Sheep	-22.0	6.9	27.1	10.1	4.2	3.14
YTV49	Iron Age	10	Sheep	-22.5	10.2	24.4	8.8	3.4	3.21
YTV50	Iron Age	10	Cattle	-21.6	7.7	21.6	8.0	4.3	3.17
YTV51	Iron Age	10	Pig	-21.5	6.1	40.2	14.8	12.6	3.18
YTV52	Iron Age	10	Cattle	-21.3	6.2	17.9	6.6	2.2	3.18
YTV53	Iron Age	10	Cattle	-21.4	6.1	19.3	7.0	3.1	3.21
YTV54	Iron Age	10	Sheep	-21.7	7.3	22.3	8.2	3.6	3.19
YTV55	Iron Age	9	Sheep	-21.6	6.2	40.7	14.6	9.8	3.25
YTV56	Iron Age	9	Sheep	-21.5	9.5	28.5	10.5	3.9	3.17
YTV57	Iron Age	9	Sheep	-21.5	4.9	16.9	6.2	1.4	3.19
YTV58	Iron Age	9	Sheep	-21.7	8.3	23.2	8.6	2.1	3.16
YTV59	Iron Age	9	Cattle	-21.8	5.0	30.6	10.9	3.9	3.27
YTV60	Iron Age	10	Pig	-21.9	5.8	22.7	8.6	2.8	3.09
YTV61	Iron Age	10	Cattle	-22.1	4.9	15.0	5.7	1.9	3.09
YTV62	Iron Age	9	Pig	-21.1	6.7	27.4	10.4	8.0	3.09
YTV63	Iron Age	9	Pig	-21.2	5.5	29.3	11.1	10.6	3.08
YTV64	Iron Age	9	Pig	-21.4	10.7	37.0	13.8	8.3	3.13
YTV65	Iron Age	9	Pig	-22.0	9.3	36.4	13.3	13.4	3.19
YTV66	Iron Age	10	Cattle	-21.8	5.8	19.5	7.1	2.5	3.20
YTV67	Iron Age	10	Cattle	-21.8	5.2	26.2	9.7		3.16
YTV68	Iron Age	10	Cattle	-21.4	6.4	18.4	6.7	2.9	3.20
YTV69	Iron Age	10	Sheep	-21.8	7.2	28.8	10.6	4.2	3.17
YTV70	Iron Age	10	Sheep	-21.5	5.4	21.7	8.0	2.2	3.17
YTV71	Iron Age	10	Pig	-22.1	7.7	18.5	6.8	3.1	3.19
YTV72	Iron Age	9	Pig	-21.3	7.1	19.6	7.2	3.9	3.17
YTV74	Iron Age	9	Pig	-21.6	7.2	30.7	11.2	9.8	3.20
YTV78	Iron Age	9	Pig	-21.6	7.2	31.3	11.5	4.5	3.17
YTV79	Iron Age	9	Pig	-20.9	6.5	24.3	8.9	2.4	3.18
YTV80	Iron Age	10	Sheep	-21.3	5.6	24.7	9.1	3.1	3.16
YTV82	Iron Age	10	Pig	-21.5	7.2	37.1	13.4	8.2	3.24
YTV83	Iron Age	10	Sheep	-21.5	6.7	25.8	9.5	3.3	3.17
YTV84	Iron Age	10	Sheep	-21.5	7.2	39.6	14.1	15.6	3.28
YTV85	Iron Age	10	Pig	-21.7	5.7	32.7	11.6	6.7	3.30
YTV86	Iron Age	10	Pig	-21.4	6.0	24.2	8.9	4.7	3.18
YTV87	Iron Age	10	Sheep	-21.8	5.2	22.4	8.3	2.3	3.13
YTV88	Iron Age	10	Sheep	-21.5	8.3	26.6	9.8	2.7	3.17
YTV89	Iron Age	10	Pig	-21.7	8.3	28.7	10.5	3.5	3.19
YTV90	Iron Age	10	Pig	-22.4	6.7	26.3	9.5	5.2	3.24
YTV91	Iron Age	10	Pig	-21.6	6.5	32.9	11.8	6.2	3.25
YTV92	Iron Age	10	Pig	-22.0	8.8	18.3	6.8	2.2	3.15
YTV93	Iron Age	10	Pig	-21.1	7.5	33.0	11.9	7.5	3.22
YTV94	Iron Age	10	Pig	-23.2	7.6	29.4	10.5	4.0	3.25
YTV95	Iron Age	9	Pig	-22.0	8.0	35.0	12.6	9.4	3.26
YTV96	Iron Age	9	Pig	-22.2	8.4	29.5	10.9	5.4	3.17
YTV97	Iron Age	9	Pig	-21.6	8.1	30.5	11.1	3.6	3.20
YTV98	Iron Age	9	Pig	-21.9	6.4	26.7	9.8	3.2	3.19
YTV99	Iron Age	9	Pig	-21.1	7.0	35.9	13.2	7.3	3.19

Sample	Period	Phase	Taxon	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C	%N	%Collagen	C:N
YTV100	Iron Age	9	Pig	-21.7	7.1	21.6	8.0	2.4	3.14
YTV101	Bronze Age	6	Cattle	-23.0	4.8	24.3	8.4	1.7	3.39
YTV102	Bronze Age	6	Pig	-21.4	5.8	32.1	11.3	1.7	3.30
YTV103	Bronze Age	6	Sheep	-21.7	5.2	22.5	7.9	3.0	3.33
YTV104	Bronze Age	6	Sheep	-21.7	6.2	29.6	10.5	1.4	3.29
YTV105	Bronze Age	6	Sheep	-21.8	4.7	40.9	15.0	7.2	3.19
YTV106	Bronze Age	6	Cattle	-21.2	5.9	39.3	14.5	7.1	3.17
YTV107	Bronze Age	6	Cattle	-22.0	4.8	27.7	9.9	1.7	3.25
YTV108	Bronze Age	6	Cattle	-22.0	6.5	40.9	15.1	13.6	3.15
YTV109	Bronze Age	7	Cattle	-21.9	7.2	25.2	9.0	1.8	3.27
YTV110	Bronze Age	7	Cattle	-21.7	7.4	38.6	14.2	10.7	3.17
YTV112	Bronze Age	8	Cattle	-22.2	7.0	25.9	8.9	2.0	3.39
YTV113	Bronze Age	8	Sheep	-21.5	5.7	39.4	14.6	5.0	3.14
YTV114	Bronze Age	8	Pig	-20.9	5.3	35.0	12.8	1.9	3.20
YTV115	Bronze Age	8	Pig	-18.4	2.8	42.4	15.4	11.0	3.22
YTV116	Bronze Age	8	Cattle	-21.4	5.5	37.1	13.6	7.3	3.19
YTV117	Bronze Age	8	Sheep	-20.9	5.6	40.0	14.8	7.3	3.16
YTV118	Bronze Age	8	Sheep	-21.5	7.6	42.7	15.9	14.8	3.14
YTV119	Bronze Age	8	Cattle	-22.0	6.7	17.7	6.2	1.9	3.36
YTV121	Roman	13	Cattle	-22.0	10.4	26.3	9.4	3.0	3.28
YTV122	Roman	13	Cattle	-21.7	3.9	17.4	6.0	1.8	3.38
YTV123	Roman	13	Cattle	-21.7	6.1	22.6	8.1	2.7	3.26
YTV124	Roman	13	Cattle	-22.0	8.7	32.7	11.7	3.2	3.25
YTV125	Roman	16	Cattle	-21.8	4.9	30.8	10.9	3.6	3.29
YTV127	Roman	16	Cattle	-21.5	6.9	35.3	13.0	4.3	3.18
YTV129	Roman	16	Cattle	-21.4	6.2	30.2	10.8	3.4	3.27
YTV130	Roman	13	Pig	-21.9	8.5	24.1	8.5	1.7	3.30
YTV131	Roman	13	Pig	-22.0	9.1	41.8	15.4	11.2	3.17
YTV132	Roman	13	Pig	-22.3	9.7	27.8	9.9	3.5	3.29
YTV134	Roman	16	Pig	-21.7	10.2	29.3	10.6	3.8	3.24
YTV135	Roman	16	Pig	-21.6	9.8	36.2	13.3	6.6	3.17
YTV136	Roman	16	Pig	-21.6	8.5	38.3	14.0	10.9	3.19
YTV137	Roman	16	Pig	-21.2	9.5	28.6	10.2	3.3	3.26
YTV138	Roman	13	Pig	-21.1	7.0	28.3	10.1	3.9	3.26
YTV139	Roman	16	Sheep	-21.6	6.3	33.3	11.8	2.0	3.30
YTV140	Roman	13	Sheep	-21.6	5.2	40.2	15.0	10.6	3.13
YTV141	Roman	13	Sheep	-21.9	10.1	26.1	9.4	2.6	3.25
YTV142	Roman	13	Sheep	-21.6	8.6	36.0	13.0	3.5	3.25
YTV143	Roman	13	Sheep	-21.8	9.5	39.6	14.7	9.6	3.15
YTV144	Roman	13	Sheep	-22.2	8.6	21.6	7.6	1.8	3.32
YTV145	Roman	16	Sheep	-21.8	6.0	21.6	7.6	2.2	3.32
YTV146	Roman	16	Sheep	-21.2	9.2	37.4	13.7	9.1	3.19
YTV148	Roman	13	Cattle	-21.9	6.1	39.7	14.8	10.1	3.13
YTV153	Roman	13	Pig	-20.9	8.7	40.2	15.0	11.8	3.14
YTV154	Roman	13	Cattle	-21.3	6.8	36.7	13.4	5.2	3.19
YTV155	Roman	13	Cattle	-22.2	10.7	23.3	8.3	2.2	3.28
YTV156	Roman	13	Cattle	-21.5	8.0	42.9	16.1	14.3	3.11
YTV157	Roman	13	Cattle	-22.1	8.3	27.5	10.0	3.7	3.22
YTV158	Roman	13	Cattle	-22.7	8.0	20.3	6.9	1.9	3.44

Sample	Period	Phase	Taxon	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C	%N	%Collagen	C:N
YTV159	Roman	13	Cattle	-21.6	7.0	38.0	14.1	10.0	3.15
YTV160	Roman	13	Cattle	-21.4	7.8	38.6	14.3	10.6	3.15
YTV161	Roman	13	Cattle	-21.5	6.8	29.6	10.7	3.3	3.22
YTV162	Roman	13	Cattle	-21.9	6.7	25.7	9.2	3.0	3.25
YTV163	Roman	13	Cattle	-21.7	7.1	38.4	14.1	8.0	3.17
YTV164	Roman	13	Sheep	-22.0	8.3	40.1	14.9	7.6	3.15
YTV165	Roman	13	Sheep	-21.0	9.4	36.9	13.6	6.0	3.16
YTV167	Roman	16	Sheep	-21.7	7.6	21.9	7.8	2.0	3.28
YTV168	Bronze Age	5	Cattle	-21.8	7.6	30.1	10.9	5.0	3.22
YTV169	Bronze Age	5	Sheep	-21.3	6.6	35.7	13.0	4.5	3.20
YTV170	Bronze Age	5	Sheep	-21.4	7.8	39.9	14.7	10.7	3.18
YTV171	Bronze Age	5	Cattle	-22.0	8.2	27.8	10.0	3.2	3.23
YTV173	Roman	16	Cattle	-21.1	3.6	36.4	13.4	6.2	3.16
YTV174	Roman	16	Cattle	-21.8	6.8	29.6	10.7	2.1	3.24
YTV175	Roman	16	Sheep	-21.7	7.3	31.1	11.3	3.2	3.22
YTV176	Roman	16	Pig	-21.5	8.9	38.7	14.3	5.8	3.15
YTV177	Roman	16	Sheep	-21.7	9.2	36.5	13.2	3.0	3.22
YTV178	Roman	16	Sheep	-21.3	5.6	34.4	12.6	3.4	3.18
YTV179	Roman	16	Cattle	-21.3	3.4	38.5	14.3	8.3	3.14
YTV180	Roman	16	Cattle	-21.5	4.3	23.9	8.6	1.7	3.25
YTV181	Roman	16	Cattle	-22.0	9.1	31.9	11.7	4.6	3.19
YTV182	Roman	16	Sheep	-21.8	5.5	41.1	15.2	8.9	3.14
YTV183	Roman	16	Sheep	-21.5	4.1	19.1	6.8	1.8	3.30
YTV184	Roman	16	Cattle	-22.1	7.9	29.2	10.5	2.6	3.24
YTV186	Roman	16	Sheep	-21.3	8.5	31.8	11.5	4.1	3.23
YTV187	Roman	16	Pig	-21.6	8.1	35.4	13.0	5.9	3.18
YTV188	Roman	16	Pig	-21.0	6.8	43.5	16.2	12.9	3.14
YTV189	Roman	16	Cattle	-21.7	4.8	26.7	9.4	2.2	3.30
YTV190	Roman	16	Pig	-21.7	8.0	32.2	11.6	2.1	3.24
YTV191	Roman	16	Cattle	-21.9	7.8	31.3	11.4	3.0	3.20
YTV192	Roman	16	Sheep	-21.9	7.0	32.4	11.9	3.5	3.19
YTV193	Roman	16	Pig	-20.5	9.9	39.2	14.5	6.7	3.16
YTV194	Iron Age	12	Cattle	-22.2	7.9	22.3	7.9	0.8	3.27
YTV195	Iron Age	12	Pig	-21.4	8.4	39.4	14.6	10.8	3.16
YTV196	Iron Age	12	Sheep	-22.2	7.3	40.0	14.8	9.4	3.17
YTV197	Iron Age	12	Sheep	-22.1	6.8	19.8	7.0	1.5	3.30
YTV198	Iron Age	12	Sheep	-21.5	7.8	40.6	15.1	11.5	3.14
YTV199	Iron Age	12	Sheep	-21.7	7.7	40.5	15.1	8.3	3.14
YTV200	Iron Age	12	Sheep	-21.7	8.0	40.0	14.8	8.9	3.17
YTV201	Iron Age	12	Pig	-21.4	6.7	41.1	15.4	11.4	3.12
YTV202	Iron Age	12	Cattle	-21.0	6.8	38.5	14.2	5.0	3.16
YTV203	Iron Age	12	Cattle	-21.9	5.5	21.5	7.7	2.4	3.28
YTV204	Iron Age	12	Cattle	-22.2	8.3	17.4	6.1	1.8	3.32
YTV205	Iron Age	12	Sheep	-21.5	6.0	33.9	12.4	5.5	3.18
YTV206	Iron Age	12	Pig	-20.9	8.5	35.1	12.9	4.7	3.18
YTV207	Iron Age	12	Pig	-21.7	8.8	39.3	14.5	4.6	3.16
YTV208	Iron Age	12	Cattle	-21.6	4.6	22.3	8.0	1.2	3.25
YTV209	Iron Age	12	Cattle	-21.9	5.9	22.5	8.1	1.6	3.25
YTV210	Iron Age	12	Sheep	-22.1	7.6	39.9	14.8	10.7	3.14

Sample	Period	Phase	Taxon	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C	%N	%Collagen	C:N
YTV212	Iron Age	12	Cattle	-21.7	6.6	34.0	12.4	3.6	3.20
YTV213	Iron Age	12	Pig	-21.6	8.7	27.9	10.0	2.9	3.27
YTV214	Iron Age	12	Pig	-21.7	8.7	29.3	10.5	3.2	3.26
YTV215	Iron Age	12	Cattle	-21.3	6.5	23.6	8.4	2.8	3.26
YTV216	Iron Age	12	Cattle	-21.4	5.4	28.2	10.2	3.9	3.22
YTV217	Iron Age	12	Sheep	-21.8	6.5	30.9	11.1	3.3	3.23
YTV218	Iron Age	12	Sheep	-21.6	9.6	37.1	13.7	5.5	3.16
YTV219	Iron Age	12	Sheep	-20.9	7.2	39.8	14.9	9.1	3.13
YTV220	Iron Age	12	Sheep	-21.8	5.2	40.1	15.0	7.3	3.13
YTV221	Iron Age	12	Pig	-21.2	7.6	40.0	14.9	8.0	3.14
YTV222	Iron Age	12	Cattle	-22.0	8.9	25.2	9.1	3.0	3.25
YTV223	Iron Age	12	Cattle	-22.3	6.9	17.9	6.2	1.7	3.35
YTV224	Iron Age	12	Sheep	-20.9	7.7	27.7	10.1	3.2	3.22
YTV225	Iron Age	12	Sheep	-21.5	7.8	39.6	14.6	5.5	3.18
YTV226	Iron Age	12	Sheep	-21.8	6.2	21.6	7.7	1.8	3.29
YTV227	Iron Age	12	Sheep	-21.2	4.5	41.8	15.4	7.1	3.16
YTV228	Iron Age	12	Sheep	-21.2	7.4	43.1	16.0	8.7	3.14
YTV229	Iron Age	12	Pig	-22.1	7.8	23.5	8.3	1.9	3.28
YTV230	Iron Age	12	Cattle	-22.0	5.9	21.5	7.6	2.4	3.31
YTV231	Iron Age	12	Cattle	-21.5	4.5	28.9	10.5	3.0	3.22
YTV232	Iron Age	12	Cattle	-21.7	9.4	31.9	11.6	3.8	3.21
YTV233	Iron Age	12	Cattle	-21.2	3.8	37.1	13.8	4.5	3.15
YTV234	Iron Age	12	Pig	-21.2	10.6	35.3	12.9	7.7	3.18
YTV235	Iron Age	12	Pig	-22.3	9.9	25.0	8.7	2.0	3.34
YTV236	Iron Age	12	Pig	-22.0	10.7	20.1	7.1	1.5	3.33
YTV237	Iron Age	12	Pig	-22.3	8.9	20.8	7.3	1.8	3.33
YTV301	Iron Age	10	Pig	-21.7	8.7	33.3	12.1	6.5	3.21

Measurements marked with an *asterisk* and in *italics* were rejected on quality criteria and were not included in the analysis

Table A1.7 $\delta^{13}C$ and $\delta^{15}N$ values measured at sites, from published results

Sample	Period	Phase	Taxon	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C	%N	%Collagen	C:N
Abingdon Causewayed Enclosure									
AB1	Neolithic	2	Sheep	-22.0	5.3	36.4	13.0	8.2	3.28
AB2	Neolithic	2	Sheep	-21.1	5.0	33.8	12.2	6.3	3.25
AB3	Neolithic	2	Sheep	-21.7	4.0	34.2	12.0	2.4	3.33
AB4	Neolithic	2	Sheep	-21.7	5.2	33.8	12.1	3.6	3.25
AB5	Neolithic	2	Sheep	-21.9	5.5	35.5	12.6	3.4	3.29
AB6	Neolithic	2	Sheep	-21.6	4.5	34.6	12.4	3.6	3.25
AB7	Neolithic	2	Sheep	-21.5	5.3	34.8	12.2	4.6	3.32
AB8	Neolithic	2	Sheep	-21.9	5.4	39.9	14.3	5.1	3.26
AB9	Neolithic	2	Sheep	-21.1	4.6	30.7	11.0	3.0	3.27
AB10	Neolithic	2	Sheep	-20.8	5.5	36.8	13.0	7.3	3.28
AB11	Neolithic	2	Sheep	-21.4	5.1	44.3	15.8	13.8	3.27
AB12	Neolithic	2	Sheep	-22.1	5.1	20.3	7.3	1.6	3.27
AB13	Neolithic	2	Sheep	-21.9	6.0	29.4	10.4	3.7	3.30
AB14	Neolithic	2	Sheep	-21.5	6.0	37.7	13.5	5.2	3.26
AB15	Neolithic	2	Sheep	-21.3	4.6	32.1	11.5	3.4	3.25
AB16	Neolithic	2	Sheep	-22.2	6.5	36.7	13.2	2.1	3.24
AB17	Neolithic	2	Sheep	-21.8	6.1	36.4	13.0	2.0	3.27
AB18	Neolithic	2	Sheep	-21.5	5.1	46.1	16.3	5.3	3.29
AB19	Neolithic	2	Sheep	-21.5	5.0	32.9	11.8	3.6	3.26
AB20	Neolithic	2	Sheep	-22.0	5.8	37.0	13.3	3.5	3.24
AB21	Neolithic	2	Cattle	-22.5	5.9	19.1	7.1	0.9	3.15
AB22	Neolithic	2	Cattle	-21.9	5.4	29.5	10.7	2.3	3.21
AB23	Neolithic	2	Cattle	-21.5	6.1	31.5	11.4	3.1	3.24
AB24	Neolithic	2	Cattle	-22.6	5.2	29.2	10.5	3.5	3.25
AB25	Neolithic	2	Cattle	-23.1	5.5	15.2	5.7	1.0	3.11
AB26	Neolithic	2	Cattle	-22.4	5.8	22.7	8.4	1.4	3.17
AB27	Neolithic	2	Cattle	-22.5	5.5	23.2	8.3	1.1	3.28
AB28	Neolithic	2	Cattle	-22.2	6.0	25.6	9.3	2.0	3.21
AB29	Neolithic	2	Cattle	-22.6	5.2	22.7	8.4	1.7	3.17
AB30	Neolithic	2	Cattle	-22.6	5.9	23.0	8.4	1.2	3.21
AB31	Neolithic	2	Cattle	-21.8	5.6	36.1	12.9	3.7	3.26
AB32	Neolithic	2	Cattle	-22.1	5.6	29.1	10.5	1.5	3.24
AB33	Neolithic	2	Cattle	-21.5	6.0	35.1	12.4	4.4	3.29
AB34	Neolithic	2	Cattle	-22.7	7.2	24.7	9.0	3.4	3.19
AB35	Neolithic	2	Cattle	-20.8	5.4	43.8	15.6	9.7	3.26
AB36	Neolithic	2	Cattle	-21.0	6.3	34.2	12.1	2.4	3.29
AB38	Neolithic	2	Cattle	-21.8	6.7	30.6	11.2	3.7	3.20
AB39	Neolithic	2	Cattle	-22.8	5.9	17.5	6.5	1.9	3.13
AB40	Neolithic	2	Cattle	-22.3	5.4	27.1	9.9	2.1	3.20
AB41	Neolithic	2	Pig	-21.5	6.0	25.7	9.4	2.4	3.20
AB42	Neolithic	2	Pig	-20.7	6.0	27.4	9.9	3.1	3.22
AB43	Neolithic	2	Pig	-21.9	5.9	27.7	10.1	3.8	3.20
AB44	Neolithic	2	Pig	-21.4	5.1	26.3	9.3	2.2	3.29
AB45	Neolithic	2	Pig	-20.7	6.2	25.4	9.2	1.7	3.22
AB46	Neolithic	2	Pig	-20.6	6.5	34.2	12.2	4.1	3.27
AB47	Neolithic	2	Pig	-21.2	6.5	32.0	11.5	2.2	3.24

Sample	Period	Phase	Taxon	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C	%N	%Collagen	C:N
AB48	Neolithic	2	Pig	-20.6	6.0	46.8	16.1	1.3	3.40
AB49	Neolithic	2	Pig	-21.0	6.1	28.6	10.3	2.9	3.24
AB50	Neolithic	2	Pig	-20.5	5.4	46.9	16.2	2.3	3.37
AB51	Neolithic	2	Pig	-20.6	5.5	35.8	12.9	2.3	3.25
AB52	Neolithic	2	Pig	-20.4	6.0	48.6	16.9	2.8	3.35
AB53	Neolithic	2	Pig	-21.2	6.5	39.0	13.4	1.8	3.39
AB54	Neolithic	2	Pig	-21.6	5.8	28.8	10.2	1.3	3.29
AB55	Neolithic	2	Pig	-20.8	6.4	40.6	14.1	1.6	3.37
AB56	Neolithic	2	Pig	-21.1	6.0	30.2	10.6	1.8	3.31
AB57	Neolithic	2	Pig	-20.2	6.8	36.6	12.9	4.1	3.31
AB58	Neolithic	2	Pig	-20.8	6.8	27.7	10.0	1.8	3.22
Ascott-under-Wychwood									
AUW01	Neolithic	2	Sheep	-22.6	6.2	-	-	-	-
AUW02	Neolithic	2	Sheep	-21.4	6.4	-	-	-	-
AUW03	Neolithic	2	Cattle	-22.0	5.2	-	-	-	-
AUW04	Neolithic	1	Pig	-20.6	6.0	-	-	-	-
AUW05	Neolithic	1	Cattle	-22.2	5.6	-	-	-	-
AUW06	Neolithic	2	Cattle	-22.6	5.6	-	-	-	-
AUW07	Neolithic	2	Sheep	-22.2	4.0	-	-	-	-
AUW09	Neolithic	2	Pig	-21.0	6.1	-	-	-	-
AUW11	Neolithic	1	Pig	-20.8	7.0	-	-	-	-
AUW12	Neolithic	2	Pig	-19.9	5.1	-	-	-	-
AUW13	Neolithic	2	Cattle	-21.8	5.0	-	-	-	-
AUW15	Neolithic	1	Sheep	-21.1	5.0	-	-	-	-
AUW16	Neolithic	1	Pig	-23.0	6.4	-	-	-	-
AUW18	Neolithic	1	Pig	-20.4	7.1	-	-	-	-
AUW19	Neolithic	2	Sheep	-22.9	6.5	-	-	-	-
AUW20	Neolithic	1	Cattle	-22.6	5.5	-	-	-	-
AUW21	Neolithic	2	Sheep	-21.8	8.1	-	-	-	-
AUW22	Neolithic	2	Cattle	-20.6	6.8	-	-	-	-
AUW23	Neolithic	2	Sheep	-21.3	5.8	-	-	-	-
AUW24	Neolithic	1	Pig	-20.9	6.2	-	-	-	-
AUW27	Neolithic	1	Pig	-20.0	5.4	-	-	-	-
AUW28	Neolithic	2	Pig	-22.0	7.2	-	-	-	-
AUW31	Neolithic	1	Cattle	-23.2	5.1	-	-	-	-
AUW32	Neolithic	1	Cattle	-22.3	5.1	-	-	-	-
AUW33	Neolithic	2	Pig	-19.8	7.3	-	-	-	-
AUW34	Neolithic	2	Cattle	-21.6	5.1	-	-	-	-
AUW35	Neolithic	2	Pig	-20.6	6.7	-	-	-	-
AUW36	Neolithic	2	Cattle	-22.1	5.3	-	-	-	-
AUW37	Neolithic	2	Sheep	-22.2	5.6	-	-	-	-
AUW39	Neolithic	1	Pig	-21.0	6.0	-	-	-	-
AUW40	Neolithic	1	Cattle	-22.6	5.1	-	-	-	-
AUW41	Neolithic	2	Sheep	-21.8	6.5	-	-	-	-
AUW42	Neolithic	2	Pig	-20.1	7.0	-	-	-	-
AUW44	Neolithic	2	Cattle	-22.2	5.4	-	-	-	-
AUW45	Neolithic	2	Cattle	-22.0	4.9	-	-	-	-
AUW46	Neolithic	2	Pig	-20.7	6.4	-	-	-	-
AUW47	Neolithic	2	Cattle	-22.0	5.1	-	-	-	-

