Neolithic Anatolia and Central Europe: Disentangling Environmental Impacts from Diet Isotope Studies

Chelsea Budd

Keble College, Oxford

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ABSTRACT

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The aim of this thesis was to reconstruct dietary choices for Neolithic populations in Anatolia and Poland using stable isotope analysis, and to examine the extent to which local environmental factors in these regions affected the isotope values recorded from skeletal collagen. In total 278 new $\delta^{13}C$ and $\delta^{15}N$ values were obtained from human and animal bone collagen for this project (161 from the site of Osłonki 1, 59 from Barçin Höyük, and 58 from the site of Aktopraklık). From an environmental perspective, the multi-level statistical modelling highlighted a clear relationship with $\delta^{13}C$ and $\delta^{15}N$ and moisture availability, which was most evident through the proxy of mean annual precipitation (MAP). The modelling highlighted a 0.4‰ decrease in $\delta^{13}C$ for every 100mm decrease of MAP, and a 0.5‰ decrease in $\delta^{15}N$ for every 100mm decrease between sites.

The $\delta^{13}C$ and $\delta^{15}N$ values for the North-West Anatolian sites are the first dietary isotopic studies for the Neolithic period in the region. The values are largely commensurate with the dietary isotope studies from Neolithic sites located on the Central Anatolian plateau, with the caveat that the North-West sites perhaps had a greater reliance on herbivore protein (instead of plant protein) than their plateau counterparts. The dietary reconstruction of Osłonki 1 uncovered a rather unexpected outcome – namely that status exerted a degree of control over human diet. If this is indeed true it will be the earliest evidence in Europe of a distinct relationship between the socioeconomic status and diet of an individual.

Acknowledgements

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Chapter 1: Introduction and Aims

1.1 Introduction

The introduction of agricultural subsistence practices is oft cited as one of the key turning points in human history (Hodder 1990, Whittle 1996, 2003, Thomas 1999), but the secondary phase of farming strategies, how they evolved and how they changed from the initial transition to farming is understudied in the academic literature. Understanding the second phase of the development of farming is an essential aspect of understanding the development of modern human populations – the (almost) global manifestation of farming practices has lead to a radical modification of the environment, such as crop cultivation, deforestation, burning - these effects are still evident in the landscape today. The development of farming as the core subsistence method, and the subsequent presence of food surplus within agricultural societies ultimately allowed greater periods of time to be dedicated to activities that are tied into the 'social evolution' of human populations (such as the creation of portable and non-portable art, the rise of status, the increase of population size, and the development of centralized administrations and political systems). The social evolution of human populations therefore is arguably built on the introduction and consolidation of agricultural subsistence practices (Currie *et al.* 2015, Turchin *et al.* 2015).

The big question for this research area therefore is; 'how do farming practices evolve through time'?

To fully answer this question - to track the development of farming through time on global scale, is far beyond the feasible scope of this study. Therefore, this research project will focus on examining how farming evolved during the secondary phases of the Neolithic period in two distinct study regions. The select study regions have archaeological sites that contain multiple, continuous, and discrete phases of Neolithic occupation in evidence. This will focus the investigation of developing agricultural practices through time at sites that have fully-formed, second phase farming communities.

The main question for this project specifically is, 'how do farming practices evolve during the second phase of the Neolithic (in two distinct study regions)'? The precise investigation of subsistence strategies for this study will require the analysis and integration of fauna and plant assemblages (*indirect household/community indicators*; *after* Pearsall 2009:610), alongside carbon and nitrogen light stable isotope analysis of human (*direct individual indicators*; *after* Pearsall 2009:610) and fauna (*indirect household/community indicators*; *ibid*.) bone collagen.

The select study regions for this project have to fulfil a number of criteria; i) they must represent human populations in the secondary phase of their Neolithic period, ii) the sites must have discrete chronological phases of occupation to allow for the investigation of change, iii) the study regions must be historically independent from one another (e.g. one region did not directly affect the development of the other), and finally; iv) the sites must have a sufficient assemblage of human and faunal skeletal remains.

In light of the study criteria, the two regions that will form the basis of the research project are Anatolia (North-West region) and Poland (North-Central region). Anatolia (which shares the same approximate boundaries with modern day Turkey) is an ideal study location for this project. The North-West region of Anatolia (also referred to as the Marmara region) is often argued to be the 'frontier zone' for the transmission of agriculture from South-East Asia into South-East Europe and further into North-West Europe (Çakirlar 2013, Roodenberg 1995, Özdoğan 1999, 2011). The Neolithic sites within this area are assigned to the Fikirtepe group, a Neolithic culture largely defined by its lithic industries. However, two different Neolithic groups have been identified within the Neolithic cultures of the Marmara region, i) a coastal group characterised by round wattle daub structures, with extensive skeletal assemblages highlighting the distinct presence of aquatic resources at the sites alongside evidence for farming subsistence practices, and ii) an inland group characterized by rectangular architecture and subsistence economies based solely on agro-pastoralism. The presence of two distinctive groups has lead to a suggestion of a hybridization of Neolithic communities in the region, with the coastal groups representing the partial adoption of agricultural subsistence practices by indigenous groups in the Marmara, and the second group reflecting the immigration of fully formed farming populations originating from the Central Anatolian Plateau.

This project examines two sites from the second group; Aktopraklık (c.6400 – 5600 cal B.C.) and Barçin Höyük (c. 6600 – 6200 cal B.C.) (see section 1.4 and figure 1.1) as they clearly represent established, second stage farming communities. The study sites demonstrate discrete phases of occupation with the Neolithic period, alongside human and faunal skeletal assemblages, allowing the main research question 'how do farming practices evolve?' to be addressed. The sites of Aktopraklık and Barçin Höyük are also located in close proximity to both freshwater and marine resources (figure 1.1). The project will therefore test the hypothesis 'is there isotopic evidence to suggest the consumption of aquatic protein resources at the Anatolian study sites?' The absence of aquatic skeletal assemblages at the study sites would suggest a lack of aquatic protein consumption, but the close proximity of freshwater and marine resources, combined with the evidence for fish and shellfish protein consumption by coastal Neolithic communities, may suggest otherwise.

The second study region that will be examined as part of this project is North-Central Poland. This area of Poland, the Kujavia region, is home to the Brześć Kujawski Neolithic group (the GB-K group), a late variant of the Lengyel culture, which is synonymous with the appearance of the initial florescence of copper-using farming communities in South-East Europe (Bogucki *et al.* 2012). The GB-K group dates to *c.*4700 – 4100 cal B.C. and is representative of second stage farming in the region. Earlier evidence for farming communities in Kujavia, representing initial phase agriculture, dates to the Linearbandkeramik phase (5600 – 4900 cal B.C), and is evidenced by a number of sites in the region.

The study site chosen for this project is Osłonki 1, a large site located within the heart of the 'Osłonki' cluster (see section 1.4, Bogucki and Grygiel 1997). Three discrete phases of occupation are present at the site (Early, Classic, and Late) alongside a very extensive suite of human and faunal skeletal remains. These factors will allow the main research hypothesis to be tested. In addition, Osłonki 1 is in part characterised by the presence of elaborate copper artefacts in select burials at the site.

The consolidation of farming practices, and the increasing presence of food surplus, has the potential to lead a rise in social inequality and differential access to foods based on social status (Hayden 2001). This project will test the hypothesis ‘is there a correlation between burial status and human isotope values at Osłonki 1’? By addressing this hypothesis the study will examine the effects of social inequalities on access to food resources, as a result the project will be well placed to consider social evolution of human populations in its earlier phases.

Overall, it is evident that the two study regions are well suited to addressing the main research question, alongside testing two region-specific hypotheses; physical access to food resources, and social access to food resources. A number of research hypotheses are applicable to both of the study regions: i) ‘is there isotopic evidence to suggest a change in diet through time at the study sites?’ and ii) ‘is there isotopic evidence to suggest that adult males and females consumed different diets?’ By testing and combining the aforementioned hypotheses, the project will be able to address to the question, ‘does the geographical location of farming populations affect the development trajectory of farming subsistence approaches?’ The geographical disparity of the study regions results in markedly different conditions in climate and environment, with semi-arid climatic conditions present in North-West Anatolia, and North-Central Poland experiencing a temperate climate.

In addition to the nature of subsistence strategies, there is a growing body of work that investigates the impact of diverse climate conditions on carbon and nitrogen isotope values in human, faunal, and plant tissues (Farquhar, O’Leary and Berry 1982, Stuiver and Braziunas 1987,Ehleringer and Cooper 1988, Ehleringer and

Hubrick 1989, van Der Merwe and Medina 1989, Kelly and Finch 1998, Heaton 1999, Peuke *et al.* 2006, Murphy *et al.* 2007, Hidy *et al.* 2009, Brüggermann *et al.* 2011, Bonafini *et al.* 2013, Wallace *et al.* 2013). The research to date has highlighted that climatic disparity between sample sites can produce significantly different carbon and nitrogen values - and this difference is clearly evident in skeletal collagen (Murphy and Bowman 2007). The issue of climate impacts on carbon and nitrogen stable isotopes in ecosystems is a problem that arises for all palaeodietary isotopes studies, and not just research pertaining to the Neolithic period. This project will investigate, and endeavour to quantify, the effects of climate on diet isotope studies within the framework of the middle/late Neolithic period in Anatolia and Poland. The project will test the following hypothesis; 'is there a correlation between climate conditions and isotope values in faunal collagen at the study sites?'

This project provides an opportunity to move away from the existing focus on the Mesolithic-Neolithic transition and the earlier Neolithic period to investigate the character of dietary practices of Neolithic populations across the middle and later Neolithic periods, in two regions that are climatically distinct. It will examine the development of agriculture into the Neolithic period and assess how subsistence strategies evolved and evaluate whether there is any isotopic evidence to suggest a firm link between dietary choices and climate conditions in the study regions. The study also has wider implications, as one of its central aims is to provide practical, quantifiable, and useable information about the effects of climate on palaeodietary isotope studies.

1.2 Research Aims

The *first* core aim for this project is to examine how Neolithic dietary choice evolved in two very different regions (and hence lacking any direct historical connection) that are undergoing their 'secondary phase' of farming development. To recap, the study sites from the two regions are selected as they are from similar cultural time periods, but occupy very different environmental zones and have distinct climate constraints. The purpose of this selection is to identify whether dramatic differences in environment and climate had a direct effect (from a palaeodietary isotope perspective) on the dietary choices that human populations made during the 'middle' Neolithic period. For example, in the region of North-West Anatolia, where the hot climate conditions produce ideal environmental conditions for crop cultivation, is there any dietary isotopic evidence to suggest higher levels of plant protein consumption (vs. animal protein) when compared to the colder regional counterpart of Poland? Furthermore, is a difference in the biodiversity of the faunal assemblage observed at the study sites in the two regions?

Directly linked to the primary aim of this study is the *second* core aim, which is to investigate the direct effect of climate conditions on palaeodietary isotope data measured from faunal skeletal collagen. As noted above, the issue of the effects of climate on carbon and nitrogen isotope studies is well researched, with arid environments often producing more enriched values in plants than their temperate counterparts (Farquhar, O'Leary and Berry 1982, Ehleringer and Cooper 1988, Farquhar, Ehleringer and Hubrick 1989, Broadmeadow and Griffiths 1993, Murphy and Bowman 2009). This difference is the result of the rate of stomatal conductance (in plants) in carbon isotope values, and a reflection of the level of soil microbial activity in nitrogen isotopes.

1.3 The Study Sites

The sites that will form the core of this research project are Aktopraklık and Barçin Höyük, located in North West Anatolia, and Osłonki 1, located within the Kuyavia region of North-Central Poland. Figure 1.1 shows the location of the study sites, alongside latitude, topographical, and environmental data. The most notable contemporary archaeological sites located in the study regions are also highlighted on the map.

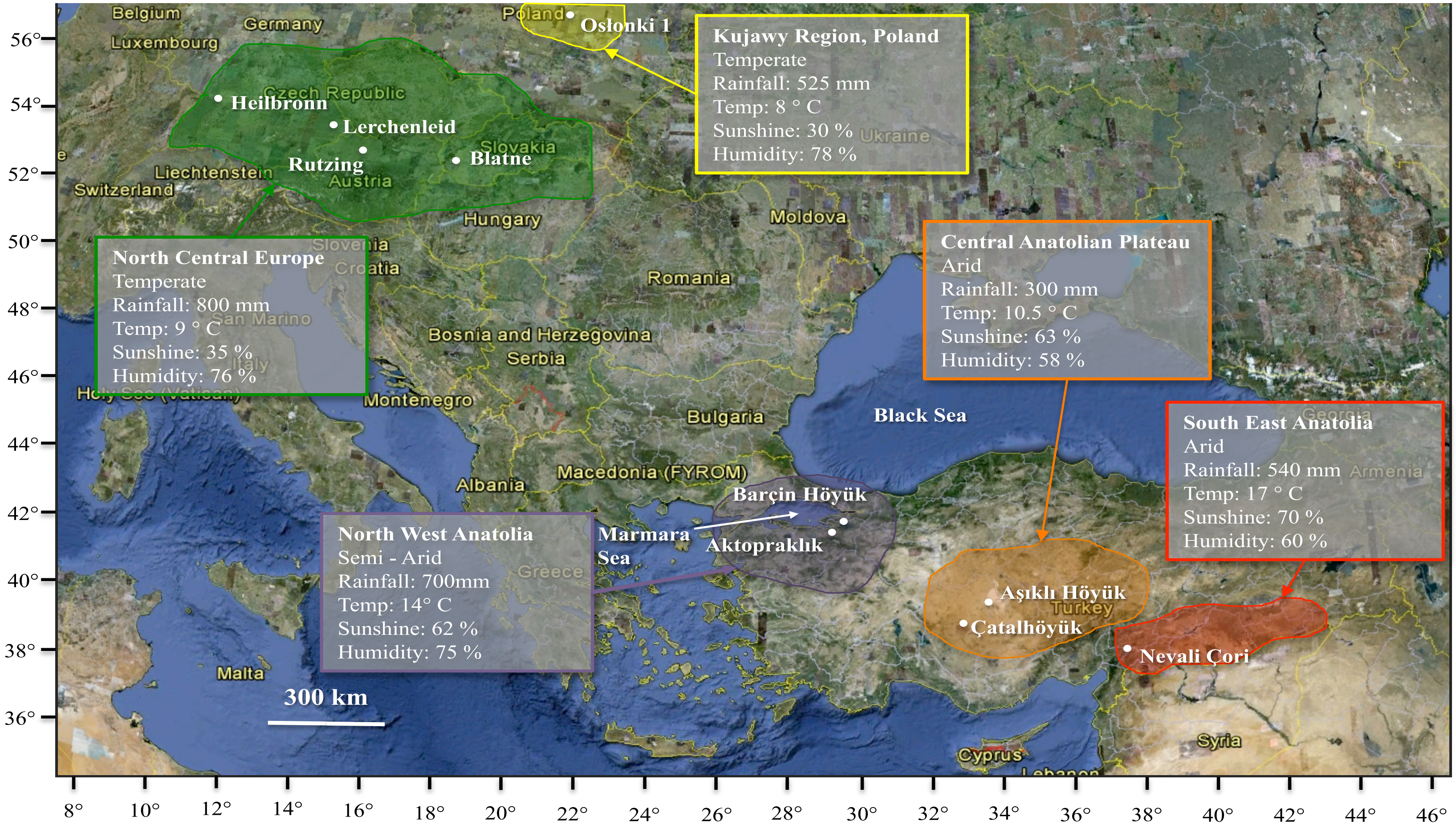

Figure 11 Location map of the study sites, and main sites mentioned in the text (modified from Google Earth).
Climate information: ‘rainfall’ represents mean annual precipitation, temperature is the annual average, sunshine is the percentage of sunlight hours per day (annual average) and humidity is the represents the daily average over a year. Further details are listed in chapter 5 (Data: AQUASTAT)

Whilst the sites are chronologically disparate, with the Anatolian sites dating to 7th to 6th millennia B.C, and the Polish site dating to 5th millennium B.C., they are all culturally representative of the same phases of the Neolithic period (e.g. middle to late phase) in their respective geographical regions.

1.1.1 North-West Anatolia

Aktopraklık and Barçin Höyük, both of which date to the 7th to 6th millennia B.C., are culturally aligned to the Fikirtepe culture in North-West Anatolia. These sites represent the settlements of small-scale, fully formed agricultural communities; the archaeological assemblages included pottery, discrete burials, and a full complement of the domesticates that are evident in the Marmara region (e.g. pig, sheep/goat, cattle, spelt, emmer, einkorn).

1.1.2 Poland

By contrast, the site of Osłonki 1 in northern Poland dates to the 5th millennium B.C., and is associated with the Lengyel culture of Poland. Osłonki 1 is a large-scale site that forms part of a cluster of farming sites known as the Brześć Kujawski Group (GB-K) in the Kuyavia region. The Lengyel culture was preceded by the late Linearbandkeramik culture in this region, although there appears to be something of a hiatus between both cultures as the post-LBK sites in this region are generally limited in extent when contrasted to those of the GB-K. The faunal assemblage from Osłonki 1 is extensive, and in general it appears to have the same compliment of domestic species as the Anatolian sites, thereby allowing for a comparison between the two regions in terms of the influence of environmental factors on the reconstruction of past dietary pathways.

However, it should be noted that the environments and climate of the study regions are substantially different. These factors, in addition to the broadly commensurate stages of economic development at the sites, make them ideal for comparative analysis.

1.2 Methods: Application and Justification

The methodology for the research project can be broadly divided into stable isotope analysis, radiocarbon dating, statistical analyses, and source partitioning models. A brief synopsis of these research methods is provided.

1.2.1 Light Stable Isotopes Analysis

Light stable isotopes have been used extensively in studies seeking to understand past human subsistence pathways. Carbon and nitrogen values ($\delta^{13}C$ and $\delta^{15}N$) from bone collagen samples largely reflect the protein component of *in vivo* diet, and the validity of using carbon and nitrogen relies on the assumption that the isotopes fractionate internally within a consumer in a consistent and predictable way. $\delta^{13}C$ and $\delta^{15}N$ values will be obtained from human and fauna (wild and domestic) bone collagen from the study sites, which reflects the average signal, albeit biased towards the protein component, of the diet for the last *c.* 10 years of life.

$\delta^{13}C$ and $\delta^{15}N$ values from human and fauna (wild and domestic) bone collagen will be obtained and examined in order to generate direct insights into the ways in which agro-pastoral subsistence strategies develop across the middle to later phases of the Neolithic in the study regions.

1.2.2 Radiocarbon Dating

Radiocarbon dating is a technique that measures the amount of radioactive carbon 14 in a (organic) sample, in order to determine its age. Carbon 14 is a weakly radioactive and unstable isotope, which is formed in the atmosphere as a result of interactions between cosmic rays and atmospheric nitrogen. It then combines with atmospheric oxygen to form carbon dioxide, which is used by plants for photosynthesis. If the plants are eaten by humans or fauna the carbon 14 is passed onto the consumer. When the plant or animal dies, it ceases to exchange carbon with the atmosphere – and carbon 14 decays in a consistent and predictable rate (its half life). The radiocarbon dating method measures the amount of carbon 14 in a sample to determine its chronological age. There are a number of limitations associated with the application of radiocarbon dating, such as the effects of fossil fuels, and these are detailed in chapter 7.

Radiocarbon dating is fundamental to studies of prehistoric diet in that an absolute chronological position is required if insights into the key research themes are to be generated. AMS dating of selected human and fauna samples will be undertaken in order to develop a baseline chronology for the sites studied. This information will subsequently inform the discussion of subsistence strategies at the sites studied, whilst also allowing the sites to be placed within their wider regional and national contexts.

1.2.3 Statistical Testing and Source Partition Modelling

Statistical testing will be undertaken for all of the isotope data in the thesis, beginning with linear regressions for the environmental data and basic significance testing for the palaeodietary data. The outcomes of these tests will help guide the selection of statistical techniques for further analyses (e.g. step-wise regressions). The purpose of the statistical testing is to look for meaningful patterns in the data, specifically for disentangling environmental signals from diet, to see if it is possible to pinpoint which environmental factors have the greatest impact on isotope values.

The source-partitioning model that will be tested as part of this thesis is SIAR – a package within the program R (Parnell *et al.* 2010). One of the major questions concerning Neolithic diet is; in what proportion did the human populations consume their resources, e.g. did plants constitute 70% of total protein and fauna 30%, or was it more of a 50/50 distribution? The source-partitioning model claims to be able to statistically allocate dietary proportions by using stable isotope values, Bayesian statistics, and dirichlet distributions. The project will compare the outputs of these models to other archaeological data (residue studies, mortality profiles of faunal assemblages etc.), to critique the models.

1.3 Materials Used in the Current Study

Samples of human skeletal material alongside both wild and domesticated fauna species are available for study from both Anatolia and Poland. A total sample set of 48 human (including 4 sub adults) and 25 domesticated and 4 wild fauna is available from the site of Aktopraklık. At Barçin Höyük, 26 human (including 8 sub adults) alongside 39 domestic fauna, and 3 wild fauna samples. Whilst at Osłonki 1, 30 human, 101 domesticated, and 30 wild fauna are available for stable isotope analysis.

1.3.1 Humans

Adult females, adult males, and sub-adults were analysed from the sites of Aktopraklık and Barçin Höyük. No sub-adults were analysed from Osłonki 1. Potential issues that are associated with the reconstruction of human diet using carbon and nitrogen isotope measurements from bone collagen include:

- The presence of nursing signals in sub-adult samples
- Differences in burial practices at the sites being studied, resulting in selection against certain individuals
- Variability in preservation of individuals within the demographic profile (*i.e.* very young and very old individuals can be poorly represented).

The biases highlighted above are frequently encountered in archaeological isotopic research (Walker *et al.* 1988, 1995, Schurr 1997, Pearson 1999, Finlay 2000, Balasse and Tresset 2002, Richards *et al.* 2002, Boric and Stefanovic 2004), and whilst it is usually possible to identify the presence of a nursing signal, the culturally imposed issue of differential burial and the taphonomic issue of differential preservation, whilst easily recognised, are not factors that can usually be corrected for in isotopic studies (Chapter 3).

1.3.2 Fauna

The majority of the fauna available from the Neolithic study sites is domesticated rather than wild and this is reflected in the sample sets. However, despite some limitations in terms of the number of wild fauna available for study, all available wild fauna species are analysed as part of the current research. The core faunal domesticates: sheep, goat, cattle, and pig are sampled from all sites. Potential issues with faunal isotopic dietary reconstruction include:

- Differences in habitat (domestic and wild) – e.g. pigs preferring woodland and the potential impact of canopy effects on carbon isotope values. In addition, as pigs are generalised browsers and can often be 'managed' with a minimum of effort, it is possible for essentially domesticated pigs to have a mixed browsing signal and be isotopically indistinguishable from their wild counterparts.
- Development of animal management strategies
- Different exploitation strategies employed between regions (and the subsequent identification of these exploitation strategies)
- Variability in management strategies applied between sites (and the definite identification of management strategies).

Again, these issues are relatively common in isotope studies in both archaeological and ecological research studies (Peterson and Fry 1987, Hobson *et al.* 1993, Vanderclift and Ponsard 2003, Fry 2007, Gannes *et al.* 2007), and as such some consideration of these factors is possible within the current research strategy.

1.3.3 Environmental Data

In the absence of usable palaeoenvironmental data for the study regions, modern climatic data is used (average values from 100 year period). Issues with environmental data include:

- The datasets are obtained from modern contexts

- The weather stations the datasets are obtained from are not located in the exact locations of the study sites.

The environmental factors that will be initially considered are evapotranspiration, temperature, mean annual precipitation, humidity, and sunlight hours. These factors have been selected after a detailed reading of the relevant literature, and additional environmental factors that are identified, and considered to be of potential significance, may also be integrated into the research study.

Whilst the use of modern climatic data in this study is clearly associated with a number of caveats, the basic information it provides will be useful in providing some general background for the study (see Hedges *et al.* 2013). The modern data will provide information about seasonality in the study regions, approximate MAP values (mean annual precipitation), temperature, etc. More importantly this data will allow for quantitative comparisons between the two regions and provide continuous data for statistical testing (rather than categorical). Assumptions of overall homogeneity of the climate for these regions will be investigated for evidence of climate change/variability. For example, research examining stable isotope records ($\delta^{18}O$ and $\delta^{13}C$) from a stalagmite in Sofular Cave (North West Anatolia), spanning a period of 50kyr, will be consulted for any indications of climate fluctuations pertinent to the temporal span of the sites being investigated (Fleitman *et al.* 2009).

1.4 Significance of the Research

It is anticipated that the current research will generate three key outcomes: i) new and important palaeodietary studies of two regions that are isotopically understudied; ii) an analysis of the extent of the environmental effects on isotope values in the study areas, and iii) an assessment of whether environmental effects influence the interpretation of the dietary isotope data (e.g. are observed isotopic differences the result of differences in diet, or differences in climate?).

1.5 Summary

The current research will examine the nature of dietary choice across the later Neolithic and Early Chalcolithic period in North West Anatolia and Poland through the analysis of light stable isotopes on human and fauna from archaeological sites in these regions. Radiocarbon dating and statistical analyses will be used to refine this dataset, and a consideration of environmental influences upon the isotope data will be used to compare and contrast the nature of subsistence across time and between regions. Given the surprising and considerable lack of research in these two study regions, the significance of the current study is readily apparent.

Chapter 2: The Environment and Archaeology of Anatolia and Central Europe

2.1 Introduction

The aim of this chapter is to review the archaeology of the study regions with particular reference to the evidence for changes in climate conditions and the archaeological evidence for palaeodiet. Section 2.2 highlights modern day climate conditions in Central and North-West Turkey and Poland, to provide a relevant environmental backdrop to the study regions. Section 2.3 reviews the evidence for human-landscape interactions during the Neolithic in Anatolia, with section 2.5 detailing the commensurate literature for Central Europe. The review of palaeodiet isotope studies from the regions is considered in chapter 3.

2.1.1 Definition Of The Study Area: Anatolia and Central Europe

Anatolia is defined as the peninsula that forms the western extremity of Asia. It is bounded to the North by the Black Sea, by the Mediterranean Sea to the South, and by the Aegean to the West. The area of Anatolia is approximately contiguous with the modern day Republic of Turkey (figure 2.1).

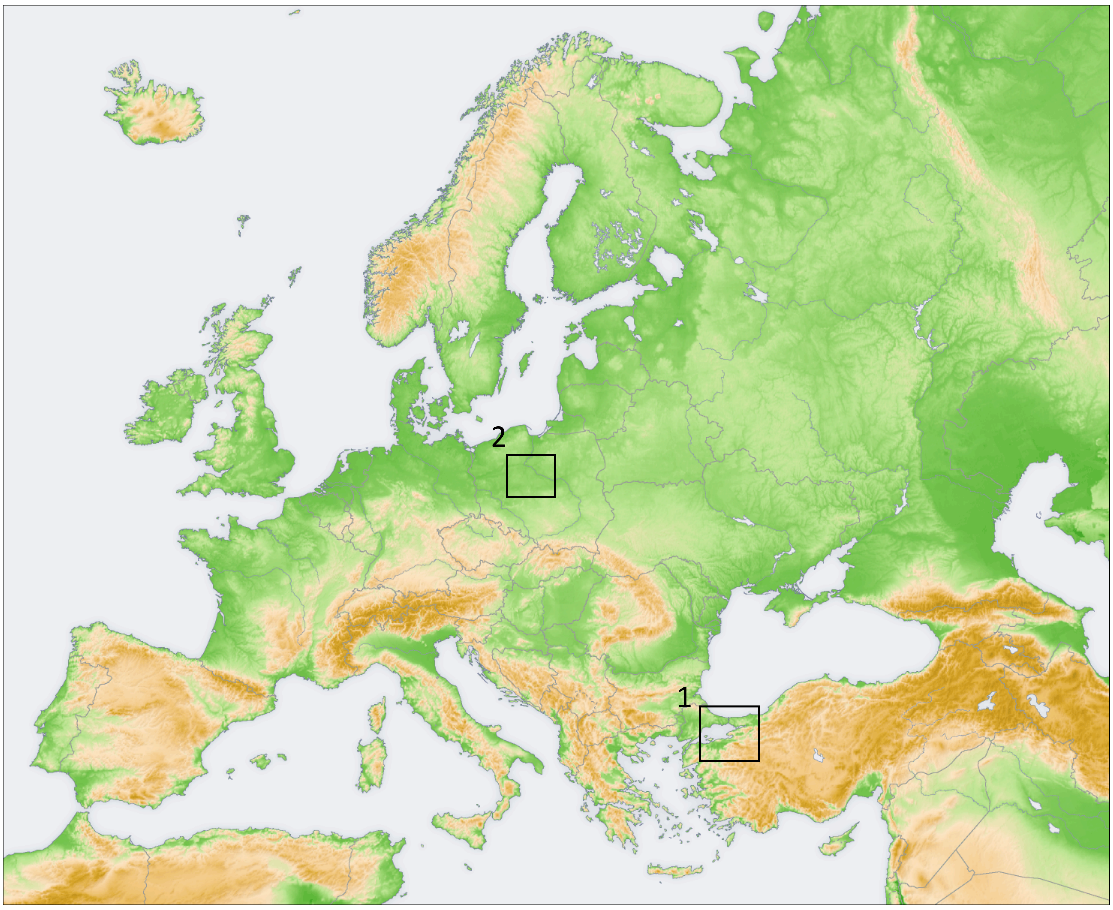

Figure 2.1: Location of the study regions.
Anatolia (1) and Central Europe (2) (upload.wikimedia.org).

The area that is defined as 'Central Europe' can vary considerably between academic research groups and national departments, and this variation largely reflects different political motivations (Johnson 1996, Leibenz Institute for Regional Geography 2011, UN 2013). For the purposes of this project, the area of Central Europe is defined as including the modern day territories of Poland, Austria, the Czech Republic, Germany, Hungary, Lichtenstein, Slovakia, Slovenia and Switzerland.

2.1.2 *The Transition to Agriculture: Near East to Europe*

The nature of the expansion of agriculture westwards from South-East Asia to Europe is an intensely debated topic (Hodder 1990, Whittle 1996, 2003, Thomas

1999, Bailey *et al*. 2005, Özdoğan 2011, Fuller *et al.* 2012, Düring 2013). There are a number of facets that frame the discussion, with chronology, the development of social trajectories, and the composition and nature of the economy receiving the greatest amount of attention. It is the development of economies, specifically whether food extraction or food production economies were being followed, which forms the mainstay of this study. One of the main study regions, the Marmara Region of Western Turkey, is identified as a crucial area for understanding the Neolithization process (Roodenberg 1995, Őzdoğan 1999), as Marmara, at the juncture of Anatolia, forms a bottleneck between the East and the frontiers of the Aegean and the Balkan expanse.

2.1.3 Origins of Domestic Flora and Fauna

Broadly speaking, the main cultivated plant remains recovered from the study regions (Anatolia and Europe) are cereals (emmer and einkorn), legumes (peas and lentils), oil/fibre plants (e.g. flax), and to a lesser extent barley (naked and hulled), millet and oats (Bottema and Woldring 1994, Fairbairn *et al.* 2002, Bogaard 2004, Kreuz 2005, Rosen 2005). The domestication of plant species is a little more complex than their faunal counterparts, and considerable research has been dedicated to examining morphological developments and DNA fingerprinting of the core domesticates and their wild progenitors (Heun *et al.* 1997, Badr *et al.* 2000). Domesticated barley (*Hordeum vulgare.*L) for example, is one of the original founder crops of agriculture in the Near East. Archaeological remains of barley grains have been recovered from various sites in the Fertile Crescent. Domesticated barley was first cultivated at approximately *c.* 8,000 cal BC (at what site) and it has been shown to be morphologically similar to its progenitor species (*Hordeum spontaneum*

C.Koch), but with the domesticated species exhibiting slightly broader leaves and larger grains (Diamond 1988, Zohary and Hopf 1993, Nesbitt and Samuel 1996). The benefits of the morphological changes of barley are obvious – broader leaves allow the plant to cope more efficiently in its original arid habitat of the Near East, and the larger grain sizes equate to a higher crop yield.

An examination of the literature highlights similar research syntheses for wheat (Heun *et al.* 1997, Özkan *et al.* 2002, Salamini *et al.* 2002, Tanno and Wilcox 2006), legumes (Zohary 1973, Webb and Hawtin 1981, Graham and Vance 2003, Alo *et al.* 2011), and fibrous plants (Rapp *et al.* 2010, Paterson *et al.* 2012, Rech *et al.* 2013).

In terms of faunal species, goat is widely regarded as the first animal species to be domesticated (Makarewicz and Tuross 2012). This is not surprising as goats are desirable livestock for animal husbandry for a number of reasons; i) they have generalized feeding habits, ii) flexible water requirements, iii) they generate relatively high yields of milk and meat, and iv) they can produce high yields even under suboptimal conditions, and v) natural sociability and (for sheep) herd instinct (van Soest 1982, McGregor 1986).

The origins of domesticated goat and sheep are quite securely tied to the Near East, as there are no native progenitors in Europe. The domestication of the wild progenitor of domestic goats, *Capra aegagrus* (Bezoar goat), took place at around 8,000 cal BC. Recent DNA research has highlighted multiple mitochondrial lineages for this species. The DNA research, alongside the archaeological evidence, suggests that goat was domesticated in a number of centres, including the Zagros mountains

(Iran), the Taurus mountains and southern Levant (Hesse 1984, Horrowitz *et al.* 1999, Vigne *et al.* 2000, Zeder and Hesse 2000, Luikart *et al.* 2001, Fernández *et al.* 2006, Makarewicz and Tuross 2012). The domestication of sheep, *Ovis orientalis* (Asiatic mouflon), most likely took place soon after this, although there is less published literature to support this (Chessa *et al.* 2009, Rocha *et al.* 2011).

The domestication of cattle, *Bos primigenus*, took place around 6,500 cal BC, and as with goat, the genetic evidence points to a number of centres of domestication within the Near East (Edwards *et al.* 2007, Bollongino *et al.* 2012, McTavish *et al.* 2013). The archaeological and genetic data pertaining to the study of taurine cattle suggest that the species were first domesticated from local wild auroch in the Near East. Recent research by Bollongino *et al.* (2012) into the mtDNA of 15 Neolithic to Iron Age samples originating from several sites in Iran, has also suggested that the initial domestication took place in a restricted area (geographically speaking), suggesting that the process was constrained by the difficulty of sustained managing and breeding of the wild progenitors of domestic cattle.

The origin of the domestic pig is more complex. Overall the archaeological and genetic evidence suggests that the earliest European pigs originate from Near Eastern progenitors, and that this domestication took place at around 7,000 cal BC (Dobney and Larson 2006, Larson *et al.* 2007). At around 4,000 – 3,500 cal BC the genetic research shows evidence for interbreeding between Near East domestic pigs and European wild boar species – the outcome of this is that modern European pig DNA is not largely commensurate with Near Eastern pig DNA.

2.2 Climate Conditions in Anatolia and Poland

2.2.1 Environmental Conditions in Anatolia

The climate in Turkey is highly variable between regions, probably due to the fact that it is located in both Europe and Asia. The different climate zones can be approximately divided into five regions; the North Coast, the North-West (Marmara), the Central Plateau, the South Coast and the East Regions (see table 2.1).

The information regarding the environmental parameters for the study regions is obtained using AQUASTAT, which is a global water information system that has been commissioned by the 'Food and Agriculture Organization of the United Nations' (http://www.fao.org/nr/water/aquastat/gis/index3.stm). This project will utilise the Climate Information Tool that provides a spatial data set containing mean monthly climate data. The data-set covers the global land surface at a 10 minute spatial resolution for the period 1961-1990. The data originates from CRU CL 2.0 data set, details of which can be found in New *et al.* (2002). The climatic information tool calculates an overview of climatic conditions based on co-ordinates of a site location.

The factors that control climate conditions in Turkey are the distribution of mountain ranges (as mountains are natural barriers to air movement) and proximity to the sea (as coastal areas can receive different air temperatures depending upon sea breezes etc.). Table 2.1 provides an overview of climate conditions in modern Turkey. The values presented are the averages for the last 40 years (with 2012 being the most recent year of collection).

Region	Climate Conditions	Average temp (°C)	Annual Rain (mm)	Altitude (m)	Biome [Holdridge[1] Classification]
North Coast [Black Sea, Mediterranean]	Hot summers, mild winters, no dry season, high rainfall	14.3	731	4	Cool temperate moist forest biome
North-West (Marmara)	Hot summers, mild winters, moderate-high rainfall	14.1	439	40	Warm temperate dry forest biome
Central Plateau [Interior]	Severe winters & hot, dry summers	11.8	362	902	Cool temperate steppe biome
South Coast [Aegean/Mediterranean]	Dry hot summers and moderate seasonality	18.9	1028	50	Subtropical dry forest biome
East Region	Very cold winters, no dry season, cool short summers	17.4	359	390	Cool temperate steppe

Table 2.1 Overview of the climate conditions of Turkey.
Divided by region (Holdridge (1967). Sources: AQUASTAT, Bottema and Woldring 1995, Sagona and Zimansky 2006).

If we focus on the main two study regions of North-West Anatolia (Aktopraklık and Barçin Höyük) and the Central Plateau (Çatalhöyük) a number of differences are apparent. The severe climate conditions (severe winters, lower rainfall) of the Central Plateau are distinct from the milder climate regimes operating in the North-West. There is a distinct difference in annual average temperature and a slight difference in annual precipitation. The difference in climate conditions between the two regions is largely the result of the difference in altitude between them - the mountain expanse in the North of the Central Plateau prevents the milder climate from expanding further inland from the North Coast. The North-West region is not without its mountainous areas, reaching altitudes of approximately 800m, but all of the Neolithic sites in this zone have been uncovered in the lowlands of the Marmara region. Figure 2.2 illustrates the monthly variation in temperature and rainfall of Çatalhöyük (on the Central Plateau) and Aktopraklık and Barçin Höyük (North-West region).

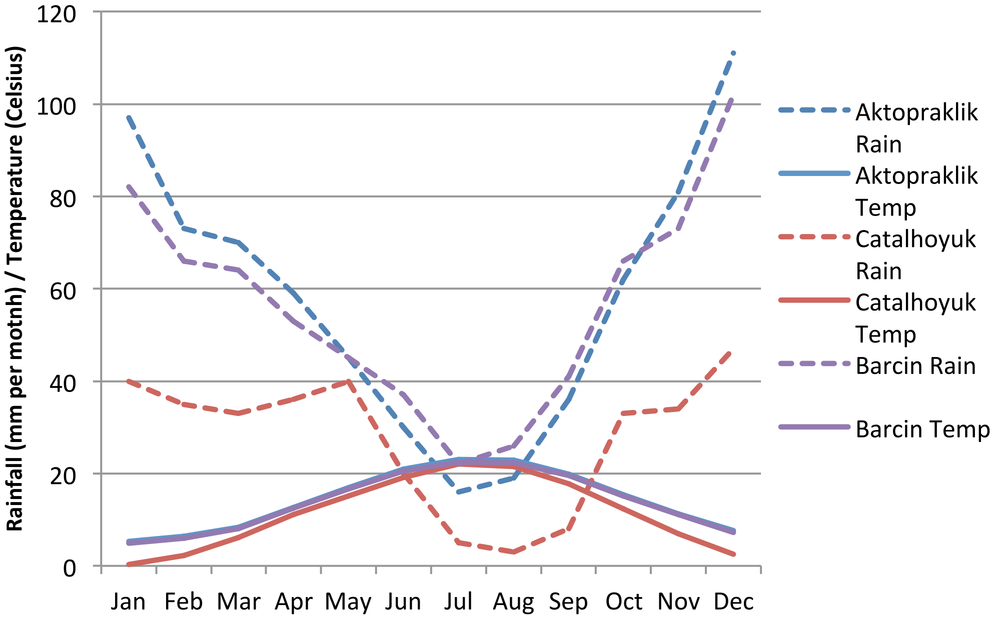

Figure 2.2 Monthly values for temperature and rainfall from modern day Aktopraklık, Barçin Höyük, and Çatalhöyük.
Aktopraklık rainfall is underneath Barçin Höyük rainfall. Data is average the value per month for the period 1961-1990 (Source: AQUASTAT).

The monthly variation recorded at the three locations are very similar to one another, demonstrating the same temperature peak in the summer months of May- September, and a corresponding drop in MAP (mean annual precipitation) during this period. Perhaps the most pronounced difference between the two regions is the monthly variation in rainfall level, with the Central Anatolian Plateau receiving less precipitation overall than its North-West region counterpart.

The temperatures in the two study regions display a Gaussian distribution, in that the highest temperatures are recorded during the summer period (May-September). These differences are important as both regions have summer growing seasons.

Growing seasons are defined as the portion of the year where the temperature of the soil at 50 cm below the surface is higher than biological zero (5.0°C) (US Department of Agriculture - Soil Conservation Science 1985). Malone and Williams (2010) state that this approximately equates with the number of frost-free days an area receives in a year. The growing season for the Central Plateau is May to September, with a slightly longer season of May to November in the North-West region (based on data from AQUASTAT).

Up to this point we have considered small changes in climate, at annual and monthly scales, but it is important to consider how the climate has changed over a much longer timescales. Fleitman *et al.* (2009) undertook $\delta^{13}C$ and $\delta^{18}O$ analysis of a stalagmite from Sofular Cave in North-West Turkey, providing information of the timing and climate impact of Greenland interstadials over a 50kyr period. The stalagmite reveals a rapid and sensitive ecosystem response to changes in climate. Between 50.3kyr to 14.6kyr the average $\delta^{13}C$ value from the stalagmite is -8‰. This value reflects the predominance of C_4 plants, alongside lower plant density and soil microbial activity due to hotter and drier climatic conditions (Fleitmann *et al.* 2009). The stalagmite data agrees with the pollen data from the area, which suggest large expansions of steppe areas. Post 14.6kyr $\delta^{13}C$ values become more depleted, and reveal a greater proportion of C_3 plants, alongside higher soil productivity (from TOC) due to increasing temperatures and effective moisture. In addition, this chronological period is characterized by 1-3‰ $\delta^{13}C$ shifts within a few decades to a number of centuries. This shift in $\delta^{13}C$ is promising as it demonstrates that the climate is having an effect on plant carbon isotope ratios in the area and that small changes in climate at a local scale in the North-West region are evident. The study by

Fleitmann *et al.* (2009) covers the last 50kyr, and as such covers the time period of the Neolithic sites used for this study (e.g. Aktopraklık and Barçin) in the Marmara region.

Extensive research has also been undertaken in the East Marmara region, e.g. specifically focused on Lakes Iznik and Lake Uluabat. Ülgen *et al.* (2012) examined the magnetic susceptibility, geochemistry, mineralogy and palynology of Lake Iznik sediments. The research uncovered a sequence which points to an oscillating trend of humid periods interrupted by rapid climate changes to aridity, particularly at 4.2kyr BP and 3.3kyr BP. The earlier period, 4.2kyr BP ties in with the Later Chalcolithic period in at the study sites, Aktopraklık and Barçin.

Kanzanci *et al.* (2004) investigated the rates of lake sedimentation at Lake Ulubat (and Lake Manyas, also in the region), and found evidence for high rates of sedimentation post 2kyr BP which they attributed to increased deforestation as the result of the intensification of agricultural practices.

Two further environmental aspects that will be compared to the isotope values are humidity and sunlight (figure 2.3). Humidity refers to the percentage of water vapour in the atmosphere and is approximately commensurate to the ‘water availability’ present in the atmosphere. Sunshine is highlighted as a percentage of day length.

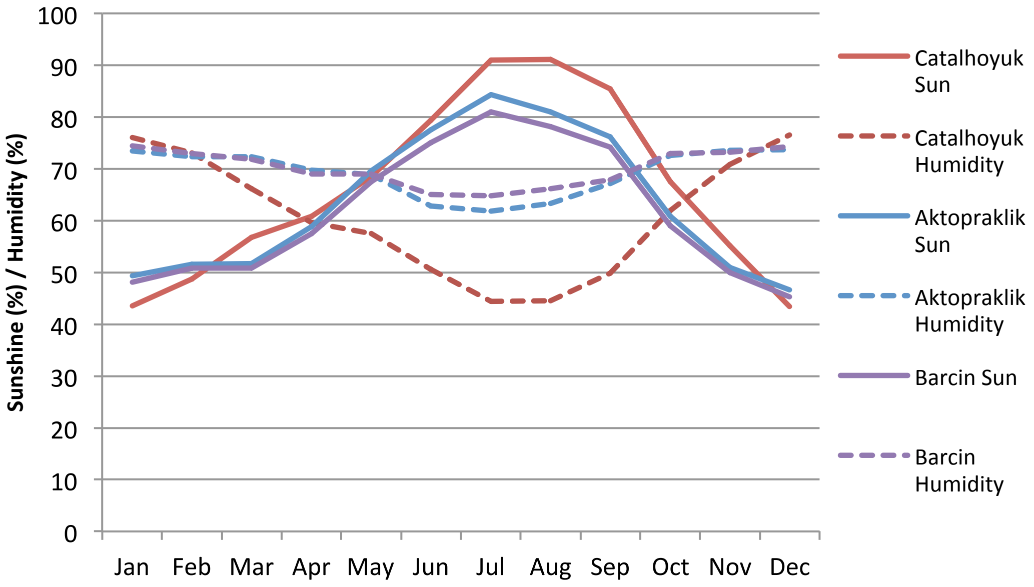

Figure 2.3 Monthly values for sunshine (% of daytime hours) and humidity (% water vapour) from modern day Aktopraklık, Barçin Höyük and Çatalhöyük.
Data is average the value per month for the period 1961-1990 (Source: AQUASTAT).

It is evident from the graph the that there is some variation in sunlight hours between the weather stations at Ankara and Istanbul, the most pronounced difference is evident during May to October. The difference in humidity levels between Ankara and Istanbul is considerable, exhibiting an 80% difference in humidity level between the stations during the month of January. Humidity and sunlight levels are selected as environmental parametres for this study, as they affect stomatal discrimination in plants (Δ), and this ultimately impacts on the ^{13}C‰ values. Carbon isotope discrimination (Δ) differs from δ^{13}C in that it describes only that change in isotopic composition induced by the plant, and this eliminates variation as a result of the starting value of atmospheric CO_2, which is used for photosynthesis (Farquar and Richards 1984, Farquar *et al.* 1982).

In summary, at Ankara (Central Anatolia) the humidity levels are considerably higher than in Istanbul, and as such we would expect to see lower δ^{13}C values in plant tissue than at Istanbul, where the moisture availability is lower. Ankara also receives more sunlight than Istanbul, and in environments with greater light intensity we would again expect to see higher $\delta^{13}C$ values. However, the difference observed between the two weather stations for sunlight is only 7 hours over the whole year, and the difference in sunlight hours during the planting/growing season is minimal, which would suggest that no temperature-related difference in $\delta^{13}C$ values should be observed.

2.2.2 Environmental Conditions in Poland

The variability of climate in Poland and Central Europe is commensurate with the conditions that are observed in Anatolia. The climate in present-day mid-northern Poland (the Kuyavian plain) is characterized by humid continental conditions. It is located at an altitude of 105m above sea level and is subject to severe winters. It has no dry seasons, and experiences warm seasons and strong seasonality. It has an average temperature of 7.7°C and an annual precipitation of 471mm. It is classified as a cool temperate steppe biome (AquaStat) Figure 2.4 highlights the monthly variation in temperature and rainfall, and figure 2.5 highlights the variation in humidity and sunlight hours.

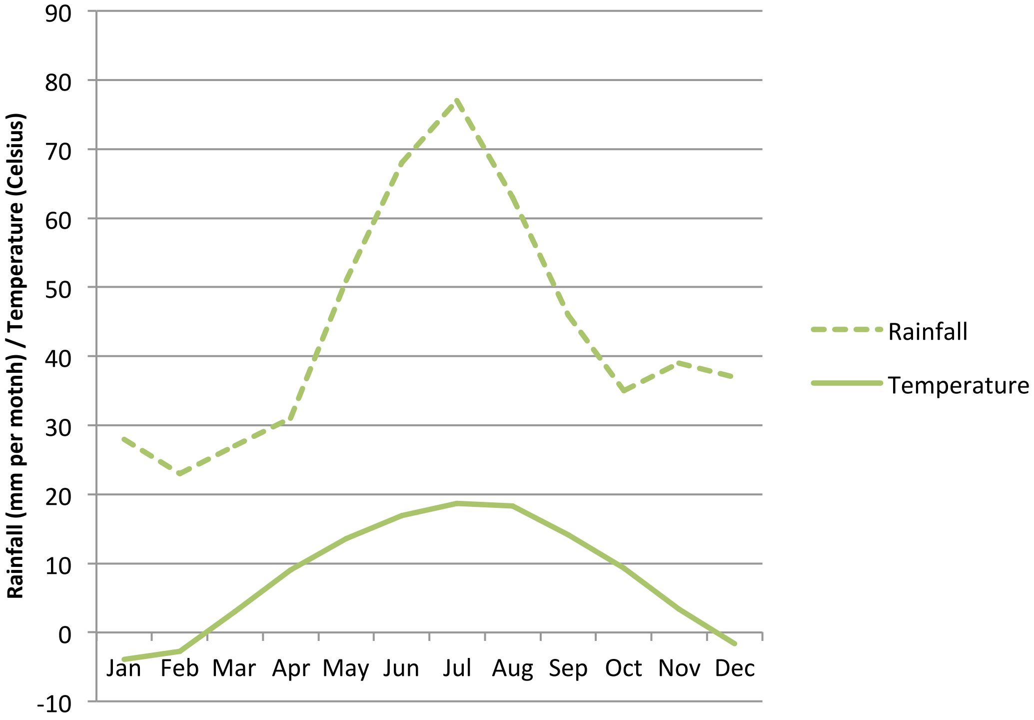

Figure 2.4 Temperature and rainfall from Osłonki 1.
(Source: AQUASTAT).

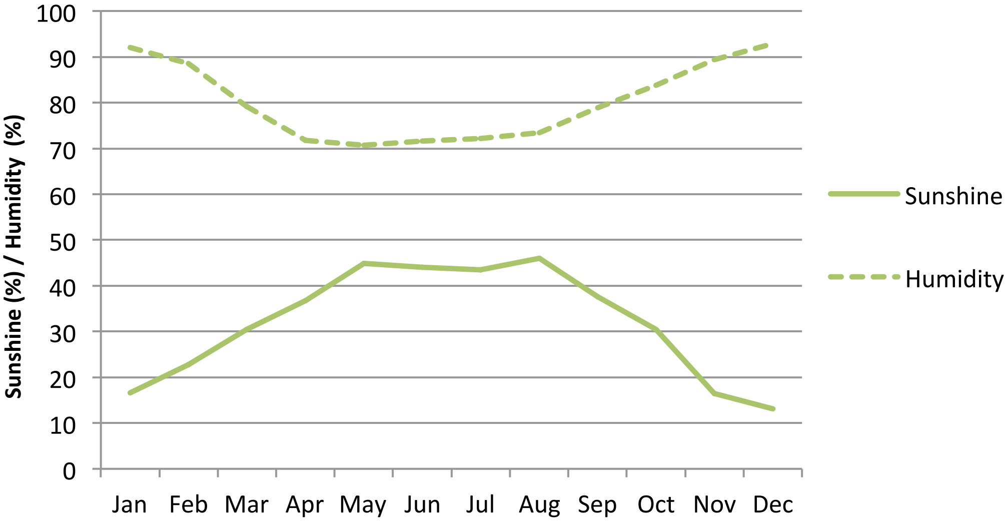

Figure 2.5 Humidity and Sunlight hours (average per day) for Warsaw.
(Source: AQUASTAT).

The main factors that are evident from figures 2.4 and 2.5 are that that Poland receives high levels of rainfall and high humidity levels, particularly in the summer months, when compared to Central and North-West Anatolia. The net result of these climate conditions is that δ^{13}C values should be more depleted in temperate Poland, as there is plenty of moisture available for stomatal conductance.

The study period in Poland dates to a stable plateau of interglacial climatic conditions (between the 8.2kyr event and the Little Ice Age). Research undertaken by Monaghan (2011) on ^{13}C and ^{18}O values from stalagmites in Niedźwiedzia Cave, southern Poland to reconstruct palaeoclimate. The ^{13}C and ^{18}O values highlight events that have been recorded elsewhere, including the rapid warming of a Dansgaard-Oeschger event at 110-15kyr, the shift to warm moist conditions during the Bølling-Allerød at 14.7 to 12.6kyr, an abrupt return to near glacial conditions at the Younger Dryas (12.8-11.5kyr), the '8.2kyr' event which sees a sudden global decrease in temperatures for approximately 2-4 centuries. After this point, there is a stable return to warm moist conditions until the Medieval period (AD1350), at which point it is punctuated by the Little Ice Age (Monaghan 2011). Overall, if we compare the Polish and Anatolian study regions, the temperature gradients follow the same Gaussian distribution. The monthly variation in rainfall, as noted previously, is commensurate to the Anatolian study region. Figure 2.6 displays the monthly precipitation levels for Aktopraklık, Barçin Höyük, Çatalhöyük, and Osłonki 1.

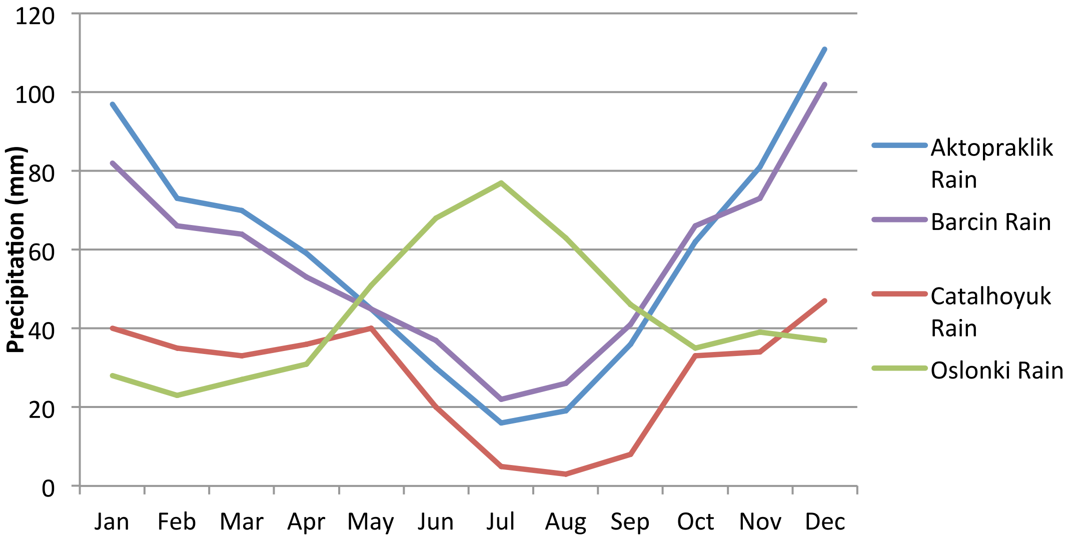

Figure 2.6 Monthly rainfall (mm) variations for Aktopraklık, Barçin Höyük, Çatalhöyük and Osłonki 1.
(Source: AQUASTAT).

The humidity levels (not shown) in Central Anatolia, despite their significant monthly fluctuations, are more similar to Poland than to the levels recorded in North-West Anatolia.

2.3 Human-Landscape Interactions during the Neolithic in Anatolia

2.3.1 Key Research Themes of Neolithic Anatolia

The onset of Neolithisation from its core beginnings in South-West Asia into Europe is intensely debated (Lichter and Meriç 2005, Gatsov and Schwarzberg 2006, Colledge and Connolly 2007, Özdoğan and Basgelen 2007, Krauβ 2011). To date, the absolute chronological frameworks for the westward expansion of the Neolithic are well studied (Boyadzhiev 2006, Reingruber and Thissen 2009, Brami and Heyd 2011, Özdoğan 2011a), but the agents of change which drive this transition, the social and economic transformations, are less well understood due to a distinct lack of archaeological evidence in the critical regions between South-East Europe and South-East Asia (Çakirlar 2013). The Anatolian study region, that forms the basis for this part of the project, is often referred to as the ‘frontier zone’ for the transition of agriculture into South-East Europe. It is located around the Sea of Marmara, at the landscape confluence of the Balkans and the Aegean (Roodenberg 1995, Özdoğan 1999, 2011).

Gatsov and Özdoğan (1994) undertook a range of surface surveys in the Marmara area, revealing a number of Mesolithic sites (referred to as the Ağaçli group) distributed along the coasts of the Bosporus. Extensive excavation work has been undertaken on six of the 26 Neolithic sites that have been uncovered in the region. These are referred to as the Fikirtepe cultural group, after the type site for this group, and two of these sites Aktopraklık and Barçin Höyük, form the basis for the Anatolian study sites for this project (Harmankaya 1983, Özdoğan 1983, 1999, 2003, Kiziltan 2007, Roodenberg and Alpaslan-Roodenberg 2008, Gerritsen and Ozbal 2011). A number of scholars have proposed cultural affinities between the Mesolithic and Neolithic populations, based on similarities between lithics, site locations and other material culture traits contemporaneity. For example, Mesolithic and Neolithic sites located on sea and coast shores share a microlithic toolkit, which is thought to have its genesis in 7th BC (Çakirlar 2013).

In contrast, a number of researchers have highlighted similarities between Neolithic sites in the Marmara region and Neolithic sites located on the Central Anatolian Plateau, and further East (Düring 2011, Özdoğan 2011, Çilingiroğlu 2012). Clear typological similarities exist between the North-West region and the Central Plateau in the form of material culture artefacts such as bone spatulas, bone polishers, chipped disks, female figurines (although these are rare), “offering tables” and red slip-ware pottery (Çilingiroğlu 2005:8). The overarching view of the academic narrative is that if these artefacts did not exist in the North-West region during the Mesolithic period, then they must be the result of knowledge transfer from the Central Plateau and areas further East.

Özdoğan (2011) has identified two groups within the Neolithic cultures of the Marmara region; i) a coastal group defined by its round architecture, flexed and cremated burials, shellfish gathering and fishing, alongside farming, and ii) an inland group characterized by rectangular architecture, flexed inhumations, and subsistence economies focusing exclusively on farming. This distinct division has led to the conclusion that the 'round-house' sub-group represents the adoption of Neolithic way of life by indigenous populations, and, conversely, that the rectilinear group represents the immigration of Neolithic groups from the Central Plateau into the Marmara region.

Çakirlar (2013) states that this model has affinities with Zvelebil's (1986) forager-farmer economies of Europe (e.g. a gradual transition from Mesolithic systems to production economies), but also highlights that the situation in the Marmara region can be considered fusionist (rather than the simple diffusion/anti-diffusion models which are sometimes applied to explain Neolithisation)(e.g Zvelebil 1986).

Anatolia is an important region when considering the transmission of agricultural knowledge from the Levant through to South-East Europe and into the Balkans. Özdoğan (2007) highlights the fact that a main focus of debate has been whether Anatolia was a barrier or a conduit to agricultural dispersals (see also Greaves 2007).

The identification of a number of earlier Neolithic sites, e.g. Hacılar, Çatalhöyük, Can Hasan, Süberde and Erbaba on the Anatolian plateau, and an enhanced resolution afforded by ^{14}C dating, has shown that early farming sites in the South-Eastern regions of the Central Anatolian basin are broadly contemporaneous with those in the Fertile Cresent (Özdoğan and Başgelen 2007), although the northern and western limits of the core area of Neolithisation remain to be defined. Özdoğan identifies an interim zone, wherein the transmission of agriculture (and the Neolithic package) from the primary zone of Neolithisation does not occur before the end of the seventh millennium BC. This interim zone is defined as covering all of the western parts of Anatolia, the Aegean, the Marmara region and most of the Balkans (Özdoğan 2008:143).

2.3.2 Ecology in Central and North-West Anatolia

This section deals mainly with the reconstruction of flora species in the study regions of the Central Plateau and the North-West region of Anatolia. Anatolia is largely characterized by distinct ecological fluctuation between areas, which leads to geographic variation in floral species (e.g. Central, North-West, East) (Hütteroth 1982, Alex 1985, van Zeist and Bottema 1991). Catalhöyük and Asikli Hoyuk are the comparative study sites for Central Anatolia.

Çatalhöyük is located on the Konya Plain, which is part of a former lake basin that extended to 4200km^2 in area. During the Pleistocene the lake was fully formed, but fluctuating environmental conditions at the onset of the Holocene led to the lake to transform into a residual marshland area. It was at this point, on the alluvial fans, that the site of Çatalhöyük was initially founded. Çatalhöyük was located in an open marshland environment with occasional woodland stands of hygrophilous arboreal species, such as *Populus* (poplars), *Salix*-Salicaceae (willows), *Fraxinus* (ash) and *Tamarix* (tamarisk). These species occurred alongside other vegetation groups, e.g. woody climbers such as *Clematis* tend to form riparian gallery forests on alluvial flats, and species such as *Platanis* (plane) trees and *Ulmus* (elm) generally occur on better drained localities towards the margins of the Konya plain (Asouti and Hather 2001). The dry sand ridges that littered the site would have been home to dryland taxa (such as *Vitex* (chaste trees) and *Capparis* (cappers), and on the hill slopes around the site, the wetter environments of the lowlying areas gave way to open park woodland (which could have been exploited for structural timber) (Asouti and Hather 2001, Fairbairn *et al.* 2002, Roberts and Rosen 2009). Charred botanical evidence from Çatalhöyük of plant species associated with deluge events suggests that during the Neolithic periods of occupation the site was subject to a number of seasonal flooding events (Roberts *et al.* 1996, 1999, Fairbairn *et al.* 2002). This once led a number of researchers to suggest the possibility of flood plain agriculture (Sherratt 1980, van Andel and Runnels 1995), although this interpretation has since fallen out of favour in the academic narrative.

Asikli Höyük is located next to the Melendiz River approximately 25 km east of the modern city of Aksaray on the western fringe of Cappadocia (Esin and Harmankaya, 1999, Pearson *et al.* 2007). The area around the site is a mosaic of volcanic plateau, riparian woodland and valleys, not dissimilar to the Konya Plain but without the open marshland environments. The academic research concerning the natural environments that surround Asikli Hoyuk (e.g. studies that are not aimed at reconstructing “food” plants) are less prevalent in the literature than the Çatalhöyük counterparts.

2.3.3 Pollen and Vegetation in the Marmara Region

The two study sites for the North-West region (Aktopraklık and Barçin Höyük) are still under investigation, and currently specific palaeoenvironmental reconstructions for these sites are not available. In light of this, a proxy from the nearby site of Ilipinar will be used. The reconstruction of vegetation zones in the Yenişehir Valley (South-East Marmara, North-West Anatolia), was investigated by Bottema and Woldring (1995:9-16). The division of vegetation zones are seriated chronologically, and are based on a number of pollen cores that were taken from drained lake sites at Ulubat/Apolyont, Kuş and Iznik. The Yenişehir valley area can be broadly divided into five vegetation zones on the basis of the palynological data. Zone 1 (commencing at *ca.* 10,000 BP) is characterised by high values of non-arboreal pollen, with Chenopodiaceae and *Artemisia* forming the dominant species. The pollen from this zone strongly suggests that the area was dominated by steppe plants (Bottema and Woldring 1995). The evidence of Chenopodiaceae and *Artemisia*, with the lesser inclusion of *Ephedra distachya*-type species indicates that the area would have been a near treeless steppe grassland. In fact, the pollen assemblage from this zone is very similar to the pollen assemblages that can be found from sites in areas of high elevation, such as from the Central Anatolian Plateau and the Near East (e.g. Çatalhöyük, Nevali Cori, Gobekli Tepe). When we consider the previous work by Bottema (1984, 1990 and Van Zeist 1991), it is likely that the pollen spectra and associated vegetation can be ascribed to the Late Glacial period (up to *ca.* 10,000 BP) from North Western Turkey.

As mentioned above, Bottema and Woldring (1995:12) state that in the area between Lake Iznik and the Uludag mountain range, there was limited evidence for tree species. Whilst some pollen from *Alnus*, *Betula* and *Quercus* species was discovered, it was in such low quantities that it is likely that this is the result of long-distance transport between sites. There is no evidence for birch in the lowland areas of the northwest region (at Yenişehir or Lake Iznik), but it is likely that the species would have been present in the high mountain areas (Abant Gölü and the Uludăg) and also at the upper tree limit (Bottema 1990). Towards the end of zone 1, there was a clear increase in deciduous oak pollen, and based on this evidence Bottema and Woldring (1995) have stated this reflects the expansion of trees into the low-lying areas.

Zone 2 was characterized by relatively high arboreal pollen values, comprising mainly of *Corylus*, *Fagus* and *Quercus* (deciduous oak type), *Tilia* and *Ulmus*. As is evident from the pollen spectra, during this period very different types of vegetation developed. The steppe plants of zone 1 gradually disappeared and were replaced with a number of different deciduous tree species (Bottema and Woldring 1995). At the onset of zone 2, *Quercus* sp. was the most common tree in the Yenişehir valley – it is likely that this species stood to benefit from the increase in precipitation levels that occurred after the dry steppe conditions of the Late Glacial period.

Present-day temperatures in western Turkey range between 4° and 28°C, and even if there were a significant reduction in temperatures during the second phase (Zone 2) this would not have been responsible for scarcity of tree growth at the time *(*Bottema and Woldring 1995:13). During the midpoint of the second phase, there is a clear shift in vegetation composition evident from the pollen record. Oak pollen values drop from *ca.* 40% to 10-20%, whilst the incidence of *Corylus* pollen increases. Towards the end of this phase there is a marked decrease in *Corylus* pollen and *Fagus* sp. begin to expand. Coniferous tree species (such as *Pinus* and *Albies*) increase and *Cedrus* and *Tilia* species all but disappear. In summary, there are clear and distinctive shifts in tree pollen types during this phase, but the total amount of tree pollen overall remains constant. It is also likely that the landscape during this phase would have been open forest, beginning with various grass species and ending with *Centaurea solsitialis* (Yellow Star Thistle, now considered an invasive weed) and related species (thistle species associated with the presence of grasslands) (Őztürk *et al.* 2009). The introduction and subsequent increase in *Centaurea solsitialis*-type species would suggest a shift towards continental climate conditions at the end of this phase.

The onset of Zone 3 sees a continuation of high arboreal pollen values and *Centaurea solsitialis* type species. The main change between zones 2 and 3 is the fact that tree species now make up 80% of the total pollen spectra. There is an increase in *Fagus* and *Pinus* pollen, and the first appearance of *Ostrya/Carpinus orientalis* pollen. It is possible that the addition of *Ostrya/Carpinus orientalis* represents either some of the first evidence for agriculture in the region (as they can potentially be considered as associated weeds of cultivation; or a slight change in climatic conditions (temperature increase) during this phase (Bottema and Woldring 1995). The significant increase in the total sum of tree pollen would suggest that the areas of open landscape that were present during zone 2 were significantly reduced during the 3rd phase.

Zone 4 is characterized by a significant reduction in high arboreal pollen and an increase in *Centaurea solsitialis* pollen (Bottema and Woldring 1995). Perhaps the most important aspect of zone 4 is the sudden marked increase in Cyperaceae and Sparganium-type pollen, which would suggest that a sudden drought took place during this phase (a very short period of rather extreme dryness); where the water level dropped considerably. At a later date the water levels stabilized and dense marsh vegetation developed. The presence of *Myriophyllum* pollen demonstrates that water was still present in some quantity where the pollen core was taken.

The final phase, Zone 5, was characterized by the expansion of tree species as indicated by increased quantities of arboreal pollen, suggesting a return to continental climate conditions. The majority of the arboreal taxa is comprised of deciduous tree species such as *Corylus*, *Abies*, *Fagus* and *Quercus*. Of particular interest at the beginning of this phase is the appearance of a number of Evergreen Oak species (Bottema and Woldring 1995). The origin of these species, together with a number of herb species, is often referred to as the "Beyşehir Occupation Phase" (van Zeist *et al.* 1975), which is a phenomenon often observed in Turkish and Greek pollen records (Bottema and Woldring 1995). The presence of these tree and herb species clearly indicates anthropogenic agricultural activity at the site, due to their clear economic value in subsistence terms. Plant species associated with the Beyşehir Occupation Phase include; walnut (*Juglans Regia*), olive (*Olea euorpaea*), sweet chestnut (*Castanea sativa*) and manna ash (*Fraxinus omus*) (used for its sweet exudates).

In summary, North-West Anatolia in the Holocene generally exhibits high arboreal vegetation, and is experiencing minor fluctuations in climate that lead to limited reductions and expansions of the total number of tree species, and also species type. When we consider the palaeoenvironmental evidence from the Yenişehir Valley the most significant event is the evidence for a spike in aridity at the onset of zone 4, which in archaeological terms relates to the Late Neolithic/ Early Chalcolithic period (see discussion of chronology in section 2.3.6).

2.3.4 Chronology and Cultures of North-West Anatolia

At the end of the Palaeolithic period the increasing climatic amelioration from *c.* 10,800BC led to the development of culture groups that were engaged in the manipulation of the wild progenitors of the animals and plants that were to become the mainstay of the subsistence economies in this region. It is at the onset of the period of warming that the rise of the Pre-Pottery Neolithic period in Anatolia occurred. The concept and definitions of the 'Neolithic', its distinguishing traits and associated terminology are wide-ranging in their nature and inherently complex. Any attempt at reviewing the beginning of the Neolithic period, regardless of the geographical region of the sites, can be demanding, often requiring intricate consideration of the application of theoretical frameworks and the use of terminology that can represent a broad range of definitions with these theoretical frameworks. In the case of Anatolia, located on the doorstep of the Fertile Crescent, and indeed playing a crucial role in the dissemination of agriculture into Europe, covering the topic can itself be a little daunting. The key points to consider are that the driving mechanisms behind the transition to agriculture in the Levant are fluctuating environmental conditions (particularly the stress of coping with the cold snap in the form of the Younger Dryas), the demographic transition and improving tool technologies, and to critique it in detail is likely outside the remit of this research study, although in addition to climate forcing some researchers see agriculture developing as a consequence of increased sedentism, and the ritual and cultural complexity that accompanied this (e.g. Thomas 1991, 1996).

For now, the review of the Neolithic in Anatolia will focus on the empirical evidence from the archaeological record: the beginnings of a sedentary lifestyle, the transformation in subsistence practices, and the technological progress of stone tool industries. From a geographical standpoint, Sagona and Zimansky (2009) suggest dividing up the regions of Neolithic settlement into three discrete areas; South-East Anatolia and the Fertile Crescent (the regions south of the Taurus), Central Anatolia (north of the Taurus) and Western Anatolia (including North-West Anatolia), claiming that the north-central and north-eastern areas of Anatolia are void of Neolithic evidence. Whilst this may be currently true, the suggestion that there is a complete absence of Neolithic activity along the route of the southern coast of the Black Sea is highly unlikely, especially given the later evidence for maritime migration along this route.

2.3.5 Pottery Neolithic 7000 – 6000 BC

The actual transition from the PPN to the pottery Neolithic period in Anatolia is rather poorly defined – it takes place somewhere between the 8th and 7th millennia BC. It is defined by the introduction of heat-altered pottery products, and the expansion of sites into new geographical areas. The nature of the development of settlements during the Pottery Neolithic period varied regionally. In the South-East there was a shift away from the cell-like building structures during the final phases of the PPN to large structures and what are referred to as ‘corridor-houses’ (e.g. as is in evidence at the site of Mezraa-Teleilat, near the Euphrates). The central area of Anatolia is more culturally developed by the Pottery Neolithic, and indeed is home to the largest Neolithic settlement in all of Anatolia: Çatalhöyük. Çatalhöyük is located on Konya Plain and has layers of occupation that begin at approximately 7400 BC and stretch on into the 7th millennium BC (Fairbairn 2005, Hodder 2007).

The evidence for the approach to settlement development in Central Anatolia is perhaps most notable from this site. The site was composed of roughly rectangular structures that were packed very tightly together (some with second floors), although the structures themselves were individual entities that did not share walls. The composition of the village layout led to the conclusion that access to the individual dwellings was by traversing the rooftops (Cutting 2005). The evidence from sites of the Western region, such as Çatalhöyük and Asikli Hoyuk, show settlements that are rectangular and larger than their earlier counterparts, but that are not on a comparable scale to the evidence from Central Anatolia. Interestingly, the settlement evidence from North-West Anatolia appears to contrast markedly to the structures and settlements found further to the east.

The study region for this project represents the final region of agricultural expansion in Anatolia before agriculture then spread to southeast Europe (Sagona and Zimanksy 2009:104). Efe (2000) and Özdoğan (2006) state emphatically that this region represents a frontier zone, where influences from both the Anatolian plateau and the Balkans are empirically evident in the nature and form of the archaeological evidence at sites in this region. The mixing of regional influences is particularly evident in the architecture during the early phases of the Pottery Neolithic, where the settlements were comprised of small, circular or oval pits that were constructed from wattle and daub and were partially subterranean; as is evident from the sites of Fikirtepe and Pendik.

At around 7,000 BC pottery was introduced into Anatolia. Prior to this date, clay had already been utilized during the PPN in Anatolia for a number of purposes including hearths, floor coatings and ovens. The uses of pottery containers are obvious and well attested in the ethnographic record: with the predominant function being portable and reliable food and water storage. The first attempts at pottery making in Anatolia were by no means uniform in their approach, which is something that was also observed from sites in the Near East. According to Sagona and Zimansky (2009:111) the pottery from Neolithic Anatolia can be divided into two categories that roughly define the Early and Late ceramic Neolithic. Firstly, the early ceramic tradition is characterised by dark coloured wares, that have mostly been recovered from sites located in the South-East regions all the way to the coast of the Marmara Sea and through into Bulgaria. This pottery is often referred to as Dark-Faced Burnished Ware and can be considered as the forerunner for the monochrome pottery typologies that are later found throughout the Balkan states. The second type of pottery recovered in Neolithic Anatolia is red-slipped ware, which marks the shift to the later ceramic Neolithic phase. This pottery has a burnished surface and mostly recovered from sites in western Anatolia. At the onset of the Early Chalcolithic period these wares appear complete with white painted designs.

2.3.6 Early and Middle Chalcolithic c. 6000 – 4000 BC

The onset of the Chalcolithic is more difficult to define than the two periods it lies between (i.e. the beginning of agriculture in the Neolithic and the introduction of bronze metallurgy in the early Bronze Age). The Chalcolithic is often characterized by the appearance of copper artefacts in the archaeological record alongside the development of more complex architecture, although the latter is perhaps secondary to the inception of copper metallurgy. Aside from the use of copper, there is a strong continuity with the Neolithic period (in that stone remained the main choice for tool production and there is no evidence for major changes in economy). The study into the Chalcolithic period in Anatolia is impeded by a confusing and inconsistent chronology. There are issues concerning the incompatibility of the Anatolian chronology with the dating frameworks of the surrounding areas of the Aegean and Near East (Bar-Yosef 1998).

In North-West Anatolia the Chalcolithic phases of occupation can be seen predominantly at the sites of Ilıpınar, Hacilartepe, Fikirtepe, Yarimburgaz, Toptepe, Aktopraklık and Hoca Çeşme. One of the most extensively excavated locations is the site of Ilıpınar, which at around 5700 cal BC saw the construction of a mud brick structure over the remains of a Neolithic building (Roodenberg and Alspaslan Roodenberg 2008). A major change that was observed at Ilıpınar was development of house structures at the site. During the Neolithic period the houses at Ilıpınar were free-standing individual single units, but by the Chalcolithic period this architecture was superseded by the introduction of multi-roomed structures which were constructed in very close proximity to one another. From the archaeological evidence at the site, it seems evident that each room had a designated purpose, such as cooking or storage. Why this change took place so quickly is at first unclear.

It is worth noting that at this point in time, i.e. the onset of the Chalcolithic period, Anatolia's links with the Near East (the Levant etc.) were weakening, and its connections with the Balkan states were gaining momentum. There are a number of examples of finds of monochrome and barbotine pottery wares from Anatolian sites (e.g. Hoca Çeşme) that have their origins in South-East Europe. In particular, Barbotine wares have been recovered alongside red painted wares in the earliest phases of the sites of Karanova I, Starčevo, Kőrös, and Criş (Sagona and Zimansky 2009:136). One interpretation is that the abrupt change in architecture in North-West Anatolia reflects a greater influence in changing cultural identities from the Balkan states. An alternate hypothesis is that the change in structure composition is the result of localized climate change. Roodenberg (1999) suggests that the onset of a drier climate period in the region is the reason for the change in architecture; on the basis of the appearance of post houses at Hacilartepe.

However, at Ilıpınar the upper or 'second floor' structures were used for grain storage, which one might suggest is usually commensurate with an increase in humidity or wetness (and therefore keeping the grain dry and away from the damp ground becomes a necessity), which would perhaps contradict Roodenberg's interpretation. Overall, it is clear that whilst the Chalcolithic period in Anatolia as a whole is not considered to be 'archaeologically significant' in the overall chronological framework (against the technological innovations (e.g. pottery) of the Neolithic or the urbanization of the Bronze Age), the increasing evidence for connections with the Baltic states *is* significant, as it demonstrates clear movement between regions during this period.

2.3.7 A History Of Research

In the past two decades around 26 Neolithic sites have been excavated in Anatolia, with the majority of these being multi-layered mound (tell) sites e.g. Ilıpınar and Menteşe (Özdoğan 2011).

Figure 2.7 shows the main sites in the study region, Fikirtepe, Pendik, Yenikapi, Yarimburgaz, which are located on the northern coast of the Marmara Sea; Ilıpınar, Menteşe, and Barçin Höyük are located in close proximity to Lake Iznik, whilst Aktopraklık is located on the western edge of Lake Ulubat. In order to provide a contextual framework for the two study sites, Barçin Höyük and Aktopraklık, the similarities and differences between the main sites, in terms of subsistence, material culture and social customs (e.g. burial practices), are outlined below.

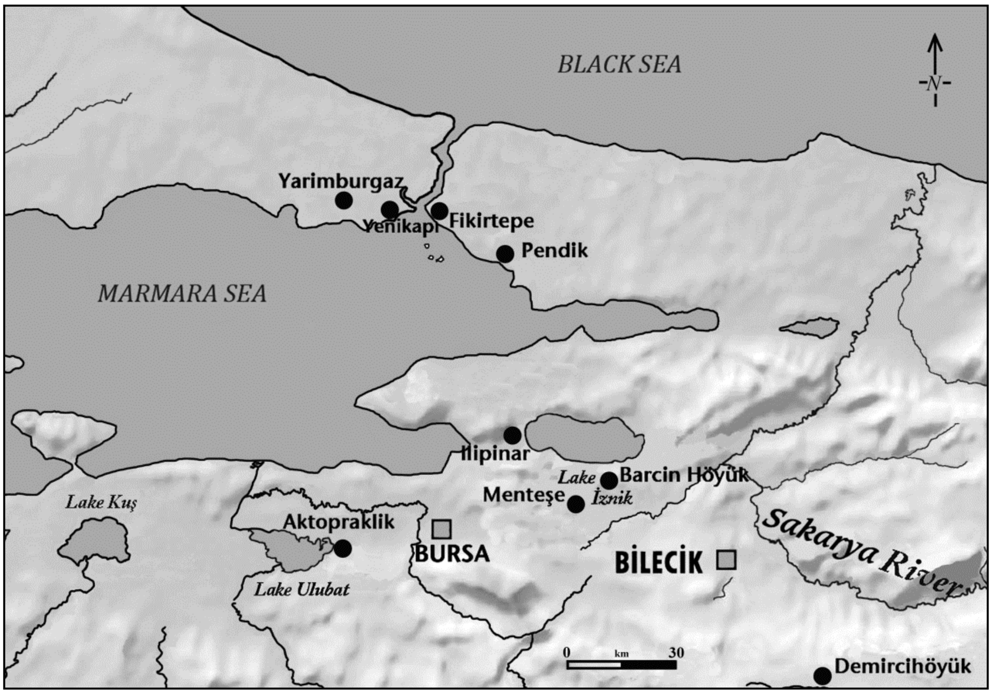

Figure 2.7 Map showing the Neolithic sites in the Marmara Region of Turkey, with the study sites of Aktopraklık and Barçin Höyük highlighted.
(redrawn from Karul and Avci 2011: 9).

A number of the early prehistoric sites in the region are flat settlement sites, which are more akin in form and layout to those found in the Balkans. The most notable flat settlement sites in the region, Fikirtepe and Pendik, are located on the northern coast of the Marmara Sea. Interestingly, Aktopraklık which is one of the sites which forms part of the present study, is the only flat settlement site excavated so far which is located to the south of the Marmara Sea (Karul and Avci 2011:5).

As a result of recent research, large areas of the Anatolian peninsula are now considered to be an integral part of the primary zone of Neolithisation (Özdoğan 2007:19), and the evidence indicates that the transmission of Neolithic cultural traits followed both maritime and inland (Anatolian plateau) routes (*ibid*). The sites which form the focus of this study are located inland, and it is anticipated that the movement of the Neolithic cultural and technological ‘package’ would arrive in North-West Anatolia via a land-based route.