Sample	Period	Phase	Taxon	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C	%N	%Collagen	C:N
AUW48	Neolithic	1	Pig	-20.3	4.7	-	-	-	-
AUW49	Neolithic	2	Cattle	-21.7	4.8	-	-	-	-
AUW51	Neolithic	1	Cattle	-24.0	6.2	-	-	-	-
AUW52	Neolithic	1	Cattle	-23.9	5.8	-	-	-	-
Eton Rowing Course									
ERC1	Neolithic	2	Cattle	-22.7	5.2	-	-	-	3.2
ERC2	Neolithic	2	Cattle	-22.2	5.0	-	-	-	3.3
ERC3	Neolithic	2	Cattle	-22.2	4.8	-	-	-	3.3
ERC4	Neolithic	2	Cattle	-21.3	5.6	-	-	-	3.3
ERC5	Neolithic	2	Cattle	-22.7	4.9	-	-	-	3.3
ERC6	Neolithic	2	Pig	-20.3	6.2	-	-	-	3.3
ERC7	Neolithic	2	Pig	-20.0	5.8	-	-	-	3.4
ERC8	Neolithic	2	Pig	-19.3	7.6	-	-	-	3.3
ERC13	Neolithic	2	Sheep	-21.4	7.1	-	-	-	3.3
ERC14	Bronze Age	7	Cattle	-22.0	7.4	-	-	-	3.3
ERC15	Bronze Age	7	Cattle	-21.4	8.6	-	-	-	3.3
ERC16	Bronze Age	7	Cattle	-21.2	8.7	-	-	-	3.3
ERC18	Bronze Age	7	Pig	-21.3	5.5	-	-	-	3.3
ERC20	Iron Age	10	Cattle	-22.3	6.3	-	-	-	3.3
ERC21	Iron Age	10	Cattle	-21.7	4.2	-	-	-	3.2
ERC22	Iron Age	10	Cattle	-21.4	4.6	-	-	-	3.2
ERC23	Iron Age	10	Cattle	-21.3	5.0	-	-	-	3.4
ERC24	Iron Age	10	Cattle	-22.5	6.0	-	-	-	3.4
ERC25	Iron Age	10	Cattle	-21.6	4.0	-	-	-	3.2
ERC29	Iron Age	10	Sheep	-21.6	5.0	-	-	-	3.2
ERC30	Roman	14	Cattle	-22.1	6.5	-	-	-	3.3
ERC31	Roman	14	Cattle	-21.9	3.9	-	-	-	3.3
ERC32	Roman	14	Cattle	-21.7	7.4	-	-	-	3.2
ERC33	Roman	14	Cattle	-21.6	5.4	-	-	-	3.2
ERC34	Roman	14	Cattle	-21.6	7.5	-	-	-	3.3
ERC41	Roman	14	Pig	-22.1	10.1	-	-	-	3.4
ERC42	Roman	14	Pig	-21.7	9.0	-	-	-	3.3
ERC43	Roman	14	Pig	-21.7	8.1	-	-	-	3.3
ERC44	Roman	14	Pig	-21.3	8.5	-	-	-	3.3
ERC45	Roman	14	Sheep	-22.2	9.4	-	-	-	3.3
ERC47	Roman	14	Sheep	-21.8	7.8	-	-	-	3.3
ERC48	Roman	14	Sheep	-21.7	6.4	-	-	-	3.2
ERC49	Roman	14	Sheep	-21.3	7.2	-	-	-	3.2
ERC46	Roman	14	Sheep	-22.1	8.3	-	-	-	3.3
Hazleton North									
HAZ2	Neolithic	2	Cattle	-22.2	5.1	-	-	-	3.4
HAZ3	Neolithic	2	Cattle	-22.0	3.5	-	-	-	3.3
HAZ4	Neolithic	2	Cattle	-21.6	3.8	-	-	-	3.4
HAZ5	Neolithic	1	Cattle	-22.5	2.8	-	-	-	3.3
HAZ6	Neolithic	1	Cattle	-21.7	4.7	-	-	-	3.4
HAZ7	Neolithic	1	Cattle	-21.7	4.5	-	-	-	3.4
HAZ8	Neolithic	1	Cattle	-22.0	3.6	-	-	-	3.3
HAZ9	Neolithic	1	Cattle	-21.8	3.7	-	-	-	3.3
HAZ10	Neolithic	1	Cattle	-22.2	4.1	-	-	-	3.3

Sample	Period	Phase	Taxon	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C	%N	%Collagen	C:N
HAZ11	Neolithic	1	Cattle	-21.9	4.4	-	-	-	3.3
HAZ12	Neolithic	1	Cattle	-21.9	5.1	-	-	-	3.3
HAZ13	Neolithic	1	Cattle	-22.0	4.8	-	-	-	3.3
HAZ14	Neolithic	2	Sheep	-22.0	4.2	-	-	-	3.3
HAZ30	Neolithic	2	Pig	-20.4	4.0	-	-	-	3.3
Windmill Hill									
WH3	Neolithic	2	Sheep	-21.9	3.8	36.6	13.3	6.3	3.20
WH4	Neolithic	2	Sheep	-21.7	6.4	34.0	13.2	5.3	3.23
WH5	Neolithic	2	Sheep	-21.7	7.2	37.0	12.2	4.2	3.25
WH7	Neolithic	2	Sheep	-22.3	4.0	35.5	13.3	5.1	3.26
WH8	Neolithic	2	Sheep	-22.4	6.3	34.7	12.7	4.9	3.27
WH10	Neolithic	2	Sheep	-22.5	4.0	33.7	12.5	4.0	3.24
WH11	Neolithic	2	Sheep	-21.8	4.9	33.4	11.9	4.1	3.30
WH12	Neolithic	2	Sheep	-21.7	4.4	32.5	11.8	3.5	3.32
WH13	Neolithic	2	Sheep	-22.1	4.2	30.9	11.5	2.9	3.30
WH14	Neolithic	2	Sheep	-22.2	5.0	32.6	11.1	3.7	3.24
WH15	Neolithic	2	Sheep	-23.0	4.6	34.7	11.7	4.5	3.25
WH16	Neolithic	2	Sheep	-21.6	4.8	34.5	12.3	3.5	3.28
WH17	Neolithic	2	Sheep	-22.2	4.3	34.9	12.5	5.1	3.21
WH18	Neolithic	2	Sheep	-22.4	4.6	32.2	12.6	4.7	3.22
WH19	Neolithic	2	Sheep	-22.9	4.8	22.7	11.5	5.0	3.27
WH28	Neolithic	2	Cattle	-22.6	4.5	24.3	8.3	1.4	3.27
WH32	Neolithic	2	Cattle	-22.5	4.5	16.6	8.7	2.3	3.24
WH33	Neolithic	2	Cattle	-22.6	4.7	18.1	5.9	1.6	3.30
WH34	Neolithic	2	Cattle	-21.8	4.5	21.2	6.4	1.6	3.28
WH35	Neolithic	2	Cattle	-21.9	5.0	32.3	7.3	2.3	3.39
WH36	Neolithic	2	Cattle	-21.8	4.6	28.1	11.6	3.7	3.26
WH37	Neolithic	2	Cattle	-21.8	4.6	24.0	10.1	3.7	3.25
WH38	Neolithic	2	Cattle	-22.4	6.0	33.9	8.6	2.8	3.27
WH39	Neolithic	2	Cattle	-22.9	5.2	32.5	12.2	4.0	3.25
WH40	Neolithic	2	Cattle	-22.3	4.9	28.5	11.8	5.4	3.21
WH41	Neolithic	2	Cattle	-22.3	4.6	35.5	10.2	3.9	3.24
WH42	Neolithic	2	Cattle	-22.3	5.1	32.5	12.8	4.3	3.23
WH43	Neolithic	2	Cattle	-23.1	6.0	35.2	11.7	3.7	3.24
WH44	Neolithic	2	Cattle	-22.2	4.6	27.0	12.7	6.3	3.22
WH46	Neolithic	2	Pig	-20.7	6.2	39.4	9.6	2.9	3.27
WH47	Neolithic	2	Pig	-20.8	6.2	31.7	14.3	6.1	3.21
WH48	Neolithic	2	Pig	-21.1	5.9	31.2	11.4	4.7	3.23
WH49	Neolithic	2	Pig	-19.9	4.4	21.8	11.2	4.8	3.25
WH50	Neolithic	2	Pig	-19.8	6.0	31.6	7.8	3.6	3.25
WH51	Neolithic	2	Pig	-20.0	6.6	35.5	11.4	6.8	3.25
WH52	Neolithic	2	Pig	-20.8	5.6	32.4	12.8	6.2	3.24
WH53	Neolithic	2	Pig	-20.8	5.8	35.3	10.9	5.2	3.49
WH54	Neolithic	2	Pig	-20.9	6.1	32.3	12.7	7.8	3.24
WH55	Neolithic	2	Pig	-20.9	6.4	30.2	11.6	4.9	3.25
WH56	Neolithic	2	Pig	-20.9	5.8	25.5	10.8	5.1	3.26
WH57	Neolithic	2	Pig	-20.7	8.6	36.0	9.1	3.4	3.27
WH58	Neolithic	2	Pig	-20.3	5.3	31.6	13.0	8.0	3.24
WH59	Neolithic	2	Pig	-20.1	6.0	34.5	11.3	6.1	3.25

Sample	Period	Phase	Taxon	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C	%N	%Collagen	C:N
WH60	Neolithic	2	Pig	-19.8	6.2	38.0	12.3	5.5	3.27
WH61	Neolithic	2	Pig	-20.9	6.5	34.2	13.9	10.8	3.20
WH62	Neolithic	2	Pig	-19.5	6.0	32.2	12.4	5.6	3.22

Table A1.8 Means and standard deviations of $\delta^{13}C$ and $\delta^{15}N$ for each species by site and period

		Cattle					Sheep					Pig				
			$\delta^{13}C$		$\delta^{15}N$			$\delta^{13}C$		$\delta^{15}N$			$\delta^{13}C$		$\delta^{15}N$	
Site	Period	n	Mean	SD	Mean	SD	n	Mean	SD	Mean	SD	n	Mean	SD	Mean	SD
Abingdon	Neolithic	19	-22.1	0.61	5.82	0.51	20	-21.6	0.35	5.27	0.60	18	-20.9	0.47	6.09	0.45
Alfred's Castle	Iron Age	19	-21.3	0.48	4.57	0.81	21	-21.3	0.35	4.64	0.85	19	-21.3	0.50	6.41	1.07
Alfred's Castle	Roman	7	-21.2	0.55	4.09	1.20	15	-21.2	0.39	4.72	0.64	10	-21.3	0.62	6.82	0.54
Ascott-u-Wychwood	Neolithic	17	-22.3	0.83	5.39	0.50	9	-21.9	0.60	6.01	1.14	15	-20.7	0.83	6.30	0.79
Barton Court Farm	Neolithic	16	-23.0	0.31	5.62	0.44	11	-22.5	0.76	7.20	1.22	8	-20.4	0.34	6.09	0.38
Barton Court Farm	Iron Age	18	-21.6	0.23	6.57	1.32	19	-21.7	0.36	5.99	1.16	11	-21.2	0.62	7.51	1.07
Barton Court Farm	Roman	25	-21.7	0.35	6.96	1.18	37	-21.5	0.32	7.23	1.25	32	-21.2	0.60	7.76	1.35
Claydon Pike	Iron Age	12	-21.6	0.25	5.83	0.95	17	-21.5	0.39	5.90	1.20	2	-21.5	0.97	7.21	0.44
Claydon Pike	Roman	25	-21.6	0.37	6.23	1.74	33	-21.5	0.39	6.19	1.22	16	-21.4	0.65	7.78	1.53
Eton Rowing Course	Neolithic	5	-22.2	0.57	5.10	0.32	1	-21.4	-	7.10	-	3	-19.9	0.51	6.53	0.95
Eton Rowing Course	Bronze Age	3	-21.5	0.42	8.23	0.72	-	-	-	-	-	1	-21.3	-	5.50	-
Eton Rowing Course	Iron Age	6	-21.8	0.49	5.02	0.95	1	-21.6	-	5.00	-	-	-	-	-	-
Eton Rowing Course	Roman	5	-21.8	0.22	6.14	1.51	5	-21.8	0.36	7.82	1.13	4	-21.7	0.33	8.93	0.87
Farmoor	Iron Age	11	-21.6	0.32	6.50	1.17	10	-21.4	0.33	6.40	1.15	6	-21.4	0.31	7.79	1.20
Farmoor	Roman	8	-21.5	0.25	7.14	1.49	7	-21.3	0.37	6.78	1.62	3	-21.6	0.53	8.75	0.86
Harlington	Neolithic	-	-	-	-	-	1	-22.0	-	8.67	-	-	-	-	-	-
Harlington	Bronze Age	9	-22.1	0.35	6.70	0.80	2	-22.1	0.09	7.54	0.43	3	-21.0	0.76	8.26	1.15
Harlington	Iron Age	2	-21.7	0.33	6.42	0.45	-	-	-	-	-	-	-	-	-	-
Harlington	Roman	7	-22.0	0.52	5.89	0.63	11	-21.7	0.44	7.42	1.37	2	-20.4	0.85	4.65	1.40
Hazleton	Neolithic	12	-22.0	0.25	4.18	0.71	1	-22.0	-	4.20	-	1	-20.4	-	4.00	-
Horton	Neolithic	-	-	-	-	-	-	-	-	-	-	1	-19.4	-	9.06	-
Horton	Bronze Age	-	-	-	-	-	1	-21.6	-	6.03	-	-	-	-	-	-
Horton	Iron Age	2	-21.9	0.13	4.24	0.62	4	-22.1	0.41	6.13	0.82	1	-21.5	-	6.22	-
Heathrow Terminal 5	Bronze Age	9	-22.3	0.58	7.20	1.74	13	-21.9	0.48	7.69	1.58	-	-	-	-	-

Site	Period	Cattle					Sheep					Pig				
		n	$\delta^{13}C$		$\delta^{15}N$		n	$\delta^{13}C$		$\delta^{15}N$		n	$\delta^{13}C$		$\delta^{15}N$	
			Mean	SD	Mean	SD		Mean	SD	Mean	SD		Mean	SD	Mean	SD
Heathrow Terminal 5	Iron Age	11	-21.8	0.38	6.32	1.19	4	-22.1	0.44	7.04	0.65	-	-	-	-	-
Heathrow Terminal 5	Roman	6	-21.7	0.37	6.50	0.63	4	-22.4	0.29	8.53	1.54	-	-	-	-	-
Latton Lands	Bronze Age	1	-22.1	-	5.73	-	3	-21.9	0.70	8.01	0.39	-	-	-	-	-
Mount Farm Berinsfield	Neolithic	2	-23.2	0.09	6.23	0.09	2	-21.6	0.20	6.95	0.47	3	-21.1	0.05	7.34	0.09
Mount Farm Berinsfield	Bronze Age	12	-21.8	0.42	6.46	0.73	4	-21.9	0.13	7.20	1.86	1	-21.2	-	7.96	-
Mount Farm Berinsfield	Iron Age	24	-21.8	0.28	6.11	1.20	30	-21.8	0.36	6.72	1.11	17	-21.7	0.38	8.21	1.26
Mount Farm Berinsfield	Roman	12	-21.7	0.35	6.53	1.05	15	-21.8	0.36	6.51	1.35	3	-22.0	0.19	8.46	0.78
Runnymede	Neolithic	28	-21.9	0.45	6.24	0.89	15	-21.4	0.30	6.49	1.18	20	-20.3	0.31	6.83	0.76
Runnymede	Bronze Age	16	-21.7	0.38	5.77	1.49	19	-21.6	0.46	7.13	0.98	18	-21.0	0.39	6.05	1.31
Shorncote Quarry	Bronze Age	6	-22.7	0.61	6.14	1.01	-	-	-	-	-	-	-	-	-	-
Shorncote Quarry	Neolithic	19	-22.3	0.59	5.85	0.63	4	-22.1	0.91	5.78	0.38	10	-20.4	0.60	6.05	0.89
Thornhill Farm	Iron Age	5	-21.6	0.17	4.93	1.91	4	-21.2	0.43	4.31	1.30	1	-21.4	-	5.71	-
Thornhill Farm	Roman	10	-21.6	0.21	5.65	1.37	8	-21.7	0.23	5.75	0.73	3	-21.2	0.20	7.98	0.46
Thorpe Lea Nurseries	Iron Age	14	-21.8	0.44	7.17	0.62	14	-21.8	0.43	7.71	0.81	11	-21.6	0.26	8.46	1.36
Thorpe Lea Nurseries	Roman	28	-21.5	0.31	7.00	1.17	33	-21.5	0.48	7.75	1.51	9	-21.2	0.50	8.40	1.15
Watkins Farm	Iron Age	4	-21.7	0.21	4.34	0.64	1	-21.9	-	7.59	-	2	-21.8	0.32	7.49	0.21
Watkins Farm	Roman	5	-21.4	0.48	5.91	1.21	5	-21.9	0.30	6.97	2.91	2	-22.2	0.18	9.82	0.09
Whitecross Farm	Bronze Age	14	-21.8	0.37	5.95	0.76	15	-21.4	0.56	5.53	1.04	13	-21.4	0.50	4.87	0.96
Windmill Hill	Neolithic	14	-22.3	0.41	4.92	0.52	15	-22.2	0.44	4.88	0.98	17	-20.5	0.51	6.09	0.82
Wyndyke Furlong	Iron Age	21	-21.6	0.22	6.38	1.87	23	-21.4	0.39	5.83	0.84	6	-21.8	0.43	7.75	0.91
Wyndyke Furlong	Roman	17	-21.5	0.27	5.78	1.44	15	-21.5	0.37	5.88	1.37	8	-21.0	0.62	9.13	1.21
Yarnton	Bronze Age	11	-21.9	0.46	6.52	1.13	8	-21.5	0.29	6.18	1.12	3	-20.2	1.58	4.62	1.60
Yarnton	Iron Age	46	-21.6	0.35	5.95	1.30	45	-21.5	0.43	7.09	1.54	41	-21.7	0.45	7.84	1.36
Yarnton	Roman	26	-21.7	0.35	6.86	1.90	18	-21.6	0.30	7.55	1.75	14	-21.5	0.48	8.76	1.04

Appendix 2: Gazetteer of sites

Abingdon Causewayed Enclosure	Site code: AB		Site number: 8
Radley	Oxfordshire	NGR: SU 511 983	Elevation: 60 m OD
Causewayed Enclosure	Early Neolithic		
Dates	Radiocarbon, from Bayesian model, 95% probability		
Building and use of enclosure	Either 3rd quarter of 37th century cal BCE or 3rd quarter of 36th century cal BCE - strongly bimodal model		
Description			
Topography, geology, soils The site is on a slight spur of the 2nd terrace gravels bounded by the valleys of two small streams which ran to the Thames, about 1200 m to the south. This is an area of fertile, freely draining circumneutral brown argillic sandy loams developing over the limestone gravel terraces. The ditches extended in arcs between the two small valleys, and the enclosure was at its highest near the centre of arc of the outer ditch, sloping gently southwards. Abingdon causewayed enclosure lies within a few hundred metres of Barton Court Farm (q.v.) and Radley Barrow Hills Bronze Age cemetery, and of Daisy Banks Fen with its long-term environmental record.			
Structures and development The site consists of two more or less parallel arcs of ditch segments. The inner ditch had been recut when substantially silted. There were abundant finds of ceramics, worked flint and other stone, animal bones and antler. Several different sequences have been proposed (discussed in Whittle et al. 2011, 407-421), but whichever is chosen, the construction and use of the site are likely to occupy no more than half a century, and for present purposes can be taken as one phase. Causewayed enclosures are currently interpreted as sites of (seasonal?) gathering and feasting rather than settled occupation.			
Environment Snails indicate very open, calcareous grassland, with a minor representation of damper or more shaded habitats (and a warmer climate than today). Charcoal of oak, beech and ash was identified but mainly included scrub/ woodland edge species. Evidence from Daisy Banks Fen also indicates a largely open environment.			
Plants Emmer and 6-row hulled barley (plant impressions), sloe, crab apple			
Animals Cattle, sheep/goat and pig, red deer bone and antler, and 1 canid (possibly wolf) bone, were found. Sheep/goat included a goat horncore. Cattle were the commonest domestic animal, and pig outnumbered sheep.			
Phases used: Early Neolithic (phase 2)			
Isotope analyses by:	JH Gathering Time project	RLAHA	
References			
Case, H.J. and Whittle, A.W.R. (1982) Settlement patterns in the Oxford region: excavations at the Abingdon causewayed enclosure and other sites. CBA Research Report 44. London: Council for British Archaeology			
Whittle, A.W.R., Healy, F. and Bayliss, A. (2011) Gathering time: dating the Early Neolithic enclosures of Southern Britain and Ireland. Oxford: Oxbow			

Alfred's Castle	Site code: AC		Site no: 15
Ashbury	Oxfordshire	NGR: SU 277 822	Elevation: 190 m OD
Enclosed settlement/hillfort	Iron Age		
Enclosed settlement	Romano-British		
Dates	From radiocarbon dating, ceramics		
Rampart construction	c. 4th century BCE (ceramics)		
Middle Iron Age occupation	4th-3rd centuries BCE		
Villa-house construction	Late 1st- early 2nd century CE		
Villa-house destruction	Late 3rd century CE		
Description			
Topography, geology, soils Situated c. 3 km south of the Ridgeway, centrally within a natural bowl in the landscape. On Coombe deposits, Pleistocene chalky drift, over Cretaceous Middle Chalk covered with Coombe 1 (511f) well-drained calcareous fine silty soils.			
Structures and development Residual Mesolithic and Neolithic flints, Bronze Age barrows; Late Bronze Age/Early Iron Age ditches/linears, part of which continued as boundary and filled gradually during enclosed phases. Rampart constructed c. 4th century BC and occupied in MIA, settlement within the small enclosure; large enclosure/annexe, ?stock enclosure, constructed about the same time. Iron Age features in the small enclosure include pits, gullies, postholes and evidence for houses, together suggesting sustained occupation, with little activity after 3rd century BC. Sporadic activity in the 1st century AD, villa-house construction in late 1st- early 2nd century AD. The house had painted walls and window-glass but no mosaics or hypocaust, permanent rather than seasonal occupation. Site abandoned and the house collapsed in the late 3rd century AD, sporadic post-Roman activity.			
Environment Most evidence is from the MIA occupation. Varied weed flora characteristic of disturbed habitats including arable, and dry ground (except *Carex* spp.). Some from short calcareous grassland, others from nitrogen-enriched environments e.g. fields or field edges. Charcoal includes hawthorn and hazel, oak, beech and birch, willow, field maple, spindle and shrubby species, indicating deciduous woodland with shrubby understorey perhaps coppiced or grazed, hedgerow/field boundary and streamside vegetation. Evidence suggests mosaic including short calcareous grassland, arable fields, hedgerow/scrub and woodland.			
Plants Most evidence is from the MIA occupation. The major cereals were spelt and hulled barley. Hazel nut, *Prunus* sp., pulse, flax, *Brassica* sp and fig (probably intrusive) were also found. Varied weed flora indicates autumn sowing, harvesting by uprooting, and large-scale cereal processing.			
Animals (overall: varies by trench) MIA: Sheep>> cattle> pig by NISP, also goat, horse, dog, deer. Roman: slightly more cattle. In both periods pastoral economy centred on sheep, animals bred, butchered and consumed on site.			
Phases used: Middle Iron Age (phase 10) Early Roman (phase 13) Mid/Late Roman (phase15)			
Isotope analyses by:	This project	RLAHA	
References			
Gosden, C. and Lock, G. 2013 Histories in the making. Excavations at Alfred's Castle 1998-2000. OUSA Monograph 79. Oxford: School of Archaeology			
Archive available at: http://www.arch.ox.ac.uk/alfreds-castle.html			