Whilst developments in pottery typology are considered to be, for the most part, identical at coastal and inland sites, there is a clear difference in the development of dwellings and the structure of settlements. The inland sites are characterized by the presence of rectangular houses (e.g. Ilıpınar and Menteşe), while the coastal sites (e.g. Fikirtepe) have round or oval wattle and daub huts with semi-sunken floors. Karul and Avci (2011:4) have also outlined a number of atypical ceramic types at Aktopraklık. Özdoğan (n.d.) also notes a dichotomy between the coastal and inland locations, wherein the coastal sites appear to indicate culture contacts with, and the integration of, indigenous populations and their subsistence strategies into the farming economies (based on similarities from the Mesolithic to Neolithic period in lithic assemblages, site location and contemporaneity (Ozdogan 1999, Gatsov 2001, Brami and Heyd 2011, During 2011)). In contrast, the inland sites remain focused on the exploitation of domesticates, indicating migrations of farmers to the coastal zones (although these observations are speculative as there is a distinct lack of evidence for indigenous populations in this region). Özdoğan (2010:887) has recently noted that throughout all of western Anatolia, the Aegean and the region around the Sea of Marmara, there is a considerable degree of heterogeneity in the ‘Neolithic Package’, such that even at contemporary sites diversity in material culture, subsistence, architecture and settlement patterns occurs.

As the above, admittedly brief overview indicates, the region of North-West Turkey in which Aktopraklık is located is a culturally diverse and complex region both in terms of the nature and origins of agriculture, and indeed, in relation to the nature of the adoption and adaptation of the various elements of the agricultural 'package' (Greaves 2007). This apparent complexity could, of course, be an artefact of research strategies aimed at identifying the onset of farming, as opposed to a research strategy that targets the evidence for indigenous hunter-gatherer groups and their role in the transition to agriculture in this region. As such, on the basis of the excavations at sites such as Fikirtepe, Pendik, Yarimburgaz, Ilıpınar, Menteşe, Barçin Höyük, Aktopraklık and Demircihöyük, alongside landscape surveys in the western areas of the plateau, it is now generally accepted that the Fikirtepe culture was widespread in the western regions of Anatolia, and that the origins of this culture lie the Central Anatolian plateau, probably in the Lake District region (Özdoğan 2008:151).

2.3.8 Neolithisation in North-West Anatolia

Understanding the process of Neolithization in North-West Anatolia is important, as the region is often considered as the 'jumping off point' for the transmission of the Neolithic package from Central Anatolia and the Levant into the Balkans, the Aegean and ultimately further beyond into mainland Europe. The beginnings of the Neolithic period in the Marmara region is naturally therefore an intensely debated issue in the academic literature, and the conflicting discourse revolves not around the timing of the transition to agriculture, but rather the 'nature' of the transition. The onset of the Neolithic period in the Marmara region is characterized by the appearance of coastal sites that are situated on the peninsula – flanked by the Black Sea to the North and the Marmara Sea to the South, that ends at the Bosporus Strait. The type-site for the region, Fikirtepe, after which the Neolithic culture for the region is named, is located within a cluster of contemporary sites from the region; including Menteşe and

Pendik. These sites date to *c.* 6000 cal BC, and one of their most notable features is the presence of fish and molluscs remains in the archaeozoological assemblages recovered. The 'Fikirtepe cluster' is surrounded by marine, freshwater, and brackish water resources, all of which are reflected in the zoological assemblage. An overview of the archaeozoological remains from Fikirtepe, Menteşe, and Pendik highlight the presence of freshwater species (wel catfish, roach, pike and perch), marine species (jackfish, tuna and stingray), and estuarine species such as seabream and mullet (Cakirlar 2013). In addition to the fish species present in the Fikirtepe cluster, there is considerable evidence for the consumption of shellfish, particularly molluscs, with high abundances of black Mediterranean mussels (*Mytilus galloprovincialis*) (which constitute >90% of the shellfish remains) and European oysters.

The presence of aquatic resources in the faunal record has heavily weighted the interpretation of the Neolithisation process in the Marmara region, and the primary definition of the Fikirtepe sites are as 'aquatic foraging populations, who exploited wild terrestrial resources' (Cakirlar 2013). This description reflects the fact that wild faunal remains are recovered from the sites of this culture. The presence of wild fauna and mixed aquatic resource base leads, perhaps, predictably, to the suggestion that there is a Mesolithic sub-base, or at least Mesolithic cultural influences on the Neolithic in this region, and consequently that there is a merging of populations in the area at this time (Özdoğan 2011, Thissen *et al.* 2010, Cakirlar 2013).

Cakirlar (2013) has recently provided an overview of the archaeozoological assemblages from the Fikirtepe cluster and surrounding areas (Durankulak in Bulgaria to the North, and the Aegean sites of Yenibademli and Troy to the South).

This research highlights the fact that fish and wild terrestrial fauna are actually only present in limited numbers (<10% NISP for wild fauna) at the Fikirtepe sites (the caveats of preservation and the influence of excavation techniques, particularly for fish remains, not withstanding). It is the terrestrial faunal resources that provide the main diet resources in the Fikirtepe region (*c.*40-70%), with the inclusion of freshwater species consolidating the diet (Cakirlar 2013: 66). The percentages of shellfish species may initially lead one to believe that they formed a significant part of the diet, but NISP values refer to number of specimens present in an assemblage. The mollusc species present in the assemblage have low trophic levels and low calorific value – one mollusc is certainly not equivalent to one cow, sheep or goat from an economic standpoint.

2.4 Overview of Study Sites

This section provides a detailed review of the two study sites of Aktopraklık and Barçin Höyük; aspects such as location, settlement characteristics, economic evidence and burial rites are reviewed. The consideration of the economic/subsistence evidence is undertaken with the aim of highlighting the resource frameworks available to the Neolithic populations at the respective sites. Unfortunately, the palaeobotanical reports for the study sites are not currently available, and as such the published botanical work from the nearby contemporary site of Ilıpınar is used in their absence.

2.4.1 Aktopraklık

The site of Aktopraklık, located in North-West Turkey, was originally discovered in 2002 during archaeological survey in advance of the development of an industrial area (Karul 2007, Karul and Avci 2010, 2011). The site was excavated under the direction of Necmi Karul. The phases of activity at Aktopraklık occurred from the mid 7th to mid 6th millennia BC, between *c*.6400-5600calBC, and include the earliest evidence for Neolithic monochrome pottery in the region. There are two AMS dates for the interments at Aktopraklık, with a Neolithic interment (individual 89D-4.4-06) placed at *c*.6400-6235 calBC (OxA-20596), and an early Chalcolithic burial (individual 88E-12.1-07) placed at 5736-5635 calBC (OxA-20597) (Budd *et al.* 2013:862). The preliminary dates currently appear to correspond with the dating established on other settlements in the eastern Marmara region, being commensurate with the earliest dates from Menteşe (Roodenberg and Alpaslan-Roodenberg 2008).

The settlement and cemetery sites were positioned between two river beds (Aktopraklık A-B), and on a ridge to their north (Aktopraklık C). Figure 2.8 shows a plan of Aktopraklık B. The settlement has been impacted upon by olive trees, which presently grow on the site, and by a Byzantine site, the ruins of which were recorded to a maximum depth of *ca*. 1m; penetrating into the Neolithic levels at this location. In addition, during the Chalcolithic period Aktopraklık C was used as the site of the cemetery after the settlement had been abandoned and relocated to area B (Karul and Avci 2011).

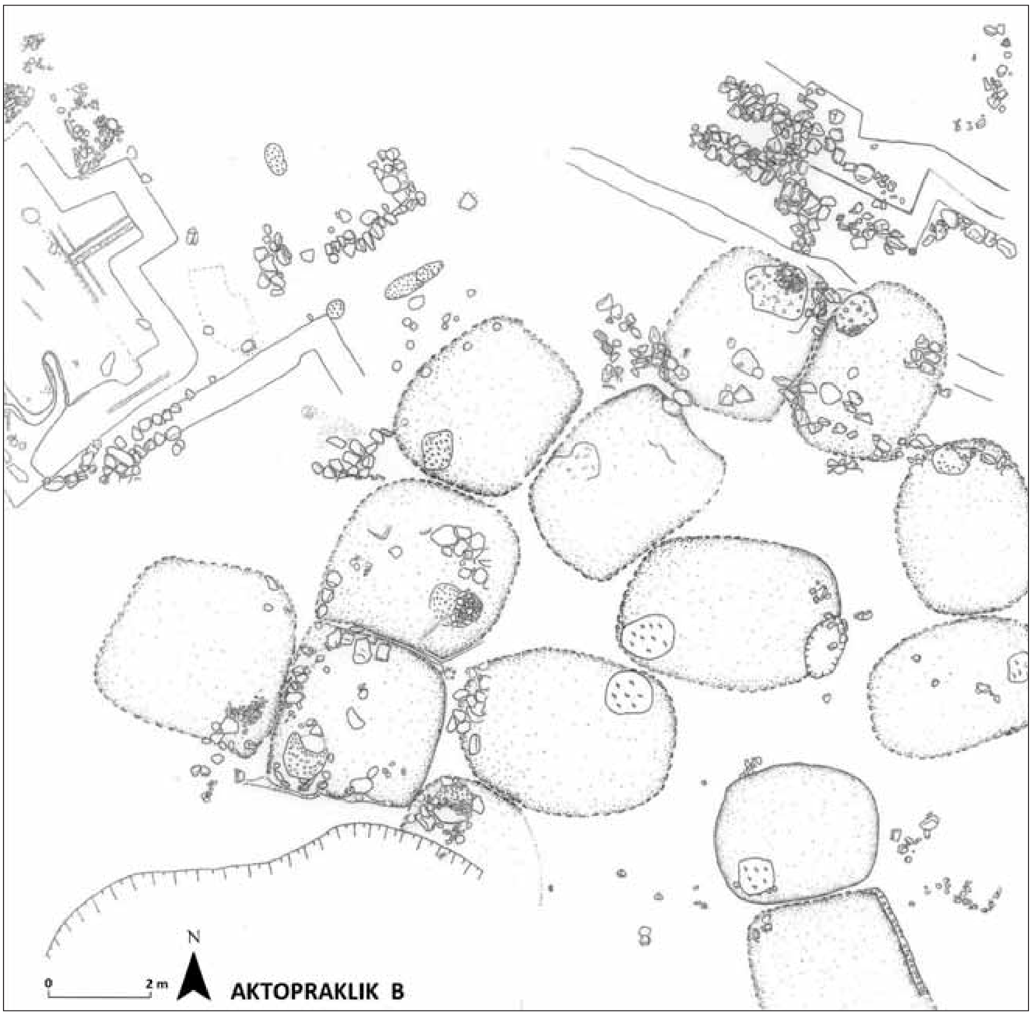

Figure 2.8 Site B at Aktopraklık.
Plan of the uppermost cultural layer showing the distribution of the dense cluster of huts (Karul and Avci 2013:48).

The excavations at Aktopraklık C have shown that the site comprised two phases of Neolithic occupation, the earliest of which is badly truncated by the overlying Byzantine activity, but with two surviving small structures *c.* 1 and 1.5m in diameter. The subsequent phase of occupation is better attested, with evidence for paved courtyards and five structures with *c.* 3-6m diameter huts, three of which had stone wall bases and concave floors (figure 2.9) (Karul and Avci 2011, 2013).

Figure 2.9 Aktopraklık Site B Photograph.
General view of the alignment of rectangular buildings with inner buttresses and niched walls protruding towards the ditch (Karul and Avci 2013:49).

The location of the site, close to an extinct river course and an extant spring, and on a level raised area on the shores of Lake Ulubat, would suggest that the occupants of the Neolithic and Chalcolithic site were ideally situated to exploit both fresh- and salt-water resources and the adjacent forest zone (Karul and Avci 2011:2). The study sites for this project are assigned to the Fikirtepe culture, which has its chronological onset in the southern Marmara region at around *c.* 6600-6500calBC. Recent excavations at the sites of Ilipinar, Barçin Höyük, Menteşe, and Aktopraklık have now firmly attributed the beginning of the Fikirtepe culture to this period (Roodenberg *et al.* 2003). This culture is often delineated into two phases; Archaic Fikirtepe (characterized by pottery decorated with monochrome and darkish brown/black surfaces and hole-mouth jar profiles) and Classical Fikirtepe (which is marked by the introduction of red burnished wares and s-shaped profiles).

In addition, the Fikirtepe culture is generally defined by its round, wattle and daub structures, with subsistence strategies based on fishing, mollusc collecting and hunting and gathering, with some inclusion of domesticated animals and plant cultivation (Özdoğan 2010). However the archaeological sites in the region exhibit architectural variation (e.g. some of the structures are rectangular in form), and some sites only employ certain subsistence strategies. For example, the site of Ilipinar, which is associated with the Fikirtepe culture, has evidence for rectangular shaped structures and its subsistence strategy indicates a fully agricultural economy, exploiting a wide range of domesticated plant species, and in which sheep and goat dominate the domesticated faunal species exploited (Özdoğan 1999, Roodenberg 1999).

It has been suggested that the variability in the material culture inventories of the Fikirtepe culture represent the conflation of incoming farmers and local traditions/adaptations, which produces a hybridized culture unlike those known from Central or Western Anatolia (Çilingiroğlu 2005). As such, using stable isotope analysis of human and faunal skeletal remains, part of the current study aims to test whether the Neolithic populations at Aktopraklık and Barçin Höyük exploited the wide range of wild resources (e.g. freshwater, marine and terrestrial resources) available at the local and regional level, or whether, as in adjacent regions (e.g. see Papathanasiou 2003), these populations were already focusing their subsistence activities on a limited range of domesticated plant and animal resources.

The terminal phase of the classical Fikirtepe period is currently radiocarbon dated to *c.* 5900 cal BC (Gatsov 2009). The immediate successor to the Fikirtepe culture was the Yarimburgaz 4 culture, which was initially observed at the eponymous cave in Istanbul, but it is also in evidence at the sites of Ilipinar, Yenikapi, Aktopraklık and Demircihoyuk. This culture is mainly defined by the appearance of more complex pottery styles/forms, with elaborate textile-like designs (Rosenberg and Erin-Ozdogan 2011). A particularly interesting factor associated with this culture is the appearance of extramural cremation burials – particularly at Yenikapi – which are the earliest examples of cremation in Turkey and the Near East (Bacarvarov 2004). The Yarimburgaz 4 culture continues until *c.*5600 cal BC.

2.4.2 Neolithic and Chalcolithic Burials

To date *c.* 60 burials have been recovered during systematic excavations at Aktopraklık, with fragmentary material from an additional 14 individuals having been recovered during assessments undertaken by the Bursa Museum. A dozen burials were recovered from the settlement area of Aktopraklık B, all dated to the Early Chalcolithic period, while *c.* 36 individuals from the Neolithic and Chalcolithic periods were recovered from the cemetery at Aktopraklık C, which covers an area of *c.* 1400m^2. At Aktopraklık B the dead were placed in a contracted position within pits, with monochrome vessels placed at their head and feet, and with ornaments and bone tools as accompanying grave goods (Roodenberg 1999).

In the cemetery area of Aktopraklık C the later Neolithic and earlier Chalcolithic burials have a range of grave goods, including pottery (figure 2.10), limestone beads, a handle of a bone spoon, worked bone tools, and a number of faunal remains placed in direct association to the burials. As noted by Karul and Avci (2011:5), the Neolithic practice of interment within the settlement is abandoned by the Chalcolithic period at Aktopraklık C as a shift away from 'living with the dead' to a concept of a 'city of the dead' develops.

Figure 2.10 Pottery at Aktopraklık.
A red slipped pot decorated with limestone bead inlays recovered with the burial in the ditch (Karul and Avci 2013: 49).

Alpaslan Roodenberg (2011a) has reported on 42 burials recovered between 2004 and 2009, recording the presence of 37 adults (comprising 15 females/probable females, 15 males/probably males and seven individuals of indeterminate sex) and seven infants and juveniles. Preservation varied across the site, with a number of individuals represented by very fragmented remains, and *c*. 80% of the adults being preserved in either a fragmentary or poor condition. Figure 2.11 shows one of the more notable interments at the site, 'Arrowhead Man', who has a transverse arrowhead lodged in his 3rd lumbar vertebrae.

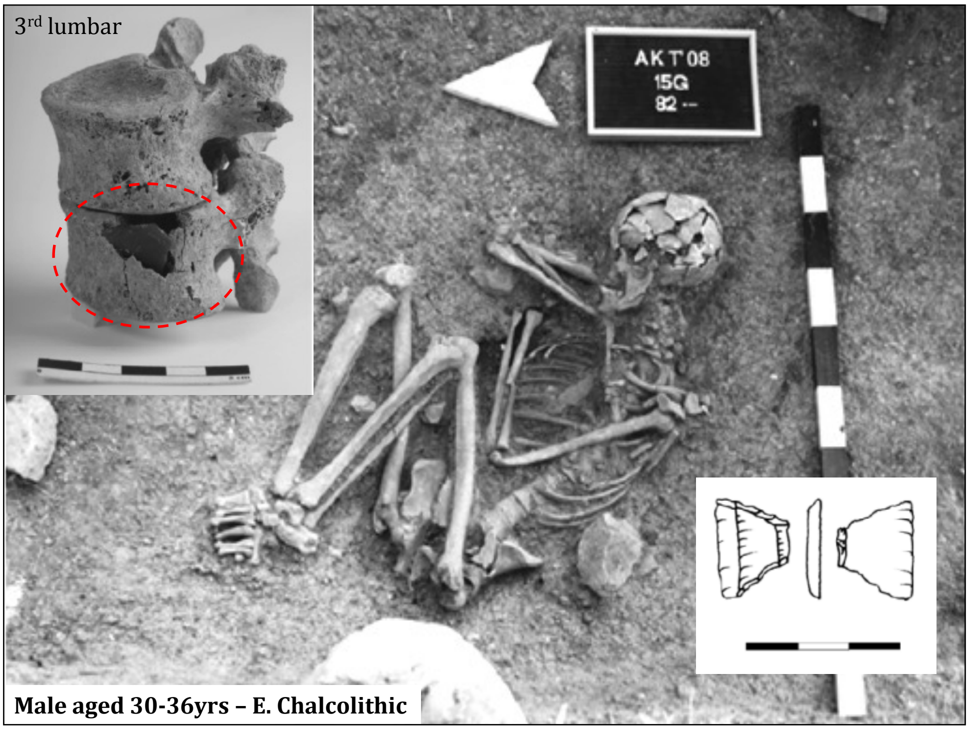

Figure 2.11 'Arrowhead man' from the Neolithic phase at Aktopraklık.
A transverse arrowhead was found embedded within his third lumbar (Image courtesy of S. Alpaslan-Roodenberg 2011).

All but a few burials were single, and interred in regular pit graves. In addition however, one multiple burial (89E-9.1-3) included three individuals and another burial included two individuals (89D-17.1 and 14.1). All are primary burials, in contrast to the partly contemporary Çatalhöyük site where secondary interment was customary (Andrews *et al*. 2005: 263).

2.4.3 Faunal and Floral Remains At Aktopraklık

To date there has been relatively little evidence for subsistence activities at Aktopraklık (Karul and Avci 2011), a situation that contrasts markedly with sites such as Ilıpınar where there is evidence for the exploitation of a range of domesticated plants including barley, wheat, oats, bitter vetch, lentils, grass pea, peas and flax, alongside the domesticated fauna. Some of the dietary information from the site comes from the refuse pits that contained cattle and deer bones. Karul and Avci (2011:3) have interpreted these features as representing the collective butchering and consumption of animals at regular intervals. In addition, the association of faunal remains with a number of Neolithic interments, and finds from other areas of the settlement site, has produced evidence for cattle, pig and sheep/goat; primarily in the form of fragmentary material, and there are also similar faunal associations with the Chalcolithic cemetery at Aktopraklık C. The fauna that date to the Late Neolithic phase, recovered from various contexts across the site, are listed in table 2.2. This information is provided by Alfred Galik (*pers.comm* 2012).

Species	Common name	n	%.
Lepus europaeus	European hare	9	0.40%
Vulpes vulpes	Red fox	7	0.30%
Meles meles	European badger	1	0.00%
Sus scrofa	Wild pig	16	0.70%
Sus scrofa?	Wild pig	52	2.20%
Dama dama	Fallow deer	101	4.30%
Cervidae	Deer	1	0.00%
Bos primigenius	Auroch	3	0.10%
Canis fam.	Dog	4	0.20%
Bos taur.	Cow	799	34.30%
Ovis/Capra	Sheep/Goat	1213	52.00%
Ovis aries	Sheep	34	1.50%
Capra hircus	Goat	91	3.90%
total		2331	100.00%

Table 2.2 Fauna recovered from the Late Neolithic phase at Aktopraklık.
(Galik, 2012, *pers.comm*).

The faunal species associated with the Late Neolithic phase are European Hare, red fox, European badger, domestic pig, fallow deer, deer sp. (un.id), auroch, dog, cattle, sheep and goat. Figure 2.12 shows the proportion of main species dating to the Neolithic phase.

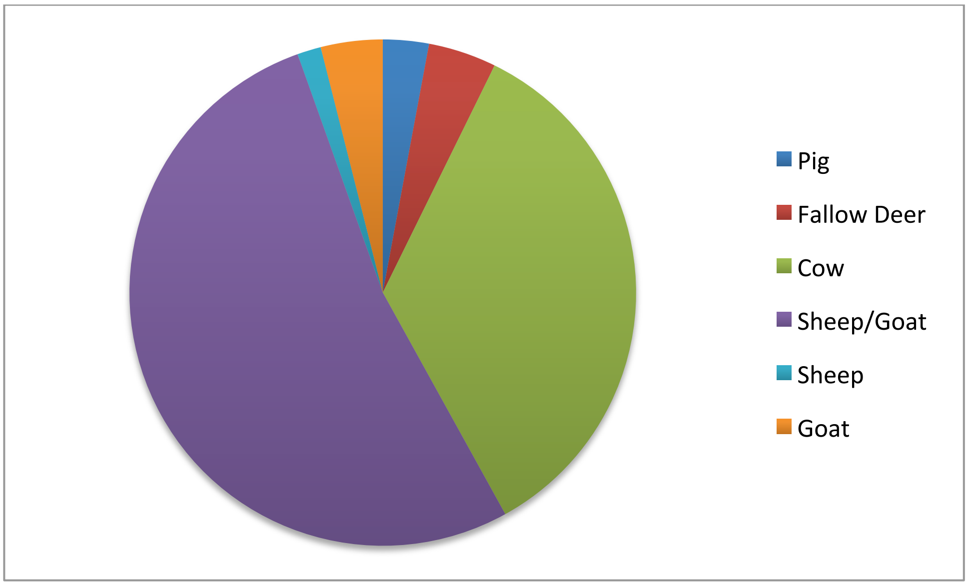

Figure 2.12 Main species present of Late Neolithic fauna at Aktopraklık.
(Galik, 2012, *pers.comm*).

The Neolithic period was dominated by the presence of sheep/goat and cattle bones, with some minor contribution from pigs, and deer species. There is very limited evidence for a wild faunal component, and whilst this is mostly commensurate with the nearby sites of Barçin Höyük and Ilipinar, it is at odds with sites located further north. Sites such as Fikirtepe and Pendik, show a higher component of wild fauna alongside evidence for aquatic exploitation. Table 2.3 highlights the fauna recovered from Chalcolithic deposits from different house contexts at Aktopraklık. The species recovered include European hamster, European hare, brown bear, domestic pig, roe deer, fallow deer, deer sp. (un.id), dog, cattle, sheep and goat. Figure 2.13 illustrates the proportion of main fauna at the site.

Species	Common name	H in 17H	H in 17I	H in 18I	H in 8K	total
Lepus europaeus	European hare		1	2		3
Cricetus cricetus	Roe deer		1			1
Ursus arctos	Brown bear				1	1
Sus scrofa	Wild pig	2	1	12	19	34
Sus scrofa?	Wild pig	9	18	53	14	94
Capreolus capreolus	Roe deer				2	2
Dama dama	Fallow deer	10	46	33	124	213
Cervidae	Deer			2		2
Canis fam.	Dog	1	2	4	1	8
Bos taur.	Cow	56	158	256	73	543
Ovis/Capra	Sheep/Goat	70	222	412	123	827
Ovis aries	Sheep	3	13	11	5	32
Capra hircus	Goat	3	10	16	6	35
total		154	472	802	368	1796

Table 2.3 Fauna recovered from the Chalcolithic phase at Aktopraklık.
(Galik, 2012, *pers.comm*).

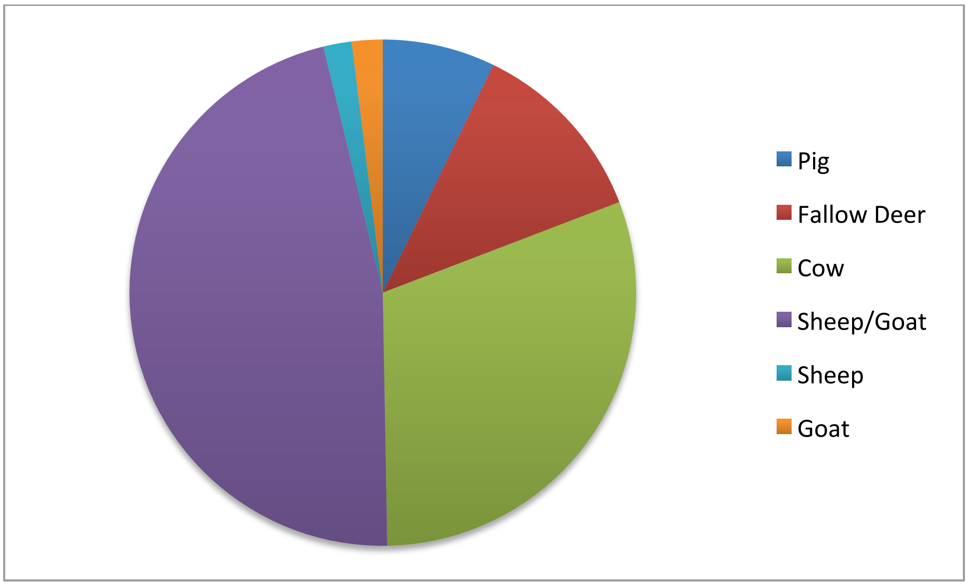

Figure 2.13 Main faunal species from Chalcolithic contexts at Aktopraklık.
(Galik, 2012, *pers.comm*).

After the onset of the Chalcolithic period, there is a change in the composition of the faunal assemblage; the percentage of sheep/goat species decreases in favour of cattle, and pig also become more prevalent. However, curiously, there is an increase in the wild fauna component, particularly fallow deer, which runs contrary to the expected trajectory of prehistoric agriculture site (where the resources become more specialised (and therefore narrow) as the subsistence aspect of the site stabilizes).

Today the site of Aktopraklık is located 3km away from Lake Ulubat, and palaeoenvironmental work undertaken in the area has led to the suggestion that during the Neolithic period the site was located in closer proximity to the lake. Despite the sites proximity to both the Black Sea and Lake Ulubat no fish or shellfish remains, or indeed fishing equipment (e.g. weirs, net sinkers, hooks etc.) have been recovered. In order to fully establish that no fish proteins were consumed during the Neolithic period, a number of modern reference fish were included in the isotopes study, obtained directly from Lakes Ulubat and Iznik. The procurement of these samples was kindly arranged by Necmi Karul, Songul Alspaslan-Roodenberg and their team. The species obtained include *Scardinius erythrophthalmus* (Common Rudd), *Esox* (Muskellunge), *Cyprinus carpio* (Yellow Carp), *Silurus glanis* (Wels Catfish), and *Gumus* (Atherina/Silverfish) (see figure 2.15, a-e).

a) Common Rudd b) Muskellunge

c) Yellow Carp d) Wels Catfish

e) Atherina (n=1)

Figure 2.14 Modern fish samples from Lakes Ulubat, analysed as part of this project.

(Photos: Karul and Alpaslan-Roodenberg 2012).

Overall it is clear that the populations at Aktopraklık had access to a number of potential dietary protein sources, which included both aquatic and terrestrial resources. From an archaeological viewpoint, Karul and Avci (2011) state that the relative scarcity of subsistence-related finds in the archaeological deposit of Aktopraklık may be an indication that plant cultivation was a secondary activity compared to other contemporary sites in the region.

2.4.4 Barçin Höyük

Barçin Höyük is a three hectare (in area), by four metre high tell located in the Yenişehir Valley, which lies east of the Sea of Marmara. Initially given the name of 'Yenişehir II', it was discovered when French (1960) was undertaking survey work in the region in the 1960s. There has recently been renewed interest in the investigation of Barçin Höyük and the first season of new excavations began in 2005 under the direction of Fokke Gerritsen. Barçin Höyük is located on the border of two catchment areas; the spurs of the mountain ridge separating the Iznik Lake and Yenişehir plains, and also the marshy surroundings of lake Ulubat (Roodenberg *et al.* 2008: 53). It should be noted that Iznik Lake, has very likely retracted in size since the prehistoric period, in particular it has been partially drained in recent years for commercial agricultural purposes. The evidence would suggest that Barçin Höyük was initially in closer proximity to the edge of the lake.

2.4.5 The Excavations at Barçin Höyük

The settlement site of Barçin Höyük consists of twin mounds connected by a low saddle that extends 300m (figure 2.15). The main circular mound is *c.* 120m in diameter and 4m in elevation, with the second lower mound measuring *c.* 50m in diameter and 2.5m in elevation. The surface layers of the adjoining saddle suggest that the area was once used as a Byzantine graveyard (Roodenberg *et al.* 2008).

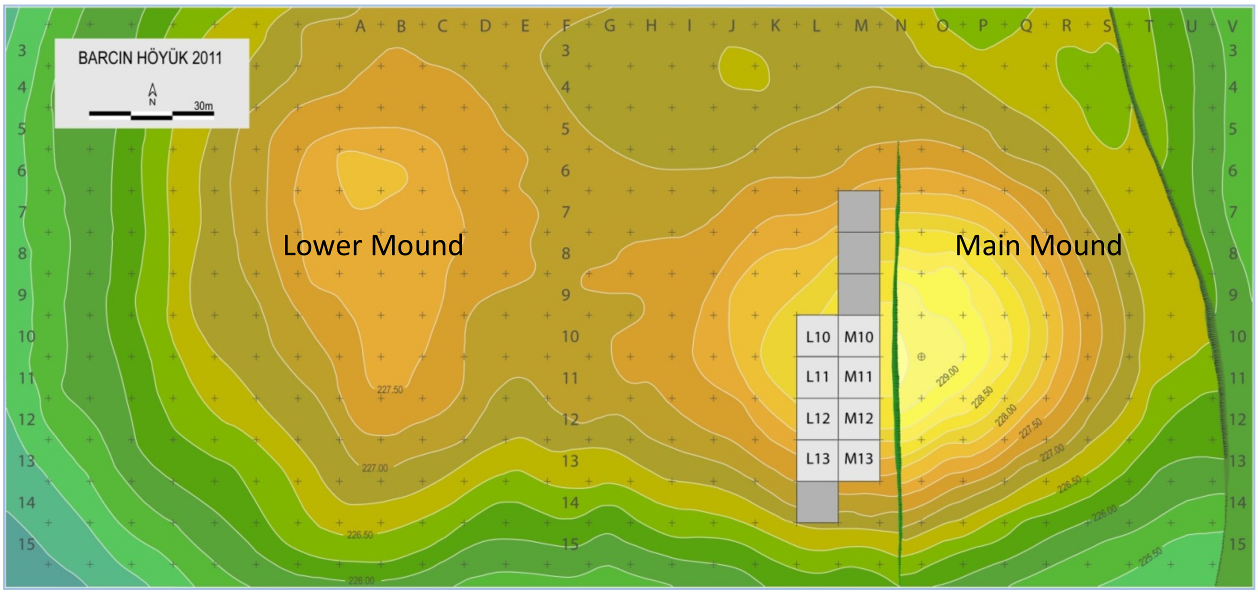

Figure 2.15 Plan of Barçin Höyük showing the extent of the excavations from 2005 – 2011. L10 represents the earliest season of excavations, and M13 demonstrates the most recent excavation season (Image courtesy of F. Gerritson 2011).

The 2005 and 2006 seasons at Barçin Höyük focused on the excavation of the main mound, which revealed evidence for phases of occupation from the Neolithic to the Roman period. The Neolithic and Chalcolithic deposits are focused within the core of the main mound, with the later Bronze Age and Roman deposits being thickest on the northern and southern edges. The later deposits, most notably from the Bronze Age, have been heavily disturbed by many generations of voles tunnelling their way through the site. The vole issue has likely to have affected the entire plain of the Yenişehir Valley (Gerritsen *et al.* 2010).

The Late Chalcolithic deposits at the centre of the main mound at Barçin Höyük are *c*. 1m thick and overlay the Neolithic layers (figure 2.16) (Roodenberg *et al.* 2008). The evidence for occupation in the Neolithic layers comes in the form of building materials which consist of chunks of burnt mud (some of which have chaff impressions), oven remains, bins, refuse pits and human graves. Layers VI (A-E) and layer VII date to the Neolithic period, and comprises the longest phases of occupation at the site. Layer V consists of Chalcolithic deposits, and the Bronze Age is represented in layer IV and Roman occupation in layer II. The single radiocarbon date obtained for the Late Chalcolithic phase is 4990±40BP, from a plant macrofossil (Gerritsen, *pers. comm.*).

Figure 2.16 Layers of occupation at Barçin Höyük.
Powerpoint slide courtesy of Fokke Gerritsen (2012).

The Upper and Middle levels of the Neolithic activity have been radiocarbon dated to between 7470±60 and 7310±40 BP (which calibrate to 6432–6232BC and 6232–6071BC respectively, using IntCal09). The earliest Neolithic layers at Barçin Höyük

(Layers VID and VIE) have been dated in high resolution using plant macro remains from the site, with the samples being processed at Groningen and Beta Analytical (figure 2.17) (Gerritsen, *pers.comm*).

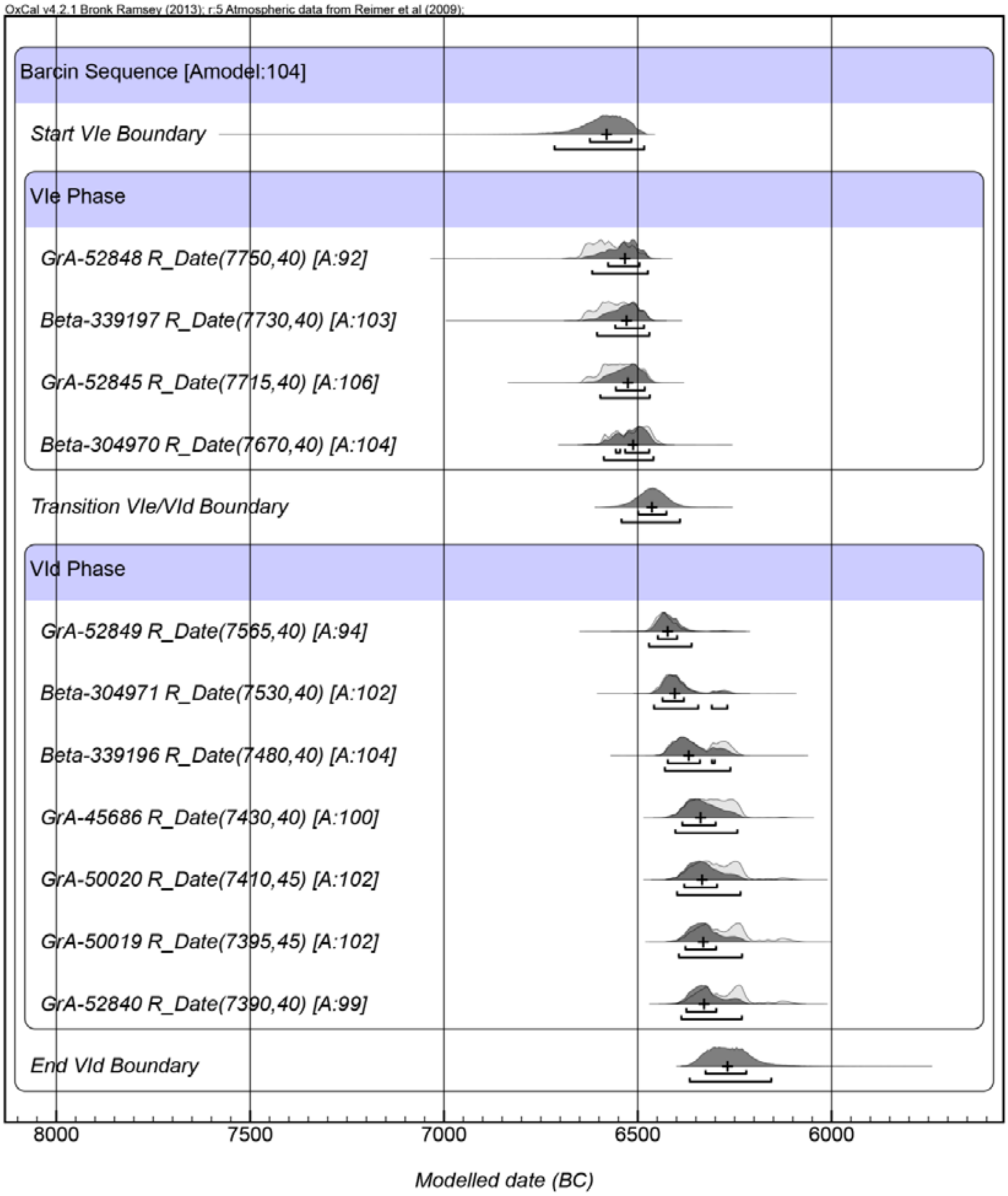

Figure 2.17 Barçin Höyük radiocarbon dates modelled for Neolithic phases VIe and Vid. (Gerritsen *et al.* 2013:92).

The dates that are presented in figure 2.17 provide the earliest evidence for Neolithic settlement/occupation in the wider region.

2.4.6 Neolithic Burials at Barçin Höyük

The human burials analysed as part of this isotopes study date exclusively to the Neolithic period. A table of the individuals sampled is present in Chapter 4: Sampling strategies and laboratory methods. During the field seasons 2005 to 2006, three adult burials from the Neolithic period were uncovered; two females and one individual of unidentified sex (Roodenberg and Alpaslan-Roodernberg 2008). A further 34 burials were uncovered from 2007-2012, comprising 19 adults and 18 non-adults (Alpaslan-Roodenberg *et al.* 2013). In total, 37 human burials have been recovered during the 2005-2012 excavation seasons, and it is the anthropological analysis of these interments that forms the basis of this section. In addition to the above, during the 2012 field season the skeletal remains of several individuals were also recovered, but the analysis of these individuals is still a work in progress (and as such not available for discussion here). The burial i.d's reflect the square they were recovered from, e.g. L13, L14, M13, and the find number in the trench (e.g. a full i.d is L13-166). The osteology examinations were performed by Songul Alpaslan-Roodenberg.

The burial customs at Barçin Höyük are largely defined by single and primary burials, with the deceased interred in a flexed position. Adults and juveniles were most commonly interred on their left side, and the position of small infants could rarely be determined (due to poor preservation). Three burials, which date to the earliest Neolithic (layers VIe to VId), do not conform to this trend. These individuals are buried either on their right side (L13-200, L14-200), or their back (L13-166). Generally speaking, the adults at Barçin Höyük were interred in open areas within the settlement site, and infants (aged 1-2yrs) were buried inside house structures (most likely in shallow pits among the rubble of abandoned houses) (Roodenberg *et al.* 2013).

In terms of grave goods, the most common inclusion is cited as animal bone (although exact figures of how many burials had animal bone is absent from the literature) (Alpaslan-Roodenberg *et al.* 2013). Notable grave goods are associated with L13-166, an old female, recovered from the one of the earliest Neolithic phases (layer VIe). This female was interred on her back, with her legs higher than her head, with a rock lying on her chest. A bone pin lay on her pelvis and an 'object of red stone ground to a fat almond shape was found to the right of her chest' (Alpaslan-Roodenberg *et al.* 2013:94). Burial M13-72 is a middle-aged female dating to the later Neolithic (layer VIb); a sheep or goat hoof was deposited on the pelvis and a small flint blade was discovered directly behind her skull. Overall, artefact inclusions in burials are rare at Barçin Höyük, but animal bone is commonplace. There are no discernable differences observed between the sexes, but there are slight differences in burial positions between the early and late Neolithic.

More than half of the burials recovered from Barçin Höyük are infants (n=18), 12 of these died during or soon after birth (e.g. 0 and *c.*3 months), one infant reached *c.*2 years, and two of the sub-adults were *c.*6-8 years at death. It was not possible to assess the pathology in this age group as the remains are fragmentary and poorly preserved. Whilst the infant mortality at Barçin Höyük seems inordinately high, it is in line with the demographic data for Ilıpınar and Menteşe (Alpaslan Roodenberg 2008, 2011), but is curiously not comparable to Aktopraklık that has much lower rates of infant mortality. The adults consist of eight females, four males and four individuals of unknown sex. The life expectancy of adults did not differ much between the sexes, and most adults died at middle to old ages (25-45 years). The adult mortality rates are inline with the demographic data from the nearby sites, including Aktopraklık.

2.4.7 Faunal and Floral Remains at Barçin Höyük

As the excavations at Barçin Höyük are ongoing, the accessible evidence for the subsistence economy at this site is currently limited. Table 2.4 illustrates the fauna that have been recovered from the site to date. These range in date from the Early Neolithic to the Roman period. The palaeobotanical data for this site are yet to be published, and are unavailable at the time of writing. As such, the plant assemblage from the nearby site of Ilıpınar is used as a proxy in the results and discussion for the Neolithic period in this region.

	II	II/IV	IV	V	V/VIA/VIB	VI	VIA or VIB	VIB	VI(VID/VIC)	VID/VIC	VID	VID/VIE	VIE	VII	total
Erinaceus concolor											1				1
Lepus europaeus			1	6	13	2	1	13			23	4	14	1	78
Vulpes vulpes				1	1			2			2	1	11		18
Ursus arctos			1												1
Martes foina											1				1
Sus scrofa	7		4	3	16	1		10	1		58		11		111
Sus scrofa?	2							6			7	5	11		31
Capreolus capreolus					3										3
Bos primigenius					2			1			1	1	1		6
Bos primigenius?											1		6		7
Cervidae			1		2										3
Dama dama				12	22			3			6	1	16	2	62
Canis fam.			3	16	4		1	3			9	1	2		39

Bos taur.	54	28	62	410	435	10	10	646	6	10	1588	214	1195	39	4707
Ovis/Capra	63	21	62	463	555	18	17	403	10	15	1384	205	1253	32	4501
Ovis aries	2	5	10	53	82		1	62			70	10	29	1	325
Capra hircus	1		1	25	14			10		1	30	3	10	4	99
Sus scrofa f. dom.	3	12	12	254	11										292
Asinus asinus			1												1
Equus cab.			1												1
total	132	66	159	1243	1160	31	30	1159	17	26	3181	445	2559	79	10287

Table 2.4 Fauna recovered from all phases at Barçin Höyük.
II = Roman, IV = Early Bronze Age, V = Chalcolithic, VI = Neolithic (Gerritsen, 2012 *pers.comm*).

The faunal species recovered from the Neolithic phases at Barçin Höyük include Southern white-breasted hedgehog, European hare, red fox, beech marten (which is similar to ferret), domestic pig, roe deer, auroch, deer sp. (un.id), fallow deer, dog, cattle, sheep and goat. Figure 2.18 highlights the main species from Neolithic Barçin Höyük.

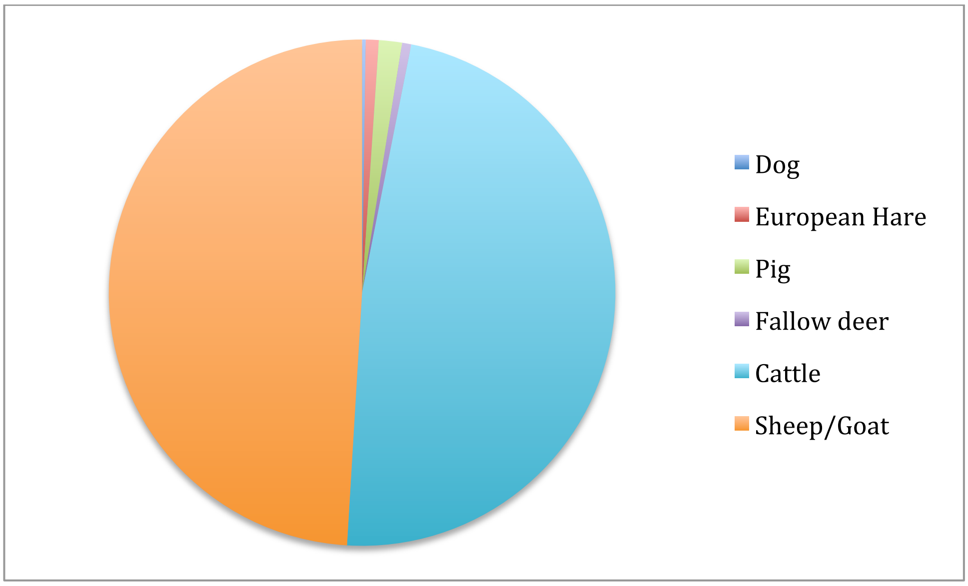

Figure 2.18 Main fauna species from Neolithic contexts at Barçin Höyük.
(Gerritsen, 2012 *pers.comm*).

As is evident from the diagram, the fauna recovered from Barçin Höyük was overwhelmingly composed of cattle and sheep/goat, with a very limited wild component. Interestingly the majority of the faunal remains date to the early Neolithic phases, with nearly 6,000 bone fragments being recovered from phase VID and VIE. This faunal assemblage is somewhat at odds with Aktopraklık, as the dietary data suggests a very specialised economy, despite the fact that Barçin Höyük is chronologically older than Aktopraklık.

2.4.8 Dairying at Barçin Höyük

Perhaps the most studied aspect of diet at Barçin Höyük is the investigation undertaken by Thissen *et al.* (2010) (see also Türkekul Biyik and Özbal 2008) into the use of milk, and the integration of dairy products as a major dietary resource. This area of research was undertaken through the analysis of milk fats (lipids and their degradation products) from pottery fragments.

At Barçin Höyük 137 pottery fragments were analysed from the 2nd/3rd stage of the Late Neolithic sequence at the site. 33 (24% of those sampled) contained organic residues from which stable isotope ratios could be determined. Of the 33 analysed, 55% contained milk lipids, 33% had adipose fat tissues from ruminant animals and 12% produced lipids from porcine adipose tissues. Thissen *et al.* (2010: 166) state that this analysis complements the analysis of the faunal assemblage from Barçin, where the majority of the skeletal material excavated was from domestic cattle and domestic sheep, with some inclusion of wild red deer.

Interestingly, there is no evidence for domestic *Sus* sp. at Barçin Höyük, and the evidence for wild boar species at the site is (so far) very limited. The aDNA from a number of Neolithic individuals at Barçin Höyük was analysed to determine whether they had the necessary mutation for lactose tolerance, but the study was unfortunately inconclusive (Thissen *et al.* 2010). Interestingly, prior to analysis of the faunal assemblage from the nearby site of Ilıpınar, the nature of the slaughter profile present in the faunal assemblage at Barçin Höyük suggested the presence of milk and dairy product use at the site. The study by Thissen *et al.* builds on the work of a much larger project by Evershed *et al.* (2008) who looked into the use of dairying in during fifth to seventh millennium BC from sites in south-eastern Europe, Anatolia and the Levant. The project analysed organic residues from *ca.* 2,200 pottery fragments, including samples from five sites in northwest Anatolia; Aşaği Pinar, Toptepe, Yarimburgaz, Fikir Tepe and Pendik.

However, the characterization of fatty acids via $\delta^{13}C$ values is not straightforward. The $\delta^{13}C$ values of fatty acids are commonly compared to modern dairy and domestic animals fats to act a reference point, but the comparison to wild fauna, such as deer, is rarely considered despite their presence on many prehistoric sites. Craig *et al.* (2012) analysed the $\delta^{13}C$ values of $C_{18.0}$ and $C_{16.0}$ fatty acids from 10 modern red deer samples from Poland. The $\delta^{13}C$ values threshold for ruminant dairy fats is 0‰ to -3‰. The $\delta^{13}C$ values for red deer ranged between -2.7‰ to -4.3‰ – which falls in the range of ruminant dairy fats. The scope for the misidentification of wild fats as ruminant dairy fats is obvious, and this may lead to false conclusions of dairying at prehistoric sites.

2.4.9 Diet reconstruction in prehistoric North-West Anatolia

The study sites are located within the Yenişehir valley in North-West Anatolia. The valley is located about 200m above sea level, enclosed by hills which rise up to approx. 900m asl to the north and southeast, and correspondingly the foothills of the 2500m high Uludağ to the South-West (Gerritsen *et al.* 2013:93). The soils of the North-West region are a mosaic of young alluvial soils, rough broken land and mountains (Oaeks and Arikok 1954). We know that the process of N_2 fixation is affected by temperature and soil dryness. Therefore the expectation is that the semi-arid (NW) and arid regions (C) the soils of Anatolia will have enriched $\delta^{15}N$ values compared to the temperate soils of Europe.

The palynology studies for the Yenişehir Valley was undertaken in the 1980s by Bottema and Woldring (1995). In summary they produced a generalized vegetation reconstruction for the Holocene. The vegetation report was divided into five phases. The most relevant phase to this research period is stage 2, which corresponds to *ca.* 10,000 to 6500 BP (based on radiocarbon dates from seeds). Stage 2 is characterized by open forest vegetation with deciduous trees, and high values of *Centaurea,* the presence of which suggests trampled ground. In the corpus of aquatic plant pollen, there is an overall dominance of watermilfoil (*Myriophyllum* sp.), indicative of standing or slow-moving water.

Detailed reconstructions of the palaeobotanical assemblages have not yet been undertaken for Aktopraklik and Barcin. Recent work by Cappers (2008) at the nearby site of Ilıpınar demonstrates that the inhabitants consumed a broad spectrum of plant resources, such as naked and hulled barley, einkorn and emmer wheat, flax (probably exploited for fibres), but also included leguminous species such as bitter vetch, (including grass and chick pea), faba beans and lentils. Leguminous species often have very low $\delta^{15}N$ values (in some cases of 0‰), which makes their consumption difficult to detect using stable isotope analysis, given problems with equifinality. It is important to consider the presence of leguminous species at the site, as they are subject to N_2-fixing (e.g. they can convert atmospheric N_2 ($\delta^{15}N$=0‰) to ammonia) (Virginia and Delwiche 1982, Marshall *et al.* 2007, Fraser *et al.* 2011).

Efforts to gain access to plant samples from Aktopraklik and Barçin Höyük for carbon and nitrogen isotope analysis have unfortunately been unsuccessful. In the absence of values from North-West Anatolia, results presented by Pearson (2004:244) on plant d^{13}C values from Catalhoyuk (Central Anatolia) will be utilised. Ten emmer grain samples were analysed and produced d^{13}C values ranging -24.2 to -20.3‰, providing an average terrestrial C_3 cereal value of *ca.* -23‰. This isotope value for C_3 plants provides a starting point for the interpretation of human and faunal isotope values from the study region. There are a number of limiting factors associated with the dataset, including the small sample size, the limited number of species analysed and the prominent issue that the environmental variables between the Central plateau and North-West region are markedly different (e.g. altitude, precipitation amount, temperature). Recent work into d^{13}C values for plants to reconstruct diet and water regimes by Bogaard and colleagues has highlighted the importance of analysing seeds and grains, rather than rachis and other plant samples (Bogaard *et al.* 2007, Fraser *et al.* 2011, Fraser *et al.* 2013, Styring *et al.* 2013).

When it comes to reconstructing the presence of animals in the Neolithic landscape we have access to faunal assemblages from all of the study sites. These assemblages give us an insight into what animals were utilised, whether as food or for other applications (traction for example). The issue with faunal assemblages is that they only provide information about the animals exploited at the site, and this record is often incomplete due to issues of preservation and recovery bias. The faunal assemblages at the study sites largely comprise of domesticated species. The species that are most frequently recovered from the Anatolian sites in general are sheep/goat, cattle and pig, with evidence at some sites for the exploitation of a narrow range of wild species, particularly red and roe deer (Roodenberg *et al.* 2013, Budd *et al.* 2013).

2.4.10 Dairying in North West Anatolia

Another factor to consider is the evidence for dairying at the site of Barcin Höyük. Research carried out by Thissen *et al.* (2010) (and Türkekul Biyik and Özbal 2008) demonstrated the extensive presence of milk lipids in pottery sherds from the $2^{nd}/3^{rd}$ Late Neolithic phase of the site, and demonstrated evidence for significant milk use as well as the integration of secondary dairy products at the site. Of particular interest with regards to this topic is the work undertaken by Gourichon and Helmer (2008) into the faunal assemblages of the very nearby and contemporary site of Menteşe (which is within walking distance of Barcin Höyük). Gourichon and Helmer (2008) investigated the slaughter profiles from this site, and concluded that the patterns observed in the Caprovine samples suggested milk exploitation, as attested by the slaughtering of milk lambs less than 3 months of age and the simultaneous slaughter of ewes aged 3-4 years – these are considered to be two complimentary strategies in flock management.

Analysis of the cattle bones from Menteşe reveal a pattern whereby the milk calves were killed exactly at the moment they would be suckled, leading Gourichon and Helmer (2008:439) to suggest post-lactation slaughtering, which would be indicative of husbandry practices geared towards dairy production. Further work on the site of Barcin Höyük, both in terms of detailed analysis of the faunal assemblage and also lipid analysis of organic residues from pottery sherds that have been recovered from the very earliest phases of the Neolithic period will help to illuminate the extent of dairying practices in the region. If it transpires that the pottery sherds do demonstrate evidence for milk fats, it will be the earliest evidence of dairying in the region. This evidence may in turn provide us with information as to the mode of the transition of agriculture and associated practices in the region, (e.g. transmission of ideas and concepts *vs.* indigenous adoption).

In addition to providing direct evidence for diet, isotope analysis can also reveal insights into weaning practices in ancient populations. A number of isotopic studies from Neolithic sites on the Central Anatolian have investigated the evidence for weaning practices. Pearson *et al.* (2010:448) have noted that the timing and duration of breastfeeding can vary dramatically as developmental pressures are mediated by responses to socioeconomic and reproductive strategies. According to Richards *et al.* (2003:74-5) at Çatalhöyük the isotope evidence indicates that juveniles over the age of 1($\delta^{15}N$) and 1·5 ($\delta^{13}C$) years do not have enriched isotope values, therefore, weaning must have started before 18 months of age in these infants. At Aşikli Höyük weaning commenced at 12months and ended by 24 months, whilst at Çayönü Höyük weaning did not occur until 24 months and was completed by 42 months (Pearson *et al.* 2010:453).

2.5 Human-Landscape Interactions During The Neolithic In Central Poland

2.5.1 Key Research Themes

The form that the transition to agriculture took in Poland has been a topic of some interest since the 1970's, but as noted by Bogucki (2000:197), the 'how' and 'why' of the establishment of agricultural communities in Poland has remained elusive.

One of the key limitations in terms of our understanding of the development of the LBK in the Kuyavia region is the role of the Mesolithic populations in this region, and the extent to which migrant farmers were instrumental in the development of farming during the earliest stages of farming (e.g. Pyzel 2009:77). Similarly, it is not easy to identify the causes for the demise of the LBK in the Kuyavia region, and the evidence does not appear to support the hypothesis that over expansion and population growth led to a cultural crisis for the farming communities in this region (*ibid*. 2009).

2.5.2 Palaeoenvironmental Reconstruction in Central Europe

Roberts (1989:115) has noted that during the initial stages of the spread of agriculture in the North European Plain, the pioneering farmer groups actually only exploited a small portion of the landscape, focussing their activities on alluvial and loessic soils (loess is a fine-grained wind-blown sediment deposited during the Pleistocene)(see also Bogucki 2000). By contrast Bogucki *et al*. (1987:1) had suggested that the introduction of food producing economies was a complicated process, which was not uniform in character, wherein the earliest farming communities occupied a variety of ecological zones. Bogucki (2000:199-200) notes that there are two key landscape zones that form the focus for farming groups in north-central Europe. These comprise upland basins drained by major river systems, and flat lowlands (*ibid*. 2000:199). The upland areas comprise dry watersheds that are dissected by dendritic stream systems formed from glacial meltwater runoff, which also contain areas of bog and lakes formed in ice waste hollows in this landscape (*ibid*. 2000:200). The lowlying areas have "chains and clusters of lakes left in meltwater valleys and ded ice features that interrupt patches of ground moraine in several parts of the plain (Bogucki 2000:200).

In essence, the distribution of early agricultural settlements in Central Europe focuses on the discontinuous loess covered upland areas that extend from Ukraine in the east westwards to the low countries and eastern France, and which extent northwards in the Rhine-Mass delta in northern Germany and Poland (Bogucki and Grygiel 1993:400). Beyond the loess belt, in areas such as Kuyavia in Poland, where the area is covered by glacial moraine and outwash deposits, the soils are characterised as gley soils (soils that develop under conditions of intermittent or permanent waterlogging), which Pyzel (2009:71) notes, are as fertile as the chernozem (loess) soils to the south.

The vegetation zonation for Europe originally followed the Blytt-Serander climatic scheme for the postglacial period, with five climatically distinct zones being identified from peat bog stratigraphies (Low and Walker 1984:132 and table 3.3), with the main zones for the Neolithic period comprising the Atlantic to Sub-Boreal periods of climatic optima (equivalent to Gowin's zones VIIa and VIIb). Blytt and Serander observed that according to the palynological data they studied, the Atlantic period was characterised by warm and wet/damp conditions whilst the Sub-Boreal was characterised by a drier, slightly cooler, climate (Bogucki 1988:18). The earlier Holocene saw the rapid expansion of forests in the northern part of the European plain as the effects of the glacial conditions receded. During the Boreal and Atlantic periods as the forest expanded to reach its climax state, human groups were beginning to limit their movements within these environments (Bogucki *et al.* 1987, Bogucki 1988).

2.5.3 Overview of Climate Change in Central Europe

The climate of Central Europe is generally considered to have been similar over much of the continent (Bogucki 1988:18), although as might be anticipated distinct local variation does occur throughout this region. Bogucki (2000:198-9) has noted that by the sixth millennium BC north-central Europe temperatures were on average ca. 2°C or so higher than today, with humidity levels varying regionally. In Central, and parts of Eastern, Europe the climate was dryer than in northwestern Europe, perhaps making the conditions more akin to those experienced in southeast Europe and Anatolia (Bogucki 2000:199).

2.5.4 Pollen And Vegetation in the Kuyavia Region, Poland

The climate in mid-northern Poland (the Kuyavian plain) is characterized by humid continental conditions. The region is located at an altitude of 105m above sea level and is subject to severe winters. It has no dry seasons, and experiences warm seasons and strong seasonality. It has an average temperature of 7.7°C and an annual precipitation of 471mm, and is classified as a cool temperate steppe biome (AquaStat).

2.5.5 The Prehistory Of Central Europe

The prehistory of Central Europe during the Neolithic period is unquestionably dominated by the appearance of the Linearbandkeramik culture (LBK), also referred to as the Linear Pottery culture. The LBK are an early Central European culture that date to approximately 5,500 – 4,900 cal BC, although these chronological boundaries are not absolute and there are a few sites which fall outside of this framework (Whittle 1996, Whittle and Bickle 2013). The genesis of the LBK is thought to lie with Starčevo-Kőrös-Criş cultures of the Hungarian Plains, dating to *c.*5600 cal BC, being identified as the original progenitors based on very similar incised pottery wares and possessing commensurate chronological frameworks (Price *et al.* 2001).

The LBK is largely archaeologically defined by homogeneity in architecture, settlement structure and material culture (Whittle 1996, Van Berg and Hauzeur 2001), although the extent of this uniformity has been questioned in recent years (Zvelebil and Lukes 2004). One factor that is agreed upon (of course) is the location of the LBK sites - discovered almost exclusively along the band of fertile loess soils that traverse from the Hungarian Plain, to the Paris Basin and terminating at the western Ukrainian Plains (Zvelebil 1998, Whittle and Bickle 2013).

The majority of LBK settlements are located on loess soils, near water sources in valleys and in low-lying regions of the landscape. More often than not sites were adjacent to woodland that was experiencing the climatic phase of post-glacial growth (Whittle 1996, Nowak 2013). There are a few sites however that fall outside the remit of the loess belt, the most notable being one of the study regions for this project – Kujavia, Poland. Whittle (1996) notes however that there are no obvious features that distinguish LBK sites in Kujavia from LBK sites on the loess belt.

2.5.6 *Neolithisation in Poland*

Bogucki has noted that the earliest sites of the Linear Pottery culture in the Polish Lowlands date to *ca*. 5400-5300cal B.C., while the later Stroke-Ornamented Pottery and Lengyel cultures date to the 4th millennium B.C., with many sites of this culture being scattered across the lakelands of Kuyavia and Wielkopolska (1988:5) (*figure 2.20*).

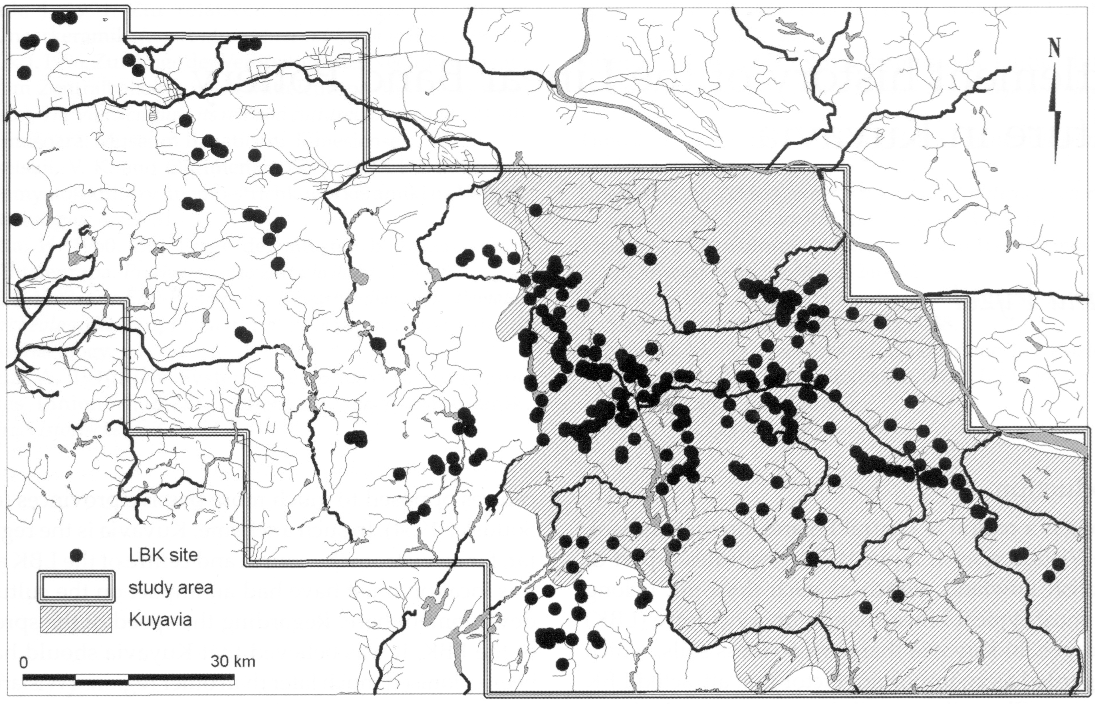

Figure 2.19 LBK sites in Kuyavia, Pałuki and eastern Great Poland.
(after Pyzel 2009: Figure 1). Note: there are a total of 386 LBK settlement site in the areas studied by Pyzel, and as the shaded area for Kuyavia indicates, a considerable number of LBK sites occur in this region of Poland.

There is in fact relatively little in the way of discussion about the origins of the LBK in Poland, and in general there is an implicit assumption that the origins of the Neolithic in Kuyavia (an area of some 4616km^2) occurs as a result of migration (or migrations) of LBK farmers into the region (Pyzel 299:71). These observations are reinforced by the fact that a: there are no precursors to the LBK pottery forms in

Kuyavia, b: Late Mesolithic lithic inventories are characterised by geometric forms, whilst early Neolithic LBK stone tools inventories are characterised by blade tools, and c: Mesolithic and Neolithic house structures are markedly different (Bogucki and Grygiel 1993:402). Bogucki (2000:209) has argued that, in general, the evidence from north-central Europe indicates that farming was not developed as a result of indigenous adoption by local foragers, but that it is intrusive to the region.

Recent research by Pyzel (2009) has suggested that the evidence for LBK settlement sites in the Kuyavia region is indicative of relatively intensive occupation in certain regions, with areas of poor soils or areas lacking water sources being avoided to some degree (Pyzel 2009:72-3). The paucity of absolutely dated sites remains an issue for the earliest stages of the LBK in this region, and whilst there are some indications that settlements were both durable and stable, often covering more than one phase of LBK activity (Pyzel 2009:75), the lack of dating resolution results in some overlaps in the chronologies that are based on artefact inventories (*ibid*. 2009). Irrespective of the limitations imposed by the lack of dating evidence it is apparent that the earliest stages of the Neolithic in this region are characterised by an initial phase of settlement that is quickly followed by the relatively rapid expansion of LBK settlement sites across the Kuyavia region. It is this phase of LBK migration into the region that forms the basis for the development of Neolithic economies in Kuyavia from *ca*. 5400calBC.

2.5.7 A History Of Research in the Brześć Kujawski Region

The earliest recorded excavation of a Neolithic site in this region was of Brześć Kujawski, and was undertaken in the early 1930's by Konrad Jażdżewski. In his

1933 report, Jażdżewski detailed the presence of significant quantities of animal bones from the site - the fact that the animal bones were systematically recovered testifies to the forward thinking method of Jażdżewski's research methods for the era (Grygiel 2008:1584). Unfortunately, a great deal of the archaeological material that was recovered during these early excavations (1933-1939) was lost during World War II.

In 1976, Ryszard Grygiel and Peter Bogucki began excavations at Brześć Kujawski, and from the beginning of the excavations they recognized the huge potential of the Neolithic features that were uncovered from the site, particularly the utility of the considerable quantity of fauna bone discovered (Grygiel 2008). High priority was placed on the detailed and systematic recovery of the fauna bones, and the material obtained from Brześć Kujawski during 1976-1979 formed the basis of Bogucki's doctoral thesis at Harvard (Bogucki 1981).

In 1987 a test trench was dug at Osłonki 1 and it indicated the presence of a Neolithic settlement as well as yielding copious amounts of well-preserved fauna bone. From 1989 to 1994 Grygiel and Bogucki conducted excavations at Osłonki 1 with support from the National Geographic Society, the Wenner-Gren Foundation for Anthropological Research Inc., and Komitet Badań Naukowych. In 2008 Grygiel published three volumes of *Neolit I Początki Epoki Brązu w rejonie Brześcia Kujawskiego i Osłonek* (The Neolithic and Early Bronze Age in the Brześć Kujawski and Osłonki Region) chronicling the finds from the sites.

2.6 Overview and Chronology of Study Sites

The area that is used to contrast Anatolia with Europe is the Kuyavia region of north-central Poland (figure 2.20), where a number of site clusters dating to the Neolithic period at *c.* 5500 – 4000 cal BC have been investigated archaeologically (Bogucki *et al.* 2012). A glossary of the major terms used to describe the archaeological context of the region is presented in table 2.5. It is not a comprehensive table of all the Neolithic cultures present in the Central and North European plain, but provides the major contextual information pertaining to the study region.

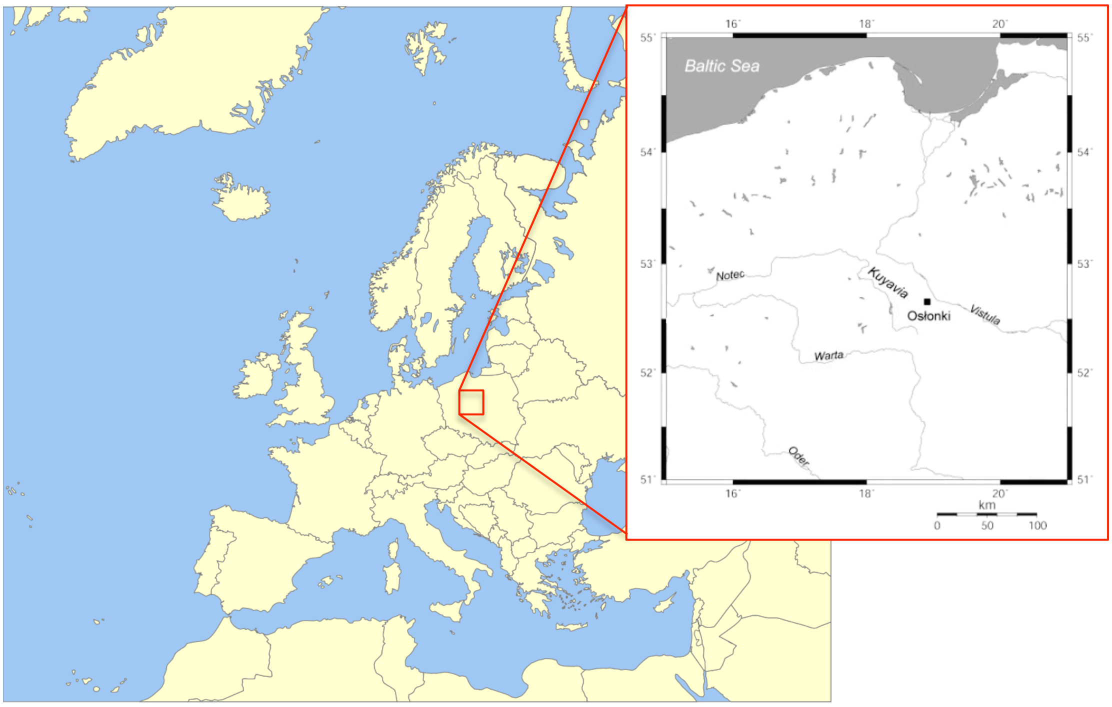

Figure 2.20 Map of Northern Poland showing the study region of the Kuyavia region and the site of Osłonki 1.
(Bogucki *et al*. 2012:46, www.wikipedia.org).

The Linear Pottery culture in the Kuyavia region is evident from 5400-5000 BC[1], and was spread out along low sections of land and over tunnel valleys and shallow lakes. By approximately 4700 BC[1] sites began to appear that belonged to the Brześć Kujawski group,[2] a late variant of the Lengyel culture (Bogucki *et al.* 2012). The Brześć Kujawski group (referred to as the GB-K in the literature) is most synonymous with the appearance of the initial florescence of copper-using societies in South-Eastern Europe. The GB-K cultural group flourished for a number of centuries, and has been divided into three phases; early, classic and late (figure 2.21).

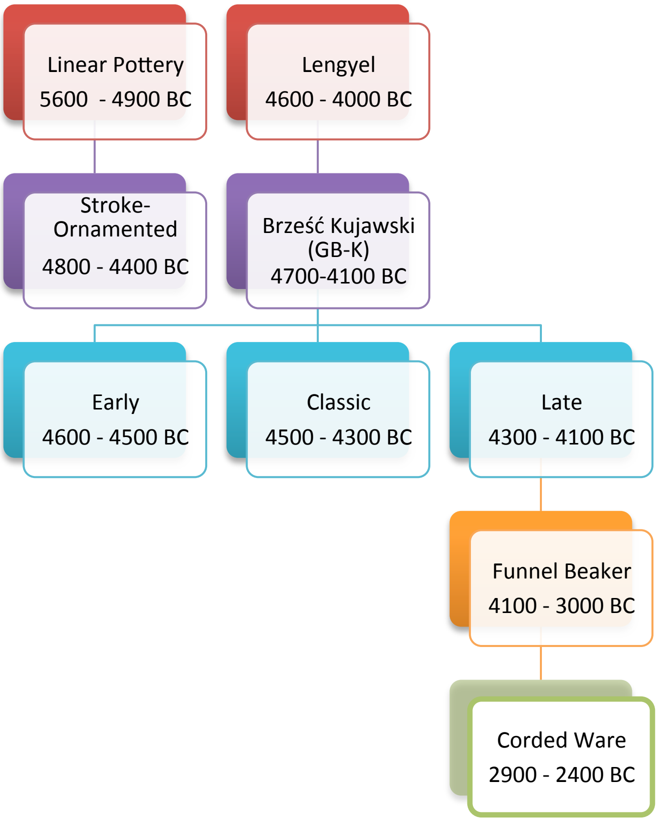

Figure 2.21 Simplified schematic of Neolithic Cultural Groups in the study region of the Kujawy Region of north Central Poland.
Note that the cultures are not necessarily linked in their genesis (e.g. GB-K is not necessarily derived from LP).

There are a number of major observable differences between the phases of occupation that date to the Linear Pottery period (5400 – 4900 cal BC) and those that

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[1] Radiocarbon determinations obtained from a number of organic proxies at the site (discussed later in the text) and calibrated in OxCal using the INTCAL04 calibration curve.

[2] The terms 'GB-K' and 'Brzsec Kujawski group' are interchangeable.

date to the GB-K phases (4700 – 4100 cal BC) across the study region. There is a clear difference in the biodiversity of the fauna assemblages between the LBK and GB-K periods, with the onset of the GB-K phases seeing an expansion of fauna resources, most notably the inclusion of fish and turtle in the record. Furthermore, the evidence for LBK settlement is largely based on post-holes and there is no clear structural, or material, remains for longhouses. This is at odds with the archaeological data recovered from the GB-K phases, which, even from the earliest phases has evidence for longhouses and re-working of these longhouses.

Term	Definition
Linear Pottery Culture/LBK **[5600 – 4900 cal BC)**	A.k.a. *Linearbandkeramik.* Major archaeological culture of the Neolithic period in Europe.
Stroke Ornamented Culture **[4600 – 4400 cal BC]**	A Neolithic culture descended from the LBK. Limited presence in Silesia in Poland, but mainly found in eastern Germany and northern Czech Republic.
Lengyel Culture **[4600 – 4000 cal BC]**	A Neolithic culture proceeding the LBK, present in Poland, Hungary, the Czech Republic and former Yugoslavia.
Funnel Beaker Ware/ TRB **[4100 – 3000 cal BC]**	Neolithic culture mainly present in north-Europe that was influenced by Lengyel and Rössen cultural groups [Rössen Neolithic group was present in Germany].
Corded Ware Culture **[2900 – 2400 cal BC]**	Neolithic culture that succeeds the Lengyel Culture. It is the direct descendant of the Lengyel culture and is considered to be the first Neolithic culture native to Central Europe.
Brześć Kujawski Group/ GB-K **[4600 – 4100 cal BC]**	A variant of the Lengyel, specifically found in the Kujavia region of North-Central Poland.
Brześć Kujawski Cluster	A cluster of Neolithic sites nearby to the Osłonki cluster. Sites include Brześć Kujawski, Pikutkowo, Smólsk, and Ludwinowo.
Osłonki Cluster	A cluster of Neolithic sites including Osłonki 1 and 1a, Konary 1 and 1a, Miechowice 1, 4 and 4a.
Osłonki 1 and 1a	Osłonki 1 is the study site from the region, Osłonki 1a is its smaller, sister site.

Table 2.5 Glossary table for the Polish study region.
(Bogucki 2012, Bogucki and Grygiel 1997, Bogucki 2008).

There are number of issues which frame the debate for understanding of the Neolithic period in the Kujavia region. The most notable of these includes assessing the extent of variation between the Linear Pottery (LBK) phases and the Lengyel phases at the sites, e.g. to what degree is there evidence for continuation and affinities between the phase, and also to consider why the hiatus in occupation during the Lengyel period occurs after the evidence for extreme violence, and why the evidence for copper ornamentation is limited to only the Classic phase. From a dietary perspective, the main points of interest are whether there is any evidence for a change in flora and fauna dietary resources between phases, and whether Bogucki's (1986) suggestion of milk processing (e.g. cheese making) based on the presence of pottery sieves at select sites, contributed significantly to the diet and reflects the development of more complex farming practices.

2.6.1 Osłonki 1

Osłonki 1 is the key Polish site for this project, and is located at 52°37'N, 18°48'E at an elevation of approximately 90masl (metres above sea level)(Bogucki and Grygriel 1997). It is the largest site in a cluster that comprises of Miechowice 4, Miechowice 4a, Konary 1 and Konary 1a among others (figure 2.22). The sites are located on the Kuyavian plain, a region consisting of morainic clays that are dissected by glacial tunnel valleys and areas of sandy outwash (Bogucki *et al.* 2012:46).

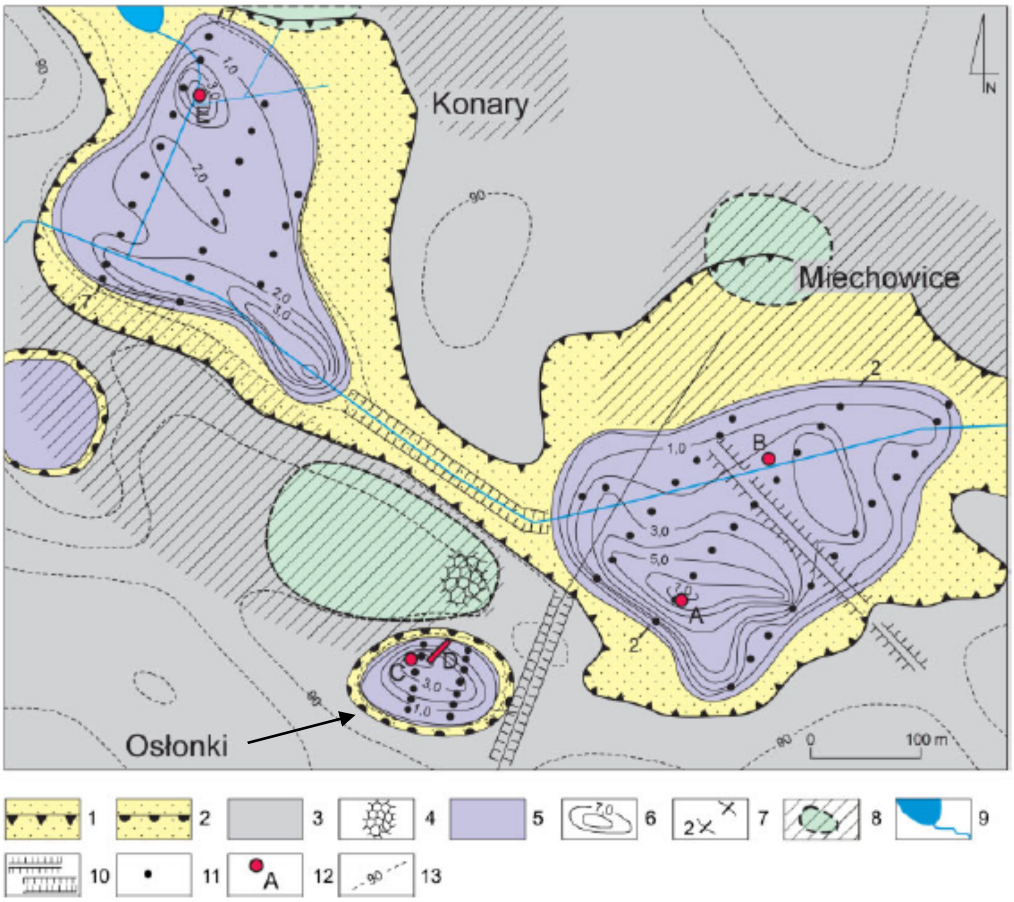

Figure 2.22 Location of Neolithic sites in the Polish study cluster.
(P. Bogucki 2012). Key from Bogucki *et al*. 2012:50; 1- margins of glacial trough showing extent of ablation sands; 2-depressions resulting from melting of buried ice; 3-flat ground moraine – moraine till; 4-frOs t fissure polygons in ground moraine; 5-biogenic accumulation plains – peats, gyttja, organic silts; 6-depth contours of biogenic depOs its; 7-lines of geological sections 2 and 8; 8-approximate extent of Neolithic settlement; 9-hydrological network; 10-contemporary anthropogenic landforms (embankments/banks and cuttings/ditches); 11-borings in biogenic basins; 12-locations of cores used for palaeobiological physical-chemical analyses were taken. (A – Os 94-9 and Os 94-9A, B - Os 16, C - Os 1-2a, D - Os 94-5, E - Os 57); 13-contour lines in 1-25 m intervals.

Osłonki 1 is located on the northern edge of the distribution of early Neolithic settlements in Central Europe, in an area that lay beyond the borderlands that separated the farmers from the foragers in the Baltic zone. The geomorphology of the landscape is punctuated with glacial and peri-glacial features (such as sub-ice channels and kettle lakes), which are largely relics of the Weichsel glaciation, (dating to *c.*20,000 BP). During the Neolithic period the area was characterized by brooks and intermittent streams, and the area was possibly connected by a chain of smaller streams and lakes although further evidence is required for corroboration. Figure 2.23

highlights the distribution of the Osłonki site cluster, and illustrates that the environmental reconstruction of the area suggests the presence of lakes and streams.