Ascott-under-Wychwood	Site code: AUW		Site Number: 2
Ascott-under Wychwood	Oxfordshire	NGR: SP 299 175	Elevation: 120 m OD
Long Barrow	Neolithic		
Dates	From Bayesian model, 95% probability		
Pre-barrow occupation/midden	3950-3800 cal BCE		
Primary construction	3760-3700 cal BCE		
Secondary construction	3745-3670 cal BCE		
Last interment	3645-3595 cal BCE		
Description			
Topography, geology, soils The long barrow is on a small spur above the Coldwell Brook, which runs down to the Evenlode about 0.9 km to the south. The underlying rock is Chipping Norton Limestone, part of the (Jurassic) Great Oolite Group, overlain by Pleistocene deposits. Soils developing on this geology tend to be calcareous, clayey brown rendzinas or deeper clayey brown earths. Buried soils beneath the barrow showed a rendzina profile to the west with an area of decalcified loams towards the east.		
Structures and development There was evidence for episodic Mesolithic activity at the site, followed by an Early Neolithic occupation of uncertain nature – there was no botanical evidence, but remains of both wild and domestic animals were found as well as pottery and flints, and a concentration of remains recognised as a midden. There was probably a gap of at least 50 years between the first Neolithic occupation/midden formation and the start of long barrow construction, long enough for a turfline to form. The barrow building sequence was complex, with human remains incorporated from an early stage. After the last interment there was occasional disturbance (Late Neolithic, Roman and Medieval) but no further intensive use.			
Environment Environmental evidence, particularly snails, showed development of woodland during the Mesolithic, and a significant open-country, probably grassland phase in the Neolithic, but the absence of certain open-ground species suggested that clearance was not widespread, and woodland re-established after the barrow went out of use.			
Plants No evidence			
Animals Cattle, pig and sheep/goat as well as aurochs, wild boar, and red and roe deer came from both the midden and the long barrow, but the widest range and highest proportion of wild species came from within the midden. Pig outnumbered sheep/goat.			
For analysis, two phases were distinguished within the Neolithic period: the pre-barrow occupation (phase 1) and the period of barrow construction and use (phase 2).			
Isotope analyses by:	R.E.M. Hedges, R.E. Stevens and J. Pearson	At RLAHA	Benson and Whittle (2007), 255-262
References			
Benson, D. And Whittle, A. (2007) Building Memories. The Neolithic Cotswold Long Barrow at Ascott-under-Wychwood, Oxfordshire. Oxford: Oxbow			

Barton Court Farm	Site code: BCF		Site Number: 10
Abingdon	Oxfordshire	NGR: SU 510 977	Elevation: 60 m OD
Occupation/Pits	Neolithic		
Enclosed farmstead	Iron Age		
Enclosed farmstead/villa	Roman		
Dating	Mainly on evidence from pottery and other artefacts including coins. *Dates from publication calibrated with OxCal, IntCal 13		
Late Neolithic occupation	Grooved Ware, c. 2500 BCE (*Uncalibrated 3970-3910 bp, 4070-4030 bp; 2565–2309, 2831–2488 cal BCE)		
Late Iron Age farmstead	1st half of 1st century CE (*Uncalibrated 2200±70 bp, 1830±80 bp; 397–61 cal BCE, 24-385 cal CE)		
Early Roman farmstead	In use latter half of 1st century to mid-2nd century CE		
Later Roman Farmhouse/villa	Constructed in the last quarter of the 3rd century CE Demolished end 4th/early 5th century CE?		
Building 2 and paddocks	Constructed/laid out mid-4th century CE In use till mid-5th century CE?		
(Post-Roman occupation, including early Saxon settlement, is not included here).			
Description			
Topography, geology, soils The site lies on the edge of the 2nd ("Summertown-Radley") gravel terrace of the Thames c. 0.7 km north of the river. It is well-drained and close to a spring-line where the underlying Kimmeridge Clay comes close to the surface. This is an area of fertile, freely draining, circumneutral brown argillic sandy loams developing over the limestone gravel terraces. The Kimmeridge Clay on the slope gives a circumneutral gleyed loam. Until the Late Iron Age much of the floodplain probably had a covering of free-draining soils similar to those on the terraces, though now covered by alluvial clays. BCF is one of a number of sites on the broad spread of gravel terraces near the confluence of the Ock and the Thames, within a few hundred metres of the Abingdon causewayed enclosure (q.v.) and Radley Barrow Hills Bronze Age cemetery, and of Daisy Banks Fen with its long-term environmental record. Many local Iron Age and Roman sites are known from aerial photography, and Abingdon itself overlies a large Roman (and possibly earlier) settlement, suggesting a concentration of monuments and settlement in the area at least from the Neolithic onwards.			
Structures and development Late Neolithic: scatter of pits and postholes, mainly along the edge of the terrace; no associated structures found. Late Iron Age: enclosure defined by ditch, within which were pits, postholes, gullies and ditches, hut(s) and possible burials. The ditches had silted up before Early Roman ditched enclosure laid out on a different axis: divided into north and south yards with a substantial timber structure, plastered and thatched, in the southern yard, 6-post structures and a cess-pit. Pottery mainly local "native" type. Later Roman enclosure was larger and included stone-lined wells. Several phases were recognised: (1) construction within its own ditched enclosure of a substantial farmhouse or cottage villa, a corn-drier and a waterhole; (2) addition of cellar to the house, construction of system of paddocks and enclosures, with wells and waterholes, construction of building 2; (3) addition of further irregular paddocks; (4) demolition of villa and infilling of cellar. From the Late Iron Age and through the Roman period BCF was a series of farmsteads exploiting the surrounding landscape (the continuing use of the site is reflected in its name which includes the word "farm" in Anglo-Saxon, Norman French and English).			
Environment Evidence from Daisy Banks Fen suggests that dense oak/lime/ash/hazel woodland was cleared early in the 4th millennium BCE and that the area remained open with a high proportion of grassland and nearby cereal cultivation thereafter. By the Late Neolithic the secondary woodland of the earlier Neolithic was gone (though charcoal included scrub species) and values of arboreal			

pollen were low. There is no evidence of substantial woodland regeneration in the area at any time after the mid-Bronze Age, and in the Iron Age and Roman periods the Thames floodplain was open grassland; suggests the area around BCF was dominated by open arable on the drier terrace soils and pasture. Alluviation from the Late Iron Age onwards would have affected the floodplain, perhaps increasing the proportion of damp pasture and meadow: an increase in weeds of wet arable soils in the Roman period suggests that arable extended on to wetter areas. There was access to woodland, most likely mixed oak-hazel coppice, not unlike Bagley Wood (3 km north of BCF on Corallian limestone).

Plants

Late Neolithic charred plant remains dominated by (collected species) hazelnut and crab apple, with emmer, bread wheat and 6-row barley. Late Iron Age plant deposits included spelt & 6-row barley, with small amounts of emmer & bread wheat, and large numbers of arable weeds, some associated with autumn sowing, and very few damp-ground species, suggesting that cereals were cultivated in the drier conditions of the 2nd terrace. Roman plant remains included spelt and 6-row barley, other cereals in smaller quantities, flax, bean, exotic herbs and fruit. Seeds of weeds adapted to a wide range of conditions from very wet to very dry suggest that cereals were cultivated on lower terraces and/or floodplain as well as 2nd terrace. Modelling of site catchment suggested that flax and bean, sensitive to drought, were cultivated on the 1st terrace.

Animals

Late Neolithic: Cattle, sheep and pig; red deer antler. The high proportion of pig often referred to may be a little illusory as it includes a fairly complete skeleton. Late Iron Age: Cattle, sheep, pig, horse, dog and cat (possibly wild); red deer, fox. Early Roman: increase in proportion of cattle relative to sheep, with pig, horse (also in higher proportion), dog, and domestic fowl. Late Roman: same species + cat, roe deer and hare; marine shell (mainly oyster); similar high proportions of cattle and horse. Sheep were older, suggesting greater importance of wool. Modelling of site catchment suggested that sheep were kept on 2nd terrace and cattle on the floodplain, and emphasised the importance of cattle in providing manure for intensive crop cultivation.

Phases used: Late Neolithic (phase 4), Late Iron Age (phase 11), Early Roman (phase 13), Late Roman (phase 15)

Isotope analyses by:	This project	RLAHA	

References

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Miles, D. (1986) Archaeology at Barton Court Farm, Abingdon, Oxon. OAU Report 3/CBA Research Report 50. Oxford: Oxford Archaeological Unit

Parker, A.G. (1998) The pollen and sediments of Daisy Banks Fen. In: Barclay, A. and Halpin, C. (1998) pp 254-267

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Claydon Pike	Site code: CP		Site number: 7
Fairford	Gloucestershire	NGR: SU 418 199	Elevation: 75 m OD
Settlement	Iron Age		
Nucleated settlement	Roman		
Aisled house, barn	Roman		
Villa	Roman		
Dates	Based on ceramics, coins, stratigraphy		
Middle Iron Age settlement, SitePhase 1	3rd-1st century BCE		
Late Iron Age nucleated settlement, SitePhase 2	Early 1st-early 2nd century CE		
Early Roman period aisled house, barn, SitePhase 3	Early 2nd-early 4th century CE		
Villa, SitePhase 4	Early 4th century – Late 4th century CE		
(Possible early 5th century & Medieval not included here)			

Description

Topography, geology, soils

The site lies on the 1st terrace of the Thames; the excavated structures are on gravel "islands" of drier land. The soil which developed on top of the gravel islands was a stone-free shallow calcareous clay loam. The underlying gravel means that these soils are normally well-drained when the water table is low and sometimes experience problems of drought.

Structures and development

Two areas of settlement, ranging from the middle Iron Age to the medieval period. The excavated settlements were all engaged in farming.

In the MIA activity at Warrens Field over three gravel islands represented a settlement of 1-2 families, shifting eastwards over time, with ≤4 roundhouses in use on an island at any one time. In the early 1st century CE a nucleated settlement was established 120 m to the south at Longdoles Field, witha series of large and intensively re-cut enclosures, gullies, pits and substantial boundary ditches. Activity areas were associated with domestic habitation, small scale metalworking, and stock management. Similar economy to Thornhill Farm (q.v.), with greater emphasis on the settlement boundary, and more imported goods. Dramatic changes in early 2nd century: enclosures, gullies and ditches replaced by two large rectangular enclosures, a substantial aisled barn and an aisled house with a tiled roof and painted plaster interior. This was probably the residence of an extended family group with "Romanised" eating, drinking and dress. By mid 2nd century CE the settlement expanded onto adjacent gravel platforms ?accommodating lower-status estate workers, with small stock enclosures and industrial areas; possible religious precinct at the heart of the settlement, overlooking a central open space. During the early 4th century CE there appears to have been deliberate and widespread clearing of the site with much domestic and structural material deposited in pits and ditches. A modest masonry-footed villa was established comprising two separate structures, the southern of which incorporated a hypocaust room. The villa was substantially modified during the 4th century, and had two successive enclosures built around it, probably signalling perception of an increased need for security. A small inhumation cemetery plot lay 100 m to the west of the villa and a well built masonry footed shrine was constructed to the east. The final abandonment of the villa is unclear, but activity of some kind continued until the start of the 5th century.

The site is interpreted as a centre for agricultural activity with an emphasis on pastoral farming throughout the Iron Age and Roman phases. There are various indicators of a greater degree of "Romanisation" and/or higher social status than at Thornhill Farm nearby.

Environment

No waterlogged remains from MIA; snails indicate dry ground on gravel islands and wetter conditions in lower areas. In the early 1st/2nd century CE grassland predominated on 1st terrace, including rush pasture on wetter areas and drier grassland on gravel islands. High proportions of scarabeoids indicate concentration of grazing animals, and weeds suggest overgrazing and trampling in vicinity of enclosures. There was little evidence of scrub or woodland close to the site, or of arable cultivation. In 2nd-early 4th century CE there is abundant evidence of haymaking, and

both wet and dry pasture (including aftermath grazing), though less intensively grazed than in Phase 2. Lower areas of the site may have flooded, but not the gravel islands. There is little evidence for cereal growing, but horticultural crops (herbs, vegetables, fruit) may have been grown at the site, and box was present. While the area was mostly open, there was a significant presence of trees and shrubs in and around the settlement. In the 4th century CE grassland was still the dominant vegetation, but there is less evidence of hay meadow. Pasture was not trampled/overgrazed. As in previous phases the landscape was open, though with some trees or shrubs around the site, there was little evidence of cereal cultivation, and there may have been horticultural plots.
Plants Cereals present in small quantities, possibly not grown in vicinity. Throughout: spelt, barley, small quantities of emmer and bread wheat; weeds associated with arable/disturbed ground or pasture, or hay meadow in Phase 3. Also in Phase 3, flax and bean. In Phase 4 cereal weeds from both dry and heavy soils which may indicate use of more diverse soils. In Phases 3 & 4 there were orchard/horticultural crops including *Prunus* spp., pear, introduced herbs, poppy, possibly cultivated *Brassica* spp., carrot
Animals Bone very fragmentary. MIA, Phase 1: Cattle>sheep>pig, horse, dog. Perhaps more sheep than cattle based on MNI (though report emphasises cattle "ranching"). Sheep & cattle killed at prime meat age or younger, with some older animals kept for wool/dairy. The proportion of cattle increases over later phases, and cattle and sheep age profiles shift towards older ages, with a higher proportion of male cattle - ?higher importance of secondary products and/or export of prime meat animals on the hoof. Butchery patterns suggest brining or curing of meat on site. Pigs show meat exploitation profile. Cattle and sheep show size increase between Phase 2 and 3, and possibly 3 and 4. Possible horse breeding in Phase 4. In phases 3 and 4 donkey, cat, domestic fowl, goose and duck, red (also in Phase 2) and roe deer, hare and other wild mammals, and wild birds, many from marshland habitats, were found, also a few eel bones: suggests hunting, fowling and fishing.
Phases used: Phases used: Middle Iron Age (phase 10), Early Roman (phase 13), Early/Mid-Roman (phase 14), Late Roman (phase 16)

Isotope analyses by:	This project	RLAHA	

References
Miles, D, Palmer, S, Smith, A and Jones, G (2007) *Iron Age and Roman settlement in the Upper Thames Valley: Excavations at Claydon Pike and other sites within the Cotswold Water Park.* Thames Valley Landscapes Monograph, Oxford Archaeology
Archive available online at ADS website http://archaeologydataservice.ac.uk/archives/view/cwp_eh_2005/

Eton Rowing Course	Site code: ERC		Site number: 16
Dorney	Buckinghamshire	NGR: SU 920 770	Elevation: 20 m OD
Occupation	Neolithic		
Waterhole, enclosures (etc)	Bronze Age		
Farmstead, nucleated settlement	Iron Age		
Farmstead	Roman		
Dates	Radiocarbon, ceramics, material culture: details not available for later periods		
Neolithic occupation	Early Neolithic middens c. 3950-3600 cal BCE (several dates)		
Late Neolithic/Early Bronze Age activities	2600-1900 cal BCE (several dates)		
Enclosures, waterholes, bridges	Mid-Late Bronze Age; Bridge construction 1200-1100 cal BCE		
Settlement	Early-Middle Iron Age		
Farmstead	Middle-Late Iron Age		
Farmstead	Early-Late Roman		
Only Neolithic/EBA report published. Details for later periods not yet available. Isotope samples mainly from palaeochannels so associations with features not clear; some directly dated			
Description			
Topography, geology, soils Sites on north bank of the river Thames. The area of excavations covers approximately 150 ha and comprises Late Glacial age gravel floodplain terrace deposits of the Taplow Series overlying London Clay. The floodplain is crossed by former palaeochannels incised to a maximum depth of 3.5 m, some of which remained active into the historic period. Sites on floodplain/terrace gravels.			
Structures and development Extensive evidence for occupation in an evolving landscape of floodplains and gravel terraces set amidst the shifting channels of the Thames. A series of early Neolithic midden deposits preserved in hollows left by infilled palaeochannels; other artefact scatters from the floodplain, pits on the gravel; pits from the middle and late Neolithic; activity areas of the Beaker and Early Bronze Age. Early, middle and late Neolithic human remains in palaeochannels. An oval barrow may have first been cut in the early Neolithic. Late Neolithic/EBA ring ditches. During the Middle Bronze Age a substantial bridge was constructed across the Thames palaeochannel, with a double row of oak piles, replaced in the Iron Age by successive smaller bridge structures, suggesting that channel was still flowing and had narrowed. Extensive use in MBA, including barrows, two areas of enclosures and waterholes, and unenclosed settlement including wells/waterholes, pits and ditches on the central gravel islands, hearths and flint scatters on the floodplain. In the Late Bronze Age the evidence is sparse but widespread, including human burials in the ditches of earlier barrows, in earlier enclosures and around earlier waterholes, activity on the floodplain and on sandbanks in the former Thames channel. A small settlement developed on the central gravel island in the Early and Middle Iron Age, with continuing use of Bronze Age enclosures. In the later MIA settlement moved to an enclosed ditched farmstead, which grew in the Early Roman period into several enclosed areas containing posthole buildings and wells, with a major crop-processing area consisting of a corn-drier with a barn, and at least one millstone. Complex development of enclosures during the 2nd - early 3rd centuries AD, with frequent recutting of enclosure ditches, abandoned during Late Roman period.			
Environment The Neolithic landscape was probably a mosaic of old woodland, clearances that were being grazed and included cereal cultivation, and abandoned clearances with developing woodland. At the start of the Neolithic pollen dominated by woodland taxa; dense alder woodland on floodplain, mixed oak-lime-hazel on terraces. Evidence for clearance at around 3640-3370 cal BCE and again 2900-2630 cal BCE, probably for pasture as there is little evidence of arable. Beetles and pollen indicate about 25% cover of lightly grazed grassland, and dung beetles indicate grazing in area throughout sequence. Late Neolithic/EBA: progressive decline in woodland, lightly grazed floodplain grasslands (meadow and/or pasture), increase in arable weeds. Suggests clearance for			

both grazing and arable. Late Bronze Age/ Early Iron Age: generally open landscape dominated by non-arboreal pollen. Residual scatters of trees including oak and bankside alder communities. Pollen/plant macrofossil evidence includes strong pastureland element. Scarabeoid dung beetles rose to c.15% of the terrestrial Coleoptera, suggesting domestic animals were being grazed on the floodplain. Limited evidence for cereal production. During MIA *Alnus* declined suggesting that the remaining bankside alder had been removed to create a very open landscape. Erosion/silting reflect clearance of the last vestiges of woodland. Decline in scarabeoid Coleoptera and a rise in pollen/plant taxa associated with hay meadows early in Late Iron Age/Roman period (+scythe: possibly earliest Thames Valley site with evidence for hay meadow yet identified). In ?Early Roman period, there was a large increase in cereal pollen, and alien cereal weed *Agrostemma githago*/spelt chaff from Roman channel sediments, possibly derived from the nearby Iron Age and Roman farmstead, where many Roman crop processing remains were found. The environmental record remains similar into the Late Roman and Saxon period although the intensity of cereal growing is reduced, along with some evidence for increased pasture and grazing elements. During the Roman period, flow along the Thames channel ceased, resulting in a pond-like feature in which peaty silts rapidly accumulated. This phase of ponding was punctuated by renewed channel activity coinciding with a major peak in cereal cultivation and related catchment disturbance of soils because of ploughing with associated runoff and inwash of soils associated with flooding.
Plants Early Neolithic: Emmer, a little barley, rivet/bread wheat, hazelnuts, sloe. Little evidence from EBA, emmer present. Charcoal (of woodland and scrub species) included early evidence of beech. No details available for later periods.
Animals Early Neolithic: Cattle>sheep (incl. goat)>pig, dog, aurochs, ?wild boar, red and roe deer, badger, beaver, fox, bear. Relatively high numbers of sheep for EN. Over Mid and Late Neolithic sheep decline and pigs rise to c. 25% NISP. Little evidence for EBA, sheep become commoner again at expense of pigs. No details available for later periods.
Phases used: Early Neolithic (phase 2) Bronze Age (phase 7) Iron Age (phase 10) Roman (phase 14)

Isotope analyses by:	Stevens et al. (2012)	RLAHA	

References

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Parker A.G., Lucas A.S., Walden J., Goudie A.S., Robinson M.A., Allen T.G. (2008) Late Holocene geoarchaeological investigation of the Middle Thames floodplain at Dorney, Buckinghamshire, UK: an evaluation of the Bronze Age, Iron Age, Roman and Saxon landscapes. Geomorphol 101:471–483

Stevens, R.E., Lightfoot, E., Allen, T., Hedges, R.E.M (2012) Palaeodiet at Eton College Rowing Course, Buckinghamshire: isotopic changes in human diet in the Neolithic, Bronze Age, Iron Age and Roman periods throughout the British Isles. Archaeol Anthropol Sci (2012) 4:167–184

Farmoor	Site code: FM		Site number: 4
Farmoor	Oxfordshire	NGR: SP 445 065	Elevation: 62 m OD
Occupation	Early Iron Age		
Open settlement	Middle Iron Age		
Droveway, fields	Early Roman		
Farmyard?	Late Roman		
Dates	Mainly ceramics – may well need revision!		
Early Iron Age	6th – 4th century BCE		
Middle Iron Age	3rd – 2nd century BCE?		
Early Roman	2nd century CE		
Later Roman pits, ditches, fields?	Late 3rd – 4th century CE		
Later Roman farmyard, garden?	Late 4th century CE?		
Description			
Topography, geology, soils The site lies partly on the present floodplain and partly on the 1st gravel terrace of the Thames. Soils developing on these substrates vary from acidic to neutral clays and clay loams on the floodplain to neutral to alkaline sandy, well-draining or clayey loams on the terraces. Flooding/ alluviation on floodplain in Iron Age, and up to edge of the 1st terrace in the Roman period.			
Structures and development Site interpreted as settlement with a strong emphasis on the pastoral economy. Traces of EIA occupation on 1st gravel terrace; clear break before Middle Iron Age enclosures on the terrace include a ditch, a palisade and a workshop building and may indicate permanent settlement. MIA floodplain enclosures (including penannular house gully and attached compounds) subject to flooding and seasonally occupied, as centres for management of summer floodplain grazing; short-lived, in use for only a few seasons. After gap in occupation, Roman period site confined to gravel terrace. There was a ditched droveway by the 2nd century CE, ?other ditches and a well. In the 3rd and 4th centuries CE droveway continued in use, with enclosed fields/paddocks with wells and waterholes; two corndriers and an accumulation of domestic waste suggested site used as a farmyard, possibly with building; box hedges suggest a garden nearby.			
Environment: EIA: no evidence. MIA: very open grassland environment, including grazed meadows, with some marsh/wetland. The floodplain was probably wet enough for grass to continue in growth over the summer and be supplied with nutrients by winter flooding. Ruderals from around the settlement: lack of perennial weeds suggests only a few seasons of habitation. Roman: mainly meadow and pasture, including hay meadow. Arable weeds and perennial weeds of disturbed habitats now present, and evidence of thorn hedges, perhaps surrounding the fields. High water table may have caused drainage problems. Occupation more permanent, but location of buildings uncertain, or whether crops were grown at/close to site or if it was still mainly pastoral.			
Plants: Iron Age and Roman: spelt wheat, with small amounts of barley and oats (possibly brought to site for processing rather than grown nearby). Seeds include dill, coriander; cultivated fruit (plum); along with hazel, sloe and apple (wild or cultivated). Perennial ruderals indicate more permanent occupation.			
Animals: Cattle, sheep/goat, pig, horse, dog and red deer were found in both periods, with some oyster shells in the Roman period. More cattle and horse relative to sheep in Roman period.			
Phases used: Early Iron Age (phase 9), Middle Iron Age (phase 10), Early Roman (phase 13), Later Roman (phase 15)			
Isotope analyses by:	This project	RLAHA	
References			
Lambrick, G. and Robinson, M. (1979) Iron Age and Roman riverside settlements at Farmoor, Oxfordshire. OAU Research Report 2. London: Council for British Archaeology			

Harlington	Site code: HAR		Site number: 18
Harlington	London	NGR: TQ 077 778	Elevation: 20 m OD
Occupation	Neolithic		
Field system, waterhole	Bronze Age		
Small settlement	IronAge		
Small settlement	Roman		
Saxon period omitted here			
Dates	Not yet published, details not available		
Middle Neolithic pits	Mortlake ware		
Field system	Middle/Late Bronze Age		
Waterhole	Late Bronze Age/Early Iron Age pottery		
Nucleated settlement	Iron Age		
Nucleated settlement	Roman		
Description			
Topography, geology, soils Imperial College Sports Grounds and RMC Land, Victoria Lane, Harlington, just north of Heathrow Airport. Brickearth (Langley silt) over gravel (Taplow terrace). No further details available.			
Structures and development Early to Middle Neolithic occupation was represented by a rectangular ditched mortuary enclosure and a large spread of pits, many containing deposits of Peterborough Ware pottery, flint and charred plant remains. A possible dispersed monument complex of three hengiform enclosures was associated with the rare remains of cremation burials radiocarbon dated to the Middle Neolithic. Limited Late Neolithic and Early Bronze Age activity. In Middle to Late Bronze Age a formalised landscape of extensive rectangular fields, enclosures, wells and pits was established. This major reorganised land division can be traced over large parts of the adjacent Heathrow terraces (q.v. Heathrow Terminal 5, Horton). A small Iron Age and Romano-British nucleated settlement was constructed, with associated enclosures flanking a trackway. There were wayside inhumations, cremation burials and middens and more widely dispersed wells and quarries.			
Environment: details not available			
Plants: details not available			
Animals: details not available			
Phases used Middle Bronze Age (phase7) Late Bronze Age (phase 8) Iron Age (phase 10) Early Roman (phase 13) Late Roman (phase 14)			
Isotope analyses by:	This project	RLAHA	
References			
Barclay, A., Mepham, L., Powell, A.B., Stevens, C.J. (in press) Imperial College Sports Grounds and RMC Land, Harlington. Oxford: Oxbow			

Hazleton North	Site code: HAZ		Site number: 1
Hazleton	Gloucestershire	NGR: SP 073 189	Elevation: 250 m OD
Long cairn with lateral chambers	Neolithic		
Dates	From Bayesian model, 95% probability		
Early Neolithic, pre-cairn occupation	4080–3800 to 3880–3660 cal BCE		
Early Neolithic, cairn construction	3695–3650 cal BCE		
Early Neolithic, cairn use	3710–3655 to 3635–3605 cal BCE		

Description

Topography, geology, soils
The cairn is one of a pair situated on the 250-m contour near a hilltop on Cotswold Great Oolite limestone. Springs ca.1 km to the east at the edge of the Oolite flow into the Sherborne Brook and thence to the Thames. Modern soils on this geology are shallow, stony/clayey brown rendzinas and calcareous brown earths. The buried soil beneath the cairn was originally a shallow decalcified argillic brown earth that had developed under forest conditions.