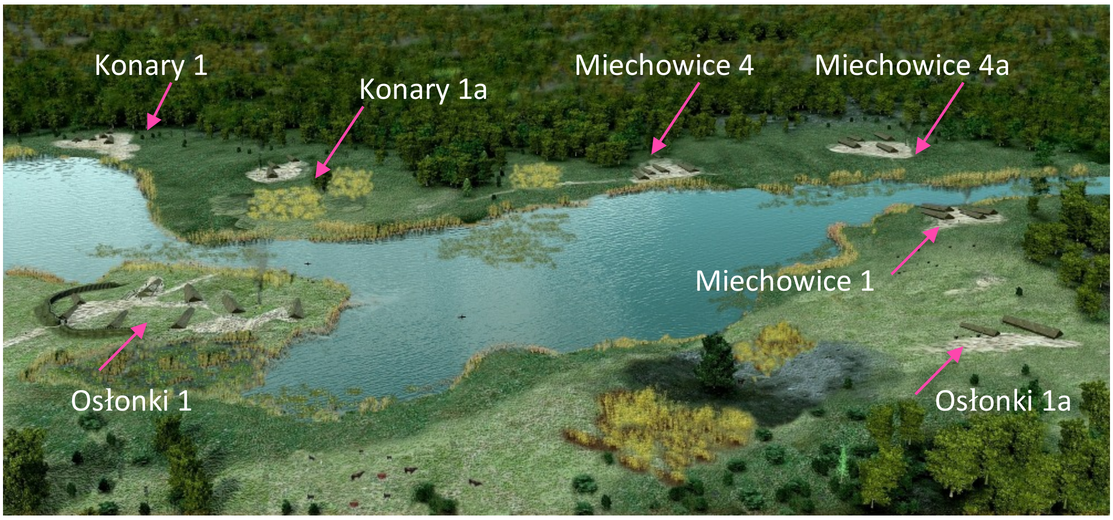

Figure 2.23 Reconstruction of Osłonki site cluster.
(Bogucki 2012).

The Linear Pottery phase in the riverine interior began at approximately 5600 cal BC and reaches its endpoint at around 4900 cal BC. This disparity between faunal assemblages appears to be largely a result of differences between the sedimentology of the areas, and consequently preservation biases in archaeological contexts. The sites that are located on/or adjacent to the loess areas are overlain by decalcified soils, and these soils prove to be conducive to bone degradation, which is why tooth remains are most often recovered from sites located in these regions. The sites that are located on clays or gravels, including the study site, are in depositional contexts that provide very good preservation environments for bone material.

The skeletons that have been sampled from Osłonki 1 are taken from the GB-K of the Lengyel culture, which was present in Kuyavia in Central Poland during the Early and Middle Neolithic periods (Lorkiewicz 2011). The Osłonki cluster began with an initial LBK settlement at Miechowice 4 during the late 6th millennium cal BC. This settlement has multiple pit features and light post structures. There is a hiatus of approximately two centuries, and Bogucki *et al.* (2012:47) state that this reflects a general interruption in settlement throughout the Polish lowlands at the onset of the 5th millennium BC. This period of absence ends with the appearance of a settlement at Konary 1, which is associated with the latest phase of Stroke-Ornamented pottery culture.

The GB-K sites in the Kujawy region are comprised of four major features: long trapezoidal longhouses (up to 40m), graves, clay extraction pits and small pits. At Osłonki 1, occupation can be divided into three phases, Early, Classic, Late and the settlement features associated with each period is evident in table 2.6 and figure 2.24.

To date, evidence for *c.*30 longhouses have been recovered from Osłonki 1. The longhouses present are characteristic of the Lengyel culture, narrow at the north end and wide at the south end, utilising continuous bedding trenches to anchor the posts (Bogucki and Grygiel 1997:166). They range in size from approx. 15-20m during the Early phases, and in some cases reaching 40m in the Late phase (figure 2.26).

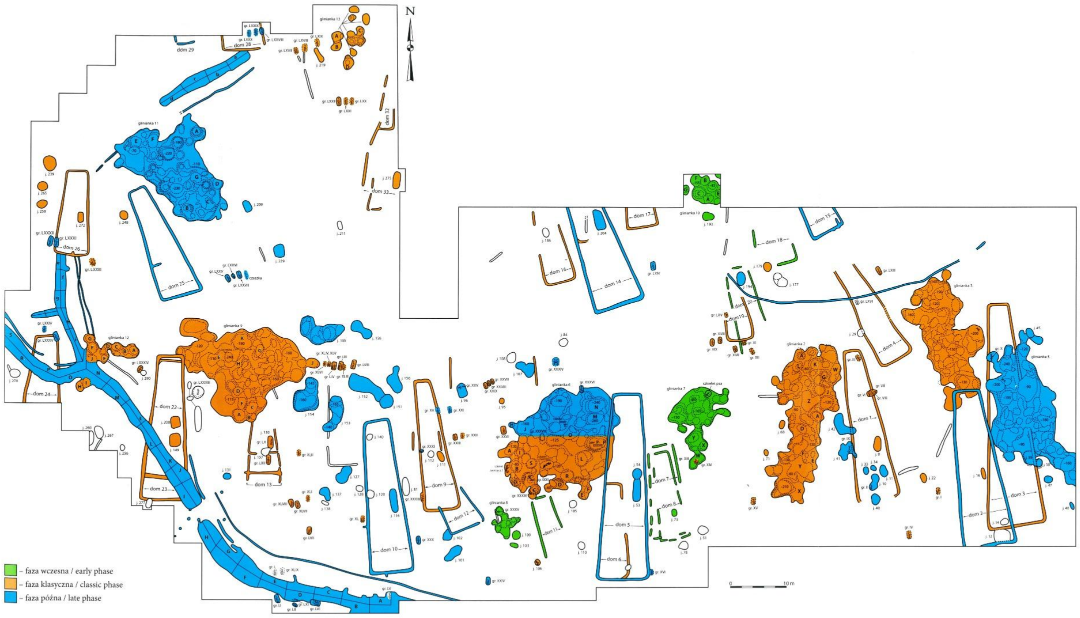

Figure 2.24 Settlement plan of Osłonki 1.
(Bogucki 2012), where features in green represent the Early, orange the Classic, and blue the Late phase.

Phase	Date (cal BC)	Features
Early (green)	4700 – 4500	□ 4 (partial) longhouses □ Evidence for re-building □ 3 clay pits.
Classic (orange)	4500 – 4300	□*c.*12 longhouses □4-5 clay pits □Burials outside houses
Late (blue)	4300 – 4100	□5 longhouses – significantly bigger than previous phases □2 partial longhouses □Burials outside houses Small pits □Cellar pits inside houses □Extensive palisade

Table 2.6 Summary of phases at Osłonki 1.
The colour key refers to figure 2.29. Longhouses are trapezoidal in shape.

The different chronological period and cultural groups are defined by variations in pottery type. Osłonki 1 is characterized by the discovery of 30 trapezoidal longhouses (figs. 2.25 and 2.26) and 80 burials. Notable finds recovered from the site include a copper diadem (representing some of the earliest evidence for metal use in Central Europe), and the burial of an 'archer' – an individual interred with a five bone arrow points (figure 2.32). The environment at Osłonki 1 was subject to alteration due to extensive land clearance, timber cutting for construction and firewood, crop cultivation and grazing of animals. In addition, the inhabitants of Osłonki 1 hunted wild animals and waterfowl and fished in nearby lakes and streams. The site is also host to a number of satellite sites that were used for tending crops and ambushing game (Bogucki 2012).

Figure 2.25 Aerial photograph of the settlement at Osłonki 1.
(Bogucki 2012).

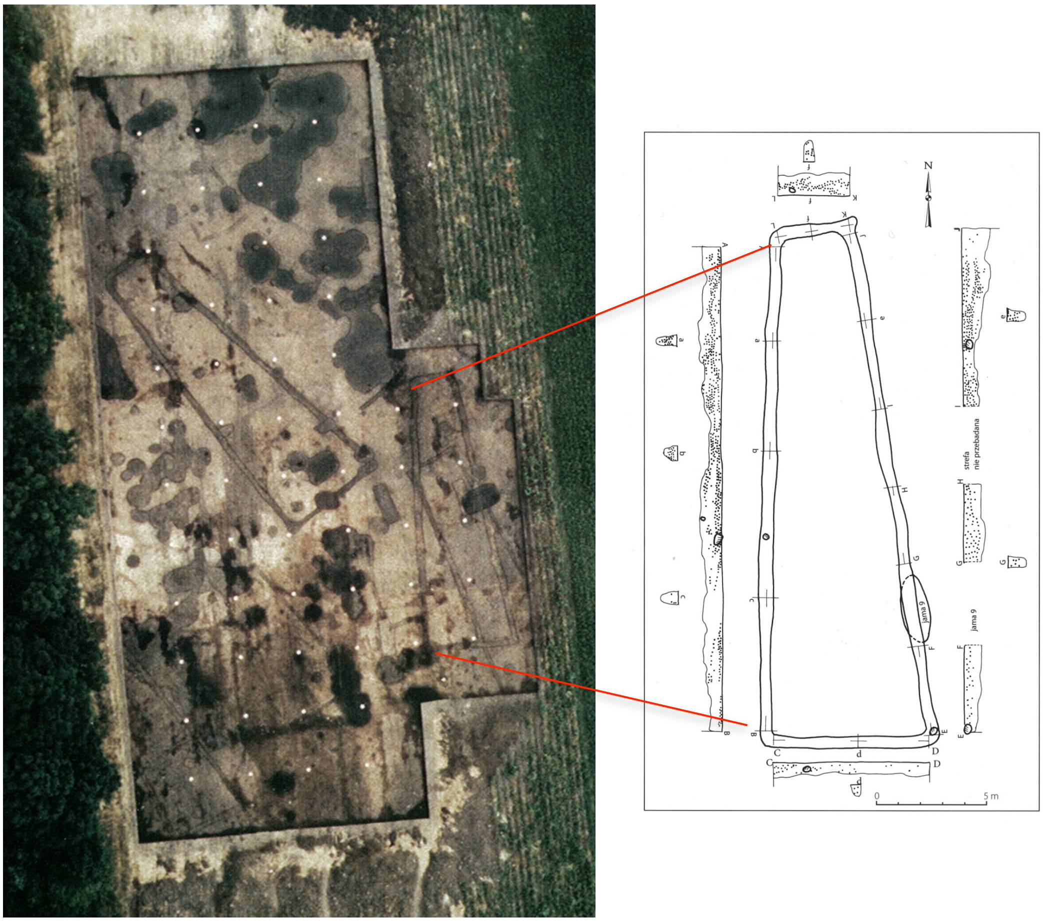

Figure 2.26 Example of a trapezoidal longhouse at Osłonki 1.
(Bogucki 2012).

In addition to the longhouses present at Osłonki 1, the settlement site is punctuated with a number of clay and rubbish pits. The clay pits are characterized by their large size and considerable depth (often running to $100m^2$ in area and >1m depth). The pits were created initially as the source for clay that was used to plaster the house walls, and presumably also for pottery manufacture. Post-extraction the pits' primary function was for domestic refuse; with Bogucki and Grygiel (1997) suggesting the deposition of 'rotten wood, disintegrating skins and fibers, inedible plant parts, ashes, offal and spoiled meat, human and animal wastes, and other by-products of sedentary existence' (Bogucki and Grygiel 1997:169). The pits lack clear stratification, and it is plausible, given their size, that sections were left open for extraction at the same time that other areas were subject to the deposition of domestic refuse.

Alongside the clay features at Osłonki 1, there are also smaller scale rubbish pits, which contain dense accumulations of artifacts (pottery, flint tools and debitage) and animal bones (and charred grain in select areas). The initial purpose of the rubbish features is unclear, but the final use was for waste disposal (Bogucki and Grygiel 1997:169). The majority of the rubbish pits are approximately oval in appearance, and have a surface area of *c.*3-4m^2 and depths of *c.*1m. A number of the pits are located inside the longhouses, which may suggest that there were utilised for storage whilst the houses were still occupied. The rubbish pits that are located in the open plan of the settlement are *c.*1-2m^2 and *c.*1-1.5m in depth, and the dense concentrations of debris have led to the suggestion of short-term deposition events (Bogucki and Grygiel 1997:170). The rubbish pits form the largest source of the faunal bone that will be used for stable isotope analysis for this study. From a practical standpoint, short-term deposition of the fauna bone is good, because this will limit long term chronological differences in the isotope values that are the result of climate fluctuations. However, the unclear stratigraphy for the fauna bone at the site, particularly for the clay pits, is a limiting factor for the study.

Finally, an aspect of the settlement that was not expected at Osłonki 1 is the extensive fortification system that dates to the Late Phase (4300 – 4100 cal BC). The system is present in the western part of the settlement and comprises of an extensive ditch that is over 2m deep in parts and has a V-shaped section. There are also traces of a banked palisade next to the ditch and evidence to suggest two phases of construction. Bogucki and Grygiel (1997) argue that the ditch is a fortification system as it is similar in structure to ditches discovered from Early Neolithic sites in Belgium, at Darion, Oleye and Longchamps (Keeley and Cahen 1989), and they highlight that it is naturally defended on three sides by wet marsh environments. The presence of a fortification system appearing during the Late Phase (c.4300 cal BC) of the GB-K is commensurate with the increased level of inter-personal violence observed in the human population during this period (Lorkiewicz 2012). The evidence for skeletal trauma and violence evident in the population at Osłonki 1 is discussed in the burials section.

The pottery recovered from Osłonki 1 is simple and plain in design, and is comprised of bowls of varying size and amphorae with cylindrical necks (Bogucki and Grygiel 1997:171). The pottery is made from mica-tempered fabric and is largely homogenous in appearance. The decoration is minimal and appears to be mostly produced using fingernail indentations on the rims and handles. This is in contrast to other Lengyel groups in the Carpathian basin, where there is widespread evidence of incised decorations and painted ware. Grygiel (1986) undertook a typology study on the pottery recovered and identified three phases of development, each phase characterized with stylistic evidence for increasing contact between the Kujawy region and the Silesia region (located in eastern Poland, and sharing borders with modern day Germany and the Czech Republic).

Tools recovered from Osłonki 1 were fashioned from either flint or ground stone. The flint tools consist mainly of blades and tools made of blades, such as knives and scrapers. The source flint for the tools at Osłonki 1 came from a number of sources in the surrounding area, the majority of flint originated from Kraków, the Holy Cross mountains (both Poland) and from Volhynia in south-eastern Poland or the Ukraine (Bogucki and Grygiel 1997). In addition, the population at Osłonki 1 had access to local flint pebbles that were distributed along the retreating ice sheets in the lowlands. The stone tool assemblage that was recovered from deposits at Osłonki 1 highlighted high quantities of adzes and ground stone axes, which came in a variety of sizes and had shaft holes, presumably these were for affixing wooden hafts. The inhabitants at Osłonki 1 also made use of a number of bone, shell and antler artefacts. The most notable antler artefacts recovered are the 'T-shaped axes" which are synonymous with both Mesolithic and Neolithic phases of occupation.

The Lengyel phase in the Kujawy region sees the onset of the Chalcolithic, a period characterized by the appearance of copper artefacts in the archaeological record. The copper recovered from Osłonki 1 may have originally originated from the Carpathians or the eastern region of the Alps, as these areas are the nearest sources of copper ore that were utilized during the Neolithic period. Four main classifications of copper artefacts are identified at Osłonki 1; small cylindrical beads, 'spectacle spiral' (strip of copper ribbon), copper plaques, and finally a copper diadem. This final copper artefact is unique to the Lengyel culture in east-central Europe, and at Osłonki 1, the diadem was recovered from Grave XIII (discussed further in section 2.6.2). The presence of copper artefacts in the archaeological record at Osłonki 1 is important as they occur exclusively during the Classic phase, and there is no evidence for copper artefacts in either the early or later graves (Bogucki and Grygiel 1997:172). The procurement of copper took place over a relatively short duration of <200 years.

2.6.2 Lengyel Burials

In total, there are 183 burials dating to the Brześć-Kujawaski Lengyel phase from the Kujawy region. At Osłonki 1 there are 62 adult, and 31 child and adolescent burials. The burials are largely associated with the Classic and Late phases of occupation, with the majority located outside of the longhouses (figure 2.27).

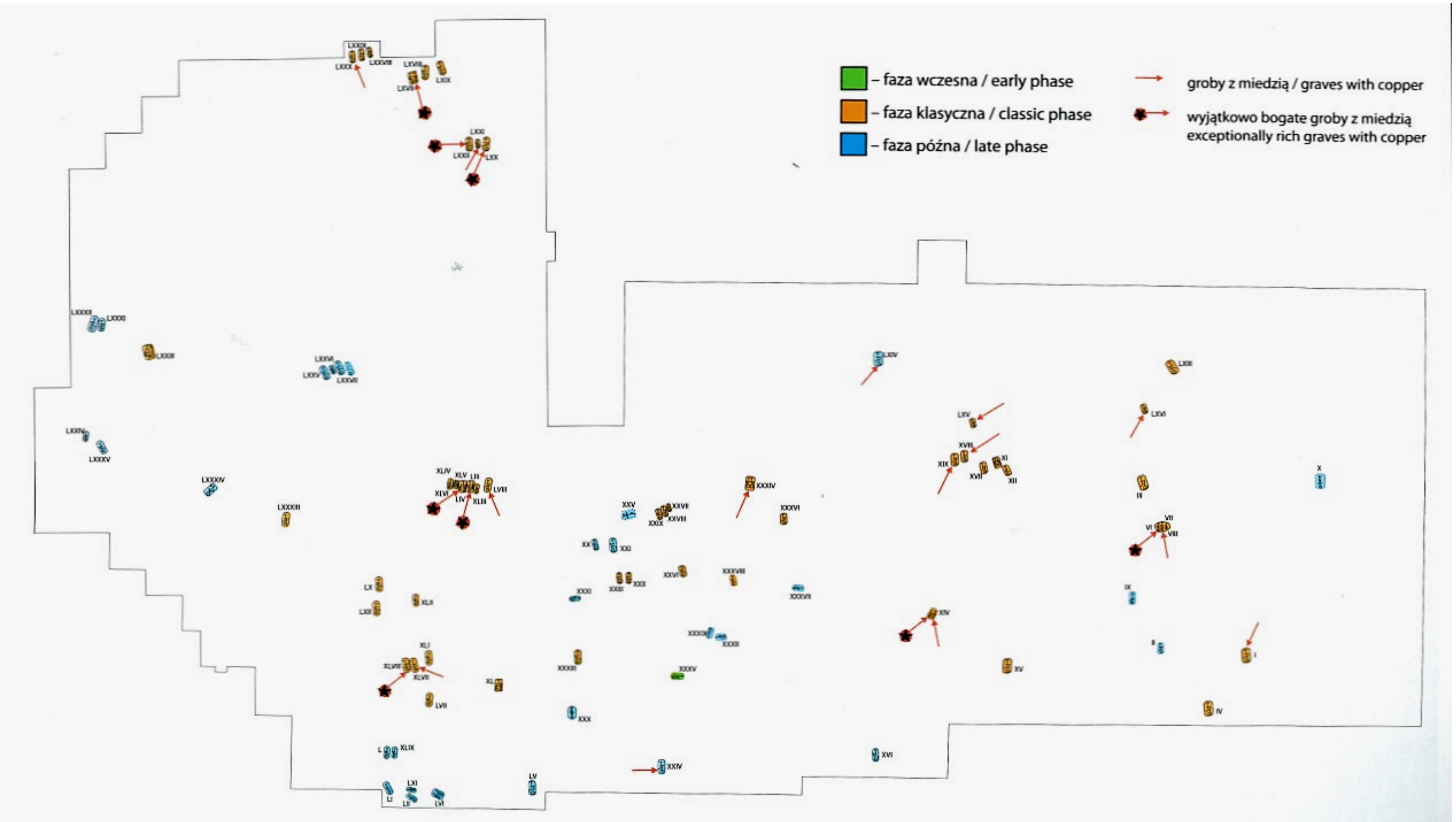

Figure 2.27 Location of burials at Osłonki 1(Bogucki 2012).

The interments at Osłonki 1 are mainly crouched single graves (figure 2.28 – 2.31), although there are a few examples of double graves, and in one case a triple interment. The grave goods vary between copper artefacts, such as small cylindrical beads, to more elaborate copper ribbons and copper plaques (during the Classic phase only (figure 2.28)). Table 2.7 highlights the associated grave goods for the humans that form part of this isotope study.

Figure 2.28. Burials 76, 77 and 75 from Osłonki 1.
(Bogucki 2012).

During the Classic phase, the inhabitants of the site strictly adhered to a number of burial rituals; all of the individuals were orientated with their heads in a SE direction, with the males lain on their right sides and the females positioned on their left sides.

Phase	Burial No.	Sex	Age	Grave Goods/Notes
Early	35	m	25-35	No grave goods.
Classic	1	f	17-25	Copper beads
	6	m	40-50	Copper beads and plaques; perforated animal teeth; none tool
	12	m	15-19	No grave goods
	18	f	17-25	Copper plaque; copper beads; shell beads
	22	m	25-30	No grave goods
	23	m	20-30	Unidentified bone object
	26	m. this guy has a lot of stuff	35-45	Antler T-axe; boar tusk, bone tools, flint blades
	27	m	50-60	No grave goods
	33	m	35-45	Antler T-axe, small vessel, shell beads
	38	m	25-35	Dug into fill of Clay Pit 6 but orientation of skeleton is classic
	40	f	20-30	Hip belt made of shell beads
	42	m	30-35	Necklace made of belemite beads.
	48	f	18-22	Diadem ornaments, binocular spiral pendant and copper beads. Necklace made of copper and calcite beads.

	53	f	25-30	Double burial, left skeleton analyzed; copper plaque and beads, bone dagger, amber ornament
	54	f	25-35	Huge amounts of copper plaques, beads, shell bead belt.
	63	m	30-40	antler beam T-axe; died violently
	67	m	20-25	Necklace made of copper beads, shell beads, and trapezoidal metal sheet. Necklace made of copper beads and shell beads.
	69	m	40-50	Large pottery vessel
	72	m	15-19	Diadem made of copper beads, necklace made of trapezoidal copper sheets and shell beads. A tool made of chocolate flint.
	73	f	25-35	Part of triple burial.
	80	m	17-25	Baltic flint artefacts, bone dagger point. Necklace made of copper beads, trapezoidal copper sheets and a shell bead. Antler axe. Looks Classic in orientation, Grygiel says Late.
Late	21	f	25-30	Base fragment of ceramic vessel
	24	f	25-35	Two whole ceramic vessels, copper beads; ceramic handle
	32	f	20-30	Looks late on basis of orientation and being dug into fill of Clay Pit 6 adjacent to grave 39; no goods

	39	f	30-40	Looks late on basis of orientation and being dug into fill of Clay Pit 6 adjacent to grave 32
	55	m	40-50	No grave goods
	61	f	30-40	No grave goods
	64	f	25-35	Vessel, copper bead, heap belt made of shell beads. Looks Classic in orientation
	81	f	20-30	Vessel. Antler object.
?	59	?	?	?

Table 2.7 Burials and grave goods from Osłonki 1.
(Grygiel 2004: 899-991)

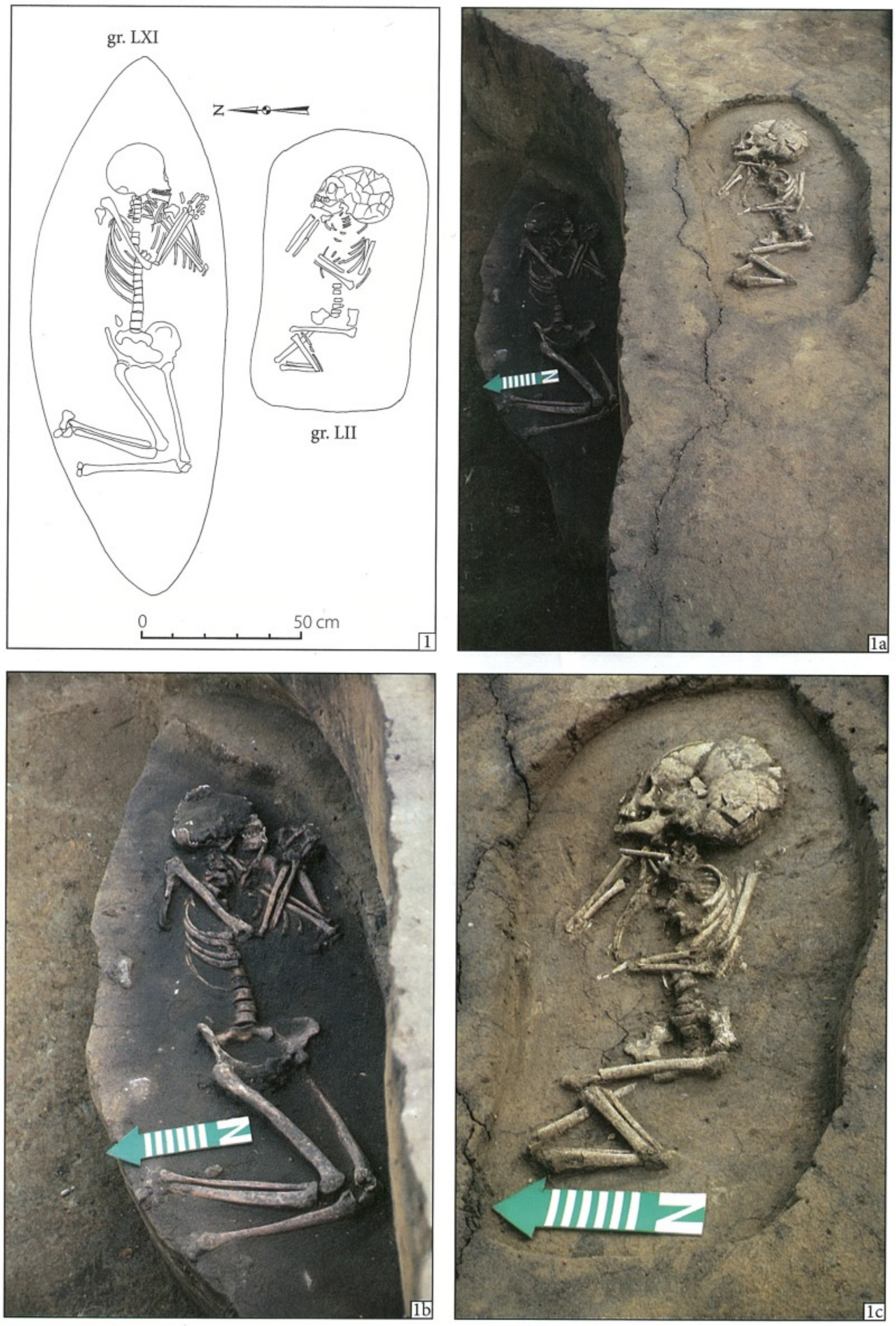

Figure 2.29 Adult female (burial 61) and child (burial 52) at Osłonki 1.
(Bogucki 2012).

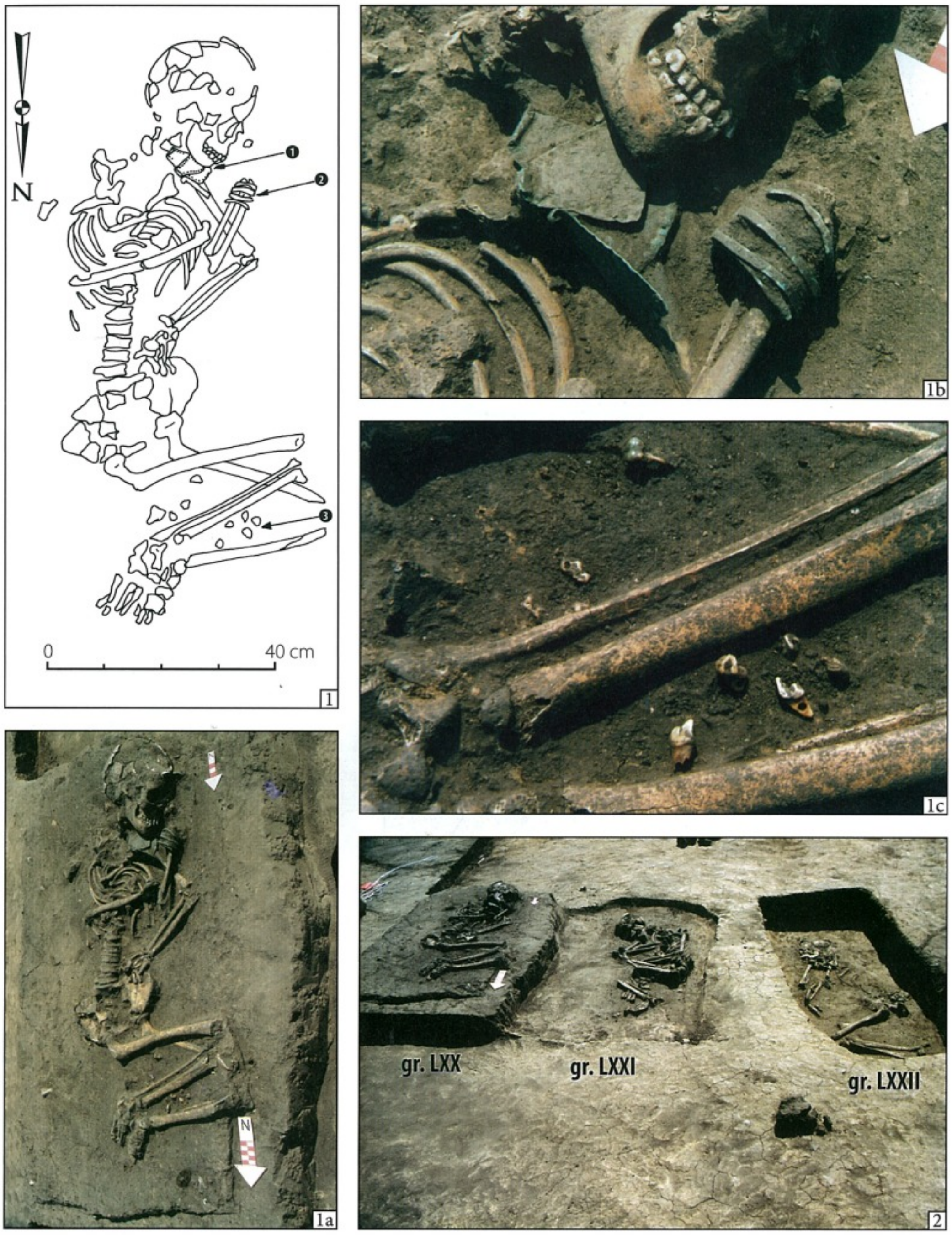

Figure 2.30 Plates 1 to 1d are images of burial 70. Plate 2 displays burials 70, 71 and 72 (Bogucki 2012).

Figure 2.31 Associated grave goods from burial 70.
[1. Copper pendant. 2. Copper bracelet. 3.Tooth pendant] (Bogucki 2012).

The anthropological analysis undertaken on the skeletal remains from the site of Osłonki by Lorkiewicz (2012) formed part of a larger study that incorporated a number of individuals from the Brześć Kujawski Group of the Lengyel Culture (4600-4000 BC). In total 183 individuals were analysed, and these individuals are from the sites of Osłonki 1, Brześć Kujawski 3 and 4, Miechowice 4 and 4a, Konary 1 and 1a, Pikutkowo 6a, Smólsk 2 and Ludwinowo 3. The analysis of Osłonki 1 will be discussed in the most detail, and a review of the findings from the other sites will be considered to provide contextual analysis of the findings from Osłonki 1. All of these sites are located in a relatively small area of Kujaway, which has a diametre of approximately 20km (Lorkiewicz 2012:180).

The sex and age of the individuals from Kujavy region were determined based on bone characteristics. Of the 183 individuals studied, 117 were adult age, 28 were juveniles (15-20 years) and the remaining 41 were children (0-14.9 years). Lorkiewicz (2012) was able to determination the sex for 125 individuals (60 females and 65 males). The collective mean age at death for adults was 35.2 years (the average for females is 34.1 and 36.5 for males), and the mortality peak for adults in this study is 20-40 years.

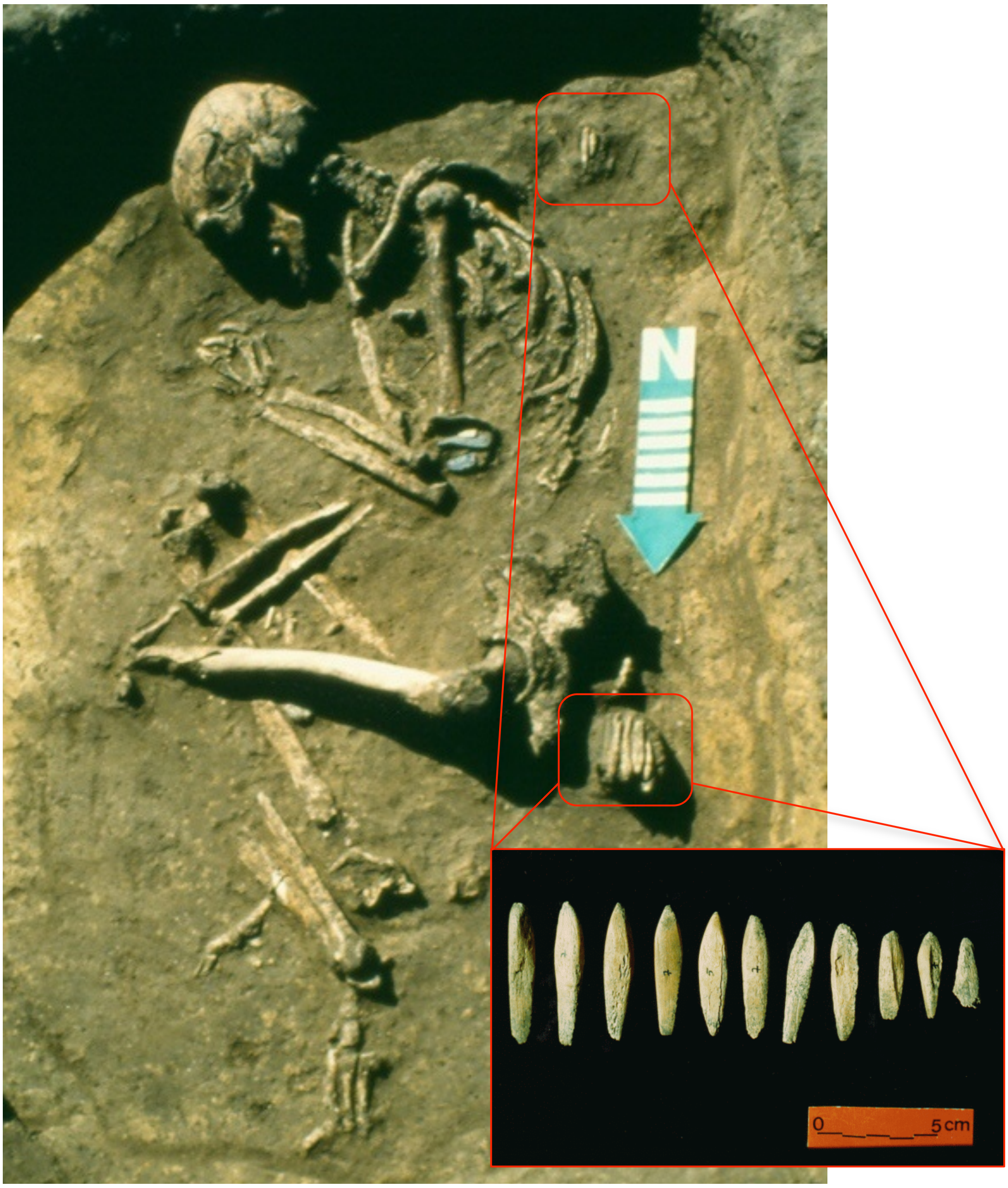

Figure 2.32 The 'archer' from Osłonki 1
(Bogucki 2012).

2.6.3 Fauna and Flora Remains in the Kuyavia Region

The palaeobotanical research undertaken at the Osłonki site cluster by Aldona Mueller-Bieniek and her colleagues has yielded some interesting results (Bieniek 2002, 2007; Mueller-Bieniek & Nalepka 2010, Nalepka 2005). Overall the palaobotanical results indicate an established suite of domestic species including emmer and einkorn wheat, a ‘new’ type of glume wheat, hulled barley and peas. Only one Linear Pottery (LP) phase of occupation has yielded plant remains, and this is from the site of Miechowice 4. All of the sites contained plant remains in their GB-K phases of occupation, and all exhibited segetal weeds (which grow in fields of grain) that are commonly associated with early farming societies in central Europe. According to Mueller-Bieniek, one unexpected result that arose from the analysis is the high concentration of feathergrass at a number of sites and features - which is an unusual component of steppe vegetation. The presence of feathergrass suggests heterogeneity in the steppe biodiversity that was not hitherto expected (*ibid.*).

2.6.4 Flora and Fauna Remains at Osłonki 1

The animal assemblages present in the region mainly consisted of domesticated livestock that ultimately arrived from their centres of domestication in the Near East and Anatolia. The zooarchaeological record from the region provided some interesting data in relation to subsistence strategies over time. The major factor is the pronounced difference between the Linear Pottery and Brzesc Kujawski faunal assemblages. The LP assemblages are dominated by cattle bone, and there are only marginal remains from sheep and goat; there are almost no pig remains at all dating to the LP phase, and wild herbivores such as red and roe deer are even fewer in number. In contrast, the beginning of the GB-K phases at the cluster witnesses an expansion in faunal diversity. The assemblages remain dominated by cattle bones at ~ 40-50%, but sheep/goat at GB-K make up ~30% of the total, while the bones of pigs comprise ~20-25% of the total MNI. The presence of wild herbivores such as red and roe deer are not common, but they are far more prevalent during these phases than previously recorded. Figure 2.33 summarises the mammalian faunal assemblage recovered from Osłonki 1. In addition, there are a number of terrestrial and aquatic bird remains, alongside fish (perch, pike and Cyprinidae), and even pond tortoise (*Emys orbicularis*). There is clearly an expansion in the range of faunal species present during this period.

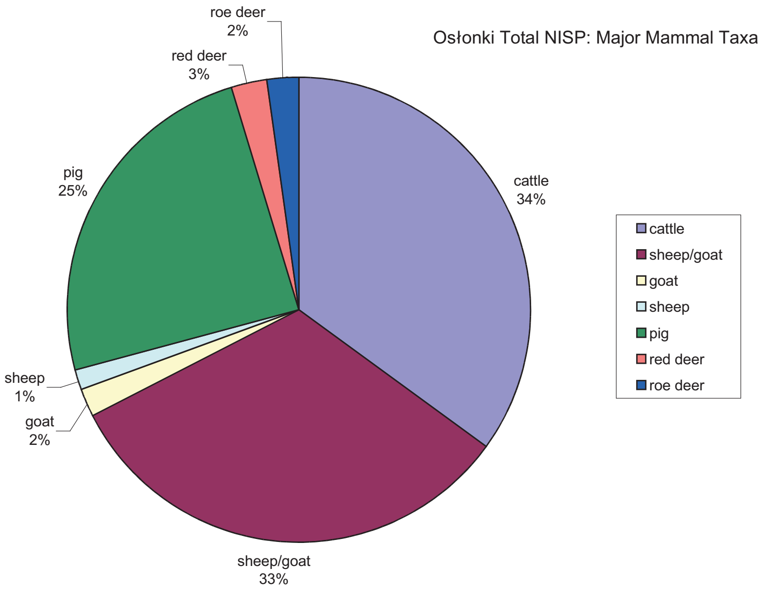

Figure 2.33 NISP for Osłonki 1.
(Bogucki 2008:1608).

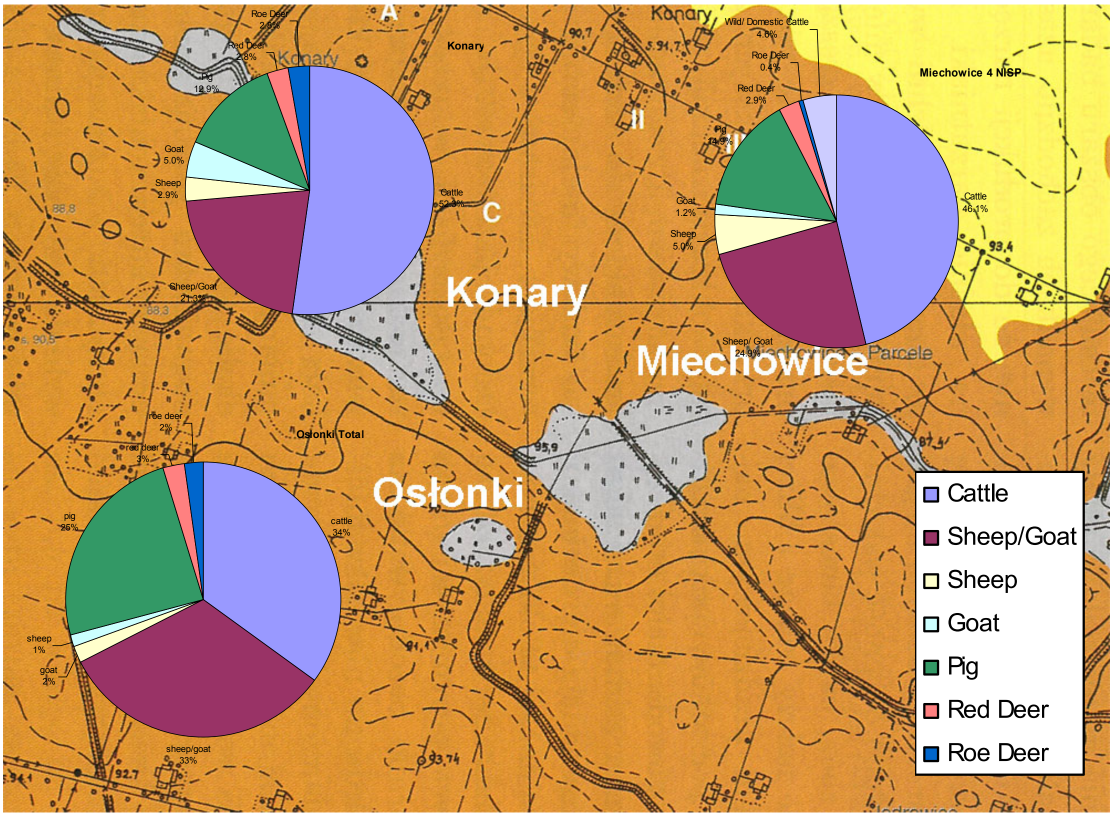

Figure 2.34 Fauna NISP from Osłonki 1 and surrounding sites.
(Bogucki 2008, 2012).