Structures and development
Pre-cairn Neolithic activity and occupation from 39th century cal BCE: tree clearance, accumulation of materials in midden area, post- and stake-holes ? wooden-framed structure; lasted about a century. Interval of a few decades of cultivation in small plots before start of cairn construction. Most stone quarried at site. Two lateral chambers constructed, human and animal remains deposited; period of "intense" use lasted ca. 2-3 generations, ?sporadic re-use many generations later. Gathering/feasting with materials placed in the forecourt and incorporated in cairn itself as well as in chambers and quarry fills. Activity then ceased (later disturbances including stone-robbing.

Environment: Snails from pre-Neolithic subsoil hollow typical of climax woodland. Pollen from soil beneath midden was 40% hazel, suggesting an open scrubby environment, with only 7% arboreal pollen., Episodic cultivation following initial clearance and occupation. No evidence of grazed grassland, so cultivated plots may have been abandoned allowing regeneration of wood-edge hazel/scrub between episodes of cultivation, giving a mosaic of cultivated/fallow/scrub within the clearing. Cleared before cairn construction; scrub/woodland regenerated after cairn went out of use.

Plants: Carbonised plant remains from beneath the cairn included emmer, a few arable weeds, and weeds of disturbed ground, including onion couch which does not occur in grazed grassland.

Animals: Low domestic animal NISP (Pre-cairn occupation 14, cairn 140). Cattle > pig > sheep/goat; 28% sheep is high for a Neolithic site. + dog, pre-cairn aurochs, red and roe deer. Animals generally killed young, for meat. NB Many samples (Hedges et al. 2008) listed as "medium mammal" i.e. either sheep/goat or pig. 2 clear groups based on $\delta^{13}C$ values correspond well with results from sheep and pig seen in other material of this date; to avoid circular argument, for statistical analyses only definitely identified samples used = 1 S/G, 1P.

Phases used: Pre-barrow occupation (phase 1), barrow construction and use (phase 2)

Isotope analyses by:	Hedges et al. (2008)	RLAHA	

References

Saville, A. (1990) Hazleton North: the excavation of a Neolithic long cairn of the Cotswold-Severn group. London: English Heritage

Hedges, R.E.M., Saville, A. *and* O'Connell, T.C. *(*2008*)* Characterizing the diet of individuals at the Neolithic chambered tomb of Hazleton North, Gloucestershire, England, using stable nitrogen analysis*.* Archaeometry 50*,* 114–*1*28

Meadows, J., Barclay, A. and Bayliss, A. (2007). A short passage of time: the dating of the Hazleton long cairn revisited. Cambridge Archaeological Journal, 17(1, suppl.) 45-64

Heathrow Terminal 5	Site code: HTV		Site number 19
Heathrow Airport	London	NGR: TQ 055 756	Elevation: 22 m OD
Occupation	Bronze Age		
Nucleated settlement	Iron Age		
Occupation	Roman		
Dates	From radiocarbon dating, some modelled; OSL, TSL; ceramics and other material culture		
Mid/Late Bronze Age farmsteads and coaxial field systems, waterholes etc	MBA 1700–1150 cal BCE; LBA 1150–750 cal BCE. Use of fields and waterholes continued into LBA; continuity of dispersed settlements uncertain		
Middle Iron Age settlement	Middle Iron Age ceramics, approx. 400–100 cal BCE		
Late Iron Age/Early Roman occupation, enclosures	Late Iron Age/Early Roman ceramics, approx 100 BCE – 120 CE		
Middle-Late Roman occupation, enclosures	Mid-Roman 2nd–early 3rd century CE Late Roman 3rd–late 4th century CE		
No samples from Mesolithic and Neolithic/Early Bronze Age periods, details omitted Post-Roman periods omitted			
Description			
Topography, geology, soils The site is roughly 4 km to the north and north-east of the middle reaches of the Thames, on a gravel terrace (Taplow Gravel) capped by the Langley Silt Complex ('brickearth'). The area lies immediately to the east of the River Colne floodplain at an altitude rising from *c* 21 m OD in the west to *c* 23.5 m OD in the east, a broadly flat landscape with a very gentle upward slope from west to east. Prior to modern changes topography was more varied, with slight rises and lower lying areas such as palaeochannels. On lower ground and along the palaeochannel on the western edge of the site, silty clay alluvial soils indicate that flooding and high ground water levels were probably regular events in some areas throughout sequence. Both the seasonally-replenished, damp alluvial soils and the better drained soils of the gravel terrace were available for exploitation by occupants of the site. Present-day soils are acid (contributing to poor bone preservation), and there is evidence of soil acidification from the later Bronze Age. Areas of London Clay form higher ground to the north-east of the site.			
Structures and development In the late 4th millennium BCE, the landscape was transformed by the construction of the C1 Stanwell Cursus, followed by the construction of a second cursus and a small horseshoe shaped enclosure. Major reorganisation of the land occurred from 1700 BCE with the formation of at least six farmsteads across the excavated area, with coaxial field systems, waterholes, enclosures and double ditched trackways. This landscape supported a mixed arable/pastoral agricultural economy, supplemented by resources from the innumerable hedgerows which divided the fields. From the late 2nd millennium BCE (LBA) the pattern changed to one of fewer and larger settlements. Major elements of the Bronze Age agricultural landscape persisted well into Iron Age. In the Middle Iron Age a nucleated settlement of roundhouses emerged. Landscape reorganised in LIA/ER, thereafter changes were gradual and piecemeal, with the core of the LIA/ER settlement remaining intact but increased construction of enclosures suggesting some degree of intensification. Beetles suggest presence of timber buildings. Alteration to field boundaries in the eastern area during the 3rd century CE created a complex "ladder enclosure" system with a central wide droveway, possibly in response to demand for meat products in the developing market towns of Staines and London.			
Environment Earlier Neolithic: Forest clearance, including by burning: landscape was no longer densely wooded when cursus built. Pollen indicates cereal cultivation and open grassland, with some woodland in the area (20% arboreal pollen). Later Neolithic: woodland regeneration (80% AP), less evidence for cereal growing. Middle/Late Bronze Age: landscape open, highly organised with ditched and hedged boundaries, dominated by grassland (nutrient-enriched grazed pasture and meadow), with some cereal and flax cultivation. Clay soils to east of site remained wooded (oak/hazel), and alder and willow grew to the west on damp ground near the palaeochannel. Heathland flora indicating soil acidification developed in LBA and agricultural activities declined.			

Little activity in Early Iron Age. Middle Iron Age: nucleated settlement established, landscape was extremely open with very few trees and shrubs. Pollen evidence indicated a drop in local arable cultivation, weeds suggested cultivation of clay soils to the north-east. Soils on the gravel terrace may have become too acidic, impoverished and perhaps damp to produce good yields. Heavily grazed pasture also present, grazing pressure falling later in the sequence (or hay/meadow being used). Late Iron Age/Early Roman period: start of a return to arable cultivation on a similar level to MBA (including oats, which can grow on acid soils). Very open landscape with (?hay) meadows and grassland, cereal cultivation, hedges and areas of waste ground. Animals pastured in damp grassland and heath. Summer grazing and hay-making probably continued in the west on the floodplain/BA field system into late Roman period. New areas of arable cultivation on higher ground on the gravel terrace in the eastern half of the site, and beyond, with some cultivation on the London Clay to the north-east. Intensification continued into the later Roman period, perhaps in response to the emergence and development of towns at Staines and London nearby – soil improvement by middening/manuring, diversity of soils used, new crops. Water levels may have risen at the start of the Roman period, probably causing increased seasonal flooding and waterlogging in some areas of the site; in the later Roman period the site was effectively drained by ditches.
Plants MBA/LBA: hulled wheats emmer and spelt (early!), and hulled barley; flax probably grown on wetter soils. By LBA cereals were cut rather than uprooted, and there may have been fallow/manuring with animals grazing cropped fields. Iron Age: emmer/spelt, barley. LIA/ER: Spelt, emmer, barley, oats; possible hay. Roman: spelt, hulled 6-row barley, emmer, rye. Also hemp/hop, raspberry, possible medicinal plants
Animals Poor preservation, so little information and bias towards large species. Bronze Age: cattle>sheep>pig, aurochs, red deer. Iron Age: cattle>sheep>pig, horse, dog, red deer. Roman: cattle>sheep>pig, horse, red and roe deer; beekeeping
Phases used: Middle Bronze Age (phase 7) Late Bronze Age (phase 8) Middle Iron Age (phase 10) Late Iron Age (phase 11) Late Iron Age/Early Roman (phase 12) Early/mid Roman (phase 14)

Isotope analyses by:	This project	RLAHA	

References
Framework Archaeology (2006) Landscape Evolution in the Middle Thames Valley. Heathrow Terminal 5 Excavations, volume 1: Perry Oaks. Framework Archaeology, Oxford and Salisbury
Framework Archaeology (2010) Landscape Evolution in the Middle Thames Valley: Heathrow Terminal 5 Excavations, volume 2. Framework Archaeology, Oxford and Salisbury.
Archive online at: http://www.framearch.co.uk/t5/

Horton Kingsmead Quarry	Site code: HOR		Site number: 17
Horton	Berkshire	NGR: TQ 016 749	Elevation: 20 m OD
Occupation	Neolithic		
Barrow etc; Farmsteads	Bronze Age		
Occupation	Iron Age		
Dates	Details not available: from radiocarbon, ceramics, other material culture		
Early Neolithic occupation	3800–3350 cal BCE		
Beaker burial	2500–2200 BCE		
Early/mid Bronze Age ritual activity	2400–1600 BCE		
Middle Bronze Age farmsteads and field systems	1500–1100 BCE (abandoned in Late Bronze Age)		
Early/Middle Iron Age roundhouse, replaced by agricultural landscape in Late Iron Age	700 BCE – 43 CE		
Roman period – no samples, not included here Unpublished, details not available: information from website			
Description			
Topography, geology, soils On floodplain, brickearth overlying river terrace gravels over London Clay. The immediate landscape was one of braided river channels for much of later prehistory. Substantial channel at the southern edge of the quarry may be a former course of the Thames.			
Structures and development Excavations at Kingsmead Quarry, Horton, Berkshire, provided an opportunity to investigate a large multi-period site with occupation dating back over 12,000 years. Early Neolithic houses, not necessarily all in use together; contemporary pits with domestic refuse; enclosure ditch with feasting remains, and later oval mound. LN/EBA Beaker burial. Early/Middle Bronze Age barrow, ring ditch, cemetery, ritual activity. At start of Middle Bronze Age the landscape was dramatically transformed from an open area to an enclosed and subdivided agricultural landscape comprising field systems, waterholes, and two substantial farmsteads. Each farm was associated with burials, domestic refuse and metalwork. These were abandoned in LBA, possibly because of increased wetness. A large roundhouse with associated 4-post structures, pits etc was the focus of activity in the early-mid Iron age, followed by a phase of landscape restructuring (agricultural ditches) and settlement relocated elsewhere.			
Environment: Details not available			
Plants: Details not available			
Animals (bone poorly preserved so bias towards larger/older animals likely) EN: Very sparse so numbers not reliable. Cattle>sheep>pig Middle Bronze Age: Cattle>sheep>pig, dog, horse, red deer. Cattle killed at 3-4y and older, suggesting importance of both meat and secondary products (but preservation bias?). Sheep mostly killed young for meat. Late Iron Age: Cattle>sheep>pig, dog, horse commoner than BA. More cattle than in BA. Cattle and sheep age profiles older – greater importance of wool, milk, traction?			
Phases used: Early Neolithic (1), Middle Bronze Age (7), Late Iron Age (12)			
Isotope analyses by:	This project	RLAHA	
References			
Alistair Barclay, Gareth Chaffey, Ruth Pelling (in preparation) Horton Kingsmead Quarry. Wessex Archaeology Reports. Oxford, Oxbow			
Website: http://www.wessexarch.co.uk/projects/horton2013			

Latton Lands	Sit code: LL		Site number: 12
Cerney Wick, Latton	Wiltshire	NGR: SU 076 970	Elevation: 82 m OD
Settlement, waterhole	Bronze Age		
Dates	From radiocarbon (2σ range), ceramics		
Middle Bronze Age waterhole	1440-1210 BCE, 1440-1130 BCE		
Samples only from Middle Bronze Age waterhole			
Description			
Topography, geology, soils Close to River Churn on First Gravel Terrace of the River Thames, forming a very flat topography. Gravels overlie fossiliferous Jurassic Kellaways clay and sand, calcareous sandstone and Cornbrash limestone of the Great Oolite Group, and Forest Marble clays lie 2 km to the north-west.			
Structures and development Middle Bronze Age settlement (possibly enclosed) with discontinuous ditches, waterhole, pits, posthole groups, roundhouses. Pits and ditches to northeast may be Iron Age (see Powell et al. 2009) and undated features include ring ditch and pits. Mixed farming including cereal processing and storage and animal husbandry.			
Environment Mainly from pollen in waterhole. Pollen dominated by herbaceous taxa: grassland, ruderals, arable weeds and cereal pollen, with some aquatic/wet ground taxa which may reflect immediate vicinity of waterhole. Low values of tree pollen indicate few trees nearby: alder, hazel, a little oak, lime, elm. (Nearby site has evidence of woodland persistence and clearance/lime decline in Late Bronze Age but) site environment had apparently already been cleared of woodland in MBA. Molluscan evidence suggests local grazed grassland.			
Plants No carbonised remains. Pollen indicates local arable.			
Animals Cattle>sheep>pig, horse, dog, and red deer. Cattle was overwhelmingly dominant but this may reflect poor preservation			
Phases used: Middle Bronze Age (7)			
Isotope analyses by:	This project	RLAHA	
References			
Stansbie D. and Laws G. (2004) Prehistoric settlement and medieval to post-medieval field systems at Latton Lands, Wiltshire. ***Wiltshire Archaeological and Natural History Magazine, 97*** 2004, 106-143			
Powell K., Laws G. and Brown L. (2009) A Late Neolithic / Early Bronze Age enclosure and Iron Age and Romano-British settlement at Latton Lands, Wiltshire. ***Wiltshire Archaeological and Natural History Magazine,*** **102, 92-97 (does not include Middle Bronze Age settlement)**			
Archive at: http://archaeologydataservice.ac.uk/archives/view/lattonlands_eh_2008/downloads.cfm			

Mount Farm Berinsfield	Site code: MFB		Site number: 11
Berinsfield	Oxfordshire	NGR: SU 548 968	Elevation: 58 m OD
Occupation	Neolithic		
Occupation	Bronze Age		
Occupation	Iron Age		
Occupation	Roman		
Dates	From ceramics; + radiocarbon dating (2σ range), unmodelled		
Note: there was often little dating evidence for particular features, and problems of residuality were particularly acute at this site. Detailed dates/phasing to be used with caution			
Neolithic & Beaker Early/Mid Neolithic: 2 pits with flintwork; Burial context (w/ sampled bone)	4000–c. 2000 BCE 4231–3700 cal BCE, 4040–3640 cal BCE 3640–3370 cal BCE		
Early/Mid Bronze Age Ring ditch, upper fills(w/ sampled bone)	1520–1050 cal BCE, Deverel-Rimbury ceramics		
Later Bronze Age, waterhole	1440–1000 cal BCE, 1260–830 cal BCE		
Early Iron Age,pits	410–40 cal BCE, 390 cal BCE–50 cal CE		
Mid-Late Iron Age Ditch, waterhole	280 cal BCE–70 cal CE, 740–200 cal BCE, MIA ceramics		
Saxon period omitted			
Description			
Topography, geology, soils The site is on the 2nd gravel terrace, on the top of a gentle rise in ground between the Rivers Thames and Thame, about 2.5km north of their confluence at Dorchester-on-Thames. The site is on a small island of second (Summertown-Radley) terrace gravel resting in a saucer of Gault clay, with more extensive gravel terraces on the floor of the two river valleys to the west, south and east Immediately to the west is a small stream running south to the Thames, while to the east streams run into the Thame. The surrounding area is geologically diverse: within a radius of 6 km there are areas of Corallian limestone, Portland/Kimmeridge Sands, Kimmeridge Clay, Lower Greensand, Gault clay, and across both rivers more elevated areas of upper Greensand, lower chalk and plateau drift. The underlying clay provides a perched water table which may have attracted settlement, as reflected in a sequence of waterholes and wells. The site is in the midst of a series of (Neolithic) ceremonial complexes around the confluence at Dorchester. The soils of the immediate area have not been systematically surveyed, but their considerable diversity may be inferred from the survey of Jarvis (1973) of soils on corresponding geological strata to the west around Abingdon.			
Structures and development A long chronological sequence extends from the early Neolithic to the early Saxon periods (3500 cal BCE – 650 cal CE) with all intervening periods at least sporadically represented, and the apparently continuous existence of a farming community from the Iron Age until the 3rd century cal CE. A relatively low-key site within the hinterland of a series of major focal complexes in and around Dorchester-on-Thames. Early/mid Neolithic and late Neolithic domestic pits, an oval barrow enclosing middle Neolithic and beaker burials, a Neolithic or Bronze Age post ring represent intermittent domestic, funerary and ceremonial activity at Mount Farm through the early, middle and late Neolithic and Beaker periods. This may have been of a very transitory, impermanent nature – perhaps quite infrequent recurrent visits to a favoured location marked by a burial ground. Cereals present throughout the sequence, but need not imply permanent settlement and may only reflect small-scale horticulture. In the Middle Bronze Age the main features were a ring ditch containing burials, with pottery and animal bone in the upper fills which may have derived from “feasting” or domestic activity, and a ramped waterhole. Early/middle Bronze Age double-ditched field system aligned on the barrow. These were ploughed over before Middle Iron Age settlement. Little or no significant domestic occupation at Mount Farm from the later Bronze Age to the early Iron Age but the site probably was in			

agricultural use, perhaps fields connected with a nearby occupation at Allen's Pit. Early Iron Age ard cultivation marks, Early Iron Age to late Roman settlement with an unusually early network of paddocks or fields that developed continuously from the middle Iron Age through to the 2nd century CE, including a succession of further waterholes. The limited range of Roman pottery includes only 2% of specialist and fineware sherds, a figure which places Mount Farm firmly in a group of rural settlement sites at the lower end of the spectrum in terms of the quality and diversity of pottery.
Environment Neolithic/EBA: little evidence available for woodland or openness; small-scale cereal cultivation. By later Bronze Age the area was predominantly covered by relatively lightly grazed flowery grassland and some scrub. Cereal pollen was at a level that suggests arable land was also present in the wider environment, and that this may have increased in the later Bronze Age. Iron Age: the generally open environment persisted. Domestic animals indicate grazed grassland, while the much greater evidence of charred crop remains and associated weeds indicates arable land. Roman: the environment was open, if anything rather more so than in the later Bronze Age. More evidence of disturbed ground around the waterholes and perhaps on arable margins, and the very low levels of beetles associated with grazed grassland suggest that pastureland was not an important habitat. There were only a few hints of meadowland species, and these could have been growing in other habitats. Only slightly more cereal pollen than in the later Bronze Age, though rather more indication of arable from beetles that live in cultivated ground, while the charred plant remains for the Iron Age and Roman periods hint at expanding arable, and the waterlogged seeds suggest diversification of crops. In line with artefactual and stratigraphic evidence, more evidence of human habitation and neglected ground than in the later Bronze Age.
Plants Neolithic/Bronze Age: Emmer, naked and hulled 6-row barley, small-scale cultivation. Iron Age/Early Roman: Spelt, hulled 6-row barley, grown in permanent, fertilised fields. Possible soil nitrogen depletion (rise in leguminous weeds) over time (or extensification, or timing of sowing). Mid/Late Roman: Spelt, hulled 6-row barley, bread wheat, flax, coriander, celery, opium poppy; fields both on and off the gravel terraces, possible horticulture plots.
Animals High proportion of pig>cattle>sheep in Neolithic, but based on very small sample. Bronze Age: cattle>sheep>pig, grassland lightly grazed. Horse present from later BA. Iron Age: Sheep increase through Iron Age, age profile suggests killing for meat with wool and milk less important. Cattle have high proportion of adult females: males killed for meat and dairy also important. Roman: Cattle increase through Roman period, killed at older ages, may reflect arable intensification (more arthropathies); also larger than IA. Sheep husbandry follows IA pattern.
Phases used: Middle Neolithic (Phase 3), Bronze Age (Phase 7), Early Iron Age(Phase 9), Late Iron Age/Early Roman (Phase 12), Roman (Phase 14)

Isotope analyses by:	This project	RLAHA	

References
Lambrick, George (2010) Neolithic to Saxon social and environmental change at Mount Farm Berinsfield, Dorchester-on-Thames. Oxford, Oxbow
Jarvis, M.G. (1973) Soils of the Wantage and Abingdon district. Harpenden: Soil Survey of Great Britain

Runnymede	Site code: RM		Site number: 21
Runnymede	Surrey (was Berkshire)	NGR: TQ 018 718	Elevation:15 m OD
Occupation	Neolithic		
Waterside occupation, midden	Late Bronze Age		
Dates	From radiocarbon dating, unmodelled; ceramics		
Early Neolithic occupation	?3700-3500 BCE / Earlier 4th millennium (called Middle Neolithic in report)		
Late Bronze Age, Waterfront Area 6	approx. 9th century BCE; Riverside zone similar, but few dates because no collagen		
Description			
Topography, geology, soils The site lies on the Thames floodplain within a complex sequence of river channel sediments and layers of alluvial deposition, and has at times been an island (eyot). Undulating Neolithic topography masked by later alluviation. Soils developed on alluvium, loams with varying amounts of clay/silt/sand, generally calcareous			
Structures and development The site was an eyot in the Neolithic, with scattered occupation and accumulations of refuse, and *in situ* pile-driven uprights. Finds comprise predominantly pottery and stone artefacts plus human and animal remains. Early Neolithic occupation was probably intermittent. There was some cultivation during the early Bronze Age, followed by major alluviation; the northern channel was blocked and the site connected to the northern bank of the Thames. By the Mid/Late Bronze Age a new channel and island had been created, but the LBA site was probably connected to the northern bank. The Late Bronze Age deposits represent a remarkably complex, largely *in situ*, array of structures and artefacts, including a waterfront pile structure and an extremely rich accumulation of midden and other refuse deposits. The LBA occupation may represent use of the site as a gathering place for social/ritual/feasting/trading purposes.			
Environment Early Neolithic: Domestic animals grazing in woodland with only slight opening of the canopy (20% non-arboreal pollen), some evidence of arable. Rich alder/fen on floodplain. Mid/late Neolithic: mosaic of clearings and woodland, pasture, some arable; alder woodland retained old woodland beetle fauna. EBA alluviation, possibly caused by clearance and cultivation in the catchment, ceased mid-2nd millennium when open land in valley bottom became grassland. The LBA settlement followed a phase of woodland regeneration (based on snail evidence) on a newly created island. By Mid/late Bronze age alder woodland had been replaced by lightly grazed grassland (≥50% NAP), pasture more important than arable. Late Bronze Age: greater intensity of grazing, willow along the watercourses. Some woodland remaining, with more secondary woodland and scrub taxa, and evidence for arable beyond the floodplain. Insects indicate presence of foul organic material in midden, but little evidence for structures or indoor habitats. River was clean and clear-flowing throughout sequence.			
Plants Early Neolithic: no evidence for crop plants (1 possible pea) Late Bronze Age: Emmer, spelt, barley, flax			
Animals (NB variation in numbers across site) Neolithic: pig>cattle>sheep (NISP), dog, red and roe deer, aurochs, wild boar, otter, beaver. In some areas cattle>pig>sheep, possibly reflecting different activities (Serjeantson 2006). The high percentage of pig is unusual (Serjeantson 2011). Late Bronze Age: sheep>cattle=pig overall (but varies by area, and cattle and sheep may increase over time), dog, horse, red deer, badger, otter, cat The unusual proportions of domestic animals reflect activities at the site rather than "economy"			
Phases used: Early Neolithic (phase 2) Late Bronze Age (phase 8)			
Isotope analyses by:	This project	RLAHA	

Runnymede References
Longley, D. (1980) Runnymede Bridge 1976: Excavations on the site of a Late Bronze Age settlement. Guildford: Surrey Archaeological Society
Needham, S. P. (1991) Excavation and Salvage at Runnymede Bridge 1978: the Late Bronze Age Waterfront Site. London: British Museum
Needham, S. P. and Spence, T. (1996) Refuse and Disposal at Area 16 East Runnymede. Runnymede Bridge Research Excavations. London: British Museum
Needham, S. P. (2000) The passage of the Thames: Holocene environment and settlement at Runnymede. London: British Museum
Serjeantson, Dale (2006) Food or feast at Neolithic Runnymede. In: Serjeantson, D. and Field, D. (eds.) Animals in the Neolithic of Britain and Europe. Neolithic Studies Group Seminar Papers 7. Oxford: Oxbow, 113-134
Serjeantson, Dale (2011) Review of Animal Remains from the Neolithic and Early Bronze Age in Southern Britain (4000 BC – 1500 BC). English Heritage Research Department Report Series 29-2011. Portsmouth: English Heritage

Shorncote	Site code: SQ		Site number: 13
Somerford Keynes	Gloucestershire	SU 031 969	92 m OD
Settlement	Bronze Age		
Dates	From ceramics, metalwork		
Late Bronze Age settlement	950-750 cal BCE		
Samples from LBA only			
Description			
Topography, geology, soils Shorncote Quarry lies on calcareous river gravels (First Terrace). The area is slightly sloping with generally flat terrain.			
Structures and development Severely truncated by later ploughing. Neolithic/Early Bronze Aage ring ditch, EBA ring and pennanular ditches, few finds. Extensive unenclosed LBA settlement with pits, 4-post structures, and 34 circular post-built structures of various sizes, some intercutting, but with no associated occupation deposits. Probable emphasis on pastoral rather than arable agriculture, but this is based on very little surviving evidence.			
Environment Neolithic/Bronze Age: open, dense grassland, not intensively grazed, little evidence of woodland (based on snails). Late Bronze Age: very little environmental evidence but charcoal suggests scrub/hedges rather than dense woodland.			
Plants: Scant and poorly preserved. Wheat, barley, little evidence of processing. LBA charcoal included oak, ash and hedge/scrub species.			
Animals: Bone scant and poorly preserved, so bias towards larger species probable. Cattle with a few sheep and pig, deer.			
Phases used: Late Bronze Age (phase 8)			
Isotope analyses by:	This project	RLAHA	
References			
Hearne, C.M., Adam, N. (1999) Excavation of an extensive Late Bronze Age Settlement at Shorncote Quarry, near Cirencester, 1995-6. Trans Bristol and Glos Arch Soc 117, 35-73			

Staines Road Farm	Site code: SRF		Site number: 23
Shepperton	Surrey	NGR: TQ 077 684	Elevation: 10 m OD
Ring Ditch	Neolithic		
Dates	From radiocarbon dating (2σ range)		
Ring Ditch lower levels	3640-3100 cal BCE, 3780-3350 cal BCE Mid-4th millennium BCE, Early Neolithic		
Samples from ring ditch lower levels only			
Description			
Topography, geology, soils The site lies on the second lowest (Kempton Park) Pleistocene gravel terrace on the north bank of the Thames, with higher terraces and London clay to the north and the Tertiary plateau to the south. It was close to a palaeochannel of the Ash, part of the Colne/Thames confluence. Brickearth, sand and calcareous clay (cut by the ring ditch) overlay the gravels. The topography is generally flat: the ring ditch/bank made of the white calcareous clay would have been conspicuous. This clay may also have raised the pH of the acid soils that would normally develop on brickearth/gravels.			
Structures and development A Neolithic ring ditch with short causeway gap to the north-east, segmented through its northern and western lengths. Soon after being dug, in the middle of the 4th millennium BCE, it was filled or lined with white clay. If filled, the clay might then have been dug out, while respecting the shape of the original ditch. A subsequent crouched burial in the ditch terminal by the causeway was of similar date, and other placements along the ditch base include antler picks, the remains of a dog/wolf and one or more large pieces of Peterborough ware. These and the remains of the white clay were buried by a soil fill containing large quantities of struck flint, animal bone, and plain and decorated pottery sherds suggestive of a domestic site. Similar radiocarbon dates were obtained for this sealing fill. Scattered later (late Neolithic/Early Bronze Age, Bronze Age) features include burnt mound, pits, hollows, ditches, with little surviving bone.			
Environment No evidence from Neolithic features. Bronze Age landscape probably open/scrubby, grazed but not heavily, with some wet/riverine species. Soils were acidic/well-drained, with cereals growing in the area.			
Plants No evidence from Neolithic features. No carbonised remains.			
Animals Lower levels of ring ditch (sampled): Cattle>Pig>Sheep, canid (?dog/wolf), red deer antler. All parts of carcase represented, butchery & burning. Little bone survived elsewhere.			
Phases used: Early Neolithic (Phase 2)			
Isotope analyses by:	This project	RLAHA	
References			
Jones, P. et al. (2008) A Neolithic Ring Ditch and later prehistoric features at Staines Road Farm, Shepperton. Monograph 1. Spoilheap: Woking			
Jones, P. (1990) Neolithic Field Monuments and Occupation at Staines Road Farm, Shepperton. Surrey Archaeological Society Bulletin 252 4-6			

Thornhill Farm	Site code: TF		Site number: 6
Fairford	Gloucestershire	NGR: SU 183 997	Elevation: 76 m OD
Pastoral settlement	Iron Age		
Pastoral settlement	Roman		
Dates	From ceramics		
Middle Iron Age (site phase A)	30—50 BCE		
Late Iron Age (site phase B)	50 BCE—1 CE		
Late Iron Age (site phase C)	1—50 CE		
Early Roman (site phase D)	50—100 CE		
Early Roman (site phases E, F)	75—120 CE		
Early Roman (site phase G)	2nd century CE		
Late Roman (site phase H)	3rd—4th century CE (no samples from this period)		
Description			
Topography, geology, soils The site is on the 1st gravel terrace near the confluence of the Coln and the Thames, about 0.75 km from Claydon Pike (q.v.), in fact the western end of the same cropmark complex, though excavated and published separately. To the south inliers of Oxford Clay and river gravels give way to alluvium on the valley floor before rising to the sands and limestones of the Corallian ridge, to the north the gravel terraces rise to meet the clay and cornbrash of the Cotswold dip slope. This varied terrain gives considerable ecological diversity around the site with scope for specialised production in different areas. The soils developing on the gravel terrace were probably calcareous to clay loams, well-drained where they lay over gravels and when the water table was low, with clays to clay loams in lower areas of the floodplain, again with drainage dependent on substrate.			
Structures and development The site is interpreted as a specialised pastoral settlement consisting of paddocks and larger enclosures for control and management of livestock, with grassland management including pasture and cutting for fodder (possibly hay in the Roman period). Middle Iron Age (site phase A): Enclosures, roundhouse gullies large amounts of domestic waste, but spatial organisation of the settlement was hard to pick out, largely because of truncation and the ephemeral nature of the structural remains. The site continued to be remodelled through to the early Roman period, creating a dense palimpsest (and difficulties in phasing). In the Late Iron Age (site phase C) large rectilinear enclosures were laid out on the gravel terrace, associated with roundhouses and a long linear boundary, and a loosely gridded enclosure system. In the Early Roman period (site phase D) there was a group of enclosures arranged around a central enclosure, a frequently recut boundary ditch and a major droveway, followed by more of enclosure rearrangements (site phases E,F). The site was radically reorganised during the 2nd century CE (site phase G) when the tightly knit group of paddocks and enclosures of earlier periods was replaced by a series of newly constructed trackways. There was no longer evidence for occupation, and the site was probably tied into a wider system of landscape use – possibly based on Claydon Pike which also underwent reorganisation at this time.			
Environment Little evidence from the Middle Iron Age; what there was included seeds of aquatic vegetation, a strong element of plants from nutrient-rich waste or disturbed ground, perhaps dung-enriched ground within the settlement, and seeds from grazed pasture, with no element of wood, scrub, or arable. In the Late Iron Age dung beetles were very abundant, suggesting a concentration of domestic animals close to the settlement, with high proportions of grassland beetles confirming extensive grazed pasture, including wet pasture, in the vicinity. Most of the carbonised seeds were derived from coarse herbage, probably cut for fodder and/or bedding for stock. Little evidence of trees or scrub/hedges. Snails included *Lymnaea truncatula*, the intermediate host of liver fluke. No evidence of flooding of settlement, which could have been permanently occupied. Charred cereals sparse, little sign that they were cultivated nearby. The environment of the Early Roman settlement was similar, and one sample from south of the settlement contained seeds typical of a hay meadow flora.			
Plants Charred cereal remains sparse, including spelt and barley in both periods, but very few arable			

weeds and no other crops, herbs or fruits. Depending on the context, seeds from plants growing on N-rich disturbed ground and on pasture, both wet and dry, predominated, with a strong element from cut rough herbage. There was no evidence of trees and very little of the presence of scrub or hedges in the landscape. This concurs with the idea that the main purpose of the settlement was the management of grazing in the valley bottom.
Animals Preservation was poor (also reflected in the number of failed samples) and this is likely to affect the representation of small vs large taxa. Quantification in the animal bone report is unconventional, and vague as to phasing: this is my interpretation of it. Cattle, sheep/goat (no positive goat), pig, equids, and dog were present in both phases (equids include a few remains of donkey in the Roman period). The proportion of cattle is high and increases at the expense of both sheep and pig between the Middle Iron Age and Early Roman period. The proportion of equids is also high, particularly in the Iron Age, though on the basis of the age-at-death distribution the zooarchaeologist thought it unlikely that the site specialised in horse-breeding. The valley-bottom grazing would have been suitable for both horses and cattle, perhaps less so for sheep which are more susceptible to foot-rot and liver fluke on wet pasture.
Phases used: Middle Iron Age (site phase A; phase 10), Late Iron Age (site phases B,C; phase11), Early Roman (site phases D-G; phase 13)

Isotope analyses by:	This project	RLAHA	

References
Jennings, D., Muir, J., Palmer, S. and Smith, A. (2004) ***Thornhill Farm, Fairford, Gloucestershire. An Iron Age and Roman pastoral site in the Upper Thames Valley.*** Thames Valley Landscapes Monograph no. 23. Oxford: Oxford Archaeological Unit
Stansbie, D., Smith, A., Laws, G. and Haines, T. (2007) Iron Age and Roman occupation at Coln Gravel, Thornhill Farm, Fairford, Gloucestershire. Final Unpublished Report submitted to English Heritage. Available via ADS website, doi:10.5284/1000290: http://archaeologydataservice.ac.uk/archives/view/colngravel_eh_2007/downloads.cfm

Thorpe Lea Nurseries	Site code: TLN		Site number: 22
Egham	Surrey	NGR: TQ 018 699	Elevation: 15 m OD
Settlement/farmstead	Iron Age		
Enclosed settlement/farmstead	Roman		
Dates	From ceramics		
Iron Age, SitePhase 3b,c	Mainly Middle/Late Iron Age ?400-50 BCE		
Iron Age and/or early Roman SitePhase 3-4 transition	Transitional between Iron Age and Early Roman, hard to identify		
Early Roman , SitePhase 4a	1st/2nd century CE		
Roman , SitePhase 4b	2nd-mid3rd century CE		
Late Roman , SitePhase 4c	Late 3rd and 4th century CE		
Many features without closely datable material: potential problems with phasing and residuality No samples were available from early prehistoric/Bronze Age features – not included here			
Description			
Topography, geology, soils Located on Pleistocene gravels 1km from the River Thames. Underlying geology, cut by archaeological features, was either gravel or calcareous or orange/brown 'brickearth' (fluvial silty clays) over gravel. Soils mainly acidic except for calcareous brickearths in SW corner of site.			
Structures and development Two principal areas of Iron Age occupation, mainly middle to late Iron Age. Smaller, eastern, settlement abandoned during the early 4th century BCE, while the western settlement continued to end of the 4th century CE. Iron Age features include pits, post holes, ditches and gullies, and two large water holes; no buildings identified, except three small four-posted structures, though two truncated features may have been ring gullies around round houses. Roman occupation mostly in western area: pits, post holes, ditches and gullies (possibly including two buildings), a burial, and wells or water holes. Most features within a large enclosure which finally infilled during the 4th century CE but may have had origins in the early Roman period. Three late Roman water holes provided a wealth of material including pottery sherds, animal bone and some small finds. It seems most likely that the settlements at Thorpe Lea represent a series of small farmsteads.			
Environment Evidence mainly from plant macrofossils, invertebrates as pollen did not survive. Roman: Beetles include spp. indicative of timber buildings, vegetable waste (hay/straw/thatch?), normal level of dung bettles for rural settlement. Weedy, waste/disturbed ground and grassland in/around settlement, not much evidence for trees/woodland or intensively used pasture. Site activities included cereal processing; probably mixed arable/pastoral agriculture, without strong evidence of intensification or horticulture			
Plants Charred plant material was sparse, included spelt, hulled barley, emmer (BA/IA) and rye (possibly a weed), with a high proportion of weed seeds. Waterlogged plants included arable weeds, crop-processing remains of spelt, gorse and bracken (possibly local on acidic soils). Possible hay in roman period. Single seed of coriander.			
Animals Iron Age: similar numbers of sheep and cattle, pig and horse comparatively high, very few wild spp. Roman: cattle numbers increase, but killed at younger ages – meat? Sheep and pig decrease, horse still high. Variety of dogs. Very few wild animals (but probable wild boar).			
Phases used: Mid/Late Iron Age (phase 11), Early Roman (phase 13), Late Roman (phase 15)			
Isotope analyses by:	This project	RLAHA	
References			
Graham Hayman, Phil Jones, Rob Poulton (2012) Settlement Sites and Sacred Offerings: Prehistoric and later archaeology in the Thames valley, near Chertsey. Monograph no 4. SpoilHeap, Woking			
Online digital supplement at http://www.surreycc.gov.uk/__data/assets/pdf_file/0004/36463/Settlement-Sites-and-Sacred-Offerings-Monograph-4-Digital-Supplement.pdf			

Watkins Farm	Site code: WF		Site number: 5
Northmoor	Oxfordshire	NGR: SP 426 035	Elevation: 63 m OD
Enclosed pastoral settlement	Iron Age		
Enclosed pastoral settlement	Roman		
Dates	From ceramics, also radiocarbon dates calibrated but unmodelled		
Middle Iron Age	250—50 BCE		
Early Roman	Late 1st — 2nd century CE		
Later Roman	3rd — 4th century CE		
Roman phase may include material from the late 1st to 4th centuries CE, though most Roman bone on the site came from earlier rather than later within the period			
Description			
Topography, geology, soils Located on 1st gravel terrace on broad stretch of gravels near Windrush-Thames confluence, on a gravel island shelving into the Thames floodplain east of the Windrush. About 4 km south of Farmoor (q.v.) on other side of the Thames. Below modern ploughsoil was a stone-free non-calcareous brown silty clay soil, potentially sticky when wet but drying rapidly when underlain by free-draining gravels.			
Structures and development Middle Iron Age: within main enclosure four small pennanular enclosures, probably surrounding houses, with pits and a well. After a hiatus the main Iron Age enclosure re-used in Early Roman period, with ditches, trackways and a field system. In the Later Roman period there was a succession of sub-rectangular enclosures that overlay and cut across the main IA enclosure. About 200 m to the north-east (site B) there were enclosure ditches and wells, with 2nd-century occupation. There was a domestic enclosure but no trace of structures – perhaps houses were constructed of turf or cob leaving no archaeological trace. Less evidence of occupation in the 3rd-4th centuries CE. The settlement was largely or entirely pastoral in both periods. There seems to have been a lower intensity of occupation than on most Roman sites, leading to the suggestion that occupation was seasonal or sporadic in the Early Roman period; possible farmyard or house at site B.			
Environment Iron Age: waterlogged remains indicated a relatively open though not entirely treeless landscape in which pasture was important, with species of aquatic and marshy habitats, disturbed ground and scrub/hedges. Roman: the landscape was very open, with very few insect species associated with trees, and a small scrub component. There was grassland, damp pasture, more evidence of meadow and less of trees or scrub/hedge than in the Iron Age, and disturbed ground, not necessarily arable. Unusually for this period, there may have been osiers growing nearby.			
Plants In both periods charred plant remains included spelt and 6-row hulled barley, with little evidence that they were cultivated at the site. Iron Age waterlogged remains included flax and weeds of disturbed ground (little evidence of arable), scrub/hedge, and aquatic plants (in a ditch). In the Roman period there was flax, and stagnant-water species, from a pond, and grassland species with a greater meadow component.			
Animals In both periods cattle, sheep/goat (including 1 possible goat) and pig were present, as well as dog and red deer. There was also hare in the Roman period. There was an unusually high proportion of horse in both periods, leading to the suggestion that the site specialised in horse-rearing (or at any rate the pasturing of horses on the floodplain grassland).			
Phases used: Middle Iron Age (phase 10), Roman (phase 13)			
Isotope analyses by:	This project	RLAHA	
References			
Allen, T.G. (1990) Iron Age and Romano-British Enclosed Settlement at Watkins Farm, Northmoor, Oxon. Thames Valley Landscapes Monograph: the Windrush Valley vol. 1. Oxford: Oxford University Committee for Archaeology			

Whitecross Farm	Site code: WX		Site number: 14
Cholsey	Oxfordshire	NGR: SU 607 882	Elevation: 44 m OD
Waterfront site/midden	Bronze Age		
Dates	Series of radiocarbon dates, unmodelled		
Late Bronze Age channel structures and palisade (site phase 4)	1000—800 cal BCE		
Midden and occupation (site phase 5)	900—700 cal BCE		
Description			
Topography, geology, soils The site developed on an eyot of sand, gravel, and fluvial silty clays, in the Thames, in a channel that has since silted up. It now lies on the (current) 300-m-wide alluvial floodplain on the west bank of the Thames. The surface beneath the LBA occupation was a yellow-gray slightly sandy silt.			
Structures and development Late Bronze Age occupation, with wooden waterfront palisades and structures built out into the river channel, possibly for ritual deposition (site phase 4). Palisades were dismantled, and the timbers, dumped in the river, are sealed by the occupation deposits/midden (site phase 5). There were also pits and postholes. The material sampled came from the midden, most from the waterlogged part. The site is explicitly compared to Runnymede (q.v.), and interpreted as a gathering place.			
Environment On the island, around the settlement there was an accumulation of organic debris and dry short-turfed grassland with bare, trampled patches, possibly shading into rough herbage and scrub in less-used areas, and bankside and reedswamp vegetation at the river's edge. The wider environment (off-island) was high in grassland, typical of relatively well-drained circumneutral to calcareous soils, some grazed and some with a herb-rich (but not hay-meadow) flora, perhaps growing on the riverbanks. There was also a background presence of woodland, perhaps still a few alders on the floodplain though not alder woodland, and mixed thorn scrub. The oak timbers and hazel poles used for the site phase 4 structures came from secondary or managed (coppiced?) woodland, but could have originated some distance from the site. There was little evidence for arable cultivation in the vicinity, though charred plant remains included arable weeds amongst cereals brought to the site for processing, which suggested arable agriculture impinging on grassland. The rich aquatic molluscan fauna was typical of "a well-oxygenated mesotrophic river in all its aspects" – from flowing water in the open channel to densely vegetated marginal reedswamp.			
Plants Emmer and spelt were both present as well as 6-row hulled barley. The charred remains were from the later stages of processing, so represent cereals brought to the site from elsewhere. There were small amounts of flax and opium poppy, and sloe and hazelnut. Wood at the site was mainly oak and hazel, with a little alder, ash and elder represented in the pollen.			
Animals Cattle, sheep/goat (including definite goat) and pig were present, with dog, red deer, roe deer, and possibly wild boar. Sheep>pig>cattle (NISP); sheep and pig mainly juvenile or sub-adult. May represent area for feasting used by smaller groups (cf. Runnymede), may not be representative of the whole animal economy. In this (personal) interpretation, remains on the eyot are mainly of animals brought to the site for feasting, other aspects of animal management represented elsewhere.			
Phases used: Late Bronze Age (phase 8)			
Isotope analyses by:	This project		
References			
Cromarty, A. M., Barclay, A., Lambrick, G. and Robinson, M. (2006) Late Bronze Age Ritual at Whitecross Farm, Wallingford. Thames Valley Landscape Series 22. Oxford: Oxford University School of Archaeology			

Windmill Hill	Site code: WH		Site number: 20
Avebury	Wiltshire	NGR: SU 086 714	Elevation:195 m OD
Causewayed enclosure	Early Neolithic		
Dates	Radiocarbon, from Bayesian model, 95% probability		
Inner ditch constructed	3680-3650 cal BCE		
Outer ditch constructed	3685-3635 cal BCE		
Middle ditch constructed	3655-3605 cal BCE		
Period of construction	5-75 years, in 37th century cal BCE		
End of early phase of use	3365-3295 cal BCE		
There was later activity at WH continuing well into the 3rd millennium BCE, possibly with hiatus in the last quarter of the 4th millennium BCE. All samples for this project came from the early phase of use, which for present purposes can be taken as one phase.			
Description			
Topography, geology, soils Located on a low, broad hill within chalk downland, with views in all directions, part of a cluster of Neolithic (and later) monuments in the Avebury region. It consists of three concentric circuits of interrupted ("causewayed") ditches dug into the chalk, with fills containing large amounts of bone (both human and animal), with pottery, flints and other stone, worked bone etc. Soil samples from beneath the bank were stony, markedly calcareous rendzinas, which had probably been disturbed, possibly by cultivation, until shortly before burial by bank construction.			
Structures and development The three ditch circuits were constructed over less than a century, probably in the order inner-outer-middle. There had been some occupation and/or cultivation on the site before that, and sporadic activity continued after the main phase of use was over. Causewayed enclosures are currently interpreted as sites of (seasonal?) gathering and feasting rather than settled occupation.			
Environment The high diversity of snails in the pre-bank soil suggests the presence of both grassland and nearby woodland, indicating either a clearing within woodland or a parkland landscape with a mosaic of woodland and grassland. The primary fill of the outer ditch contains almost exclusively woodland snails. Higher up the sequence, there is a gradual change towards open grassland, perhaps complete by the Late Neolithic/Early Bronze Age.			
Plants Charred plant remains included emmer, 6-row hulled barley and possibly einkorn, with seeds of weeds of disturbed ground/arable/grassland, tubers of pignut and lesser celandine, and sloe. It is uncertain to what extent these might reflect the immediate environment or activity at the site. Oak was common among the identified charcoal, with hazel, hawthorn, ash and blackthorn; derived from woodland and woodland edge or scrub.			
Animals Cattle predominated, with fairly even numbers of pig and sheep/goat – this is uncommon on early Neolithic sites where pigs generally outnumber sheep/goat. Goat was present (there is a juvenile goat skeleton from Windmill Hill in the Alexander Keiller museum), also dog. There were a few wild animals including aurochs, red deer, roe deer, fox, wild cat, and otter.			
Phases used: Early Neolithic (phase 2)			
Isotope analyses by:	JH Gathering Time project	RLAHA	
References			
Whittle, A.W.R., Pollard, J. and Grigson, C. (1999) The harmony of symbols: the Windmill Hill causewayed enclosure, Wiltshire. Oxford: Oxbow			
Whittle, A.W.R., Healy, F. And Bayliss, A. (2011) Gathering time: dating the Early Neolithic enclosures of Southern Britain and Ireland. Oxford: Oxbow			