As is evident from figure 2.34 the composition of fauna assemblages does vary slightly between Neolithic sites located in the Osłonki cluster. Konary and Miechowice have similar compositions, comprising approximately 50% cattle, 25% sheep/goat and 20% pig. Osłonki 1 fauna however exhibits a slightly different composition, with approximately 35% cattle, 35% sheep/goat and 25% pig species. The reason for this differentiation of fauna assemblage remains unclear, but is a little surprisingly in light of the dairying in evidence at Osłonki 1 (section 2.6.5). Further divisions in fauna are in evidence in the Brześć Kujawski and Osłonki region between the Linear Pottery and Lengyel phases (figures 2.35 and 2.36).

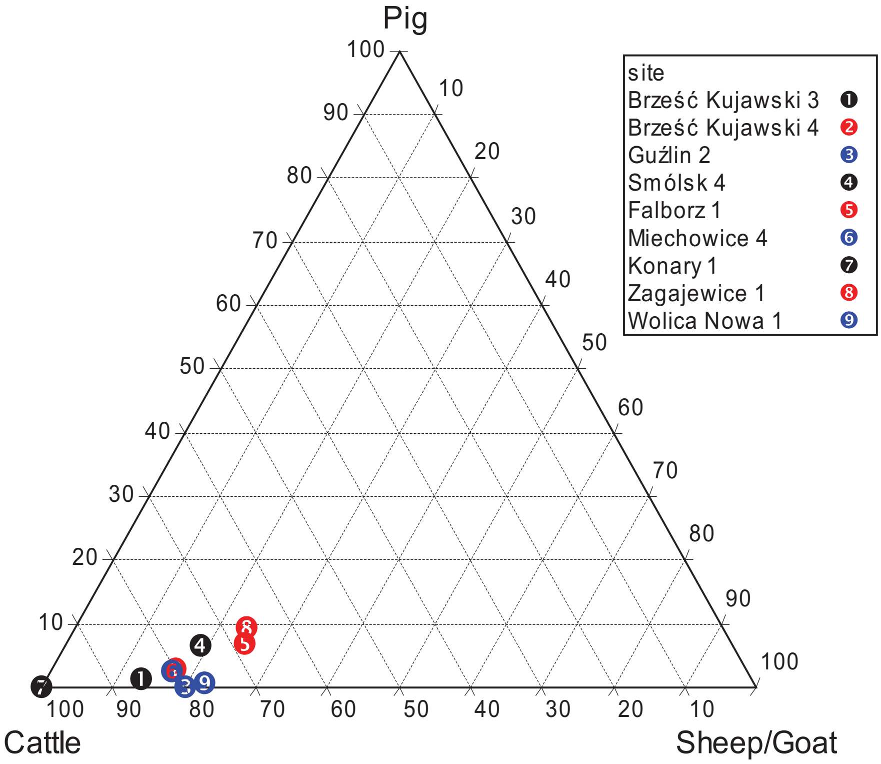

Figure 2.35 LBK phase tertiary fauna diagram for sites in the southeastern Kujawy region. (Bogucki 2008:1586).

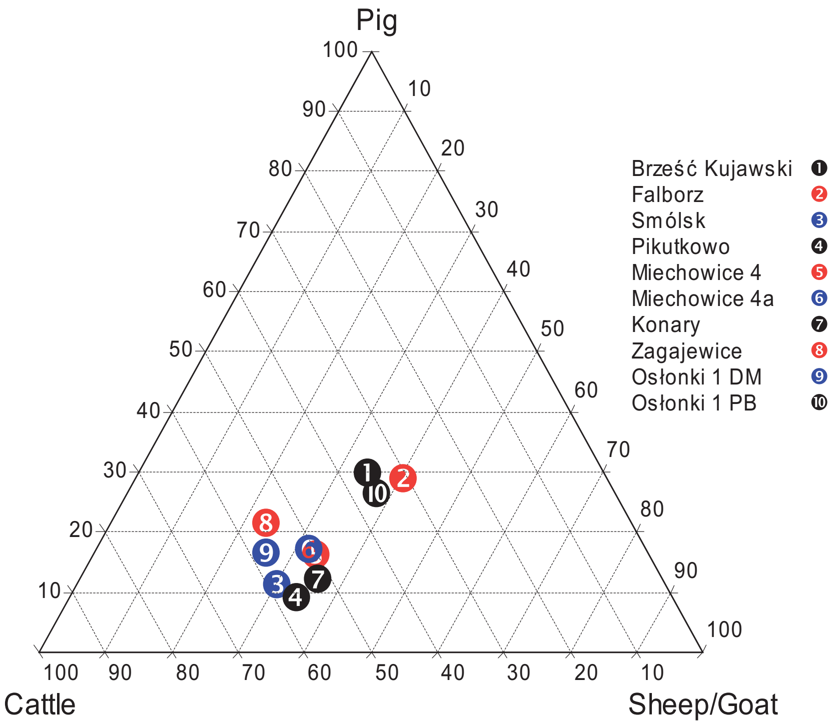

Figure 2.36 Lengyel phase tertiary fauna diagram for sites in the South-East Kujawy region. (Bogucki 2008:1635).

During the Linear Pottery phase, cattle overwhelmingly made up the majority of the fauna assemblage at all sites, ranging between *c.*70% to *c.*>99% of the total assemblage (Bogucki 2008). By the Lengyel phase the fauna assemblage was a more inclusive mix of cattle, sheep/goat and pig, with the sites of Osłonki 1, Falborz and Brześć Kujawski showing a diversification of resources at this time.

2.6.5 Dairying and Cheese Making in the Kuyavia Region

It is widely established in the literature that the emergence of dairying was a major innovation for prehistoric societies. It was a critical step in the development of early agriculture, and the use of milk products was rapidly adopted by prehistoric farmers, as well as pottery using hunter-gatherers (Evershed *et al.* 2008, Dunne *et al.* 2012, Craig *et al.* 2005, 2011, Copley *et al.* 2003). The pioneering research undertaken by Evershed *et al.* (2008) (discussed earlier), has conclusively demonstrated an abundance of milk residues in pottery vessels from 7th millennium sites located in North-West Anatolia provided the earliest evidence of milk processing.

The processing of milk, particularly the production of cheese, would have been an important development as it allows the preservation of milk products in a non-perishable and transportable form, but it also made dairy products more digestible for prehistoric farmers (Salque *et al.* 2012, Bogucki 1984, McCracken 1971). The production of cheese is a fairly complex process, which, briefly explained, involves the coagulation of milk, the yielding of curds and the straining of liquid whey. The straining of whey in modern contexts in achieved using coarse cheesecloth, or metal or plastic sieves (Salque *et al.* 2012). Of course, the straining of whey could be achieved during the Neolithic period using textiles, or even wicker containers. However, a number of fragments of pottery pierced with small holes have been recovered from Central LBK settlements, including a number of sites located within the Kujavia region; Miechowice 4, Smólsk 3 and 4, Ludwinowo 6 and 7, Wolica Nowa 1, Brześć Kujawski 3 and 4, and Stare Nakonowo 2.

Salque *et al.* (2012) examined the organic residues found on these pottery sieves to look for evidence of milk processing; and analysed the residues from 'cooking pots' to act as a control group. The study was looking for the presence and $\Delta^{13}C$ values of $C_{16.0}$ and $C_{18\cdot0}$ fatty acids, as well as the presence of triacylglycerols (TAGS) and their degradation products (diacylglycerols (DAGS) and monoacylglycerols (MAGS)). TAGS (and accompanying degradation products) were recovered from 90% of the animal fats recovered from the pottery sherds. The $\Delta^{13}C$ values of the fatty acids analysed from the pottery sieves are commensurate with dairy fats, at approx. 0‰ to -3‰. The cooking pots yielded residues with $\Delta^{13}C$ values of -3‰ to -7‰, which is within the range expected for adipose fats. Despite Craig *et al.*'s (2012) research (discussed earlier) demonstrating an overlap in values between dairy ruminant of wild adipose fats, this possibility would seem unlikely in light of the very limited wild fauna remains recovered from the site.

This study demonstrates the first evidence for the specialized use of vessels during the Neolithic between approx. 5,300/5,400 and 4,900/4,800 cal BC (Salque *et al.* 2012:4). In contrast to the sieves [and bowls] that were analysed, the cooking pots were predominantly used for processing of large ruminant carcass products, probably cattle, or sheep and goats. As discussed earlier, the fauna assemblage from Osłonki 1 is characterized by a high proportion of domestic cattle bone, and the other LBK sites in the Kuyavia cluster are no exception. Salque *et al.* (2012) interpret this high abundance of cattle at milk-yielding sites as reflecting the importance of cattle and the intensification of milk use. Furthermore, the authors highlight that their research is consistent with the work of i) Burger *et al.* (2007), who suggest that the processing of milk to manufacture low-lactose-content cheese is consistent with the predicted low level of lactase persistence in northern Europe during the early Neolithic, and ii) Itan *et al.* (2009), who highlight the evidence of milk use by LBK populations is consistent with the predicted increase of the frequency of the -13,910*T allele (which is associated with lactase persistence in prehistoric northern Central Europeans).

2.7 Summary

Overall, the review of the archaeological evidence for the study regions demonstrates evidence for similarities in the type of species present in the two regions (Anatolia and Central Europe) despite the chronological differences in occupation. Both of the regions experience a widening of fauna resource breadth during the later phases, and in both regions this diversification coincides with a shift to less optimum climate conditions.

Chapter 3: Isotopes

3.1 Introduction

This chapter provides an overview of the application of carbon and nitrogen isotope analysis of bone collagen for palaeodietary reconstruction of past populations. The chapter reviews the basic principles underlying the use of stable isotope analysis, and details the environmental controls that can affect isotopic composition in bone collagen.

3.2 Isotopes in the Biosphere

There are 300 natural stable isotopes in the biosphere, and 1500 unstable isotopes (both artificial and natural) (Hoefs 1997). Elements and their isotopes circulate in the biosphere, the processes of fractionation and mixing combine to produce regular, characteristic isotope distributions on this planet. There are 92 natural chemical elements, and most of these occur in more than one isotopic form. Most of the isotopes are stable, that is, they do not undergo a process of radioactive decay, unlike their unstable 'chemical siblings' - radioisotopes. Stable isotopes are chemical elements that have the same atomic number, but a different atomic mass.

3.3 Carbon Isotopes

The element of carbon occurs in the atmosphere in three isotopes, ^{12}C (98.89%), ^{13}C (1.11%), and ^{14}C (1.2×10^{-10}%). ^{12}C and ^{13}C are stable and do not undergo radioactive decay. ^{14}C is radioactive and decays at a predictable rate. The carbon cycle involves active exchanges of CO_2 among the atmosphere, terrestrial ecosystems and the surface ocean - it represents one of the most important cycles in nature, and circulates between organic and inorganic environments. Carbon isotope abundances are measured in the standard per mil notation according to the following formula (eq.1):

$$\delta^{13}C = [(R_{sample} - R_{standard})/R_{standard}]*1000$$

Equation 1. Measuring carbon isotope abundances.

where $R={}^{13}C/{}^{12}C$ and the accepted standard is VPBD (Vienna Pee Dee Belemnite).

3.3.1 Fractionation of Stable Carbon Isotopes in Plants

The isotopic fractionation of carbon (${}^{13}C/{}^{12}C$) provides direct information about pathways utilised in the terrestrial carbon cycle. Plants that use C^3, C^4, and crassulacean acid metabolism (CAM) photosynthetic pathways display characteristically different discrimination against ${}^{13}C$ during photosynthesis (O'Leary 1981). C_3 plants discriminate against ${}^{13}C$ more heavily than their C_4 counterparts, and as a result C_3 plant taxa exhibit lower $\delta^{13}C$ than C_4 plants (Farquhar et al, 1982, O'Leary 1995, Vogel 1980). The principle components that dictate the rate of fractionation during the process of photosynthesis are the diffusion of CO_2, the interconversion of CO_2 and HCO^-_3, the incorporation of CO_2 by phosphoenolpyruvate carboxylase or ribulose bisphosphate carboxylase, and respiration (Park and Epstein 1960, Smith and Epstein 1971, O'Leary 1981). Farquhar *et al.* (1982, 1989) explain the fractionation of stable carbon isotopes in plants using the following equation (eq.2):

$$F = a + (b - a)\ \frac{C_i}{C_a - d}$$

Equation 2. Fractionation of stable carbon isotopes in plants

Where F represents the magnitude of isotopic fractionation (also referred to as discrimination) and a, b and d are isotope effects due to diffusion (*c.*4.4‰), carboxylation, and a combination of respiration, liquid-phase diffusion and carbon export. C_i/C_a represents the ratio of $[CO_2]$ in the interstitial spaces of photosynthesizing leaves to that of the atmosphere (Codron *et al.* 2013:302). These physiological processes are affected by local environmental conditions, such as *p*CO2, solar insolation, temperature, moisture availability etc. (Codron *et al.* 2013, Ehleringer 1993, Dawson *et al.* 2002).

It is important to note that carbon isotope discrimination (Δ) differs from $\delta^{13}C$ as it describes only the change in isotopic composition induced by the plant, eliminating any variation as the result of the starting value of the atmospheric CO2 that was used for photosynthesis (Cernusak *et al.* 2013:2). The definition of Δ was first stated by Farquhar and Richards (1984), through the following equation (eq.3):

$$\Delta = \frac{R_a - R_p}{R_p} = \frac{\delta_a - \delta_p}{1 + \delta_p}$$

Equation 3. Definition of Δ

where R_a represents the $^{13}C/^{12}C$ ratio of atmospheric CO_2, and R^p is the value of plant carbon. In the proceeding form of this equation, δ_a is the $\delta^{13}C$ if atmospheric CO_2 and δ_p is that of plant carbon. The $\delta^{13}C$ value is defined in the equation above.

The CO_2 fixation of terrestrial plants results in the formation of a 'C_3 body', 3-phosphoglycerate (3-PGA), an organic compound that is comprised of three atoms

(Bassham *et al.* 1956, Falkowski *et al.* 2000, Meier-Augenstein 2010). Plant species that utilize the 3-PGA pathway for CO_2 fixation are referred to as 'C_3 plants' in the literature, and are mostly (but not exclusively) found in terrestrial environmental settings. C_3 plants have $\delta^{13}C$ values that broadly range between -20‰ to -30‰. C_3 plants that form part of human diets include trees (i.e. fruits and nuts), temperate grasses, legumes and most major plant food groups including wheat, barley, rye and rice (O'Leary 1981). The majority of plant species are C_3 taxa.

In response to hot climatic conditions some plant species have adapted a response to utilize a different pathway in order to increase their rate of glucose production. For this alternative photosynthetic pathway, CO_2 fixation by RuBisCO is compartmentalized and fuelled with CO_2 from a preceding carbon fixation step that uses the enzyme phosphoenolpyruvate carboxylase (Meier-Augenstein 2010:25). The first major product that this process produces is C_4-dicarboxalic acid, oxaloacetate. This is referred to as the Hatch-Slack cycle, and plant species utilizing this photosynthetic pathway are referred to as 'C_4 plants' (Langdale *et al.* 2011). C_4 plants have $\delta^{13}C$ values that range between -10‰ to -20‰. Different taxa of C_4 plant species also utilise different sub-pathways, i.e. nicotinamide adenine dinucleotide phosphate-malic enzyme (NADP-ME), nicotinamide adenine dinucleotide-malic (NAD-ME), and phosphoenolpyruvate carboxykinase (PCK), discriminate differently against ^{13}C. This results in small (approximately 1‰) but significant variations in $\delta^{13}C$ values between different C_4 taxa. Generally speaking, C_4 taxa that use PCK and NAD-ME pathways (^{13}C-depleted) are found in xeric habitats, whilst those (C_4 taxa) using the ^{13}C-enriched NADP-ME sub-pathway typically occur is mesic habitats (Hattersley 1982, Sage *et al.* 1999, Cerling and Harris 1999, Codron *et al.* 2005, 2013). Well-known C_4 plants species that comprise part of human diet include sugar cane, sorghum, maize and millet (O'Leary 1988, Pechenkina *et al.* 2005).

The final photosynthetic pathway is Crassulacean Acid Metabolism, referred to as 'CAM' species, and is utilized by plant species that thrive under desert conditions. CAM plants use the preceding carbon fixation step, and utilize the enzyme phosphoenolpyruvate carboxylase to produce C_4-dicarboxalic acid, oxaloacetate (Szarek and Troughton 1976).

3.3.2 Environmental Controls affecting Carbon Isotopes in Plants

There is a considerable amount of literature that is dedicated to understanding the environmental and physiological mechanics that affect $\delta^{13}C$ values in plant tissues. The main factors that directly affect $\delta^{13}C$ values in plant tissues are aridity (moisture availability), canopy effects (including light intensity), and humidity. There are also a number of factors that act as a secondary proxy for these effects, such as altitude (Rehder and Schafer 1978, Jacot 2000), latitude and seasonality (Lowdon and Dyck 1974, Smedley *et al.* 1991). For example, $\delta^{13}C$ plant values vary with altitude, as rainfall levels and temperature change with altitude (Körner *et al.* 1988, Sparks and Ehleringer 1997, Hultine and Marshall 2000, Körner 2007).

The final ^{13}C content of a plant's tissues is a function of the amount of isotopic fractionation during photosynthesis. C_3 isotopic fractionation is directly affected by environmental parameters (listed above) and these can impact the $^{13}C/^{12}C$ ratio of a plant by increasing stomatal conductance and potentially causing a decrease in carboxylation rates. At a basic level, fractionation in C_3 plants species is large (~20‰) and the rate of progress is affected largely (but not exclusively) by the concentration of CO_2 within the leaf of the plant (O'Leary 1981, 1988, Farquar *et al.* 1989), and by the function of stomatal control.

3.3.3 Moisture

Farquhar *et al.* (1982) state that $\delta^{13}C$ values in plants can be used as a measurement of comparative water use efficiency. The measurement of $\delta^{13}C$ provides a simple method for estimating the average partial pressure of CO_2 in the intercellular spaces of the plant during the growth of a leaf in the field, and this is weighted according to the instantaneous rate of net photosynthesis (Farquhar *et al*. 1982:127).

According to Jones (1998:387) the 'stomata occupy a central position in the pathways for both the loss of water in plants and the exchange of CO_2', and this implies that fractionation rates (and photosynthesis) are controlled by water availability. O'Leary's early work lead to a spate of research agendas which investigated a number of 'wetness' environmental parameters including; atmospheric moisture (Stuiver and Braziunas 1987, Brüggermann *et al.* 2011), soil moisture (Duquesnay and Dupouey 2000, Wang *et al.* 2010) and temperature (Heaton 1999). The issue of how to distinguish between similar environmental parameters for the purposes of this study is not without its complications. For example the parameters of drought, aridity and moisture availability all have distinct definitions in the academic literature, but the net affect to the carbon isotope values in plant tissues is the same. Furthermore the extent of 'drought' 'aridity' and 'moisture availability' is largely a function of temperature and rainfall (among other factors such as elevation, geomorphology etc.).

The issue of how moisture availability affects stomatal discrimination in plants, and how this impacts on their carbon isotope values has been investigated at length (Farquhar *et al.* 1982, Ehleringer and Cooper 1988, Farquhar, Ehleringer and Hubrick 1989, Broadmeadow and Griffiths 1993, Ehleringer, Hall and Farquhar 1993, Hidy *et al.* 2009, Bonafini *et al.* 2013, Cernusak *et al.* 2013, Wallace *et al.* 2013).

Stewart *et al.* (1995) processed *c.*350 samples from 12 plant communities along a 900km precipitation gradient in Southern Queensland, Australia, and demonstrated a strong relationship between $\delta^{13}C$ and rainfall levels ($r^2=0.7$). Wallace *et al.* (2013) took this research further by measuring $\delta^{13}C$ values from experimentally grown crops subject to different levels of watering at Tal Jebbin, Syria (as well as measuring carbon isotope values from plants collected from farm's in Syria, Jordan and Greece also grown under different watering profiles). The research highlighted that well watered wheat grains on average had $\delta^{13}C$ values above 17‰, and poorly watered wheat grains had carbon isotope values typically below 16‰. The overall pattern observed in moisture availability and plants is that environments that have wetter conditions will produce plants with higher $\delta^{13}C$ values. This is because the environmental parametres that affect ^{13}C in plants have some level of control over how efficiently the plant is able to use water during photosynthesis (which affects the level of CO_2 used). However it should be noted that a couple of studies have highlighted a non-significant relationship between rainfall and $\delta^{13}C$ (Schulze *et al.* 1996, Codron *et al.* 2006).

3.3.4 Light

There have been a number of studies investigating how light intensity can affect $\delta^{13}C$ in plant tissues, and a few of these studies examine the effects as part of the research remit of the canopy effect on $\delta^{13}C$ (Zimmerman and Ehleringer 1990, van der Mewe and Medina 1991, Schleser 1995, Bonafini *et al.* 2013). Yang *et al.* (2011) undertook a study looking at the effects of low intensity continuous light against a low intensity diurnal light source on carbon and hydrogen bulk isotope values from artic floras. They recorded that the plant $\delta^{13}C$ values were 1.75‰ to 4.63‰ more depleted when grown under a continuous light source, than when compared to diurnal light conditions. This depletion in $\delta^{13}C$ was due to a 'higher ratio of intercellular to atmospheric CO_2 concentration and more water loss for plants under continuous light conditions during a 24 hour transpiration cycle' (Yang *et al.* 2011:461). Recent research by Bonafini *et al.* (2013) has demonstrated a strong correlation between carbon isotopic depletion of plant tissue and lowered light intensity, recording up to a 5‰ shift between grass grown in open and closed locations. This is commensurate with previous research that highlighted a relationship between $\delta^{13}C$ values and daily photon flux, with $\delta^{13}C$ becoming less negative when the total photon flux increases (Zimmerman and Ehleringer 1990).

The issue of seasonality can also affect carbon isotope values in plant material and rainfall, temperature and humidity (etc.) can vary between seasons. In 1974 Lowdon and Dyck recorded a seasonal cycle in $\delta^{13}C$ of -22‰ in early spring and -28‰ in late autumn of maple leaves growing in natural conditions in Canada, and a variation of -25‰ to -30‰ in grasses recovered from the same area. Smedley *et al.* (1991) examined the grassland communities of arid western North America, and demonstrated that the carbon isotope discrimination occurred throughout the growing.

Seasonality is an important issue to consider specifically when measuring carbon isotopes from plant material, as the isotope measurement represents the $\delta^{13}C$ value of a particular season (e.g. doesn't represent an averaged long term value, as we would find in bone collagen).

In addition to environmental factors, significant isotopic variation exists between plant species with different ecophysiological adaptations (Dawson *et al.* 2002, Codron *et al.* 2013). The rate of carbon discrimination in plants has been shown to vary in relation to leaf size (Geber and Dawson 1990), leaf thickness (Vitousek *et al.* 1990, Hanba *et al.* 1999, Hultine and Marshall 2000), stomatal density (Hultine and Marshall 2000) and branch length (Waring and Silvester 1994, Panek and Waring 1995, Panek 1996, Walcroft *et al.* 1996). Furthermore, the rate of carbon discrimination in plants is genetically determined to a certain extent, and these differences are often maintained despite variation in environmental factors (Farquhar *et al.* 1989, Ehleringer 1990, Ehleringer *et al.* 1990, Geber and Dawson 1990, Johnson *et al.* 1990, Schuster *et al.* 1992, Dawson and Ehleringer 1993, Zhang *et al.* 1993, Donovan and Ehleringer 1994, Johnsen and Flanagan 1995, Zhang and Marshall 1995, Damesin *et al.* 1998, Johnsen *et al.* 1999).

3.3.5 Stable Carbon Isotopes in Animals

The environmental factors affecting $\delta^{13}C$ values of faunal bone collagen are largely the result of the *in vivo* $\delta^{13}C$ values of plant species consumed. Therefore, patterns in $\delta^{13}C$ (and indeed $\delta^{15}N$ values) are often recorded along climatic gradients in a way similar to plant species (Heaton *et al.* 1986, Drucker *et al.* 2003 Swap *et al.* 2004, Murphy and Bowman 2009). The physiological factors affecting $\delta^{13}C$ values in fauna collagen are largely the result of isotopic fractionation (e.g. ~4 ‰ shift between diet consumed and bone collagen value), and this is discussed in section 3.9.

3.4 Nitrogen Isotopes

There are two stable isotopes of nitrogen, ^{14}N and ^{15}N. Nitrogen begins its journey into the ecosystem via the atmosphere, and this atmospheric reservoir is well mixed with an isotopic composition that is essentially 0‰. Naturally, nitrogen is present in other parts of the biosphere, and whilst the $\delta^{15}N$ values can range between -10‰ to 10‰, the mean value is essentially 0‰ (and this largely reflects the fact that the rate of nitrogen supply often limits the reactions such as plant growth and bacterial mineralization) (Fry 2006).

Nitrogen isotope abundances are measured in the standard per mil notation according to the following formula:

$$\delta^{15}N = [(R_{sample} - R_{standard})/R_{standard}]*1000$$

Equation 4. Measuring nitrogen isotope abundance.

where $R={}^{15}N/{}^{14}N$ and the accepted standard is atmospheric N_2 (AIR).

Species of bacteria obtain N_2 from the atmosphere and convert it into ammonia (NH_3). This process is referred to as nitrogen fixation. This is an essential process for all life forms as nitrogen is required for the biosynthesization of nucleotides and amino acids (the ‘building blocks’ of life). As the majority of available atmospheric N_2 has limited reactions due to the rate of supply, the net affect of this is that available nitrogen can be consumed without regard to isotope content and with no overall isotopic fractionations. The N_2-fixing bacteria either have symbiotic relationships with plants or live independently in the soil. In most soil profiles the overall affect of N_2-fixing/denitrification is an increase in soil ^{15}N levels relative to the atmosphere (arbitrarily defined as 0‰).

It is of note that there are some cumulative and large fractionations which occur in the nitrogen cycle, with faster cumulative losses of ^{14}N over ^{15}N during particulate decomposition, resulting in relatively enriched ^{15}N (*c.* 10‰ to 15‰), but this largely occurs at considerable depth in soil, ocean, and lake, profiles, and so is not overtly relevant to this research study.

3.4.1 Nitrogen isotopes in Plants

The $\delta^{15}N$ value plant species is directly influenced by the soil. The amount of soil organic nitrogen (SON) storage in undisturbed ecosystems is a function of a number of variables, with MAP (mean annual precipitation) and MAT (mean annual temperature) forming the two key factors (Jenny 1928, 1941, Post *et al.* 1985, Stuart *et al.* 1995, Amundson *et al.* 2003, Swap *et al.* 2004, Liu *et al.* 2005, Hartman and Danin 2010, Ma *et al.* 2012). Olson (1958) postulated that climate affects SON storage as it moderates nitrogen input and output rates. Later research by Holland *et al.* (1999) and Cleveland *et al.* (1999) confirmed that input rates are dictated by combined rates of atmospheric deposition and nitrogen fixation, whereas output rates are controlled by microbial nitrogen processing and are proportionally related to the total SON, MAT and MAP (Amundson *et al.* 2003).

How do these processes affect $\delta^{15}N$ values in plants? On a global scale, and across a broad range of climates and ecosystems, it has been demonstrated that soil and plant $\delta^{15}N$ values systematically decreased with increasing MAP and decreasing MAT (put simply more rain and low temperatures cause low $\delta^{15}N$ values) (Murphy and Bowman 2009, Hartman and Danin 2010). The trend is thought to reflect the efficiency of wetter and colder ecosystems conserving and recycling mineral nitrogen when compared to their hotter and drier counterparts (Ma *et al.* 2012).

Amundson *et al.* (2003) investigated global patterns of the isotopic composition of soil and plant nitrogen. They compiled a considerable amount of new, and published data of soil and plant organic matter from around the world (including Hawaii, Tanzania, California, Nevada and France). From the results they concluded that MAP and MAT have a first-order control on the $\delta^{15}N$ values of soils and plants. Interestingly, they demonstrated that $\delta^{15}N$ values of plants are consistently lower than $\delta^{15}N$ values of soil. The extent of this difference ($\delta^{15}N_{plant}$ - $\delta^{15}N_{soil}$) increases with decreasing MAT, and this is interpreted as reflecting a systematic change in the source of plant-available nitrogen (organic/NH^{+}_{4} versus NO^{-}_{3}). Recently, Ma *et al.* (2012) measured $\delta^{15}N$ and $\delta^{13}C$ values from C_3 and C_4 plants and SOM across a precipitation gradient with an isotherm in northern China. They demonstrated that $\delta^{15}N$ and $\delta^{13}C$ values from the plants decreased significantly with increasing MAP, which is commensurate with the previous research.

As we have demonstrated that MAP distribution has an effect on $\delta^{15}N$ values in plants, it is inherent that, at the other end of the scale, aridity has an effect on $\delta^{15}N$ values. There have been a number of studies that illustrate $\delta^{15}N$ trends across climatic gradients (Sealy *et al.* 1987, van der Merwe *et al.* 1990, Vogel *et al.* 1990, Hobson 1999, Stevens and Hedges 2004, Cerling *et al.* 2006). This trend of ^{15}N enrichment with aridity is thought to reflect the degree of 'openness' (e.g. nitrogen losses relative to internal nitrogen cycling) of the nitrogen cycle (Handley *et al.* 1999, Aranibar *et al.* 2004, 2008).

Furthermore, research has been pursued into the effect of land-use gradients (e.g. the intensity of land cultivation and grazing) on δ^{15}N values in plants (Aranibar *et al.* 2008). The research objective revolved around the concept that an enrichment of ^{15}N in areas of cultivation and grazing are thought to fractionate the nitrogen within the system, which would favour loss of ^{14}N in the harvested or consumed plants. Land management strategies, such as the use of fires, urine/manure of herbivores, would also enhance the atmospheric losses of ^{14}N. Samples were collected from four sites along a precipitation gradient in southern Africa, and the results demonstrated that the δ^{15}N values of soils and plants were generally higher in sites with greater land intensity, and this likely reflects the increased volatilization of ammonium, exports of plant material and decreased N_2 fixation by the destruction of cyanobacterial soil crusts (Aranibar *et al.* 2008:326). One interesting result from this study is that in general, the data illustrated that C_3 plants had significantly higher δ^{15}N than C_4 plants from the same location, suggesting different nitrogen use by the two plant types.

3.4.2 Legumes

Leguminous species often (but not always) exhibit low δ^{15}N values (or in some cases δ^{15}N values of 0‰), which make their consumption very difficult to detect using stable isotope analysis. It is important for the present research to consider the presence of leguminous species at the study sites, as they are N_2-fixing plants (e.g. they can convert atmospheric N_2 ($\delta^{15}N$=0‰) to ammonia) (Virginia and Delwiche 1982, Marshall *et al.* 2007, Fraser *et al.* 2011). It is worth noting though, that if sufficient nitrogen is available in the soil, leguminous species will exhibit $\delta^{15}N$ values that are commensurate with non-leguminous C_3 plants. As a result, the issue of leguminous species as a significant dietary protein component is often used to tentatively explain isotopically small trophic shifts between humans and fauna in semi-arid areas (Franche *et al.* 2009, Szpak *et al.* 2013, 2014, Warinner *et al.* 2013, Webb *et al.* 2013).

3.4.3 Nitrogen in Animals

The environmental and physiological factors affecting $\delta^{15}N$ values in fauna tissues are moisture availability, water stress response, and excretion dynamics. This section is weighted towards the effects of moisture availability as the literature review highlighted this parameter as the commonly recurring theme. The majority of the published literature observes a negative correlation between $\delta^{15}N$ of herbivore collagen and mean annual precipitation (MAP) (Sealy *et al.* 1987, Gröcke, Bocherens and Mariotti 1997, Murphy and Bowman 2006, Pate and Anson 2008). Sealy *et al.* (1986:2707) highlights the impact of rainfall on faunal $\delta^{15}N$ values for a number of sites in African ecosystems (the South-West, Northern and Eastern Cape, as well as samples Botswanna and Malawi), demonstrating that 'high $\delta^{15}N$ values for herbivores occur in areas receiving less than 400mm of rain per annum'.

Gröcke, Bocherens and Mariotti (1997) undertook the first of three isotopic studies that examined the effects of rainfall availability on the δ^{15}N values of bone collagen from modern kangaroo species. This study examined *Macropus eugenii, M. antilopinus, M. fuliginosus, M. rufus, M. robustus* in Western and Southern Australia. 38 macropod samples were analysed and the δ^{15}N ratios produced a good negative correlation against rainfall for kangaroos (at r^2=0.96), although less significant for the marsupial species that were also analysed as part of this project (r^2=0.73). The overall conclusion from this project is that δ^{15}N values increased 0.8‰ to 1.5‰ per 100mm of rainfall specifically for the study area. The small sample size for this project maybe considered insufficient, and which may have led to spurious conclusions in relation to the strength of the correlation between rainfall and δ^{15}N in bone collagen.

Murphy and Bowman (2006) produced the next study on kangaroo $\delta^{15}N_{collagen}$ and rainfall, collecting 779 samples (from larger kangaroo species) from roadkill along a rainfall transect (exact length of transect absent from paper). In addition to the kangaroo bones, the study examined 408 grass specimens from 173 locations in close proximity to the kangaroo bones – sampling with a preference for the dominant taxa at the sites. The study highlights that the δ^{15}N offset between the grass and bone collagen varied by only 0.05‰ – with a trophic shift of 4.74‰ in the areas with the highest water availability, and by 4.79‰ in the areas with the lowest water availability. The relationship between δ^{15}N and rainfall is r^2=0.6 for kangaroos, and r^2= 0.4 for grass, interpreted as a strong negative correlation by Murphy and Bowman (2006:1065) The study highlighted that dietary δ^{15}N was the main cause of the negative relationship between kangaroo $\delta^{15}N_{collagen}$ and water availability – it neatly demonstrated that metabolic factors had little discernable effects.

Finally, Pate and Anson (2008) investigated $\delta^{15}N$ values from kangaroo bone collagen from eight field sites along a 1160km South-North transect from temperate coastal to arid interior environments in South Australia to examine variability in relation to rainfall. Interestingly, in the arid environments (defined as having 176-238mm MAP), the $\delta^{15}N$ becomes more positive in response to decreasing rainfall at $r^2=0.98$. In the temperate and semi-arid environs (350-775mm MAP) no correlation was observed at $r^2=0.0011$.

A recent study by Hartman *et al.* (2011) investigates elevated $\delta^{15}N$ in herbivores from hot arid environments to ascertain whether it is the result of diet or physiological adaptions. $\delta^{15}N$ from horn keratin of desert-adapted bovids (Dorcas gazelle and Nubian ibex) and plant samples (C_3/C_4 samples from Hartman and Danin 2010) were compared to individual climatic factors as well as diet. Hartman *et al.* demonstrated that $\delta^{15}N$ against individual factors (e.g. temperature, climate) were not significant, but with the factors combined the regression is significant ($p < 0.05$). The relationship between Dorcas gazelle species and temperature, humidity and rainfall is particularly significant. Overall, Hartman *et al.*'s study rebukes the previously published hypothesis that physiological stress in herbivores predicts a negative correlation between rainfall, humidity and $\delta^{15}N$ values. They conclude that the correlation is the result of denitrification processes in the soil that directly affect the values of the nitrogen value plants.

Moving on from moisture availability, another factor that affects nitrogen levels in fauna is how they internally process their urine (which is dictated by aridity and hence climate, and so is a valid 'environmental' concern). Referred to as 'physiological water conservation'; it is observed that in basic terms herbivores from arid areas have the highest nitrogen values, and within a specific environment (e.g. arid), the herbivores that are drought-tolerant, urine-concentrating species have the most elevated nitrogen values (Heaton *et al.* 1986). Research undertaken by Ambrose and DeNiro (1986) illustrated that bone collagen carbon and nitrogen ratios were dictated by the diet consumed, water balance and habitat. They argued that drought tolerant herbivores were more enriched in ^{15}N compared to other herbivores because they lose more ^{15}N-depleted urea in their urine, which is a direct result of their ability to increase urine osmolality and conserve water (Sponheimer *et al.* 2003:81). Sealy *et al.* (1987) do not necessarily agree with this hypothesis; first of all suggesting that differences in the approach to urine recycling may be the cause for differences in ^{15}N values in herbivores, and also that digestive anatomy (e.g. foregut fermenters *vs.* hindgut fermenters) plays a distinct role in dictating herbivore ^{15}N values (later work published by van Klinken *et al.* 2000 is in agreement with Sealy *et al.*'s hypothesis).

Whilst this theory likely holds importance in some form (e.g. affects ^{15}N values somewhere along the way), there are a number of caveats that also hold true in this scenario. The effects of other physiological, anatomical and dietary factors on nitrogen values in herbivores are significant. Ambrose (1991) and Ambrose and Norr (1993) state that there is plentiful evidence of nitrogen (and carbon) isotope variation (both intra- and interspecific) between bone collagen and tooth dentine, and within and between different habitats. Ambrose (2000) tried to look further into the determinants of nitrogen values through a modern study of the effects of heat and protein stress on rat tissues, although found little evidence that either of these factors affected the stable nitrogen isotope results.

An isotopic feeding study published by Sponheimer *et al.* (2003) investigated the impacts of digestive anatomy on herbivore δ^{15}N values (e.g. potential differences between foregut and hindgut fermenters). The study also examined whether the protein composition of the consumers diet (e.g. high *vs.* low) had an impact on nitrogen values (by feeding the consumers either high protein alfalfa or low protein coastal bermudagrass). The results demonstrated no discernable difference between the ^{15}nitrogen values of foregut and hindgut fermenters, but did show a diet-hair fractionation factor was 2.3‰ greater for herbivores that had consumed a high protein diet compared to those who had ingested a low protein diet.

The study also revealed that same species herbivores eating the exact same diet exhibit δ^{15}N hair values that vary by 3.6‰ – quite a striking difference. As this study was a modern feeding experiment the nitrogen values were collected from hair keratin rather than bone collagen, and whilst studies into the isotopic differences between hair keratin and bone collagen have demonstrated a bone-hair enrichment factor of 0.86‰ for nitrogen, the mechanisms behind this are not yet fully understood (O'Connell *et al.* 1999, O'Connell *et al.* 2003). The importance of the Sponheimer study is that it demonstrates the amount of δ^{15}N variability that can present itself even in a situation where the parameters are tightly controlled.

3.5 Ruminants *vs.* Non Ruminants

One further aspect to consider for the fauna from the study regions is the potential difference in isotope values between ruminant species (e.g. cattle, sheep and goats) and non-ruminants species (e.g. domesticated pigs and horses).

Ruminants are polygastric animals that use foregut fermentation as a digestive process. Foregut fermenters have rumen, reticulum, omasum, and abomasum – little compartments where microorganisms process food before it reaches the stomach. These animals chew and regurgitate their food before excreting urea from their salivary glands to give their microorganisms a nitrogen source for manufacturing amino acids. They also digest these microorganisms as a source of protein (Chivers and Langer 1994, Bomba *et al.* 2006,). Non-ruminant, monogastric herbivores are hindgut fermenters, with a simple, single chambered stomach, in which cellulose is digested with the aid of symbiotic bacteria. The actual process of bacterial fermentation occurs in the digestive organs that come after the small intestine (e.g. the large intestine and cecum) (Parra 1978).

There have been a number of isotopic studies that have investigated for potential differences between ruminants and non-ruminant species. The general expectation is that ruminants would exhibit enriched δ^{15}N, as a result of additional nitrogen fractionation occurring during the process of rumination and foregut fermentation. One of the key studies examined skeletal collagen δ^{15}N values of Pleistocene remains from Saltville Quarry in Virginia (USA), with the aim of the study was investigate differences between ruminants and non-ruminants, and further sub-divide these groups into browsers and grazers (France *et al.* 2007). The ruminants and non-ruminants clustered into two distinct groups, with the ruminants exhibiting enriched $\delta^{15}N$ values when compared to their non-ruminant counterparts. France *et al.* (2007) state that ruminants will generally seek protein-rich diets and digest their stomach microbial symbiotes, whereas their non-ruminant counterparts have a low-protein diet and exhibit lower levels of microbial symbiosis, which may further explain the isotopic differences (Stevens and Hume 1995).