Wyndyke Furlong	Site code: WY		Site number: 9
Abingdon	Oxfordshire	NGR: SU 482 977	Elevation: 60 m OD
Open settlement	Iron Age		
Field system	Roman		
Dates	From ceramics (and Ashville radiocarbon dates, no modelling)		
Middle Iron Age	4th – 2nd century BCE		
Late Iron Age	1st century BCE and 1st century CE		
Roman	2nd century CE onwards		
Samples from "Early/Mid Iron Age" included with Middle Iron Age			
Description			
Topography, geology, soils Located on the 2nd gravel terrace 0.4 km north of the Ock in a wide area of gravels, on the crest of a rise overlooking the Ock-Thames confluence. Just north of, and continuous with, the Bronze Age to Roman site at Ashville Trading Estate (Parrington 1978), and some environmental information from that excavation is applied here. To the north and west gravels give way to heavy clay and this seems to define the limits of the site. Gravels are covered with free-draining clay/loam soils. Within <1 km of the site to the north the land rises towards the Corallian limestone ridge and to the south falls away towards the damp ground on the Ock floodplain, giving a wide variety of environments within reach.			
Structures and development A rather vague early phase with post-built structures, not closely dated, was followed by denser occupation in the Middle Iron Age, with pits, postholes, boundaries, waterholes and ditched circular structures that may have been roundhouses. Together with Ashville Trading Estate site this would have been a substantial settlement. Occupation then ceased and structures were replaced by a system of linear ditches. The Iron Age site was (part of) an open agricultural settlement with an emphasis on cereal cultivation and processing. After the Middle Iron Age the landscape was reorganised to reduce the amount of damp ground under cereal cultivation, and at Ashville drainage was improved by installation of ditches. In the Roman period activity at Wyndyke Furlong included use of a trackway and field system but not organised settlement.			
Environment			
Plants Spelt, 6-row hulled barley, emmer, bread wheat. Ubiquitous evidence of cereal processing in charred plant remains, weeds may indicate autumn sowing. Arable weeds of both dry/calcareous and wet/cleggy/acid fields indicate arable spreading off 2nd terrace. Increase in vetches and tares over time suggesting N depletion; decrease in wet-ground arable weeds (Eleocharis) after MIA could reflect lower intensity of cultivation or better drainage – probably drainage.			
Animals Iron Age: Sheep>cattle>pig, goat, dog, horse, red deer antler Roman: Cattle>sheep>pig, dog, horse. Horse is commoner than in Iron Age			
Phases used: Middle Iron Age (phase 10) Early Roman (phase 13)			
Isotope analyses by:	This project	RLAHA	
References			
Muir, J. and Roberts, M.R. (1999) Excavations at Wyndyke Furlong, Abingdon, Oxfordshire, 1994. Oxford, Oxford Archaeology			
Parrington, M. (1978) The excavation of an Iron Age settlement, Bronze Age ring-ditches and Roman features at Ashville Trading Estate, Abingdon (Oxfordshire) 1974-76. Oxford: Oxfordshire Archaeological Unit			

Yarnton	Site code: YT		Site number: 3
Cassington/Yarnton	Oxfordshire	NGR: SP 465 115	Elevation: 60 m OD
Occupation	Neolithic		
Occupation	Bronze Age		
Small unenclosed settlement	Iron Age		
Enclosed settlement	Roman		
Dates	From ceramics, extensive radiocarbon dating		
Neolithic	Not yet published, no details available		
Early Bronze Age	Not yet published, no details available		
Late Bronze Age	?1200—750 BCE		
Early Iron Age	750-—400 BCE		
Middle Iron Age	400—50 BCE		
Late Iron Age/ early Roman	50 BCE—80 CE		
Early Roman	80-250—CE		
Late Roman	250-410—CE		
There was a hiatus before occupation in Anglo-Saxon period (not included here) "Bronze Age" samples are from vaguely dated "Late Neolithic/Early Bronze Age" contexts Intensive sampling in Iron Age/Roman periods to look for changes within periods Neolithic-Bronze Age report not yet published, details not available			
Description			
Topography, geology, soils Located in an area of floodplain and wide gravel terraces east of Evenlode-Thames confluence. Earlier settlement on floodplain, shifting onto 2nd gravel terrace as water tables rose in 1st millennium BCE. Soils developing over floodplain gravels were thin, non-calcareous ungleyed brown earths of sandy loam to silty clay, with poorly drained alluvial clays developing in Roman period after major alluviation. On 2nd terrace were light, free-draining, stone-free non-calcareous silt-loam brown earths, with poorly drained more acidic soils on Oxford Clay to the north.			
Structures and development The site at Yarnton comprises a fairly continuous series of occupations and settlements based on agricultural exploitation of the local area. Early Neolithic: a series of short-lived occupations within woodland clearings on the floodplain; structures included a longhouse and a mortuary enclosure. Early Bronze Age: circular structures and the area was more extensively cleared. Late Bronze Age: circular structures on gravel "islands" on floodplain and dispersed occupations on the 2nd gravel terrace; waterholes, pits and postholes that may represent ephemeral structures (cf. more organised settlement with pits and waterholes at nearby Cassington), and evidence of land division. Early Iron Age: small unenclosed settlement on 2nd terrace with post-built structures and a string of pits along the terrace edge, and a stream running through it. From then on settlement shifted eastward as it developed, probably in response to rising water table and onset of overbank flooding. Middle Iron Age: pit scatters and post-built structures, inhumation cemetery; Yarnton was one of a series of similar settlements spaced 1-2 km apart on this spur of the 2nd gravel terrace, suggesting increased settlement density, infilling of the landscape, and potentially increasing pressure on resources. Late Iron Age: change from open settlement to one with sub-circular and -rectangular gullies or ditches, within a more substantial enclosure. Enclosures probably paddocks or fields, others surrounding areas of domestic activity, but the houses left no trace, possibly turf or cob walls. Early Roman settlement overlay the Late Iron Age one, no shift in settlement location. Four major enclosed areas, each becoming more rectangular than circular over time, probably used as paddocks/fields and for houses though again there is no structural evidence. Late Roman settlement, largely superimposed, more regular in layout and shape within a rectangular enclosure, and included buildings, corndriers, trackways and an inhumation cemetery: a small rural settlement into which Roman material possessions were introduced very gradually.			
Environment Neolithic/EBA: shifting pattern of woodland clearings. MBA: few wood- and tree-dependent Coleoptera but fragments of alder/oak suggest trees not entirely absent. By the LBA the			

landscape was open: on the floodplain alder pollen declined to absent by end of LBA; the 2nd gravel terrace was clear of trees though there may still have been woodland on the Oxford Clay to the north and the slopes of Wytham Hill to the south. Thorn scrub grew around abandoned waterholes but otherwise the area was open grassland used as pasture. As water tables rose, settlement shifted to the 2nd terrace. The EIA environment was similar to that in the LBA, summarised as an open mixed agricultural landscape; the quantity of charred crop-processing remains suggested a greater emphasis on arable production. From the Iron Age onwards, beetles indicate more permanent settlement structures. In the MIA the floodplain was becoming wetter with overbank flooding by LIA/Roman period. The area was very open with a range of habitats including wet, marshy and also dry pasture, diverse grassland not closely grazed (meadow?) and arable cultivation on both well-drained and wet soils. In the Early Roman period agricultural production intensified, higher areas on the floodplain were being ploughed, and there were organised field systems, boundaries, droveways and drainage ditches. Alluvial sediments were accumulating on the floodplain and intensified cultivation on the 2nd terrace was causing colluviation. Grassland habitats included marshy and drier pasture (no evidence for/against hay meadow). In the Late Roman period the open, mixed agricultural landscape persisted despite alluviation; cultivation on the floodplain was abandoned and it was used for pasture, but there is evidence that arable extended onto clayey soils to the north. There is no evidence for woodland or willows/sallows in the vicinity.

Plants: In the Neolithic and Bronze Age, emmer and 6-row hulled barley were the major cereals, and in the Iron Age and Roman periods emmer was replaced by spelt. The weed flora indicates extension of arable off the free-draining soils of the 2nd terrace into wetter areas from the Iron Age. In the EIA the weed flora suggested plough cultivation of circumneutral soils such as those found on the 2nd terrace, with annual weeds of spring cultivation of N-rich soils, with some evidence of both autumn sowing and cultivation of wetter soils beyond the edge of the 2nd terrace. By the Early Roman period floodplain grassland was being ploughed. Higher proportions of leguminous weed seeds suggest declining soil fertility, though there was also increased manure application (evidence from pottery scatters), and possibly a greater emphasis on autumn sowing. No waterlogged samples from Roman period so evidence for/against haymaking is absent. Few introduced horticultural crops.

Animals: Cattle, sheep/goat (including goat), pig and dog are present throughout, with horse from ?Iron Age.
Neolithic/Bronze Age: Not yet published, no details available
In the Iron Age and Roman periods, the proportion of cattle is high compared to other Oxfordshire sites. The proportion of cattle is lower in the Roman period than the Iron Age and the proportion of sheep higher. Pig is low except in the Early Roman phase and equids, though never high, increase from 2-3% to 5-6% of domestic animals in the Late Iron Age/Early Roman phase and remain at this level. No neonates were found, but very young cattle and sheep suggest that they were bred “nearby”, with seasonal movements of flocks and herds to areas around or away from the site. Age profiles suggest that the emphasis was on meat production in most phases, with the slaughter of prime age cattle in the Roman period particularly noted, though sheep seem to have been kept somewhat longer, for secondary products, in the Middle Iron Age and Late Roman phases. There were few remains of wild animals. Red and roe deer were more frequent in the Iron Age, while hare was more frequent in the Roman period.

Phases used: Neolithic/EBA (phase 5), Early BA (phase 6), Middle BA (phase 7), Late BA (phase 8),Early IA (phase 9), Middle IA (phase 10), LIA/Roman (phase 12),Early Roman (phase 13), Late Roman (phase 16)

Isotope analyses by:	This project	RLAHA	

References

Hey, G. and Timby, J.R. (2011) Yarnton: Iron age and Romano-British settlement and landscape: results of excavations 1990-98. OA Monograph 35. Oxford: Oxford Archaeology

Hey, G. et al. in preparation Yarnton vol 3 (Neolithic-Bronze Age). No details available

Lightfoot, E. et al. (2009) An investigation into diet at the site of Yarnton, Oxfordshire, using stable carbon and nitrogen isotopes Oxford Journal of Archaeology 28(3) 301–322 (Isotope results not included in present analysis)

Henig, M. And Booth, P. (2000) Roman Oxfordshire. Stroud: Sutton

Appendix 3: R outputs

Table A3.1 Results of (**a**) linear model and (**b**) linear mixed model including site as grouping factor, for variation in $\delta^{13}C$ depending on species and period.

```
(a)Linear model (ANOVA)
Formula: δ13C ~ sp * per
Analysis of Variance Table:
            Df Sum Sq Mean Sq  F value    Pr(>F)
sp           2  94.46  47.229 199.1642 < 2.2e-16 ***
per          3   3.87   1.289   5.4374  0.001018 **
sp:per       6 103.72  17.287  72.8984 < 2.2e-16 ***
Residuals 1478 350.48   0.237
Coefficients:
              Estimate Std. Error  t value Pr(>|t|)
(Intercept)  -22.25909    0.04238 -525.168  < 2e-16 ***
spPig          1.72909    0.06532   26.471  < 2e-16 ***
spSheep        0.38555    0.06927    5.566 3.09e-08 ***
per2           0.30650    0.06873    4.459 8.84e-06 ***
per3           0.61186    0.05489   11.148  < 2e-16 ***
per4           0.65727    0.05574   11.792  < 2e-16 ***
spPig:per2    -0.88342    0.11522   -7.668 3.16e-14 ***
spSheep:per2  -0.06880    0.10665   -0.645 0.518956
spPig:per3    -1.64374    0.08666  -18.968  < 2e-16 ***
spSheep:per3  -0.29412    0.08511   -3.456 0.000564 ***
spPig:per4    -1.44651    0.08840  -16.364  < 2e-16 ***
spSheep:per4  -0.34775    0.08520   -4.081 4.71e-05 ***

Residual standard error: 0.487 on 1478 degrees of freedom
Multiple R-squared:  0.3657,  Adjusted R-squared:  0.361
F-statistic: 77.46 on 11 and 1478 DF,  p-value: < 2.2e-16
```

```
(b) Linear mixed model fit by REML
Formula: δ13C ~ sp + per + (1 | site)
Random effects:
 Groups   Name        Variance Std.Dev.
 site     (Intercept) 0.01987  0.1410
 Residual             0.28865  0.5373
Number of obs: 1490, groups: site, 23

Fixed effects:
             Estimate Std. Error t value
(Intercept) -21.92165    0.05337  -410.7***
spPig         0.62794    0.03653    17.2***
spSheep       0.17756    0.03236     5.5***
per2          0.01437    0.06287     0.2
per3          0.12847    0.05790     2.2*
per4          0.20070    0.05730     3.5**
```

Notes: *sp* species (reference species is Cattle), *per* period. Reference period is *per1*, Neolithic; *per2* Bronze Age, *per3* Iron Age, *per4* Roman period. Note that the ANOVA in (a) is type 1, i.e. the effect of species is not adjusted for the effect of period. In a model where *per* was entered first, and in a Type 3 ANOVA, both *per* and *sp* remained significant. (b) All models with site as a grouping factor fit significantly better (P<0.001) than models without (see text); 6-7% of total variance is at the site level. Note that the estimated intercept and coefficients differ somewhat in the mixed model, and Period 2 is not significantly different from Period 1. Effects with t values >2 are likely to be significant. P values, for guidance only, were calculated using the nlme package in R. *P<0.05, **P<0.01, ***P<0.001

Table A3.2 Results of (**a**) linear model and (**b**) linear mixed model including site as grouping factor, for variation in $\delta^{15}N$ depending on species and period.

(a)Linear model (ANOVA)

Formula: $\delta^{15}N \sim sp * per$

Analysis of Variance Table:

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
sp	2	281.04	140.522	74.488	< 2.2e-16 ***
per	3	227.12	75.706	40.130	< 2.2e-16 ***
sp:per	6	150.69	25.114	13.313	9.707e-15 ***
Residuals	1478	2788.25	1.887		

Coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	5.56811	0.11955	46.576	< 2e-16 ***
spPig	0.76481	0.18424	4.151	3.50e-05 ***
spSheep	0.33316	0.19538	1.705	0.088362 .
per2	0.81942	0.19386	4.227	2.51e-05 ***
per3	0.40159	0.15481	2.594	0.009579 **
per4	0.86013	0.15721	5.471	5.24e-08 ***
spPig:per2	-1.39798	0.32497	-4.302	1.80e-05 ***
spSheep:per2	0.07608	0.30081	0.253	0.800369
spPig:per3	0.90020	0.24442	3.683	0.000239 ***
spSheep:per3	0.02057	0.24004	0.086	0.931730
spPig:per4	0.84950	0.24932	3.407	0.000674 ***
spSheep:per4	0.05133	0.24032	0.214	0.830904

Residual standard error: 1.374 on 1478 degrees of freedom
Multiple R-squared: 0.1911, Adjusted R-squared: 0.1851
F-statistic: 31.75 on 11 and 1478 DF, p-value: < 2.2e-16

(b) Linear mixed model fit by REML

Formula: $\delta^{15}N \sim sp + per + (1 | site)$

Random effects:

Groups	Name	Variance	Std.Dev.
site	(Intercept)	0.4693	0.685
Residual		1.6187	1.272

Number of obs: 1490, groups: site, 23

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	5.59421	0.18564	30.135***
spPig	1.23647	0.08683	14.241***
spSheep	0.37729	0.07686	4.909***
per2	0.25749	0.16279	1.582
per3	0.22798	0.15750	1.447
per4	0.65899	0.15590	4.227***

Notes: *sp* species (reference species is Cattle), *per* period. Reference period is *per1*, Neolithic; *per2* Bronze Age, *per3* Iron Age, *per4* Roman period. Note that the ANOVA in (a) is type 1, i.e. the effect of species is not adjusted for the effect of period. In a model where *per* was entered first, and in a type 3 ANOVA, both *sp* and *per* remained highly significant. For (b) all models with site as a grouping factor fit significantly better ($P<0.001$) than models without (see text); 20-26% of total variance is at the site level. Note that in the mixed model the estimated coefficients differ somewhat, and periods 2 and 3 are not significantly different from period 1. P values, for guidance only, were calculated using the nlme package in R. *P<0.05, **P<0.01, ***P<0.001

Table A3.3 Linear mixed models including *lat* latitude, *long* longitude and *ele* elevation, for (**a**) $\delta^{13}C$ and (**b**) $\delta^{15}N$

(a)Linear mixed model fit by REML
Formula: $\delta^{13}C$ ~ sp + per + lat + long + ele + (1 | site)

Random effects:

Groups	Name	Variance	Std.Dev.
site	(Intercept)	0.02296	0.1515
Residual		0.28848	0.5371

Number of obs: 1490, groups: site, 23

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	-16.019972	19.402862	-0.826
spPig	0.626518	0.036547	17.143***
spSheep	0.177059	0.032372	5.470***
per2	0.030350	0.065140	0.466
per3	0.147700	0.060393	2.446*
per4	0.220874	0.060001	3.681***
lat	-0.113799	0.377787	-0.301
long	0.104655	0.157613	0.664
ele	0.001160	0.001068	1.086

(b) Linear mixed model fit by REML
Formula: $\delta^{15}N$ ~ sp + per + lat + long + ele + (1 | site)

Random effects:

Groups	Name	Variance	Std.Dev.
site	(Intercept)	0.239	0.4889
Residual		1.619	1.2724

Number of obs: 1490, groups: site, 23

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	-14.840257	58.371016	-0.254
spPig	1.233422	0.086725	14.222***
spSheep	0.375347	0.076787	4.888***
per2	0.205572	0.160270	1.283
per3	0.196887	0.152170	1.294
per4	0.624749	0.150953	4.139***
lat	0.407574	1.136375	0.359
long	-0.054840	0.458129	-0.120
ele	-0.009041	0.003112	-2.906**

P values, for guidance only, were calculated using the nlme package in R. *P<0.05, **P<0.01, ***P<0.001

TableA3.4 Linear mixed models including region, for (**a**) $\delta^{13}C$ and (**b**) $\delta^{15}N$

```
(a)Linear mixed model fit by REML
Formula: δ13C ~ sp + per + reg + (1 | site)

Random effects:
 Groups   Name        Variance Std.Dev.
 site     (Intercept) 0.01227  0.1108
 Residual             0.28812  0.5368
Number of obs: 1490, groups: site, 23

Fixed effects:
             Estimate Std. Error t value
(Intercept) -21.75962    0.07364 -295.47***
spPig         0.62599    0.03653   17.14***
spSheep       0.17658    0.03233    5.46***
per2         -0.03046    0.06493   -0.47
per3          0.15355    0.05804    2.65**
per4          0.23900    0.05798    4.12***
reg2         -0.24169    0.07991   -3.02**
reg3         -0.24064    0.07438   -3.24**
reg4         -0.15783    0.13169   -1.20
reg5         -0.04158    0.11207   -0.37

(b)Linear mixed model fit by REML
Formula: δ15N ~ sp + per + reg + (1 | site)

Random effects:
 Groups   Name        Variance Std.Dev.
 site     (Intercept) 0.2919   0.5403
 Residual             1.6104   1.2690
Number of obs: 1490, groups: site, 23

Fixed effects:
            Estimate Std. Error t value
(Intercept)  5.48096    0.23344  23.479***
spPig        1.23570    0.08662  14.265***
spSheep      0.37856    0.07664   4.939***
per2         0.30719    0.16722   1.837
per3         0.09168    0.15841   0.579
per4         0.51243    0.15742   3.255**
reg2         0.31224    0.25578   1.221
reg3         0.70934    0.23827   2.977**
reg4        -0.72927    0.48577  -1.501
reg5        -0.89551    0.45250  -1.979
```

Notes: *per1*, Neolithic, is the reference period, and *reg1*, floodplain, is the reference region; *reg2* 1st terrace, *reg3* 2nd terrace, *reg4* limestone, *reg5* chalk. *P<0.05, **P<0.01, ***P<0.001. P values, for guidance only, were calculated using the nlme package in R (P value for reg5 is 0.062)

T able A3.5 Linear mixed model including region and elevation, for (**a**) $\delta^{15}N$, all periods and (**b**) $\delta^{15}N$, Neolithic only

(a)Linear mixed model fit by REML
Formula: $\delta^{15}N$ ~ sp + per + reg + ele + (1 | site)

Random effects:

Groups	Name	Variance	Std.Dev.
site	(Intercept)	0.2156	0.4643
Residual		1.6116	1.2695

Number of obs: 1490, groups: site, 23

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	5.814413	0.263803	22.041***
spPig	1.229514	0.086646	14.190***
spSheep	0.375856	0.076644	4.904***
per2	0.341144	0.165292	2.064*
per3	0.138142	0.155225	0.890
per4	0.552150	0.154252	3.580***
reg2	0.414779	0.245049	1.693
reg3	0.730628	0.225797	3.236**
reg4	0.535569	0.699576	0.766
reg5	0.470690	0.724288	0.650
ele	-0.008944	0.003926	-2.278*

(b)Linear mixed model fit by REML
Formula: $\delta^{15}N$ ~ sp + ele + reg + (1 | site)(Neolithic only)

Random effects:

Groups	Name	Variance	Std.Dev.
site	(Intercept)	0.9124	0.9552
Residual		0.6558	0.8098

Number of obs: 307, groups: site, 11

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	6.77814	0.64138	10.568***
spPig	0.67881	0.11122	6.103***
spSheep	0.26029	0.11909	2.186*
ele	-0.01548	0.01015	-1.525
reg2	-0.95727	1.14395	-0.837
reg3	0.39095	0.85560	0.457
reg4	0.90612	1.89865	0.477
reg5	1.24228	2.10945	0.589

P values, for guidance only, were calculated using the nlme package in R. *P<0.05, **P<0.01, ***P<0.001

Table A3.6 Comparisons of models including region and soil characteristics for (**a**) $\delta^{13}C$ and (**b**) $\delta^{15}N$.

(a) Comparisons of models for $\delta^{13}C$:

tvs.m9c: $\delta^{13}C$ ~ sp + per + stype + sph + sdrain + (1 | site)

tvs.m8c: $\delta^{13}C$ ~ sp + per + stype + sph + sdrain + reg + (1 | site)

	Df	AIC	BIC	logLik	deviance	Chisq	Chi Df	Pr(>Chisq)	
tvs.m9c	15	1699.3	1773.5	-834.65	1669.3				
tvs.m8c	19	1667.4	1761.4	-814.70	1629.4	39.902	4	4.536e-08	***

tvs.m7c: $\delta^{13}C$ ~ sp + per + reg + (1 | site)

tvs.m8c: $\delta^{13}C$ ~ sp + per + stype + sph + sdrain + reg + (1 | site)

	Df	AIC	BIC	logLik	deviance	Chisq	Chi Df	Pr(>Chisq)	
tvs.m7c	12	2413.8	2477.5	-1194.9	2389.8				
tvs.m8c	19	1667.4	1761.4	-814.7	1629.4	760.43	7	< 2.2e-16	***

(b) Comparisons of models for $\delta^{15}N$:

tvs.m9n: $\delta^{15}N$ ~ sp + per + stype + sph + sdrain + (1 | site)

tvs.m8n: $\delta^{15}N$ ~ sp + per + stype + sph + sdrain + reg + (1 | site)

	Df	AIC	BIC	logLik	deviance	Chisq	Chi Df	Pr(>Chisq)	
tvs.m9n	15	3564.6	3638.8	-1767.3	3534.6				
tvs.m8n	19	3549.5	3643.5	-1755.8	3511.5	23.114	4	0.0001201	***

tvs.m7n: $\delta^{15}N$ ~ sp + per + reg + (1 | site)

tvs.m8n: $\delta^{15}N$ ~ sp + per + stype + sph + sdrain + reg + (1 | site)

	Df	AIC	BIC	logLik	deviance	Chisq	Chi Df	Pr(>Chisq)	
tvs.m7n	12	5000.5	5064.2	-2488.3	4976.5				
tvs.m8n	19	3549.5	3643.5	-1755.8	3511.5	1465	7	< 2.2e-16	***

Notes: *sp* species *per* period *reg* region *stype* soil type.*P<0.05, **P<0.01, ***P<0.001

Table A3.7 (**a–d**) Linear mixed models looking at the effects of *reg* region, *ele* elevation, and *PMS* summer mean monthly precipitation, on $\delta^{15}N$, together and separately. (**e–f**) model comparisons

```
(a)Linear mixed model fit by REML
Formula: δ15N ~ sp + per + reg + ele + pms + (1 | site)
Random effects:
 Groups   Name        Variance Std.Dev.
 site     (Intercept) 0.2017   0.4491
 Residual             1.6119   1.2696
Number of obs: 1490, groups: site, 23
Fixed effects:
             Estimate Std. Error t value
(Intercept) 10.834269   3.933162   2.755*
spPig        1.231894   0.086673  14.213***
spSheep      0.375123   0.076646   4.894***
per2         0.324667   0.165415   1.963*
per3         0.115440   0.156027   0.740
per4         0.528331   0.155171   3.405***
reg2         0.426778   0.241861   1.765
reg3         0.713162   0.223109   3.196**
reg4         0.155169   0.748536   0.207
reg5         0.223395   0.734801   0.304
ele         -0.004393   0.005263  -0.835
pms         -0.109740   0.085794  -1.279
```

```
(b)Linear mixed model fit by REML
Formula: δ15N ~ sp + per + reg + pms + (1 | site),    Data: tv
Random effects:
 Groups   Name        Variance Std.Dev.
 site     (Intercept) 0.2016   0.449
 Residual             1.6116   1.269
Number of obs: 1490, groups: site, 23
Fixed effects:
            Estimate Std. Error t value
(Intercept) 12.99541    2.96031   4.390***
spPig        1.23468    0.08660  14.257***
spSheep      0.37561    0.07664   4.901***
per2         0.30883    0.16430   1.880
per3         0.09538    0.15414   0.619
per4         0.50940    0.15348   3.319***
reg2         0.40327    0.24018   1.679
reg3         0.69364    0.22185   3.127**
reg4        -0.34423    0.44970  -0.765
reg5        -0.24981    0.46736  -0.534
pms         -0.15888    0.06240  -2.546*
```

Table A3.7 continued

```
(c)Linear mixed model fit by REML
Formula: δ15N ~ sp + per + ele + pms + (1 | site)
Random effects:
 Groups   Name        Variance Std.Dev.
 site     (Intercept) 0.194    0.4405
 Residual             1.620    1.2729
Number of obs: 1490, groups: site, 23
Fixed effects:
             Estimate Std. Error t value
(Intercept) 10.666124   3.508876   3.040**
spPig        1.232507   0.086705  14.215***
spSheep      0.373952   0.076771   4.871***
per2         0.215449   0.157223   1.370
per3         0.213648   0.148099   1.443
per4         0.640830   0.146755   4.367***
ele         -0.005773   0.002671  -2.162*
pms         -0.096758   0.075857  -1.276
```

```
(d)Linear mixed model fit by REML
Formula: δ15N ~ sp + per + pms + (1 | site)
Random effects:
 Groups   Name        Variance Std.Dev.
 site     (Intercept) 0.2322   0.4818
 Residual             1.6207   1.2731
Number of obs: 1490, groups: site, 23
Fixed effects:
            Estimate Std. Error t value
(Intercept) 16.11638    2.57603   6.256***
spPig        1.23474    0.08676  14.232***
spSheep      0.37416    0.07681   4.871***
per2         0.24539    0.15800   1.553
per3         0.22062    0.15040   1.467
per4         0.64972    0.14897   4.362***
pms         -0.21895    0.05325  -4.112***
```

```
(e) comparing models (a), (b) and (d)
refitting model(s) with ML (instead of REML)
Models:
mod4: δ15N ~ sp + per + pms + (1 | site)
mod2: δ15N ~ sp + per + reg + pms + (1 | site)
mod1: δ15N ~ sp + per + reg + ele + pms + (1 | site)
     Df    AIC    BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
mod4  9 5005.6 5053.4 -2493.8   4987.6
mod2 13 4998.0 5067.0 -2486.0   4972.0 15.663      4   0.003507 **
mod1 14 4998.9 5073.1 -2485.4   4970.9  1.111      1   0.291875
```

Notes: (**a**) Full model: reg is significant, ele and PMS are not, (**b**) without ele, reg and PMS are significant, (**c**) without reg, ele is significant but PMS is not, (**d**) without reg or ele, PMS is significant, (**e**) and (**f**) comparing models shows that including region makes a significant difference even when elevation is already included, but including elevation when region is already included does not.

Table A3.8 Linear mixed models looking at the effect of site vegetation type on faunal $\delta^{13}C$ values in the Neolithic and Bronze Age. (**a**) All species together (**b**) Cattle (**c**) Sheep (**d**) Pig

```
(a) Linear mixed model fit by REML
Formula: δ13C ~ sp + vt2 + (1 | site)

Random effects:
 Groups   Name        Variance Std.Dev.
 site     (Intercept) 0.08882  0.2980
 Residual             0.31530  0.5615
Number of obs: 418, groups: site, 11

Fixed effects:
             Estimate Std. Error t value
(Intercept) -22.20167    0.17304 -128.31***
spPig         1.36631    0.07017   19.47***
spSheep       0.38029    0.06700    5.68***
vt21          0.22971    0.10131    2.27*
vt22         -0.01761    0.25821   -0.07
vt23         -0.08425    0.23152   -0.36
```

```
(b) Linear mixed model fit by REML
Formula: δ13C ~ vt2 + (1 | site)
   Data: subset(tvegNBA, sp == "Cattle")

Random effects:
 Groups   Name        Variance Std.Dev.
 site     (Intercept) 0.1533   0.3915
 Residual             0.2477   0.4977
Number of obs: 174, groups: site, 11

Fixed effects:
            Estimate Std. Error t value
(Intercept) -22.0025     0.2277  -96.62***
vt21         -0.1426     0.1492   -0.96
vt22         -0.1320     0.3341   -0.40
vt23         -0.3168     0.3081   -1.03
```

```
(c) Linear mixed model fit by REML
Formula: δ13C ~ vt2 + (1 | site)
   Data: subset(tvegNBA, sp == "Sheep")

Random effects:
 Groups   Name        Variance Std.Dev.
 site     (Intercept) 0.1301   0.3607
 Residual             0.2243   0.4736
Number of obs: 130, groups: site, 10

Fixed effects:
             Estimate Std. Error t value
(Intercept) -21.81909    0.21460 -101.67***
vt21          0.09122    0.15436    0.59
vt22          0.26703    0.38600    0.69
vt23         -0.17065    0.29104   -0.59
```

Table A3.8 continued

(d) Linear mixed model fit by REML

Formula: $\delta^{13}C$ ~ vt2 + (1 | site)

Data: subset(tvegNBA, sp == "Pig")

Random effects:

Groups	Name	Variance	Std.Dev.
site	(Intercept)	0.1431	0.3783
Residual		0.2981	0.5460

Number of obs: 114, groups: site, 9

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	-21.0026	0.2381	-88.22***
vt21	0.6689	0.1688	3.96***
vt22	-0.1424	0.4211	-0.34
vt23	0.2278	0.3574	0.64

Notes: Vegetation type *vt2: 1* woodland, *2* scrub/hedge, *3* scrub/grassland, *4* open grassland – used as reference. (**a**) All species together: $\delta^{13}C$ at woodland sites is significantly higher; (**b**) cattle and (**c**) sheep: $\delta^{13}C$ in other vegetation types not significantly different from open grassland sites (**d**) pig: $\delta^{13}C$ at woodland sites significantly higher than at open grassland sites. P values, for guidance only, were calculated using the nlme package in R *P<0.05, **P<0.01, ***P<0.001

Table A3.9 Linear mixed models looking at the effect of site vegetation type on faunal $\delta^{13}C$ values in the Iron Age and Roman periods. (**a**) All species together (**b**) Cattle (**c**) Sheep (**d**) Pig

```
 (a) Linear mixed model fit by REML
Formula: δ13C ~ sp + vt2 + (1 | site)
   Random effects:
 Groups   Name        Variance Std.Dev.
 site     (Intercept) 0.01841  0.1357
 Residual             0.16811  0.4100
Number of obs: 949, groups: site, 11
Fixed effects:
             Estimate Std. Error t value
(Intercept) -21.659785   0.058046  -373.1***
spPig         0.134283   0.035895     3.7***
spSheep       0.053438   0.030489     1.8
vt23          0.081690   0.157729     0.5
vt25          0.309808   0.152852     2.0 (P=0.07)
vt26         -0.001808   0.068577     0.0
vt27          0.237140   0.160335     1.5
vt28         -0.005844   0.086646    -0.1
```

```
(b) Linear mixed model fit by REML
Formula: δ13C ~ vt2 + (1 | site)
   Data: subset(tvegIAR, sp == "Cattle")
Random effects:
 Groups   Name        Variance Std.Dev.
 site     (Intercept) 0.002493 0.04993
 Residual             0.115294 0.33955
Number of obs: 354, groups: site, 11

Fixed effects:
             Estimate Std. Error t value
(Intercept) -21.62362    0.03632  -595.4***
vt23         -0.01876    0.09645    -0.2
vt25          0.33747    0.09081     3.7**
vt26         -0.04952    0.05265    -0.9
vt27          0.16833    0.10293     1.6
vt28          0.01892    0.10854     0.2
```

```
(c) Linear mixed model fit by REML
Formula: δ13C ~ vt2 + (1 | site)
   Data: subset(tvegIAR, sp == "Sheep")
Random effects:
 Groups   Name        Variance Std.Dev.
 site     (Intercept) 0.05451  0.2335
 Residual             0.14839  0.3852
Number of obs: 378, groups: site, 11

Fixed effects:
             Estimate Std. Error t value
(Intercept) -21.645595   0.091839 -235.69***
vt23          0.282117   0.263424    1.07
vt25          0.390039   0.258964    1.51
vt26         -0.026079   0.101329   -0.26
vt27          0.156262   0.269875    0.58
vt28          0.008888   0.113716    0.08
```

Table A3.9 continued

```
(d) Linear mixed model fit by REML
Formula: δ13C ~ vt2 + (1 | site)
   Data: subset(tvegIAR, sp == "Pig")

Random effects:
 Groups   Name        Variance Std.Dev.
 site     (Intercept) 0.04258  0.2063
 Residual             0.25887  0.5088
Number of obs: 217, groups: site, 11

Fixed effects:
             Estimate Std. Error t value
(Intercept) -21.50279    0.10569 -203.45***
vt23         -0.33388    0.31128   -1.07
vt25          0.17899    0.25035    0.71
vt26          0.01030    0.16252    0.06
vt27          0.50904    0.29344    1.73
vt28         -0.08492    0.37684   -0.23
```

Notes: vegetation type *vt2: 3* scrub/grassland, *4* open grassland – used as reference, *5* calcareous grassland, *6* arable/grassland, *7* arable *8* wet grassland) on faunal $\delta^{13}C$ values in the Iron Age and Roman period. (**a**) All species together: $\delta^{13}C$ in other vegetation types not significantly different from open grassland sites (though t-value>2 for calcareous grassland). (**b**) cattle: $\delta^{13}C$ at calcareous grassland sites is significantly higher than open grassland sites; (**c**) sheep and (**d**) pig: $\delta^{13}C$ in other vegetation types not significantly different from open grassland sites. P values, for guidance only, were calculated using the nlme package in R *P<0.05, **P<0.01, ***P<0.001

Table A3.10 Linear mixed models looking at the effect of site vegetation type on faunal $\delta^{15}N$ values in the Neolithic and Bronze Age. (**a**) All species together (**b**) Cattle (**c**) Sheep (**d**) Pig

```
(a) Linear mixed model fit by REML
Formula: δ15N ~ sp + vt2 + (1 | site)

Random effects:
 Groups   Name        Variance Std.Dev.
 site     (Intercept) 0.5059   0.7112
 Residual             1.0780   1.0383
Number of obs: 418, groups: site, 11

Fixed effects:
            Estimate Std. Error t value
(Intercept)   5.6473     0.3915  14.425***
spPig         0.3365     0.1300   2.589**
spSheep       0.3397     0.1241   2.738**
vt21          0.1411     0.1898   0.744
vt22         -0.5269     0.5894  -0.894
vt23          0.6961     0.5336   1.305
```

```
(b) Linear mixed model fit by REML
Formula: δ15N ~ vt2 + (1 | site)
   Data: subset(tvegNBA, sp == "Cattle")

Random effects:
 Groups   Name        Variance Std.Dev.
 site     (Intercept) 0.6921   0.8320
 Residual             0.8080   0.8989
Number of obs: 174, groups: site, 11

Fixed effects:
            Estimate Std. Error t value
(Intercept)  5.49741    0.46674  11.778***
vt21         0.34310    0.27236   1.260
vt22        -0.09111    0.69061  -0.132
vt23         0.76474    0.63751   1.200
```

```
(c) Linear mixed model fit by REML
Formula: δ15N ~ vt2 + (1 | site)
   Data: subset(tvegNBA, sp == "Sheep")

Random effects:
 Groups   Name        Variance Std.Dev.
 site     (Intercept) 0.7576   0.8704
 Residual             1.2254   1.1070
Number of obs: 130, groups: site, 10

Fixed effects:
            Estimate Std. Error t value
(Intercept)   6.4012     0.5134  12.468***
vt21         -0.6768     0.3619  -1.870
vt22         -1.2653     0.9237  -1.370
vt23          0.4024     0.6975   0.577
```

Table A3.10 continued

(d) Linear mixed model fit by REML

Formula: $\delta^{15}N \sim vt2 + (1 \mid site)$

Data: subset(tvegNBA, sp == "Pig")

Random effects:

Groups	Name	Variance	Std.Dev.
site	(Intercept)	0.1685	0.4105
Residual		0.7847	0.8859

Number of obs: 114, groups: site, 9

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	5.4740	0.3087	17.732***
vt21	0.8224	0.2654	3.098**
vt22	-0.7693	0.5290	-1.454
vt23	0.8197	0.4477	1.831

Notes: Vegetation type *vt2: 1* woodland, *2* scrub/hedge, *3* scrub/grassland, *4* open grassland – used as reference. (**a**) All species together, (**b**) cattle, (**c**) sheep: $\delta^{15}N$ in other vegetation types not significantly different from open grassland sites, (**d**) pig: $\delta^{15}N$ at woodland sites significantly higher than at open grassland sites. P values, for guidance only, were calculated using the nlme package in R *P<0.05, **P<0.01, ***P<0.001

Table A3.11 Linear mixed models looking at the effect of site vegetation type on faunal $\delta^{15}N$ values in the Iron Age and Roman periods. (**a**) All species together (**b**) Cattle (**c**) Sheep (**d**) Pig

(a) Linear mixed model fit by REML

Formula: $\delta^{15}N$ ~ sp + vt2 + (1 | site)

Random effects:

Groups	Name	Variance	Std.Dev.
site	(Intercept)	0.2184	0.4674
Residual		1.7930	1.3390

Number of obs: 949, groups: site, 11

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	6.28124	0.19655	31.96***
spPig	1.68434	0.11725	14.37***
spSheep	0.36297	0.09958	3.65***
vt23	-0.36013	0.53857	-0.67
vt25	-1.75611	0.52335	-3.36**
vt26	0.14287	0.22815	0.63
vt27	-0.26597	0.54671	-0.49
vt28	-0.40163	0.28332	-1.42

(b) Linear mixed model fit by REML

Formula: $\delta^{15}N$ ~ vt2 + (1 | site)

Data: subset(tvegIAR, sp == "Cattle")

Random effects:

Groups	Name	Variance	Std.Dev.
site	(Intercept)	0.2455	0.4955
Residual		1.8581	1.3631

Number of obs: 354, groups: site, 11

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	6.1911	0.2273	27.232***
vt23	0.1913	0.6210	0.308
vt25	-1.7515	0.6072	-2.885*
vt26	0.3305	0.3129	1.056
vt27	-0.4070	0.6376	-0.638
vt28	-0.3932	0.4633	-0.849

(c) Linear mixed model fit by REML

Formula: $\delta^{15}N$ ~ vt2 + (1 | site)

Data: subset(tvegIAR, sp == "Sheep")

Random effects:

Groups	Name	Variance	Std.Dev.
site	(Intercept)	0.4693	0.6851
Residual		1.7165	1.3102

Number of obs: 378, groups: site, 11

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	6.7680	0.2796	24.202***
vt23	-0.9423	0.7888	-1.195
vt25	-2.0958	0.7715	-2.717*
vt26	0.1059	0.3301	0.321
vt27	-0.8913	0.8136	-1.096
vt28	-0.3551	0.3855	-0.921

Table 3.11 continued

```
(d) Linear mixed model fit by REML
Formula: δ15N ~ vt2 + (1 | site)
   Data: subset(tvegIAR, sp == "Pig")

Random effects:
 Groups   Name        Variance Std.Dev.
 site     (Intercept) 0.02139  0.1463
 Residual             1.54948  1.2448
Number of obs: 217, groups: site, 11

Fixed effects:
            Estimate Std. Error t value
(Intercept)   8.1309     0.1631   49.85***
vt23         -0.3825     0.5534   -0.69
vt25         -1.5767     0.3185   -4.95***
vt26         -0.2313     0.2260   -1.02
vt27          1.0004     0.4916    2.03*
vt28         -0.8569     0.9001   -0.95
```

Notes: vegetation type *vt2: 3* scrub/grassland, *4* open grassland – used as reference, *5* calcareous grassland, *6* arable/grassland, *7* arable *8* wet grassland) on faunal $\delta^{13}C$ values in the Iron Age and Roman period. (**a**) All species together, (**b**) cattle, (**c**) sheep, (**d**) pig: $\delta^{15}N$ in calcareous grassland significantly lower than at open grassland sites, and for pig only, $\delta^{15}N$ at arable sites significantly higher than at open grassland sites. P values, for guidance only, were calculated using the nlme package in R *P<0.05, **P<0.01, ***P<0.001

Table A3.12 Linear mixed model looking at faunal $\delta^{15}N$ values and (**a**) presence/absence of bread wheat at sites in the Neolithic/Bronze Age period and (**b**) presence/absence of sloe at sites and in the Iron Age and Roman period.

```
(a) Linear mixed model fit by REML ['lmerMod']
Formula: δ13C ~ sp + bw + (1 | site)
   Data: tvapNB

Random effects:
 Groups   Name        Variance  Std.Dev.
 site     (Intercept) 0.0005815 0.02411
 Residual             0.3038992 0.55127
Number of obs: 286, groups: site, 8

Fixed effects:
            Estimate Std. Error t value
(Intercept) -22.06187    0.05480  -402.6***
spPig         1.24263    0.08217    15.1***
spSheep       0.31415    0.07639     4.1***
bw           -0.59318    0.10295    -5.8**
```

```
(b) Linear mixed model fit by REML
Formula: δ15N ~ sp + per + reg + sloe + (1 | site)
   Data: tvapIR

Random effects:
 Groups   Name        Variance Std.Dev.
 site     (Intercept) 0.1138   0.3374
 Residual             1.7541   1.3244
Number of obs: 949, groups: site, 11

Fixed effects:
            Estimate Std. Error t value
(Intercept)  5.503791   0.393599  13.983***
spPig        1.695240   0.115686  14.654***
spSheep      0.360274   0.098480   3.658***
per4         0.469540   0.096041   4.889***
reg2        -0.002298   0.372855  -0.006
reg3         0.772625   0.417042   1.853
reg5        -1.512851   0.516089  -2.931*
sloe         0.565548   0.261671   2.161*
```

Notes: Faunal $\delta^{15}N$ values were (**a**) significantly lower at earlier sites with bread wheat (*bw*), and (**b**) significantly higher at later sites with sloe. P values, for guidance only, were calculated using the nlme package in R *P<0.05, **P<0.01, ***P<0.001

Table A3.13 Linear mixed models looking at (**a**) the presence/absence of aurochs at sites and faunal $\delta^{15}N$ values (all periods); (**b**) the presence/absence of red deer at sites and faunal $\delta^{15}N$ values in the Iron Age/Roman periods.

```
(a) Linear mixed model fit by REML ['lmerMod']
Formula: δ15N ~ sp + per + reg + aurochs + (1 | site)
   Data: tvap

Random effects:
 Groups   Name        Variance Std.Dev.
 site     (Intercept) 0.199    0.4461
 Residual             1.674    1.2938
Number of obs: 1235, groups: site, 16

Fixed effects:
            Estimate Std. Error t value
(Intercept)  4.91826    0.36481  13.482***
spPig        1.34455    0.09844  13.659***
spSheep      0.34616    0.08519   4.064***
per2         0.65582    0.32511   2.017*
per3         0.59755    0.21950   2.722**
per4         0.99642    0.21654   4.601***
reg2         0.15310    0.32129   0.477
reg3         0.79264    0.34687   2.285*
reg4        -1.66360    0.79851  -2.083
reg5        -0.99827    0.52007  -1.920
aurochs      0.78886    0.38238   2.063*
```

```
(b)Linear mixed model fit by REML ['lmerMod']
Formula: δ15N ~ sp + per + reg + reddeer + (1 | site)
   Data: tvapIR

Random effects:
 Groups   Name        Variance Std.Dev.
 site     (Intercept) 0.07225  0.2688
 Residual             1.75619  1.3252
Number of obs: 949, groups: site, 11

Fixed effects:
            Estimate Std. Error t value
(Intercept)  5.35550    0.39503  13.557***
spPig        1.69254    0.11564  14.636***
spSheep      0.34714    0.09847   3.525***
per4         0.48802    0.09586   5.091***
reg2        -0.22754    0.35162  -0.647
reg3         0.33701    0.36212   0.931
reg5        -1.62492    0.45519  -3.570**
reddeer      0.62660    0.22951   2.730**
```

Notes: Faunal $\delta^{15}N$ values were significantly higher at (**a**) sites with aurochs, and (**b**) later sites with red deer. P values, for guidance only, were calculated using the nlme package in R *P<0.05, **P<0.01, ***P<0.001

Table A3.14 Linear mixed models for cattle and sheep $\delta^{15}N$ values in the Bronze Age and Iron Age in (**a**) the Middle Thames, (**b**) the Upper Thames.

```
 (a)Linear mixed model fit by REML ['lmerMod']
Formula: δ15N ~ per + sp + (1 | site)
   Data: tvm.BIA.b

Random effects:
 Groups   Name        Variance Std.Dev.
 site     (Intercept) 0.5475   0.7399
 Residual             1.3607   1.1665
Number of obs: 130, groups:  site, 6

Fixed effects:
            Estimate Std. Error t value
(Intercept)   6.7584     0.3757  17.989
per3         -0.9404     0.3012  -3.122**
spSheep       0.7959     0.2171   3.666***
```

```
(b)Linear mixed model fit by REML ['lmerMod']
Formula: δ15N ~ per + sp + (1 | site)
   Data: tvu.BIA.b

Random effects:
 Groups   Name        Variance Std.Dev.
 site     (Intercept) 0.4566   0.6757
 Residual             1.5738   1.2545
Number of obs: 404, groups:  site, 12

Fixed effects:
            Estimate Std. Error t value
(Intercept)   5.9255     0.2739  21.631
per3         -0.1506     0.2182  -0.690
spSheep       0.2510     0.1264   1.985*
```

Notes: Faunal $\delta^{15}N$ values were significantly lower in the Iron Age *per3* than the Bronze Age (used as reference) (**a**) in the Middle Thames but not (**b**) in the Upper Thames. Sheep had significantly higher $\delta^{15}N$ values than cattle in both periods. P values, for guidance only, were calculated using the nlme package in R *P<0.05, **P<0.01, ***P<0.001

Table A 3.15 Linear mixed models looking at Iron Age cattle and sheep $\delta^{15}N$ values in (**a**) the Middle Thames, (**b**) the Upper Thames.

```
 (a)Linear mixed model fit by REML ['lmerMod']
Formula: δ15N ~ sp + phL + reg + (1 | site)
   Data: TVm.IA.L

Random effects:
 Groups   Name        Variance Std.Dev.
 site     (Intercept) 0.2996   0.5474
 Residual             0.6878   0.8293
Number of obs: 58, groups:  site, 5

Fixed effects:
            Estimate Std. Error t value
(Intercept)   5.4164     0.5147  10.523
spSheep       0.6863     0.2359   2.910**
phLi2        -0.8946     0.4583  -1.952 P=0.056
reg2          1.0036     0.9531   1.053
reg3          1.3957     0.6346   2.199*
```

```
(b) Linear mixed model fit by REML ['lmerMod']
Formula: δ15N ~ sp + phL + reg + (1 | site)
   Data: TVu.IA.L

Random effects:
 Groups   Name        Variance Std.Dev.
 site     (Intercept) 0.02315  0.1522
 Residual             1.82988  1.3527
Number of obs: 290, groups:  site, 8

Fixed effects:
            Estimate Std. Error t value
(Intercept)   6.2799     0.3406  18.436
spSheep       0.3523     0.1591   2.214*
phLi2         0.1303     0.2149   0.606
reg2         -0.9976     0.4051  -2.462 P=0.057
reg3         -0.1382     0.3568  -0.388
```

Notes: Phase *phL* is defined to match Lambrick (1992*): phL i1*, earlier Iron Age, is the reference, *i2* Late Iron Age. Region: *reg1* floodplain is the reference, *reg2* 1st terrace, *reg 3* 2nd terrace. Faunal $\delta^{15}N$ values were close to significantly lower in the Late Iron Age than in the Early Iron Age. Faunal $\delta^{15}N$ values were significantly higher on the 2nd terrace in the Late Iron Age (**a**) in the Middle Thames but not (**b**) in the Upper Thames. Faunal $\delta^{15}N$ values were significantly lower on the 1st terrace than the floodplain (**b**) in the Upper Thames but not (**a**) in the Middle Thames. Sheep had significantly higher $\delta^{15}N$ values than cattle in both phases. P values, for guidance only, were calculated using the nlme package in R *P<0.05, **P<0.01, ***P<0.001

Table A3.16 Linear mixed models looking at Iron Age/Roman cattle and sheep $\delta^{15}N$ values in (**a**) the Middle Thames, (**b**) the Upper Thames

```
(a)Linear mixed model fit by REML ['lmerMod']
Formula: δ15N ~ sp + phL + reg + (1 | site)
   Data: TVm.IA.L

Random effects:
 Groups   Name        Variance Std.Dev.
 site     (Intercept) 0.000    0.000
 Residual             1.606    1.267
Number of obs: 108, groups:  site, 5

Fixed effects:
            Estimate Std. Error t value
(Intercept)   4.7480     0.4591  10.341
spSheep       1.1551     0.2462   4.692***
phLr1         1.6437     0.4965   3.311**
phLr2         1.2655     0.5403   2.342*
reg2         -0.1852     0.4747  -0.390
reg3          0.5827     0.4022   1.449
```

```
(b)Linear mixed model fit by REML ['lmerMod']
Formula: δ15N ~ sp + phL + reg + (1 | site)
   Data: TVu.IA.L

Random effects:
 Groups   Name        Variance Std.Dev.
 site     (Intercept) 0.2186   0.4675
 Residual             2.0655   1.4372
Number of obs: 324, groups:  site, 8

Fixed effects:
            Estimate Std. Error t value
(Intercept)   5.8304     0.3905  14.929
spSheep       0.2575     0.1611   1.599
phLr1         0.2862     0.2560   1.118
phLr2         0.4295     0.2892   1.485
reg3          0.3875     0.3894   0.995
```

Notes: Phases *phL* are defined to match Lambrick (1992*): phL i2*, later Iron Age, is the reference, *r1* earlier Roman, *r2* later Roman. Region: *reg1* floodplain is the reference, *reg2* 1st terrace, *reg 3* 2nd terrace. (**a**) In the Middle Thames, Faunal $\delta^{15}N$ values were significantly higher in both Roman phases than in the Late Iron Age, and sheep $\delta^{15}N$ values were significantly higher than those of cattle. (**b**) In the Upper Thames there were no significant differences in faunal $\delta^{15}N$ values according to phase, region or species. P values, for guidance only, were calculated using the nlme package in R *P<0.05, **P<0.01, ***P<0.001

Appendix 4: R scripts

Type 1 ANOVA for species by period (Appendix Tables A3.1a, A3.2a)

```
# data
tv <- TVAllDataR
tv$per <- factor(tv$per)

# models
tv.lm1c <- lm(δ13C~sp*per, data=tv)
summary(tv.lm1c)
anova(tv.lm1c)

tv.lm1n <- lm(δ15N~sp*per, data=tv)
summary(tv.lm1n)
anova(tv.lm1n)
```

Linear mixed models, accounting for spatial autocorrelation by using site as a grouping factor (Appendix Tables A3.1b, A3.2b), and testing whether effect of period is significant

```
library(lme4)

tv.mod1c <- lmer(δ13C~sp + (1|site),data=tv)
tv.mod1c
summary(tv.mod1c)

tv.mod2c <- lmer(δ13C~sp + per + (1|site),data=tv)
tv.mod2c
summary(tv.mod2c)

anova(tv.mod1c,tv.mod2c)

tv.mod1n <- lmer(δ15N~sp + (1|site),data=tv)
tv.mod1n
summary(tv.mod1n)

tv.mod2n <- lmer(δ15N~sp + per + (1|site),data=tv)
tv.mod2n
summary(tv.mod2n)

anova(tv.mod1n,tv.mod2n)
```

Linear mixed model to test effect of period for each species separately, shown for cattle $\delta^{13}C$ (Table 5.3)

```
library(lme4)

tv.mod3c <- lmer(δ13C~per + (1|site),data=subset(tv, sp=="Cattle"))
summary(tv.mod3c)

# model checking
plot(tv.mod3c)
hist(resid(tv.mod3c,main="Histogram of residuals", xlab="Residuals")
qqnorm(resid(tv.mod3c), main="Normal Q-Q plot")
qqline(resid(tv.mod3c))
```

Similar models were used for analysis of the effects of other variables. Variables can be added/substituted in the above model specification and the model run in the same way. The model

and dataset are specified in the output (Appendix 3). The “plot.lmerMod” function in lme4 can be used to produce various plots for model checking, including the one shown here which plots residuals against fitted values to check homogeneity of variance; code to produce a histogram of residuals and a Q-Q plot to check normality of residuals also shown.