However, it is important to note that the difference in $\delta^{15}N$ values may simply reflect natural variation in soil and plant values. Bonafini *et al.* (2013) have demonstrated considerable variation in $\delta^{15}N$ values at the base of the food chain (~4‰ difference in plants of the same species), and this is also seen in herbivores (Schoeninger and DeNiro 1989, Ambrose 1991, Bocherens *et al.* 1994, 1996). The cause of this variation may be the result of different $\delta^{15}N$ values in soil and fractionation during methods of nitrogen incorporation (N fixing and non-N fixing) (Shearer and Kohl 1989, Virginia *et al.* 1989, Gebauer 1991, Nadelhoffer and Fry 1994). This being said, examinations of ecosystems and other basal herbivores reveal consistent differences between the nitrogen isotope values of ruminants and non-ruminants. Coltrain *et al.* (2004) found higher $\delta^{15}N$ values for known ruminants in a Pleistocene ecosystem, whereas Bocherens *et al.* (1996) highlighted relatively lower $\delta^{15}N$ values for ruminants.

Mukherjee *et al.* (2007) has approached this issue from a different perspective, by utilizing the application compound-specific isotope analysis ($\delta^{13}C$) of hydrolysed residues absorbed in pottery from Neolithic sites located in the UK to investigate the use of porcine products as a dietary resource. As part of this study, the authors analysed $\delta^{13}C$ values of modern animal fats as a comparative reference, and these include porcine and ruminant adipose fats as well as ruminant dairy fats. Previous residue studies highlighted the differences between porcine and ruminant values for $C_{16.0}$ and $C_{18.0}$ fatty acids (Copley *et al.* 2003, 2005a-d, Craig *et al.* 2005a-b, Spangenberg *et al.* 2006), and these differences are thought to reflect differences in metabolic and physiological processes between the two groups (Christie 1981, Enser 1981, Evershed *et al.* 1997, Mottram *et al.* 1999).

The study by Mukherjee *et al.* (2007:747) focuses on modern reference samples, and highlight that the $\delta^{13}C$ values between the porcine and ruminants are distinct, with $\delta^{13}C_{16.0}$ porcine adipose fats exhibiting values 6.9‰ more positive (at approximately -26‰ for porcine adipose and -30‰ for ruminant adipose, and -29‰ for ruminant dairy fats), and the $\delta^{13}C_{18.0}$ having values which are 3.8‰ more positive than the ruminant adipose (at -32‰) and dairy fats (-35‰). Overall, there is evidence to suggest $\delta^{13}C$ isotopic differences in adipose between pigs and other domesticated fauna that were present in the study regions.

3.6 Environmental Factors in the Study Regions

If we now consider these factors with reference to the environmental data from the study regions, a few points are evident. The Anatolian study regions are located across a precipitation gradient (figure 3.1).

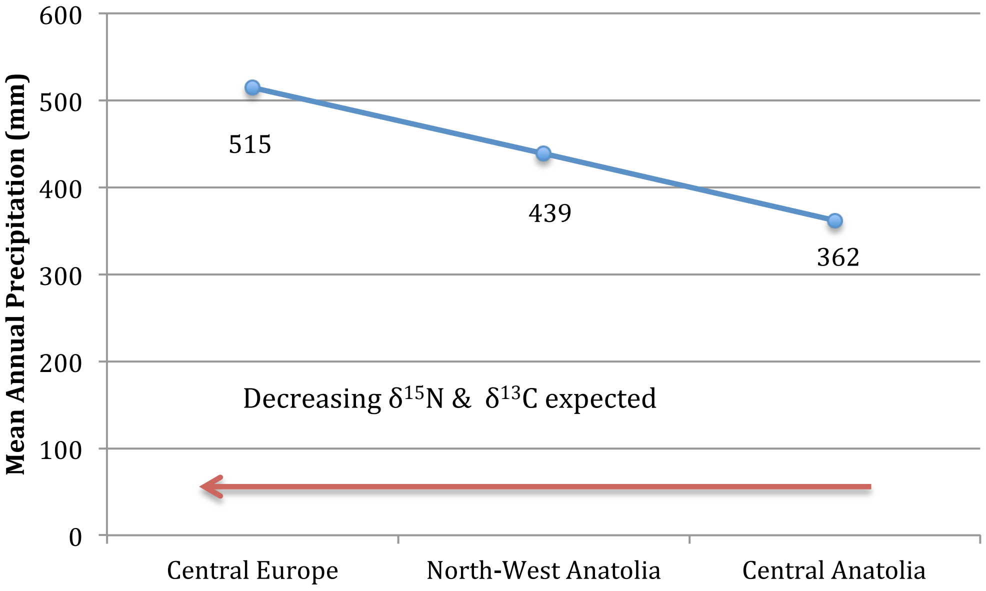

Figure 3.1 Precipitation gradient for the study regions.

If the rainfall was the only variable affecting δ^{15}N and δ^{13}C values in plants, we would expect a consistent enrichment in isotope values from West to East, and would expect Central Anatolia to have the most enriched isotope values. However, as discussed above, mean annual temperature also exhibits first order effects on δ^{15}N and δ^{13}C values. Figure 3.2 highlights the mean annual temperatures for the study regions.

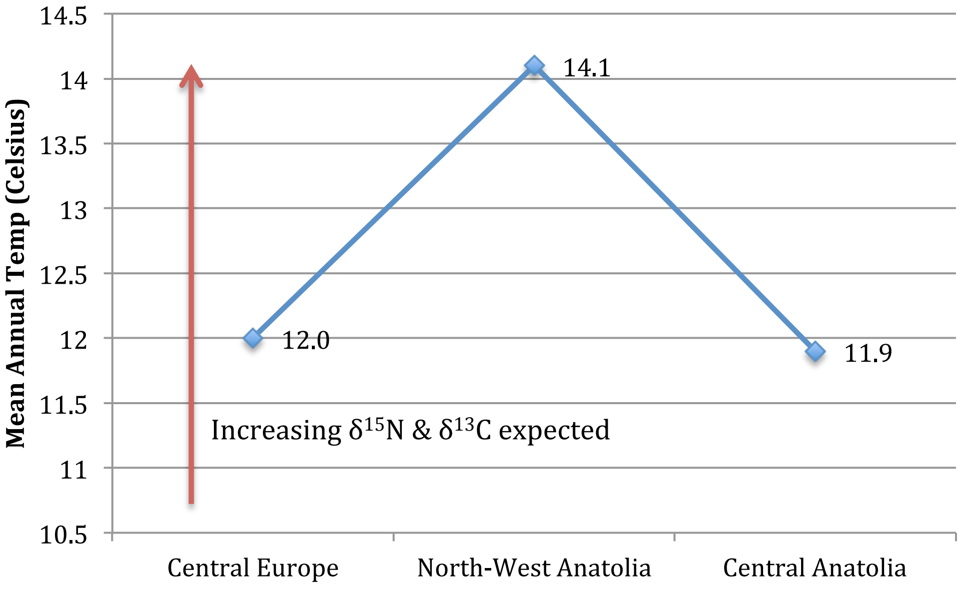

Figure 3.2 Temperature gradient of the study region.

It is evident that temperature does not follow the same linear trend as precipitation, with North-West Anatolia exhibiting much higher temperatures than the other regions. From these data, one would expect North-West Anatolia to have the most enriched $\delta^{15}N$ and $\delta^{13}C$ values. It is well established that moisture availability has a direct affect on the distribution of plant species and on their carbon isotope values, and it is evident that the geographical extent of present-day cereal species is limited by mean annual rainfall.

3.7 Animal Management and Isotope Values

There are a number of human management practices that can influence $\delta^{15}N$ and $\delta^{13}C$ values in (soil), plants and animals. This section will briefly discuss prehistoric approaches to habitat management, the effects they have on carbon and nitrogen isotope values, and to evaluate whether these practices could potentially influence the collagen isotope values for samples from the study sites.

3.7.1 Water management and irrigation regimes

The management of water sources by ancient agricultural societies, particularly for crop watering and landscape irrigation, is well studied (Charles 1988, Smit *et al.* 1996, Butzer 1996, Davies 2009, Mithen 2010). Theoretically, there is a clear argument to suggest that differences in the moisture availability of growing conditions (e.g. the amount of water available in the growing soil) would directly affect the $\Delta^{13}C$ values of plant samples – thus providing us with the ability to investigate the nature of water use for agriculture at prehistoric sites (Farquhar *et al.* 1982).

3.7.2 Foddering of domestic fauna

The provisioning of fodder as an animal management strategy in prehistory has been postulated by a number of researchers (Rasmussen 1993, Halstead *et al.* 1996, Hass *et al.* 1996, Charles *et al.* 1998, Akeret and Rentzel 2001, Makarewicz and Tuross 2012). It has been speculated that foddering was adopted by human herders as an emergent husbandry practice, and included early on within the domestication process. More recently, a number of isotope studies have provided direct evidence for the use of foddering (Makarewicz *et al.* 2006, Makarewicz 2007, 2014, Balasse *et al.* 2012).

Makarewicz (2006) examined foddering practices in modern domestic and wild capravines in Mongolia, through the analysis of $\delta^{15}N$ and $\delta^{13}C$ bulk values of dentinal collagen in molar teeth. The study showed that foddered capravines displayed significantly differently $\delta^{13}C$ values to their wild counterparts, as the domestic capravines were fed of C_4 plants throughout the year, whilst non-foddered animals only had access to C_4 plants during the summer months.

Balasse *et al.* (2012) investigated the 4th millennium BC site of Bercy, located on the Seine River (Paris, France). Seasonality and foddering practices were examined through the analysis of $\delta^{13}C$ and $\delta^{18}O$ values from sheep and cattle sequential enamel samples. From the $\delta^{13}C$ values, it is evident that some of the sheep and cattle were fed on a ^{13}C-depleted resource in winter, potentially leafy fodder. Interestingly, the $\delta^{18}O$ values revealed that the cattle had a 6-month birthing period, which Balasse *et al.* (2012:29) highlight is an unexpected result when compared to the 2-3 month calving period observed in free-ranging cattle populations. They postulate that this extension of calving may be related to the supplementation of food. Balasse *et al.* (2012:29) conclude that a direct result of this extended calving period would be the "availability of cow milk, which would have covered the entire year at Bercy".

The results of this study are interesting, and have direct relevance to this research project. Two of the study sites have evidence of dairying practices (section 3.7.4), and the Polish site of Osłonki is located in a clearing within a woodland forest region (chapter 2). However, this project focuses on the analysis of $\delta^{15}N$ and $\delta^{13}C$ values from bulk collagen, and it is not possible to investigate the issues of seasonality and foddering using this method.

3.7.3 Manuring

The use of manure to enhance crop production rates in prehistory, and its subsequent effect on $\delta^{15}N$ crop values, is well studied (Barker 1985, Bakels 1997, Kenward and Hall 1997, Evershed *et al.* 1997, Bogaard *et al.* 2007, 2013, Commisso and Nelson 2008, Fraser *et al.* 2011, Bogaard 2012, Jones 2012). In its most basic form, the use of manure in ancient agriculture was allowing animals to graze in fields during a fallow period. As a result of this, their dung then renews the soil and the field can then be farmed in subsequent seasons. Cattle was most probably the optimum species of choice for manure, as sheep/goat only produce 1/8th to 1/10th of the amount of manure that cattle can achieve. The net production amount of manure is largely correlated to animal weight (Defra 2010: 34).

The use of manure in the landscape changes the ^{15}N composition of the soil, which has a direct impact on the soil's $\delta^{15}N$ values. The application of manure on fields increases the $\delta^{15}N$ value of soils, because it mediates the preferential volatization of the lighter ^{14}N isotopes, which results in ^{15}N enrichment of the residual soil (Heaton 1986, Kendall *et al.* 2007). The identification of manuring in the archaeological record has largely focused on the identification of specific biomarkers in the soil (Bull *et al.* 1999), or the analysis of plants remains (Bogaard *et al.* 2007, Fraser *et al.* 2011), but its detection and identification at a site-by-site basis is not routinely applied in archaeological research.

With regards to this study, it is distinctly possible that manure was used as a soil management technique at one or all of the study sites, which, if present, would cause the enrichment of $\delta^{15}N$ values in the bone samples (e.g. the $\delta^{15}N$ enrichment factor passes from the soil, to the plants, to the animals that consume them). However, it would not be possible to distinguish the effects of manure on collagen $\delta^{15}N$ values from the effects of aridity on $\delta^{15}N$ values, without the addition of further archaeological study (e.g. the identification of biomarkers in the soil etc.).

3.7.4 Dairying

The emergence of dairying, alongside the introduction of wool, traction, riding and pack riding, formed the basis for Sherratt's Secondary Products Revolution hypothesis (Sherratt 1983). The addition of dairy products to diet was a critical step in the development of early agriculture, and milk products were rapidly adopted by prehistoric farmers, in addition to pottery using hunter-gatherers (Copley *et al.* 2003, Craig *et al.* 2005, 2011, Evershed *et al.* 2008, Dunne *et al.* 2012). Chapter 2 discusses the available evidence for dairying at the sites of Osłonki 1 and Barçin Höyük through the analysis of organic residues from pottery sherds. To date, similar analysis has not been undertaken on the pottery from Aktopraklık (e.g. the absence of research does not equate to the absence of dairying practices at Aktopraklık). The $\delta^{15}N$ and $\delta^{13}C$ values from the meat and milk of an animal, in terms of protein, are identical, and it is not possible to separate them isotopically (Hedges and Reynard 2007). However, the protein components (by weight) of meat and milk are different. Table 3.1 displays the USDA's (2011) protein composition estimations, for a number of common diet products, based on weight.

Food Type	**Protein (g/100g)**
Cow meat (cooked)	27g
Cow milk	3.4g
Cow's milk cheese*	6g
Goat meat (cooked)	27g
Goat milk	9g
Goat cheese*	18g
Sheep meat (cooked)	23g
Sheep milk	5.5g
Sheep cheese*	17g
(C_3) wheat	10g

Table 3.1 USDA protein compositions of modern common dietary foods.
(Patterson *et al.* 2010). *These are the values for cream/soft cheese, as it is produced by sieving milk, and milk sieves have been recovered from the study region in Poland (Bogucki 1984).

$\delta^{15}N$ and $\delta^{13}C$ analysis of bone collagen largely reflects the amount of protein consumed (rather than carbohydrates or fats, see section 3.9 for details). As a result of this, the protein weight content of a dietary source (e.g. meat or milk) is important, and affects the $\delta^{15}N$ and $\delta^{13}C$ collagen values of an individual. For example, if individual A consumed a diet of 50% cow sirloin (100g) and 50% C_3 wheat (100g), this would mean that 72% of the *total weight of the protein* ingested would be cattle meat, and 27% would be wheat. This is because the concentration dependence of protein in the two dietary resources is different. In fact, the bias towards sirloin protein would be potentially be even stronger, as wheat lacks the adequate balance of essential amino acids and so cannot be used as efficiently by the body (Woychik *et al.* 1961, Konzak 1977, Abdel-Aal and Hucl 2002).

If individual B consumed 50%(100g) of cow milk and 50%(100g) of wheat, this would mean that 25% of the *total weight* of the protein ingested would be cow milk, and 75% of the protein would be wheat. In the application of $\delta^{15}N$ and $\delta^{13}C$ analysis of bone collagen, the values mostly reflect the proportion of dietary proteins consumed. Therefore, despite the fact that milk and meat have the same $\delta^{15}N$ and $\delta^{13}C$ value, the protein concentration by weight would cause different $\delta^{15}N$ and $\delta^{13}C$ values in the bone collagen of individuals A and B. A number of researchers have postulated mixing models to deal with this issue (section 3.7).

3.8 Expected Isotope Values of the Core Domesticates: Habitats and Dietary Preferences

The chapter will now progress to consider the isotopic details of the main flora and fauna in the study regions; cattle, sheep, goat, pig, wheat, legumes, barley and grass sp. (as components of herbivore diet). For fauna, it considers the natural dietary environments of the species and highlights dietary preference (e.g. browsers *vs.* grazers), its utility as a dietary resource for human populations (e.g. reproductive cycles and economic output), and any factors which may affect the carbon and nitrogen isotope ratios of the flora or fauna consumed as a dietary resource by human populations (e.g. factors which would eventually affect human isotope ratios). The review focuses how these species function in temperate and semi-arid environments, as these conditions reflect the study regions.

3.8.1 Plants

There are a number of factors that can contribute to isotopic variation in plant species, some of these have already been discussed as they are largely climatic factors. To recap then, the main factors affecting $\delta^{13}C$ values include natural geographic spacing, growing degree days, rainfall, light intensity, canopy effects, variation in baseline soil values, and natural, and anthropogenically influenced, water regimes (Farquhar *et al.* 1982, 1989, Ehleringer and Cooper 1988, Zimmerman and Ehleringer 1990, van der Merwe and Medina 1991, Bonafini *et al.* 2013, Wallace *et al.* 2013). There are a smaller number of factors that can affect $\delta^{15}N$ values in plants, and these include the baseline soil nitrogen values (particularly for leguminous plants), aridity, salinity, in addition to anthropogenic factors such as foddering and manuring.

The main plant species recovered from the study regions that were directly consumed by humans are cereals (wheat and barley), legumes (lentils and bitter vetch), fruits and tree species, both fruit and nut (pistachios, plums) The geographic spacing of different plant species is largely dependent on the climate of the region (Wilcow 2005), and the factors that dictate isotopic variation in plant species are largely environmental, as discussed in the preceding section. The major environmental factor that controls carbon isotope discrimination in plants is moisture availability (Helmer *et al.* 1998, Wilcox 1999, Zohary and Hopf 2000, Wallace *et al.* 2013, Yasir *et al.* 2013). The issue of moisture availability (which is also referred to as drought, water stress, water availability, aridity effects) is also a major factor of crop grain yield. There are extensive studies into water use efficiency (WUE[1]) for different plant species on a global scale (Zhang and Yang 2004). Moisture availability dictates stomatal conductance in plants, and this has a direct effect on the carbon isotope values of the plants. $\Delta^{13}C$ values from plant samples can be used to screen water use.

From a habitat perspective, wild wheats and ryes are calcifuge plants, and on a global scale they approximately correspond to geographical areas of basalt bedrock and decalcified alluvial soils (Yashir *et al.* 2013). Experimental research undertaken by Wilcox (1999) on *T. boeticum thaouder* has shown that wheat species are capable of surviving in arid environments, and in natural landscape wheat species are not able to compete with the dense vegetation and perennial grasses that develop in the moister regions. This explanation is commensurate with the widespread distribution of wheat species that is observed in temperate regions.

3.8.2 Cattle

One of the major fauna species that is synonymous with the Neolithic subsistence economy in Asia and Europe is cattle. The domestication of taurine cattle species, e.g. from *Bos primigenus* (aurochs) to *Bos taurus* (cattle), took place around 6,500 cal BC, and is the result of a limited number of centres of domestication (Bollongino *et al.* 2012). There are no definite auroch bones present in the archaeological assemblages from the Anatolian study regions, but there are a limited number of auroch bone

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[1] Dry matter produced *vs.* water transpired

samples from Osłonki 1, and as such they will be considered alongside cattle. Aurochs and domestic cattle have broadly similar dietary preferences, but occupy different ecological niches and habitats as the result of domestication (Hamilton *et al.* 2008:1025). Aurochs and cattle are grazers, which means that their natural dietary preference is to consume grasses and growing grass shoots. To date, there has been limited research into the carbon and nitrogen isotopic differences between auroch and cattle bone collagen. This paucity in the literature is due to the small number of available auroch bones, the difficulty in morphologically distinguishing auroch from cattle bones in fauna assemblages, and the limited number of auroch bones that occur alongside cattle bones in the same region and dating to the same chronological period. The two primary studies in the literature that investigate isotopic variation between auroch and cattle bone collagen are by Noe-Nygaard *et al.* (2005) and Hamilton *et al.* (2008).

Noe-Nygaard *et al.* (2005) analysed *Bos* bones from Denmark, observing that overall the $\delta^{13}C$ values of auroch show greater variation and are generally more depleted than their domestic counterparts. The authors suggest this reflects the consumption of ^{13}C-depleted foods – most likely obtained from the forest floor and exhibiting the canopy effect. The study shows no significant variation between $\delta^{15}N$ values of auroch and cattle, which *may* suggest the absence of animal management strategies for domestic cattle, (e.g. higher $\delta^{15}N$ values in domestic cattle may be indicative of specific, anthropogenically influenced diets, and not natural grazing), although it's worth noting that animal management practices may not drastically alter isotope values. The main issue with this study is that there is *c.*1000 years gap between the date of the auroch bones and the date of the cattle bones, and so the isotopic observed may reflect changing environmental conditions between chronological periods, rather than different grazing patterns (although this is perhaps unlikely given the scale of climate during this period).

Hamilton *et al.* (2008) investigated auroch and cattle bones from 14 (relatively) contemporaneous sites located in Britain. This isotope study again recorded depleted auroch δ^{13}C values when compared to cattle δ^{13}C values, and this was also interpreted as reflecting consumption of ^{13}C-depleted foods from woodland with canopy effects. If we consider the fauna assemblages in the study region of Anatolia, it is evident that only domestic cattle species are present, and there is a complete lack of auroch bones. This may reflect the surrounding landscape, which is grassland rather than woodland environments, or may be reflective of fully formed agricultural subsistence practices. Interestingly, despite the fact that the study site of Osłonki 1, Central Poland post-dates the Linear Pottery phase (which is associated with a narrow dietary breadth of domesticates), auroch bones are present in the later phase. This would suggest that i) auroch species continued to survive in the wildwood along their domesticate counterparts during the Linear Pottery phases; and ii) there is a change in subsistence methods from the Linear Pottery phase to the Lengyel phase (e.g. from pure agriculture of domesticates (e.g. horticulture, pastoralism), to subsistence method which is largely agricultural but is now consolidated with at least 10% wild resources.

3.8.3 Sheep and Goats

Goats and sheep are often considered together in the archaeological record, as the post cranial remains are difficult to identify to species level, and the carbon and nitrogen isotope values they produce from bone collagen often overlap and are not statistically different in Anatolian studies (Pearson *et al.* 2007). However, from an eco-physiological perspective, sheep and goats are distinct. Sheep are grazers and prefer to feed from open grasslands, goats are browsers and whilst they prefer to forage for shoots and fruit, they can adapt to eat almost anything (Balasse *et al.* 2005). Goats are one of the first ruminant species to be domesticated, and currently comprise 12% of species diversity in mammals. Of the 19 goat species that are now extinct, 16 originate from Europe (FAO 2010). The role of goat species as part of the livestock package is a little controversial, their presence as an active resource is not questioned, and is clearly visible in the fauna record, but their popularity as a food source is under scrutiny. Often referred to as ‘the cows of the poor’, goats are often the last species utilised by impoverished farmers when they cannot afford to keep more demanding, larger herbivores (particularly cattle, but also sheep) (Nyong *et al.* 2007, Garcia *et al.* 2012).

From a global standpoint, many of the worlds rangelands have deteriorated as a result of overgrazing by sheep and cattle, so the remaining pasture could only be used as a food source by goats (Huss 1972, Garcia *et al.* 2012). The ability of goats to feed in decimated grassland may have provided scope for a ‘resource rotation’ between browsers (goats) and grazers (sheep/cattle), not unlike examples of Roman and Medieval crop rotation from Europe. Goats are highly adapted to their environments, and the switch to relying on goat species over cattle/sheep often occurs in times of drought, as goats have different (lesser) moisture requirements to cattle/sheep (Silankove 2000). Goats are an ideal resource for farming populations, as after severe droughts their populations recover more quickly than other ruminants (e.g.

cattle/sheep) due to shorter gestation periods and lower mortality rate, providing food (e.g. milk) even before other resources, such as cereals, are available (Wilson 1991).

Sheep are domesticated pastoral grazers. They can survive in areas with lower rainfall than is required for the cultivation of horticultural crops, but they do not have the same tolerance for temperature and moisture variation as goats. The majority of the academic literature pertaining to using sheep as livestock is concerned with i) grazing strategies on salt marshes (Ranwell 1961, Kiehl *et al.* 1996, Bouchard *et al.* 2003, among others), ii) the issue of transhumance (Akeret and Jacomet 1997), and to a lesser extent, iii) foddering of sheep species on domestic wheat stalks (e.g. the section of wheat not consumed by human populations) (Mullholland and Coombe 1979, Rowe *et al.* 1989, Brand *et al.* 1999).

In reference to the study regions, it is unlikely that sheep herds would have been taken to salt marshes for grazing purposes, as the sites in Anatolia and Poland are not located in close proximity of the coast. The issue of wheat (or other crop) foddering is a distinct possibility, particularly at Osłonki 1. The identification of wheat foddering from $\delta^{13}C$ at the study sites may not be possible, as the carbon isotope values for wheat species would probably not be sufficiently different from the carbon isotope values of the surrounding natural steppe grasslands (Anatolia) or mixed deciduous forest (Poland). The issue of transhumance and seasonality of cattle/sheep in the Neolithic period is much debated in the academic literature (Geddes 1983, Perlés 2001, Kienlin and Valde-Nowak 2002, Luick 2008, Műller-Scheeβel *et al.* 2010, Festi 2012). Transhumance is concerned with the movement of ruminant herds between distinct food resources from one season to the next. To investigate seasonality in cattle or sheep populations from the study region would require of sections of dental enamel, and so is outside the remit of this research study.

3.8.4 Pigs

Pigs would have been a valuable resource to prehistoric populations in the study regions, as they have a short reproductive cycle and produce large numbers of offspring, and so in favorable conditions they possess an impressive ability to reproduce (Grigson 1982, Mukherjee *et al.* 2007). They have a natural preference for woodland environments (and perhaps would not have been of importance on the Anatolian steppes), and obtain their food through grazing and rooting (Hook Presto *et al.* 2008, Pistoia *et al.* 2009). Despite their preference for woodland environments it is of note that pigs have a broad dietary spectrum (Schley and Roper 2003). They can exploit parts of the ecosystem that ruminants do not generally utilize; invertebrates, carrion, tubers, fungi, fruits and seeds (Hamilton *et al.* 2009:999). They could certainly survive on fodder and scraps from a settlement: thereby converting inedible organic debris to meat and in doing so providing a means of controlling settlement waste (Gregg 1988). However, the debate continues as to whether pigs were fed from the "human-produced" resources found on settlement sites, or if they were allowed to LAO forage in their natural environments as part of agricultural subsistence approach. In the medieval period in Britain for example, pigs were allowed to graze in woodland, and this practice was integrated with woodland management (e.g. coppicing, hunting) (Dawson 2004).

In North West Anatolia during the Neolithic period, there is palaeobotanical evidence to suggest the presence of woodland areas in the elevated mountainous regions –

although neither the sites of Barçin Höyük or Aktopraklık are located in elevated regions. This would suggest that the pigs from these sites were fed from settlement scraps, or grazed from the local environment (largely C_3 grasses) (Bottema and Woldring 1994). However, Osłonki in Central Poland is located within an outcrop of mixed deciduous forest (oak, linden, ash and hazel), and wildwood grazing and rooting by pigs at this site is a distinct possibility.

Research undertaken by Hamilton *et al.* (2009) into British pig populations highlighted more enriched $\delta^{13}C$ collagen values in the Neolithic when compared to the Iron Age – which was interpreted as greater use of the wildwood during the Neolithic period. In particular, the consumption of saprotrophic and mycorrhizal fungi were thought to play a major part in pig diet – as they have more enriched $\delta^{13}C$ values than their substrates and/or plants in several woodland ecosystems (Hobbie *et al.* 1999, Hogberg *et al.* 1999, Hamilton *et al.* 2009:1002).

From an isotopic perspective, in addition to the consumption of fungi species, the natural preference for woodland environments may lead to an influence from the canopy effect for $\delta^{13}C$ values obtained from collagen, with lowered light intensity being associated with depleted $\delta^{13}C$ values (van der Merwe and Medina 1989, Bonafini *et al.* 2013). In terms of $\delta^{15}N$ values, there is no conclusive evidence to suggest that canopy woodland environments would alter the nitrogen values in pig species. Interestingly, there is considerable research as to the damage pigs cause whilst grazing in temperate woodlands. Grazing pig populations cause soil erosion and nitrogen losses to groundwater, which eventually return to the atmosphere (Williams *et al.* 2000, Evans 2004), they cause soil compaction (Brandt *et al.* 1995), N loss to atmosphere *via* denitrification (Peterson *et al.* 2001) volatilization (Sommer *et al.* 2001) and increased risks of nitrogen leaching (Erikson 2001).

Whether the effects that the pigs cause on N in the woodland ultimately impact on their own $\delta^{15}N$ values remains unclear (e.g. self-perpetuating feedback loop). There are a limited number of studies that investigate the impact of pig grazing in Mediterranean woodlands, but these focus on the extent of the damage, rather than the effects on nitrogen (Pistoia *et al.* 2010).

3.9 Isotopes in Skeletal Tissues

Collagen is a fibrous insoluble protein, which is found in bone, skin, cartilage, and other connective tissues. Bones (by weight) are comprised of approximately 25% of this fibrous protein, with bioapatite mineral forming the remaining 75%. $\delta^{13}C$ and $\delta^{15}N$ values can be obtained from human and fauna skeletal bone collagen, which reflects the average signal, albeit biased towards the protein component, of the diet for the last *c.* 10 years of adult life. The use of isotope analysis for diet studies works by constraining the possibilities of resource consumption. If collagen is well preserved in a bone sample (surviving the rigours of diagenesis) it still has its original *in vivo* isotopic composition. The composition of carbon isotope ratios for example is the result of the consumer's diet, therefore when the eating patterns of the consumer are fixed we can use the isotope values to estimate the eating patterns of their predators (DeNiro and Epstein 1978, Ambrose 1991: 294). The utility of carbon isotopes lies with their ability to distinguish between terrestrial, marine foodwebs and C_3, C_4 and CAM plant species. Nitrogen isotopes demonstrate a similar utility – the ability to differentiate between trophic levels based upon step-wise enrichment factors.

There are a number of factors (aside from diet and trophic position) that can affect the isotopic ratios of a skeletal tissue (Casey and Post 2011). The amount of individual variation within a species can be considerable and observed differences between the whole body isotopic signature and that of bulk diet and specific tissues can differ due to compositional differences or isotopic routing differences (Schwarz 1991, Tieszen and Farge 1993). Compositional differences are often related to the differences between tissue types or variation in lipid content.

Carbon^{13} has a relatively small metabolic fractionation rate (of >1‰) after the process of photosynthesis that makes ^{13}C a useful tracer for identifying the relative contribution of dietary resources (DeNiro and Epstein 1978, Casey and Post 2011). For fauna, there is a *c*. 4‰ negative shift between the diet consumed and collagen, and for humans (or other omnivores/carnivores) there is a further 1‰ metabolic fractionation from muscle tissues to bone collagen (figure 3.3) (DeNiro and Epstein 1978, Tieszen *et al.* 1983, Hobson and Clark 1992a,b, Hobson *et al.* 1996, Bearhop *et al.* 2002, Hartman 2011).

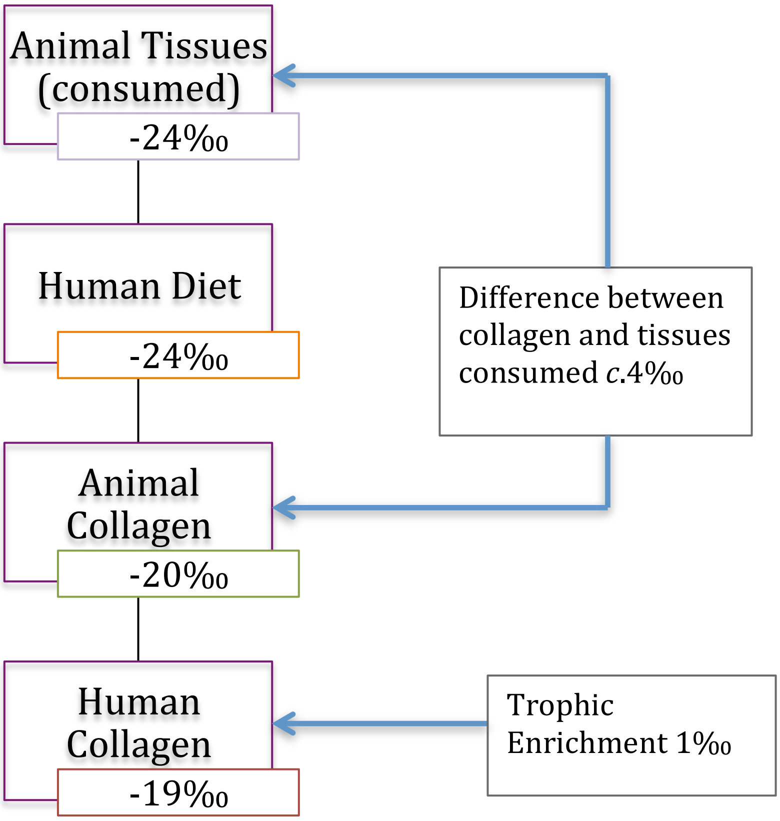

Figure 3.3 Chart illustrating the fractionation of δ^{13}C between consumer and prey, and internal metabolic fractionation of the consumer.

Nitrogen fractionates in a different way to carbon. During the process of excretion, animals preferentially retain ^{15}N over ^{14}N (Sutoh *et al.* 1987). Therefore, the nitrogen isotopic composition of an animal reflects its diet but is offset by higher ^{15}N due to the enrichment of ^{14}N in urine and other related waste products. Nitrogen isotopic compositions are shown to step ~3.0 – 5‰ with each trophic level in the food chain, although there is some conflict in the research environment as to the actual trophic values (DeNiro and Epstein 1981, Minagawa and Wada 1984, Schoeninger and DeNiro 1984, Post 2002, Bocherens and Drucker 2003).

Compared to carbon, the biological fractionation of nitrogen is relatively large at *c*.3-5‰, which makes ^{15}N a useful proxy for calculating the trophic position of consumers in the food web (DeNiro and Epstein 1981, Hobson *et al.* 1993, 1996, 1997, Roth and

Hobson 2000, Casey and Post 2011). For example a two end-member linear mixing model would require the measurements of the $\delta^{13}C$ and $\delta^{15}N$ isotope signatures of the organism of interest (e.g. a human or animal) alongside the 'base' of both food webs (e.g. whether littoral or pelagic primary producers, or organisms which can serve as reliable comparison proxies (e.g. cattle can often indirectly provide the isotope values for the plants they consume (assuming that they graze on the natural grasslands, and are not subject to foddering or other forms of diet-restricting animal management)).

3.10 Limitations of the Method

There are a number of limitations associated with the application of isotope analysis for palaeodietary reconstruction. Firstly, the analysis of $\delta^{15}N$ and $\delta^{13}C$ values from bone collagen can only provide information of broad changes in diet, as the collagen isotopic value reflects a mixed signal of the last *c.*10 years of an individual. Consequently, it is not possible to identify periods of short-term dietary stress or the consumption of 'famine foods'. Equally individual feasting events, which are widely considered to have occurred during the Neolithic (Russell 1993, Hayden 1996, Pappa *et al.* 2004, Goring-Morris and Horwitz 2007), cannot be isotopically identified from bone collagen.

The proportional weight of protein consumed by an individual has a direct impact on the final $\delta^{15}N$ and $\delta^{13}C$ values measured (section 3.5.4 and section 3.6). The carbon and nitrogen values represent a proportional mix of the total amount of protein consumed. Therefore, the interpretation of the $\delta^{15}N$ and $\delta^{13}C$ values is not necessarily straightforward, and so a number of mixing models are suggested to compensate for this issue (section 3.11).

In addition, the application of the method relies on the assumption that the dietary components are isotopically distinguishable from one another. This is not always the case. For example, it is sometimes very difficult to differentiate terrestrial $\delta^{15}N$ isotope signals from freshwater $\delta^{15}N$ signals, particularly freshwater shellfish which have comparable $\delta^{15}N$ values to C_3 plants and terrestrial herbivores (Vander Zanden *et al.* 1997, Zanden and Rasmussen 1997). Recently, the analysis of sulphur isotopes has been suggested as a tool to differentiate between freshwater and terrestrial diets (Richards *et al.* 2001, 2003, Nehlich and Richards 2009, Nehlich *et al.* 2010), but this technique is not routinely applied to dietary studies, and further research into the application of this technique is required.

Finally, there are a number of environmental and anthropogenic factors that can influence the $\delta^{15}N$ and $\delta^{13}C$ values at source (e.g. aridity, water irrigation, sunlight, foddering, penning etc.), and it is these factors that are carefully examined in this project.

3.11 Mixing Models in Palaeodietary Reconstruction

It is standard practice in palaeodietary reconstruction to compare human skeletal collagen isotope values to faunal skeletal collagen values from the same site or region. The difference in the starting isotopic composition of primary producers provides an isotopic baseline between the primary producers and the fauna that consume them. This ratio difference sets up an isotopic baseline that is used for comparison when calculating diet or trophic position (Casey and Post 2011:131). The isotopic baseline in a particular region is known to vary seasonally due to variation in a number of physical and chemical factors. These include factors such as mean annual rainfall, soil maturity, soil pH levels in terrestrial settings and depth and distance from the shore in marine aquatic settings – but this list is by no means exhaustive. Whilst it is true that human isotope values in region (and from a particular chronology period) can produce very similar isotope ratios (e.g. North-West Europe during the Neolithic period generally has $\delta^{13}C$ values of approximately -20‰) this isotopic consistency is not always reflected in the faunal isotope values, as they are averaging the plant isotope values.

Mixing models for palaeodietary stable isotope analysis are mathematical constructs that have been developed in order to estimate the proportional contribution of each protein resource to a consumer's diet (Fry 2006, Philips 2012). They are based on the premise that a consumer's carbon and nitrogen isotope values reflect the isotopic composition of the assimilated diet - not the ingested diet, as not all foods are completely digestible and it is possible for food sources to pass through the digestive tract of an individual without being absorbed (Martínez del Rio and Carleton 2012, Philips 2012).

There are a number of limitations and conditions associated with the use of mathematical models to reconstruct specific inputs of palaeodiet. These issues can be largely segregated into physiological or mathematical problems. First of all, as is mentioned above, is the issue that the actual food ingested may not reflect the composition of food that is subsequently absorbed by the consumer, which may lead to false readings of diet composition. In addition, a considerable amount of the assimilated protein is used to keep the basic metabolic rate (BMR) functioning, and some of these food resources are lost to processes such as excretion and respiration.

Philips (2012:342) highlights that a number of physiological processes can often occur at different rates for compounds containing light isotopes compared to their heavier counterparts (e.g. ^{12}C compared to ^{13}C, or ^{14}N compared to ^{15}N), which reflects the difference in their chemical masses. These isotopic fractionation differences between different isotopes causes a systematic bias in the measured data values, which has to be corrected for before the mixing analysis can be performed (Fry 2006). This bias can be addressed using a correction factor: this can be achieved by either subtracting the correction factor from the consumer's tissue value or adding it to the food resource (Ben-David *et al.* 1997). There are a number of other issues that affect diet-tissue discrimination factors, such as variation between environments, trophic levels (in terms of total quantity, e.g. marine *vs.* freshwater), physiological types of the animal consumer's concerned (e.g. homeothermic or poikilothermic, ammonotelic, ureotelic or uritelic[6]), and issues such as the taxa of the consumer or the tissues analysed (in the case of archaeological research, mainly bone collagen, bioapatite and phosphate, dentine and enamel), quality of diet and variations in sample pre-treatments used (McCutchan *et al.* 2003). Another major factor underlying the use of mixing models is the assumption that all of the assimilated nutrients are completely homogenized in the body before synthesis into a given tissue (Fuller *et al.* 2005).

From a mathematical perspective, there are a number of issues associated with the application of end member mixing models to dietary reconstruction. Firstly, the models are theoretical underpinned by a number of assumptions that are made about the consumer and the ecosystem within which it resides. To begin with, the model assumes that all of the food sources are included in the analysis – this is certainly a tricky endeavor in archaeological reconstructions, even with ‘domestic’ food webs; as we often have to reconstruct the food webs and trophic levels using fragmented faunal remains and incomplete botanical assemblages.

An obvious caveat to this issue is that the exclusion of a food source will result in false conclusions of the apparent proportions of the other food sources consumed, and may in fact result in posterior density estimate (or final datum value) outside of the theorized mixing model (Phillips and Gregg 2003, Philips 2012).

A number of different isotope mixing models have been suggested in an attempt to calculate the exact proportion of a particular type of protein to an individual’s diet. If we assume that carbon and nitrogen traverse through the food web with a similar stoichiometry, we can use mass-balance mixing models to calculate the contribution of each protein source to the consumers’ diet (Moore and Semens 2008).