PCA of climate variables (Fig. 5.8)

```
#data:
tv <- TVSMpcaR
tv$per <- factor(tv$per)
tv$reg <- factor(tv$reg)

# for graphical outputs:
reg.cols <- c("blue", "turquoise","green",  "orange","red")
legreg <- c("Floodplain", "Terrace 1", "Terrace 2", "Limestone",
"Chalk")


#scaling variables for PCA:
# these are centred and scaled:
tv2 <- tv
for (i in c(4:24)) {
  tv2[,i] <- scale(tv2[,i])
}

#PCA of climate factors (and lat, long, ele), labelled by site, points
#jittered for greater visibility:
clim.pca <-prcomp(tv2[4:24])
summary(clim.pca)
#use first 2 PCs (83% of variance) or 3 (90%)

plot(jitter(clim.pca$x[,1],10),jitter(clim.pca$x[,2], 10),
     xlim=c(-6,8),pch=21,bg=reg.cols[tv2$reg])
text(jitter(clim.pca$x[,1],10),jitter(clim.pca$x[,2], 10),
     tv2$site, cex=0.7, pos=4)

plot(jitter(clim.pca$x[,2],10),jitter(clim.pca$x[,3], 10),
     xlim=c(-6,8),pch=21,bg=reg.cols[tv2$reg])
text(jitter(clim.pca$x[,2],10),jitter(clim.pca$x[,3], 10),
     tv2$site, cex=0.7, pos=4)

#PCA biplot, points unlabelled and coloured by region (Fig. 5.8):
biplot(clim.pca, col=c("grey40","black"),cex=0.8,
       xlabs=rep("",23 ), xlim=c(-0.45,0.4))
points(jitter(clim.pca$x[,1],10),jitter(clim.pca$x[,2], 10),
        pch=21, bg=reg.cols[tv2$reg])
legend(3,-3.2, legend = legreg, pt.bg = reg.cols,bty="n",
       lty= "blank", pch = 21, cex = 0.6)
```

Checking the effects of climate variables on $\delta^{13}C$ and $\delta^{15}N$ (Table 5.9)

```
#data:
tv<-TVAllDataGeogClimR
tv$per <- factor(tv$per)
tv$reg <- factor(tv$reg)

#running through each climate factor for each isotope:
for(i in c(15:32)) {
  mod<-lmer(δ13C~sp+per+tv[,i] + (1|site),tv)
  print(names(tv[i]))
  print(anova(mod))
  print("##########################################")
}
```

```
for(i in c(15:32)) {
  mod<-lmer(δ15N~sp+per+reg+ele+tv[,i] + (1|site),tv)
  print(names(tv[i]))
  print(anova(mod))
  print("########################################")
}
```

Variables other than climate variables were included in the model only if they had a significant effect in earlier analyses. The output was scanned for models where the climatic factor might have a significant effect based on the F-value, and such models were examined further (shown for the effect of pms on $\delta^{15}N$).

```
summary(mod<-lmer(δ15N~sp+per+reg+ele+pms + (1|site),tv))
```

Correlations between species (Fig. 5.15)

```
### correlations between pairs of species coloured by period ###
#data:
tvm <- TVSiteMeansR
tvm$per <- factor(tvm$per)

mean.cs<-subset(tvm,cn>0 & sn>0)
mean.ps<-subset(tvm,pn>0 & sn>0)
mean.cp<-subset(tvm,pn>0 & cn>0)

cor.test(~cδ13C+sδ13C,data=mean.cs)
cor.test(~pδ13C+sδ13C,data=mean.ps)
cor.test(~cδ13C+pδ13C,data=mean.cp)

cor.test(~cδ15N+sδ15N,data=mean.cs)
cor.test(~pδ15N+sδ15N,data=mean.ps)
cor.test(~cδ15N+pδ15N,data=mean.cp)

cor.test(~cδ13C+sδ13C,data=mean.cs, method="spearman")
cor.test(~pδ13C+sδ13C,data=mean.ps, method="spearman")
cor.test(~cδ13C+pδ13C,data=mean.cp, method="spearman")

cor.test(~cδ15N+sδ15N,data=mean.cs, method="spearman")
cor.test(~pδ15N+sδ15N,data=mean.ps, method="spearman")
cor.test(~cδ15N+pδ15N,data=mean.cp, method="spearman")

## separately for NB and IR

mean.csNB<-subset(mean.cs,per=="1"|per=="2")
mean.csIR<-subset(mean.cs,per=="3"|per=="4")

mean.psNB<-subset(mean.ps,per=="1"|per=="2")
mean.psIR<-subset(mean.ps,per=="3"|per=="4")

mean.cpNB<-subset(mean.cp,per=="1"|per=="2")
mean.cpIR<-subset(mean.cp,per=="3"|per=="4")

cor.test(~cδ13C+sδ13C,data=mean.csNB)
cor.test(~pδ13C+sδ13C,data=mean.psNB)
cor.test(~cδ13C+pδ13C,data=mean.cpNB)

cor.test(~cδ13C+sδ13C,data=mean.csIR)
cor.test(~pδ13C+sδ13C,data=mean.psIR)
```

```
cor.test(~cδ13C+pδ13C,data=mean.cpIR)

cor.test(~cδ15N+sδ15N,data=mean.csNB)
cor.test(~pδ15N+sδ15N,data=mean.psNB)
cor.test(~cδ15N+pδ15N,data=mean.cpNB)

cor.test(~cδ15N+sδ15N,data=mean.csIR)
cor.test(~pδ15N+sδ15N,data=mean.psIR)
cor.test(~cδ15N+pδ15N,data=mean.cpIR)

##  sets of plots for all per, NB, IR  ######################
##  (site means, Pearson correlation)  ######################

per.cols=c("green","orange","red","purple")
per.names=c("Neolithic","BronzeAge","IronAge","Roman")


par(mfrow=c(3,2),mar=c(4,4,3,2))

plot(cδ13C~sδ13C,data=mean.cs, las=1,
     cex.axis=0.6,cex.lab=0.6, xlim=c(-23.5,-19),ylim=c(-23.5,-19),
     xlab=expression(paste("Sheep ", delta^{13}, "C \u2030")),
     ylab= expression(paste("Cattle  ", delta^{13}, "C \u2030")),
     main=expression(paste(delta^{13}, "C \u2030")),pch=21,
     bg=per.cols[per])
text(-23.4,-19.1,pos=4,cex=0.7,
     labels=expression(paste("All periods ",
       r[P], "= 0.49, P<0.001, df = 40")))
text(-23.4,-19.4,pos=4,cex=0.7,
     labels=expression(paste("N/BA  ",
       r[P], "= 0.41, NS, df = 14")))
text(-23.4,-19.7,pos=4,cex=0.7,
     labels=expression(paste("IA/R  ",
       r[P], "= 0.62, P<0.01, df = 24")))
text(-19,-19, labels="(a)")
abline(0,1, lty=2)
abline(-0.5,1, lty=3)
legend(-20.6,-22.5,legend=c("slope = 1","intercept  0","intercept -
0.5"),
       lty=c(0,2,3),cex=0.6, bty="n")
legend(-20.6,-21.5,legend=per.names, pch=21, pt.bg=per.cols,
       cex=0.6, bty="n")

plot(cδ15N~sδ15N,data=mean.cs, las=1,
     cex.axis=0.6,cex.lab=0.6, xlim=c(4,10),ylim=c(4,10),
     xlab=expression(paste("Sheep ", delta^{15}, "N \u2030")),
     ylab= expression(paste("Cattle  ", delta^{15}, "N \u2030")),
     main=expression(paste(delta^{15}, "N \u2030")),pch=21,
     bg=per.cols[per])
text(4.2,9.9,pos=4,cex=0.7,
     labels=expression(paste("All periods ",
      r[P], "= 0.60, P<0.001, df = 40")))
text(4.2,9.55,pos=4,cex=0.7,
     labels=expression(paste("N/BA  ",
      r[P], "= 0.62, P<0.01, df = 14")))
text(4.2,9.2,pos=4,cex=0.7,
     labels=expression(paste("IA/R  ",
      r[P], "= 0.59, P<0.05, df = 24")))
text(10,10, labels="(d)")
abline(0,1, lty=2)
abline(-1,1, lty=3)
legend(8.1,5.2,legend=c("slope = 1","intercept  0","intercept -1"),
       lty=c(0,2,3),cex=0.6, bty="n")
```

```
plot(pδ13C~sδ13C,data=mean.ps, las=1,
     cex.axis=0.6,cex.lab=0.6, xlim=c(-23.5,-19),ylim=c(-23.5,-19),
     xlab=expression(paste("Sheep ", delta^{13}, "C \u2030")),
     ylab= expression(paste("Pig ", delta^{13}, "C \u2030")),
     pch=21,bg=per.cols[per])
text(-23.4,-19.1,pos=4,cex=0.7,
     labels=expression(paste("All periods ",
       r[P], "= -0.18, NS, df = 35")))
text(-23.4,-19.4,pos=4,cex=0.7,
     labels=expression(paste("N/BA  ",
       r[P], "= -0.08, NS, df = 12")))
text(-23.4,-19.7,pos=4,cex=0.7,
     labels=expression(paste("IA/R  ",
       r[P], "= 0.28, NS, df = 21")))
text(-19,-19, labels="(b)")
abline(0,1, lty=2)
abline(1,1, lty=3)
legend(-20.6,-22.5,legend=c("slope = 1","intercept  0","intercept +1"),
       lty=c(0,2,3),cex=0.6, bty="n")

plot(pδ15N~sδ15N,data=mean.ps, las=1,
     cex.axis=0.6,cex.lab=0.6, xlim=c(4,10),ylim=c(4,10),
     xlab=expression(paste("Sheep ", delta^{15}, "N \u2030")),
     ylab= expression(paste("Pig ", delta^{15}, "N \u2030")),
     pch=21, bg=per.cols[per])
text(4.2,9.9,pos=4,cex=0.7,
     labels=expression(paste("All periods ",
        r[P], "= 0.51, P<0.01, df = 35")))
text(4.2,9.55,pos=4,cex=0.7,
     labels=expression(paste("N/BA  ",
        r[P], "= 0.72, P<0.01, df = 12")))
text(4.2,9.2,pos=4,cex=0.7,
     labels=expression(paste("IA/R  ",
        r[P], "= 0.42, P<0.05, df = 21")))
text(10,10, labels="(e)")
abline(0,1, lty=2)
abline(1.5,1, lty=3)
legend(8.1,5.2,legend=c("slope = 1","intercept  0","intercept +1.5"),
       lty=c(0,2,3),cex=0.6, bty="n")

plot(pδ13C~cδ13C,data=mean.cp, las=1,
     cex.axis=0.6,cex.lab=0.6,xlim=c(-23.5,-19),ylim=c(-23.5,-19),
     xlab=expression(paste("Cattle ", delta^{13}, "C \u2030")),
     ylab= expression(paste("Pig ", delta^{13}, "C \u2030")),
     pch=21,bg=per.cols[per])
text(-23.4,-19.1,pos=4,cex=0.7,
     labels=expression(paste("All periods ",
                             r[P], "= -0.55, P<0.001, df = 36")))
text(-23.4,-19.4,pos=4,cex=0.7,
     labels=expression(paste("N/BA  ",
                             r[P], "= -0.23, NS, df = 13")))
text(-23.4,-19.7,pos=4,cex=0.7,
     labels=expression(paste("IA/R  ",
                             r[P], "= -0.16, NS, df = 21")))
text(-19,-19, labels="(c)")
abline(0,1, lty=2)
abline(1.5,1, lty=3)
legend(-20.6,-22.5,legend=c("slope = 1","intercept  0","intercept
+1.5"),
       lty=c(0,2,3),cex=0.6, bty="n")

plot(pδ15N~cδ15N,data=mean.cp, las=1,
     cex.axis=0.6,cex.lab=0.6, xlim=c(4,10),ylim=c(4,10),
     xlab=expression(paste("Cattle ", delta^{15}, "N \u2030")),
     ylab= expression(paste("Pig ", delta^{15}, "N \u2030")),
     pch=21, bg=per.cols[per])
text(4.2,9.9,pos=4,cex=0.7,
```

```
     labels=expression(paste("All periods ",
                             r[P], "= 0.37, P<0.05, df = 36")))
text(4.2,9.55,pos=4,cex=0.7,
     labels=expression(paste("N/BA  ",
                             r[P], "= 0.28, NS, df = 13")))
text(4.2,9.2,pos=4,cex=0.7,
     labels=expression(paste("IA/R  ",
                             r[P], "= 0.53, P<0.01, df = 21")))
text(10,10, labels="(f)")
abline(0,1, lty=2)
abline(2,1, lty=3)
legend(8.1,5.2,legend=c("slope = 1","intercept  0","intercept +2"),
       lty=c(0,2,3),cex=0.6, bty="n")
```

Isotope values and models of agricultural change (Tables A3.14-16), shown for all species/$\delta^{13}C$ and cattle/ $\delta^{13}C$

```
#data
tvlam <- TVLamR
tvlam$per <- as.factor(tvlam$per)
tvlam$ph <- as.factor(tvlam$ph)
tvlam$reg <- as.factor(tvlam$reg)
str(tvlam)

require(lme4)
require(nlme)

###  regroup phase levels ####################

levels(tvlam$ph)
#[1] "9"  "10" "11" "12" "13" "14" "15" "16"
levels(tvlam$ph)<-list(i1=c("9","10","11"),
                       i2="12",r1=c("13","14"),r2=c("15","16"))
levels(tvlam$ph)
#[1] "i1" "i2" "r1" "r2"
tvlam$ph

c.tvlam <- subset(tvlam,sp=="Cattle")
s.tvlam <- subset(tvlam,sp=="Sheep")
p.tvlam <- subset(tvlam,sp=="Pig")

######################  δ13C  ####################

mod.lam1.c <- lmer(δ13C~sp+per+reg + (1|site),tvlam)
mod.lam2.c <- lmer(δ13C~sp+ph+reg + (1|site),tvlam)
mod.lam3.c <- lmer(δ13C~sp+per + (1|site),tvlam)
mod.lam4.c<- lmer(δ13C~sp+ph + (1|site),tvlam)
mod.lam5.c<- lmer(δ13C~sp+reg + (1|site),tvlam)
mod.lam6.c<- lmer(δ13C~sp + (1|site),tvlam)

summary(mod.lam1.c)
summary(mod.lam2.c)
summary(mod.lam3.c)
summary(mod.lam4.c)
summary(mod.lam5.c)
summary(mod.lam6.c)

anova(mod.lam1.c,mod.lam3.c,mod.lam6.c)
anova(mod.lam1.c,mod.lam5.c,mod.lam6.c)
anova(mod.lam2.c,mod.lam4.c,mod.lam6.c)
anova(mod.lam2.c,mod.lam5.c,mod.lam6.c)

summary(mod.lam2.cp <- lme(δ13C~sp+ph+reg, data=tvlam, random= ~
1|site))
```

```
## now by species  ######################################
## using lambrick phase, not per  ########################

c.tvlam <- subset(tvlam,sp=="Cattle")
s.tvlam <- subset(tvlam,sp=="Sheep")
p.tvlam <- subset(tvlam,sp=="Pig")

## Cattle
######################  δ13C  ###################

mod.c.lam1.c <- lmer(δ13C~ph+reg + (1|site),c.tvlam)
mod.c.lam2.c <- lmer(δ13C~ph + (1|site),c.tvlam)
mod.c.lam3.c <- lmer(δ13C~reg + (1|site),c.tvlam)

summary(mod.c.lam1.c)
summary(mod.c.lam2.c)
summary(mod.c.lam3.c)

anova(mod.c.lam1.c,mod.c.lam2.c)
anova(mod.c.lam1.c,mod.c.lam3.c)

## model summaries & significance (nlme)

summary(mod.c.lam1.cp <- lme(δ13C~ph+reg, data=c.tvlam, random= ~
1|site))
```

Model of expected faunal values (Table 7.1, Fig.7.3)

```
# base values as in Table 7.1

#1.Grazing + up to 50% woodland

plantδ13C<--26.6
cerealδ13C<-plantδ13C
legδ13C<-plantδ13C
wasteδ13C<-plantδ13C+3
woodδ13C<-plantδ13C-3
fungδ13C=plantδ13C+5

plantδ15N<- 2
cerealδ15N<-plantδ15N+2.1
legδ15N<-plantδ15N-1.7
wasteδ15N<-plantδ15N+6
woodδ15N<-plantδ15N
fungδ15N=plantδ15N+2


plantprot<- 0.1
cerealprot<-0.1
legprot<-0.1
wasteprot<-0.6
woodprot<-0.1
fungprot=0.3

cerealdiet<-0
legdiet<-0
wastediet<-0
wooddiet<-0
fungdiet=0
```

```
grzwoodδ13C <- rep(0,50)

for(i in 1:50){
  wooddiet <- wooddiet+0.01
  plantdiet <- 1-wooddiet
  dietmeanδ13C <- (plantdiet*plantδ13C)+(wooddiet*woodδ13C)
  collδ13C <- dietmeanδ13C+5
  grzwoodδ13C[i] <- collδ13C
}
wooddiet=0

grzwoodδ15N <- rep(0,50)

for(i in 0:50){
  wooddiet <- wooddiet+0.01
  plantdiet <- 1-wooddiet
  dietmeanδ15N <- (plantdiet*plantδ15N)+(wooddiet*woodδ15N)
  collδ15N <- dietmeanδ15N+4
  grzwoodδ15N[i] <- collδ15N
}
wooddiet=0

par(mar=c(4,5,4,2))
plot(grzwoodδ13C,grzwoodδ15N, col="darkgreen",
     xlim=c(-24,-20), ylim=c(5,8),
     xlab= expression(paste(delta^13,"C")),
     ylab=expression(paste(delta^15,"N")), las=1,
     main="Faunal collagen isotope values - model diets")

#2. Grazing + up to 50% cereals (crop residues etc, not grain)

grzcerealδ13C <- rep(0,50)

for(i in 1:50){
  cerealdiet <- cerealdiet+0.01
  plantdiet <- 1-cerealdiet
  dietmeanδ13C <- (plantdiet*plantδ13C)+(cerealdiet*cerealδ13C)
  collδ13C <- dietmeanδ13C+5
  grzcerealδ13C[i] <- collδ13C
}
cerealdiet<-0

grzcerealδ15N <- rep(0,50)

for(i in 0:50){
  cerealdiet <- cerealdiet+0.01
  plantdiet <- 1-cerealdiet
  dietmeanδ15N <- (plantdiet*plantδ15N)+(cerealdiet*cerealδ15N)
  collδ15N <- dietmeanδ15N+4
  grzcerealδ15N[i] <- collδ15N
}
cerealdiet<-0

points(grzcerealδ13C,grzcerealδ15N,col="orange")

#3.Grazing + up to 20% fungi

grzfungδ13C <- rep(1,40)

for(i in 1:40){
  fungdiet <- fungdiet+0.005
```

```
  plantdiet <- 1-fungdiet
  dietprot <- (plantdiet*plantprot)+(fungdiet*fungprot)
  dietmeanδ13C <- (plantdiet*plantδ13C)+(fungdiet*fungδ13C)
  protmeanδ13C <- (((plantdiet*plantprot)/dietprot)*plantδ13C)+
    (((fungdiet*fungprot)/dietprot)*fungδ13C)
  collδ13C <- (0.5*protmeanδ13C)+(0.5*dietmeanδ13C)+5
  grzfungδ13C[i] <- collδ13C
}
fungdiet=0

grzfungδ15N <- rep(1,40)

for(i in 1:40){
  fungdiet <- fungdiet+0.005
  plantdiet <- 1-fungdiet
  dietmeanδ15N <- (plantdiet*plantδ15N)+(fungdiet*fungδ15N)
  collδ15N <- dietmeanδ15N+4
  grzfungδ15N[i] <- collδ15N
}
fungdiet=0

points(grzfungδ13C,grzfungδ15N,col="grey20")

#4.Grazing + up to 30% waste
# adjusted for different DELs for plant & waste

grzwasteδ13C <- rep(1,40)

for(i in 1:40){
  wastediet <- wastediet+0.005
  plantdiet <- 1-wastediet
  dietprot <- (plantdiet*plantprot)+(wastediet*wasteprot)
  dietmeanδ13C <- (plantdiet*plantδ13C)+(wastediet*wasteδ13C)
  protmeanδ13C <- (((plantdiet*plantprot)/dietprot)*plantδ13C)+
    (((wastediet*wasteprot)/dietprot)*wasteδ13C)
  collδ13C <- ((0.5*protmeanδ13C)+(wastediet*1))+
    ((0.5*dietmeanδ13C)+(plantdiet*5))
    grzwasteδ13C[i] <- collδ13C
}
wastediet=0

grzwasteδ15N <- rep(1,40)

for(i in 1:40){
  wastediet <- wastediet+0.005
  plantdiet <- 1-wastediet
  dietmeanδ15N <- (plantdiet*plantδ15N)+(wastediet*wasteδ15N)
  collδ15N <- dietmeanδ15N+4
  grzwasteδ15N[i] <- collδ15N
}
wastediet=0

points(grzwasteδ13C,grzwasteδ15N,col="brown")

#4.Grazing + up to 50% legume

grzlegδ13C <- rep(1,20)

for(i in 1:20){
```

```
  legdiet <- legdiet+0.025
  plantdiet <- 1-legdiet
  dietmeanδ13C <- (plantdiet*plantδ13C)+(legdiet*legδ13C)
  collδ13C <- dietmeanδ13C+5
  grzlegδ13C[i] <- collδ13C
}
legdiet=0

grzlegδ15N <- rep(1,20)

for(i in 1:20){
  legdiet <- legdiet+0.025
  plantdiet <- 1-legdiet
  dietmeanδ15N <- (plantdiet*plantδ15N)+(legdiet*legδ15N)
  collδ15N <- dietmeanδ15N+4
  grzlegδ15N[i] <- collδ15N
}
legdiet=0

points(grzlegδ13C,grzlegδ15N,col="blue")
points(-21.6,6, pch=21,bg="black", cex=2)

legend(-24.1,8.1, legend="100% grazing",pch=19,
       col="black", bty="n")
legend(-24.1,7.9, legend=c("cereals 0-50%", "legumes 0-50%",
                   "woodland 0-50%","waste 0-20%",
                   "fungi 0-20%"), pch=21,
                   col=c("orange", "blue","darkgreen","brown",
                   "grey20"), bty="n", cex=0.8)

text(-22.9,5.8,labels="woodland", col="darkgreen")
text(-22,5.3,labels="legumes", col="blue")
text(-22,7,labels="cereals", col="orange")
text(-20.8,7,labels="waste", col="brown")
text(-20.8,5.9,labels="fungi", col="grey20")
```