Chapter 4: Sampling Strategies and Laboratory Methods

4.1 Introduction

This chapter details the sampling strategies implemented as part of this project, and highlights the laboratory methods used to obtain stable isotope values from skeletal collagen samples. The sampling strategies and methodology used for radiocarbon dating skeletal collagen is detailed in chapter 7.

4.2 Overview of the Sampling Process – Stable Isotope Analysis

The method of carbon and nitrogen stable isotope analysis of skeletal remains for palaeodietary study is underpinned by the use of animal isotopes to provide a baseline for comparison for the human samples. In general, the carbon isotope values retrieved from animal bone collagen should reflect the carbon isotope signatures from the landscape[1], specifically between C_3, C_4 and CAM plants. There are number of factors that can affect animal isotope ratios, such as environment parameters and human management, and these are discussed elsewhere in the thesis (Chapter 3, section 3.3). The analysis of nitrogen isotopes in human collagen also requires an isotope baseline for comparison, as nitrogen provides information on trophic enrichment in food webs.

The sites that were processed as part of this study (Aktopraklık, Barçin Höyük and Osłonki 1), adhered to a very similar sampling strategy. The key issue to obey when sampling bones for palaeodiet is to ensure that each individual, whether human or

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[1] It is also possible to differentiate between marine and freshwater resources, but this is not relevant for this study as the protein resources consumed are land based.

animal, is only sampled once. Taking two or three samples from the same individual will provide the same isotopic outcome (and produces false clustering in the data set). Fortunately, the majority of burials at the study sites have been excavated from discrete interments, as opposed to group burials, and so accidental repeat sampling of the same human is unlikely. This can be more problematic for faunal material as it is frequently recovered from refuse pits, or other occupation/activity horizons, within a settlement. As a consequence, the deposition of faunal bone is often as a mixed collection of bones, so it can be difficult to differentiate between separate animals and between species. Often a single diagnostic element is selected to produce an MNI for a site, and it is this data that is consulted when sampling for isotopic analysis.

With regards to the human samples, the sampling strategy has a preference for rib bones (as they turnover quickly), but in their absence metacarpals are selected as they are small and easy to sample. The skeletal samples from Aktopraklık and Barçin Höyük were sampled in Turkey by Dr. Songul Alpaslaan-Roodenberg and sent to RLAHA for analysis. Dr. Lorkiewicz sampled the human bone samples from Osłonki 1, and the Osłonki 1 faunal bones were sampled by Prof. Peter Bogucki.

All of the available human and faunal bone samples from Aktopraklık and Barçin Höyük were processed as they were not recovered in great abundance from the sites. In total 30 human samples were available for analysis from the site of Osłonki 1 from a total of *c.*180 individuals interred at the site, and >5,000 faunal bones were available for analysis. 150 faunal samples were selected for study, these were chosen with the aim of sampling as many different species as possible as well as aiming to be representative of the chronological span of the site.

4.3 Skeletal Samples

This section features all of the skeletal samples that were processed as part of this study. The tables will provide information about age, sex and associated burial information for the human interments, and will provide age information where possible for the faunal samples.

4.3.1 Aktopraklık Sample List

Tables 4.1-4.2 below outline the faunal and human samples processed for carbon and nitrogen isotope analysis for Aktopraklık. The fauna species do not have associated burial/context information, and as such the information in table 4.1 is a summary of the samples collected and processed. A number of human bone samples were processed (by the author) prior to the commencement of this thesis and these are clearly highlighted in the table. The human skeletal assemblage was aged and sexed by Songül Alpaslan-Roodenberg.

LAB I.D	**Species**	**Age**
AKF1 – AKF13	Ovicaprid	12 = adult 1 = juvenile
AKF14 – AKF22	*Bos tarus*	8 = adult 1 = juvenile
AKF23 – AKF26	*Sus domestus*	Adult
AKF27 – AKF28	*Cervus elaphus*	Adult
AKF29	*Sus scrofa*	Adult
AKF	*Dama dama*	Adult

Table 4.1 Faunal bone samples from Aktopraklık.

LAB I.D	**Burial Location**	**Age**	**Sex**	**Element**	**Isotope analysis?**
AK 1	AK 92D 101	?	M?	ribs	This project
AK 2	AK 90E.13	old	?	-	This project
AK 3	AK 19K35.1	middle aged	M	-	This project
AK 4	AK 88D106	middle aged	F	-	This project
AK 5	AK 90E16	mid-old aged	F	ribs	This project
AK 6	AK 89F5	mid-old age	F		This project
AK 7	AK 87E6	12-14 years	?		This project
AK 8	AK 19k42.1	4 years (±12months)	?	-	This project
AK 9	AK 89d16.1	25-35 years	F		This project
AK 10	AK 14F6.47	?	?	ribs	This project
AK 11	AK 19K33.3	4 years	?	-	This project
AK 12	AK 92D102a	Young adult	F?	-	This project
AK 13	AK 92D102b	middle aged	M?	-	This project
AK 14	AK 89F6	?	M?	-	This project
AK 15	AK88F15.1	?	M?	-	This project
AK 16	AK16G12.1	25-35 years	?	-	This project
AK 17	AK89E17	50-70 years	M	-	This project
AK 18	AK89E21	?	M	-	This project
AK 19	AK90E.6	Old	F?	-	This

					project
AK 20	AK89F21.1	middle aged	F?	-	This project
KA 7	19K 67.-	Old	F	-	This project
KA 5	19K 87.-	Child	?	-	This project
KA 2	22K 17.-	?	?	-	This project
KA 12	88E 22.-	?	?	-	This project
-	15G-58.1-07	35-45 years	M	-	Budd *et al.* 2013
-	16H-25.2-04	25-35 years	F	-	Budd *et al.* 2013
-	16H-43.17-05	35-35 years	F	-	Budd *et al.* 2013
-	16H-136.1-07	?	M	-	Budd *et al.* 2013
-	17H-50.1-05	35-45 years	M	-	Budd *et al.* 2013
-	18G-21.1-07	35-45 years	F	-	Budd *et al.* 2013
-	88E-8.4-07	Young	F	-	Budd *et al.* 2013
-	88E-9.1-07	25-35	F	-	Budd *et al.* 2013
-	88E-14.1-07	-	-	-	Budd *et al.* 2013
-	89D-7.1-06	35-45 years	F	-	Budd *et al.* 2013
-	89D-8.1-06	25-35	M	-	Budd *et al.* 2013
-	89D-14.1-07	?	M	-	Budd *et al.* 2013
-	89D-15.1-07	25-35 years	F	-	Budd *et al.* 2013
-	89D-17.1-07	mid-old age	M	-	Budd *et al.* 2013

-	89E-9.2-07	?	M	-	Budd *et al.* 2013
-	89E-10.1-07	25-35	M	-	Budd *et al.* 2013
-	89E-11.1-07	?	?	-	Budd *et al.* 2013
-	90C-5.10-06	40-60 years	M	-	Budd *et al.* 2013
-	90D-4.4-06	35-45 years	F	-	Budd *et al.* 2013
-	90D-11.1-07	35-45 years	M	-	Budd *et al.* 2013

Table 4.2 Human bone samples from Aktopraklık.

The samples processed as part of the Budd *et al.*'s 2013 study were processed at RLAHA, and the same modified Longin (1971) method was used to obtain collagen.

4.3.2 Barçin Höyük Sample List

Table 4.3 below displays the faunal bone samples that were processed for carbon and nitrogen isotope analysis of collagen. Table 4.4 outlines the human samples from Barçin Höyük. All of the samples from Barçin Höyük date to the Neolithic period. The human skeletal collection was aged and sexed by Alpaslan-Roodenberg *et al.* (2013).

Lab I.D.	Species	Age
BAFA 5 –BAFA 8, BAFA 9 – BAFA 22	Ovicaprid	Adult = 17 Juvenile = 1
BAFA 1 – BAFA 4, BAFA 23 – BAFA 35	*Bos taurus*	Adult = 16 Juvenile = 1
BAFA 36	*Sus domestic*	Adult = 1
BAFA 37	*Sus scrofa*	Adult =1
BAFA 38	*Vulpes vulpes*	Adult = 1
BAFA 39	*Capreolus capreolus*	Adult = 1

Table 4.3 Faunal samples processed for stable isotope ratios from Barçin Höyük.

LAB I.D.	Burial Loc.	Sex	Age (years)	Element	Preservation	Condition/position
BAHU 13	M10-L113	Indet.	>25	Ribs	bad	disturbed
BAHU 93	M11-93	M	35-45	Ribs	good	flexed left
BAHU 101	-	-	-	Right tibia fragment	-	-
BAHU 173	M10-173	F	old age	Ribs	good	flexed left
BAHU 102	M10-102	F	mid-old age	Ribs	bad	disturbed
BAHU 101	-	-	-		-	-
BAHU 106	M10-106	F*	25-35		good	flexed left
BAHU 115	-	-	-		-	-
BAHU 129	L13-129	M	old age	Ribs	bad	extreme flexed on back
BAHU 130	L13-130	indet.	15-17	Ribs	bad	partly excavated
BAHU 185	-	-	-	Right radious fragment	-	-
BAHU 207	L13-207	F	old age	Ribs	good	flexed left

Table 4.4 Human adult burials recovered from Barçin Höyük.
Table partly reproduced from Alpaslan-Roodenberg *et al.* (2013:105).

Table 4.5 details the sub-adult humans that were sampled from Barçin Höyük. The ageing information for the human samples is obtained through bone measurements and dental estimations by Maresh (1970), Ubelaker (1979), and Fazekas and Kosa (1978).

LAB I.D	**Burial Loc**	**Age**	**Element**	**Source**
BAIN 166	M10-166	6-7	Ribs	Ubelaker 1979
BAIN 180	M10-180	10 lunar months	Ribs	Fazekas and Kosa 1978
BAIN 197	M10-197	9 ½ lunar months	Ribs	Fazekas and Kosa 1978
BAIN 203	-	-	-	-
BAIN 211	M10-211	10 lunar months	Ribs	Alpaslan-Roodenberg *et al.* 2013
BAIN 212	L11-212	Newborn	Ribs	Fazekas and Kosa 1978
BAIN 213	L11-213	3 months	Ribs	Maresh 1970
BAIN 215	L11-215	10 lunar months	Ribs	Fazekas and Kosa 1978

Table 4.5 Sub-adults from Barçin Höyük.
Table modified from Alpaslan-Roodenberg *et al.* (2013:104).

In table 4.5, ‘element’ refers to what was sampled for isotope analysis, not bone measured for ageing.

4.3.3 Osłonki 1 Sample List

Table 4.6 below details the faunal skeletal samples processed from Osłonki 1, and table 4.7 displays the human samples that were analysed from Osłonki 1.

LAB I.D	**Burial Loc.**	**Species**	**Element (age*)**
OS 1	gl2	Ovicaprid	femur
OS 2	gl2	*Bos taurus*	metacarpal
OS 3	gl2	*Bos taurus*	metatarsal
OS 4	gl2	*Sus domestus*	humerus
OS 5	gl2	*Bos taurus*	femur
OS 6	gl2	*Sus domestus*	ulna
OS 7	gl2	*Cervus elaphus*	antler
OS 8	gl2	*Sus scrofa*	Un.id
OS 9	gl2	*Castor fiber*	Un.id
OS 10	gl2	*Cervus elaphus*	Un.id
OS 11	gl2	Ovicaprid	Un.id
OS 12	gl2	*Emys orbicularis*	Un.id
OS 13	gl2	Ovicaprid	Un.id
OS 14	gl2	*Sus domestus*	pelvis
OS 15	gl2	*Bos taurus*	scapula
OS 16	gl2	*Bos taurus*	ulna
OS 17	gl2	*Bos taurus*	metatarsal
OS 18	gl2	*Bos taurus*	metatarsal
OS 19	gl2	*Bos taurus*	m/p shaft
OS 20	gl2	*Bos taurus*	femur
OS 21	gl2	*Bos taurus*	metatarsal
OS 22	gl2	*Sus domestus*	m/p
OS 23	gl2	Ovicaprid	Radius/ulna
OS 24	gl2	*Sus domestus*	ulna
OS 25	gl2	*Cervus elaphus*	antler
OS 26	gl2	*Sus domestus*	radius
OS 27	gl2	*Capreolus capreolus*	scapula
OS 28	gl2	*Capreolus capreolus*	antler
OS 29	gl2	*Capreolus*	scapula

		capreolus	
OS 30	gl2	*Sus domestus*	m/p
OS 31	gl2	Ovicaprid	distal tibia
OS 32	gl2	*Emys orbicularis*	carapace
OS 33	gl3 a/93 97/6	*Cervus elaphus*	scapula
OS 34	gl5	*Sus scrofa*	Un.id
OS 35	gl5	Ovicaprid	frontal
OS 36	pit137	*Bos taurus*	tibia
OS 37	pit137	*Bos taurus*	radius
OS 38	pit137	*Bos taurus*	proximal m/c
OS 39	pit137	*Bos taurus*	proximal radius
OS 40	pit137	Ovicaprid	tibia
OS 41	pit137	Ovicaprid	radius
OS 42	pit137	Ovicaprid	tibia
OS 43	pit137	*Sus domestus*	metatarsal
OS 44	pit137	*Sus domestus*	distal humerus
OS 45	pit137	*Sus domestus*	distal humerus
OS 46	pit137	*Sus domestus*	distal humerus
OS 47	pit204	Ovicaprid	occipital
OS 48	pit204	Ovicaprid	occipital
OS 49	pit204	*Sus domestus*	distal humerus
OS 50	pit204	*Sus domestus*	Tibia JUVENILE
OS 51	pit204	*Bos taurus*	tibia FETAL
OS 52	pit204	Ovicaprid	distal femur
OS 53	pit204	Ovicaprid	distal femur
OS 54	pit204	Ovicaprid	distal femur
OS 55	pit204	Ovicaprid	distal femur
OS 56	pit204	*Bos taurus*	metatarsal
OS 57	pit204	*Bos taurus*	humerus
OS 58	pit204	*Bos taurus*	metatarsal
OS 59	pit204	*Bos taurus*	metatarsal
OS 60	gl9	*Bos taurus*	distal radius

OS 61	gl9	*Bos taurus*	metacarpal
OS 62	gl9	Bos taurus	metatarsal
OS 63	gl9	*Bos taurus*	distal tibia
OS 64	gl2	*Emys orbicularis*	carapace
OS 65	gl9	*Bos taurus*	metacarpal
OS 66	gl2	*Bos taurus*	metacarpal
OS 67	gl9	*Bos taurus*	metacarpal
OS 68	gl9	*Ovicaprid*	distal tibia
OS 69	gl9	*Sus domestus*	radius
OS 70	gl9	*Bos taurus*	distal tibia
OS 71	gl9	*Sus domestus*	distal humerus
OS 72	gl9	*Bos taurus*	metatarsal
OS 73	gl9	*Bos taurus*	metatarsal
OS 74	gl9	*Sus domestus*	ulna
OS 75	gl9	*Sus scrofa*	distal tibia
OS 76	gl9	*Bos taurus*	scapula
OS 77	gl9	*Emys orbicularis*	carapace
OS 78	gl9	*Bos taurus*	humerus/femur
OS 79	gl9	*Bos taurus*	proximal radius
OS 80	gl9	*Capreolus capreolus*	distal radius
OS 81	gl9	Ovicaprid	radius/ulna
OS 82	gl9	Ovicaprid	occipital
OS 83	gl9	*Sus domestus*	distal tibia
OS 84	gl9	*Sus domestus*	ulna
OS 85	gl9	Ovicaprid	occipital
OS 86	-	Ovicaprid	occipital
OS 87	gl9	Ovicaprid	proximal radius
OS 88	-	*Bos taurus*	distal humerus
OS 89	gl9	*Bos taurus*	distal tibia
OS 90	gl9	*Bos taurus*	humerus/femur
OS 91	gl9	*Bos taurus*	metacarpal

OS 92	gl9	*Sus scrofa*	-
OS 93	gl9	*Sus domestus*	metacarpal
OS 94	gl9	*Cervus elaphus*	radius
OS 95	gl9	*Cervus elaphus*	metacarpal
OS 96	gl9	*Sus scrofa*	distal radius
OS 97	gl9	Equus sp.	phalanx 3
OS 98	pit272	*Bos taurus*	tibia
OS 99	pit127	Ovicaprid	radius
OS 100	pit272	Ovicaprid	proximal tibia
OS 101	pit153	*Bos taurus*	distal metacarpal JUVENILE
OS 102	pit153	*Bos taurus*	femur
OS 103	pit153	Ovicaprid	humerus INFANT
OS 104	pit153	Ovicaprid	humerus INFANT
OS 105	pit272	*Sus domestus*	radius
OS 106	pit272	*Capreolus capreolus*	-
OS 107	pit153	Ovicaprid	femur INFANT
OS 108	pit153	Canid sp.	mandible
OS 109	pit153	Ovicaprid	metatarsal
OS 110	pit127	*Cervus elaphus*	antler
OS 111	pit208	*Emys oribicularis*	carapace
OS 112	pit130	Ovicaprid	proximal radius
OS 113	pit130	*Bos primigenus*	calceneum
OS 114	pit130	*Capreolus capreolus*	distal tibia
OS 115	pit130	Canid sp.	-
OS 116	pit130	*Cervus elaphus*	antler

OS 117	pit130	Ovicaprid	tibia
OS 118	pit153	*Sus scrofa*	distal humerus
OS 119	pit153	Ovicaprid	distal tibia
OS 120	pit153	*Sus domestus*	metatarsal
OS 121	pit153	*Capreolus capreolus*	metatarsal
OS 122	-	*Cervus elaphus*	Mandible JUVENILE
OS 123	pit205	*Bos taurus*	proximal metacarpal
OS 124	pit208	*Bos taurus*	radius
OS 125	pit153	*Bos taurus*	ulna
OS 126	pit127	*Bos taurus*	mandible
OS 127	pit127	*Bos taurus*	metacarpal
OS 128	pit127	*Sus domestus*	distal humerus
OS 129	pit153	Ovicaprid	proximal radius
OS 130	pit153	*Bos taurus*	distal humerus

Table 4.6 Faunal bone samples from Osłonki 1.
*If no age is stated, the sample is from an adult animal.

LAB I.D	**Burial No.**	**Age**	**Sex**
OSH 1	33	35-45	m
OSH 2	38	25-35	m
OSH 3	53	-	-
OSH 4	35	25-35	m
OSH 5	64	25-35	f
OSH 6	21	25-30	f
OSH 7	40	1-2 years	-
OSH 8	23	20-30	m
OSH 9	54	-	-
OSH 10	61	17-20	-
OSH 11	12	30-40	f
OSH 12	18	old	f?
OSH 13	32	20-30	f
OSH 14	26	35-45	m
OSH 15	81	20-30	f

OSH 16	6	old	-
OSH 17	59	-	-
SO 1	48	18-22	f
SO 2	39	30-40	f
SO 3	42	30-35	m
SO 4	67	20-25	m
SO 5	73	25-35	f
SO 6	72	15-19	m
SO 7	22	30-40	m
SO 8	24	25-35	f
SO 9	1	17-25	f
SO 10	69	40-50	m
SO 11	80	17-25	m
SO 12	27	14-17	f
SO 13	55	40-50	m
SO 14	63	25-30	m

Table 4.7 Human bone samples from Osłonki 1.

All of the skeletal samples from the sites used in this study were examined macroscopically for signs of deterioration, and any areas of bone that appeared poorly preserved were avoided during sampling.

4.4 Stable Isotope Analysis: Pre-Treatment Chemistry Processes

The samples included in this study were processed by the author at RLAHA, based at Oxford University. The collagen extraction method is a modified version of the Longin (1971) method, and is detailed below. The human and faunal bone samples are cleaned for surface detritus using a shot-blasting air-abrasion system using grade 5 aluminum oxide at 30µ or smaller. The sample is then placed on the scale to ascertain its start weigh. The sample is then drilled until ~600mg of bone is available for analysis[2]. The sample is drilled with a preference for the cortical section of the bone as this section preserves better due to its compact internal structure (unlike trabecular bone). The sample can be drilled into powder or into chunks, as this has a negligible impact on the outcome of the isotopic value of the sample.

The 600mg of sample is then transferred into a 10ml glass test tube and labeled accordingly. The sample is subject to three acid washes over the space of 3-5 days. The acid is 0.5M HCl, and is made from pesticide residue grade hydrochloric acid. Each time the acid is changed the sample is eZee filtered (pore size 80 microns) to ensure that the bone powder and the partial free-floating organic fraction does not escape. This step is done to demineralize the inorganic fraction of the bone. The samples processed for stable isotope analysis are not ultrafiltered (unlike the samples processed for radiocarbon dating, see chapter 7). Ultrafiltration is a method of purification that can be 'very effective in reducing environmental contamination from soil-derived amino acids as well as removing degraded collagen or other short-chain proteins' (Brock *et al*. 2007:187). This type of filtration is not routinely applied in the stable isotope laboratory at RLAHA, and a recent comparative study of ultrafiltered and non-ultrafiltered collagen samples has highlighted no significant differences for either $\delta^{13}C$ or $\delta^{15}N$ values (Sealy *et al.* 2014).

After the sample has demineralized, the sample is cleaned three times using MilliQ water. The water is then emptied out and 10ml of a pH3 solution is added to the samples. The samples are then placed upon a 'hot block' at 75° for 48hours. This is called lypholization and is performed to separate the collagen. The supernatant (the

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[2] This is referred to as the 'used' weight.

liquid with the collagen floating in it but minus the remaining bone fragments) is then eZee filtered into 10ml plastic transport tubes, covered with parafilm and the placed in the freezer.

After 24 hours the samples are removed from the freezer and flash-freezed using liquid nitrogen. The samples are then transferred into the freeze drier and the moisture is removed from the collagen over a period of 48 hours. On completion of moisture removal the samples are weighed so that the total yield of collagen can be calculated using the starting weight of the bone (~600mg) and the final weight of the collagen. A bone is usually approx. ~20% collagen, so we would expect an outcome of this value or lower. If the collagen yield is below 5% then the preservation of the sample is considered to be poor and the sample is pre-treated again (from scratch), or disregarded from the study if the yield is <1%.

The collagen is then weighed into tin capsules to be run on the mass spec. The samples are weighed in triplicate, and the average value is taken. The collagen is weighed out at 1.5mg, as this is what the mass spec (discussed below) is set to perform at. The reference for the mass spec is alanine, and reference pairs are used after every six samples for drift correction (discussed below).

4.5 Isotope Ratio Mass Spectrometry

The samples for this study were run on a SerCon continuous flow duel inlet isotope ratio mass spectrometer - an elemental analyser hooked up to a multisource IRMS. The samples are weighed into tin capsules and then loaded onto an automated carousel. A continuous flow is when a helium carrier gas passes continuously into the ion source and sweeps bands of analyte gas into to the source for analysis.

The sample is then dropped into a heated reactor and oxidized, and the reaction takes place in a helium atmosphere with an excess of oxygen. During this time, a number of combustion products are produced, and in terms of this study these products are N_2, NO_x, CO_2 and water. These products are transported down the helium carrier stream into a reduction furnace where the excess oxygen is removed and nitrous oxides are converted in N_2 (Meier-Augenstein 2010). A drying tube removes the excess traces of water. The helium gas and its products are then passed through a GC column under isothermal conditions and are the products are detected in a non-destructive way and then are passed into the IRMS.

4.5.1 Standards and calibration

Standards are used in mass spectrometry runs to calibrate the readings taken from the bone samples. Isotopic ratios of samples are calculated with reference to an in-house standard, which at RLAHA is alanine. Alanine is used as the internal standard as its C:N ratio is 3.42, which is similar to the C:N ratio of bone collagen (Meier-Augenstein 2010, Brock *et al.* 2010). Additionally, the expected isotope values for alanine are not overtly dissimilar to bone collagen (e.g. the $\delta^{13}C$ value for alanine is -26.9%, and the $\delta^{15}N$ value is 1.63%). The stable isotope data that is produced has to be reported in the literature on a scale in reference to the calibration material. ^{13}C is reported on the VPDB scale and ^{15}N is reported with reference to AIR (Chapter 3). The associated measurement error is ±0.2%.

4.6 Environmental parameters: AQUASTAT and CRU datasets

AQUASTAT is the FAO's (Food and Agriculture Organization for the European Union) global water information system (http://www.fao.org/nr/water/aquastat). The *climate information tool* forms part of this programme, and provides a spatial dataset that contains a range of mean monthly climate data that covers the global land surface at a 10minute spatial resolution for the period 1961-1990. The climate information tool includes (but is not limited to) the parameters of; mean monthly rainfall (mm), mean monthly temperature, humidity (percentage of water vapour in the atmosphere, and is approximately commensurate to the 'water availability' present in the atmosphere), sunshine (percentage of day length where sunshine is present), and reference evapotranspiration (the rate of the amount of water lost through evaporation and transpiration in mm per time unit) (FAO 2015).

The majority of the data used in the climate information originates from the New *et al.* (2002) CRU 2.0 dataset, which is the result of collaboration between the School of Geography at Oxford University, International Water Management Institute World Water and Climate Atlas and the Climatic Research Unit of the University of East Anglia. The remaining data was sourced by the FAO.

The main caveats associated with this approach to climate modeling are the issues that i) the climate data is modern, and ii) the data used in AQUASTAT are mean circumstance values that occur as a result of interpolating data from different climate stations. In response to these issues, a number of salient points are raised. Firstly, the use of modern data is necessary in the absence of direct climatic data from the prehistoric period. It is of course recognised that palaeoclimate reconstruction is widely practiced using a number of different techniques, such as analysis of $\delta^{18}O$

from ice cores and stalagmites, the analysis of pollen and plant macrofossils from sediment cores, and the study of diatoms and forams from limnological and marine contexts (Lowe and Walker 1984). However the *resolution* of these techniques is often broad, and whilst they do provide valuable information about long-term climate changes (e.g. periods of warming and cooling), information pertaining to small-scale changes is not generated from these proxies. Therefore it is not possible to use palaeoclimatic data to model the effects of climate on carbon and nitrogen isotope values.

Modeling the effects of climate change requires quantitative data, which is currently only available through modern measurements. As Hedges *et al.* (2013:345) state in their AHRC funded *LBK Lifeways* project, which in part also considered climate effects on carbon and nitrogen isotope values, "…whilst it is acknowledged that the absolute values of the modern data may not apply well to the Neolithic period, (given the change in climate and vegetation) the relative difference between regions should hold firm".

With regards to the use of AQUASTAT, the main issue is the use of interpolation to provide data values. By definition the use of geostatistical interpolation involves errors, as it is the error structure of the input data that helps to define the fitted surface (New *et al.* 2002). Admittedly, there are a number of climate related local topographical issues that could be affected by this interpolation technique (e.g. its inability to mitigate for the presence of rain shadows (etc.)), but the resolution of the dataset remains sufficient for the purposes of this research.

4.7 Statistical Methods

A number of statistical methods are applied to analyze the isotopic data in this project. The use of statistics in archaeological and ecological carbon and nitrogen isotope datasets are widely applied (Lee-Thorp *et al.* 1989, Turner *et al.* 2010, Schmidt *et al.* 2007, Baxter 2003, Hedges and Reynard 2007, Post 2002, Martínez del Rio *et al.* 2009, Casey and Post 2011), and are so are not repeated here. The statistical/graphical interface of R is discussed, as are the main packages that were used to analyse the data. Unless otherwise stated, the statistics were undertaken in R.

4.7.1 R

R is a free software environment for statistical computing and graphics (www.r-project.org). It is an implementation of the computer language S, combined with lexical scoping semantics. At a very basic level, R can perform basic statistical testing and modeling (such as linear and non-linear modeling, regression modeling, time series, and cluster, analysis etc.), and also provides a means of graphing datasets (e.g. xy scatterplots). However, R is an open source platform, and the addition of user-created packages (such as SIAR) *greatly* extends the functionality and capability of R. The packages that have been used in this project (in addition to established R pacakges) are `lme4`, `nlme`, `SIAR`, `3dscatterplot`, `car`, `ggplot2`, `MASS` (Bates *et al.* 2014, Pinheiro *et al.* 2011, Parnell *et al.* 2008, Ligges and Mächler 2002, Fox *et al.* 2009, Wickham 2009, Ripley *et al.* 2014).

4.7.2 Multi-level modeling: `lme4` *and* `nlme`

Multi-level analysis is a type of linear regression model that takes into account hierarchical data (further explanation is present in chapter 5, section 5.5). For this project, hierarchical variables (e.g. variables which could affect the carbon and nitrogen isotope values of the human and fauna samples) are factors such as specific animal species, site (e.g. to acknowledge potential differences in animal management techniques), and climatic variables. This modeling is undertaken to i) analyze the extent of the climatic influence on carbon and nitrogen isotope values, and ii) to analyze whether differences exist in fauna isotope values between sites that *cannot* be explained as a result of different climatic conditions.

4.7.3 SIAR

Stable Isotope Analysis in R (SIAR) is a source-partitioning program that is designed to solve mixing models for isotopic data within a Bayesian framework (Parnell *et al.* 2010). The use of this source partitioning model, and others like it (e.g. IsoSource and FRUITS), comes with a long list of caveats and assumptions. These caveats range from the nature of isotopic fractionation in consumer/source tissues, to the way in which the model performs the statistical analyses.

For example, from a biological perspective the model assumes homogenization of dietary resources in the consumer’s body prior to tissue synthesis, and doesn't account for preferential routing of dietary proteins and lipids (Newsome *et al.* 2004). From a statistical standpoint, the model will always try to fit the data even if it is nonsensical. Despite the caveats and assumptions these models are still useful for palaeodiet reconstruction because they provide a method for constraining the isotope data, even if the method is not perfect. The models should not be considered as stand-alone outputs, and a consideration of the accompanying archaeological evidence, such as faunal assemblages and evidence for dietary resource procurement (e.g. the presence of fishing weirs/equipment) is essential.

Chapter 5: Fauna Stable Isotope Results

5.1 Introduction and Overview of Analysis

This chapter details the faunal δ^{13}C and δ^{15}N values for the study sites. The human δ^{13}C and δ^{15}N values are reported in chapter 6. The biological state of preservation of the samples is assessed, and failed samples are removed. The datasets generated are subjected to statistical testing, both to check for outliers and to examine the nature of their distributions.

5.2 Sample Preservation

The faunal bone collagen δ^{13}C (‰) and δ^{15}N (‰) values for Aktopraklık, Barçin Höyük, and Osłonki 1 are summarised in appendix 1, table A1.1 (these are the averages of the duplicate measurements). A number of quality control parameters are in place at RLAHA to ensure the accuracy of the data produced, these include a collagen yield of 1% or above, a C:N ratio of between 2.9 and 3.6, and an collagen yield of 5mg (DeNiro and Epstein 1978, Brock *et al.* 2010). The %C and %N of the collagen samples is also calculated as this provides a reliable indicator of sample preservation (Ambrose 1990, Van Klinken 1999, Sealy *et al.* 2014). The ideal range for %C is *c.* 40-48%, and for %N is approximately c. 12-17% - it should be noted these ranges are approximate, with the individual studies (e.g. Ambrose 1990, Van Klinken 1999, Sealy *et al.* 2014) producing slightly different ranges. The purpose of these parameters is to ensure that sufficient organic material (e.g. mainly collagenous protein) was preserved, and that this material remains uncontaminated in the bone sample (as assessed by the C:N ratio).

5.3 Dietary Reconstruction

5.3.1 Aktopraklık

In total 30 faunal samples were processed from the Late Neolithic/Chalcolithic site of Aktopraklık, including sheep/goat, cattle, domestic pig, wild boar, red and fallow deer species. Five modern fish samples were also analysed from Lake Ulubat due to the close proximity of the site to a potential source of freshwater resources. Two samples (both sheep/goat) failed the quality control parameters, due to insufficient collagen yield (samples KA11 and KA13). These bones were re-sampled and subjected to pre-treatment, and subsequently passed the quality control parameters. One cattle outlier was noted to have a δ^{13}C value of -23‰. At the time of writing, there was insufficient dating information pertaining to the faunal samples (e.g. whether Neolithic/Chalcolithic), only 9 of the analysed samples had been chronologically assigned – and no difference was observed between the Neolithic and Chalcolithic (with the issue of species difference noted). Table 5.1 provides the summary statistics for the faunal isotope values.

Species	**n**	**d^{13}C Min**	**d^{13}C Max**	**d^{13}C Ave**	**1 s.d**	**δ^{15}N Min**	**d^{15}N Max**	**d^{15}N Ave**	**1 s.d**
Cattle	9	-20.5	-18.0	-19.8	1.0	5.0	8.8	6.5	1.2
Sheep/Goat	13	-20.9	-19.2	-20.1	0.6	4.8	7.8	5.9	1.0
Pig	3	-20.6	-19.6	-20.1	0.5	3.5	8.0	6.3	2.4
Wild Boar	1	-	-	-19.5	-	-	-	3.5	-
Red Deer	2	-21.5	-21.5	-21.5	0	4.6	5.0	4.8	0.1
Fallow Deer	1	-	-	-20.1	-	-	-	4.1	-
Modern Fish	5	-26.0	-21.2	-23.5	2.1	11.8	14.1	11.8	2.3

Table 5.1 Human bone samples from Osłonki 1.

Figure 5.1 highlights the δ^{13}C and δ^{15}N values for the fauna and fish from Aktopraklık. The fish species analysed, (*Esox masquinongy* [muskellunge], *Cyprinus carpio* [yellow carp], *Scardinius erythrophthalmus* (Common rudd), Atherinidae sp. [atherina] and *Silurus glanis* [Wels catfish]) have very depleted δ^{13}C values. The δ^{13}C values vary by approximately 6‰, which reflect the different feeding areas and trophic levels present within a lake (e.g. deep water feeders have more depleted $\delta^{13}C$ values than species feeding at higher levels, and carnivores will differ due to predation on other species) (Fuller *et al.* 2012, Dufour *et al.* 1999, Mackay *et al.* 2013). The $\delta^{13}C$ values for the terrestrial fauna (both wild and domestic) from Aktopraklık range from *c.* -22‰ to -18‰, which is representative of the consumption of predominantly C_3 terrestrial resources.

The modern $\delta^{15}N$ fish values range between 8.6‰ and 14‰. These values are again commensurate with known values for freshwater lake systems, and the *Atherina* value reflects the fact that it is an opportunistic feeding species, which have a preference for zooplankton, but will resort to benthic organisms as a secondary food source (Bartulović *et al.* 2004). Previous $\delta^{13}C$ and $\delta^{15}N$, and gut investigation studies into modern day *Atherina* species have highlighted a discrepancy between the conclusions drawn from the analysis of the gut and from isotope studies, suggesting differences between the assimilated nutrients and diet that is ingested (Vizzini and Mazzola 2002). The $\delta^{15}N$ values for the terrestrial animals range between *c.* 4‰ to 8‰ (as shown in figure 5.2).

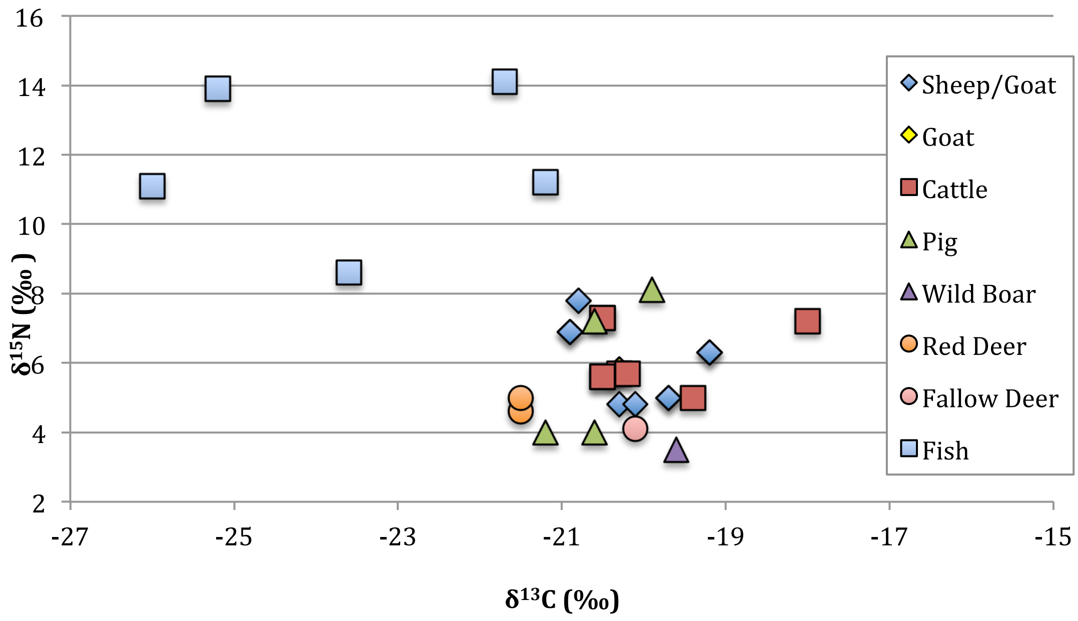

Figure 5.1 $\delta^{13}C$ and $\delta^{15}N$ for terrestrial fauna samples from Aktopraklık.
(error bars are to small to be seen).

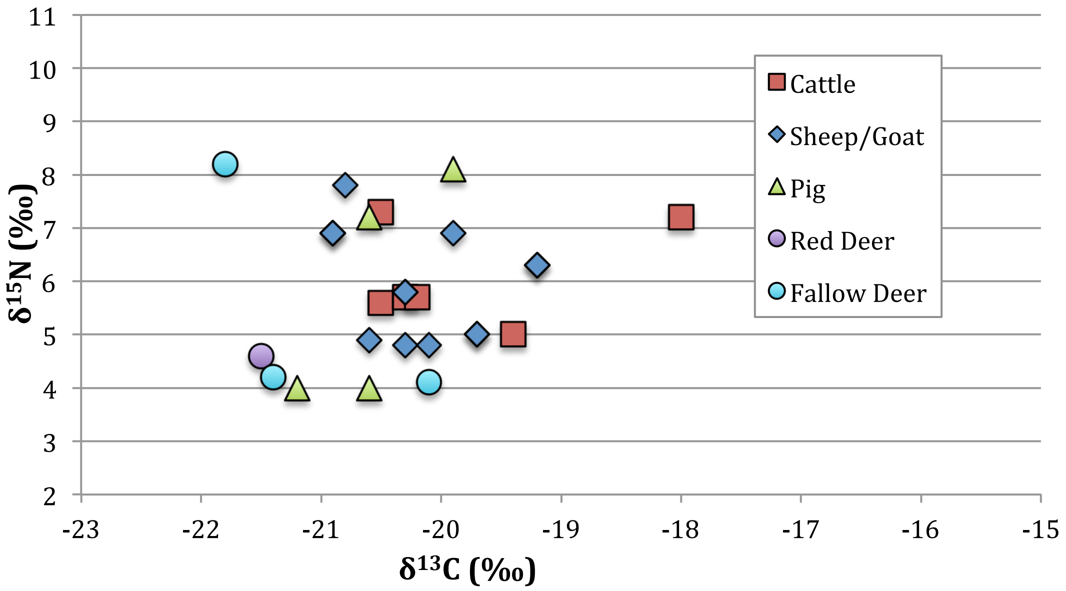

Figure 5.2 $\delta^{13}C$ and $\delta^{15}N$ for the main fauna from Aktopraklık.
(error bars are too small to be seen).

The average cattle $\delta^{13}C$ value for Aktopraklık is -19.8‰±1.0, which reflects the grazing of C_3 terrestrial plant species. Palaeobotanical reports from North-West and Central Anatolia (for the Neolithic period) suggest an abundance of Poaceae and

Gramineae species (Bottmea and Woldring 1995, Asouti *et al.* 2001, Bogaard *et al.* 2013), and these C_3 grasses are commensurate with the cattle isotope values.

There is a single exception, a cattle sample that has a $\delta^{13}C$ of -18‰, which may reflect the consumption of a small amount of C_4 grass. In this context it would likely reflect the consumption of Chenopodiaceae or Cyperaceae (sedges), but does not exclude the consumption of Boraginaceae, Alopecurus or Aeluropus (Bottema and Woldring 1995, Fairburn 2002, Fairburn *et al.* 2005).

The cattle $\delta^{15}N$ values range from 5‰ to 7.3‰, with the majority of the distribution falling around 5.5‰. It is tempting to suggest that the two Aktopraklık cattle with higher $\delta^{15}N$ values are misidentified juvenile samples, but an inspection of the two bones in question reveal that this is not the case. One of the samples has enriched ^{13}C which may reflect C_4 plant consumption. One could argue that the higher $\delta^{15}N$ reflects this C_4 consumption (as C_4 plants are associated with arid environments, see Chapter 3 for discussion). The other high $\delta^{15}N$ value however is less easily explained, and may simply reflect different grazing patterns between individual animals.

The $\delta^{13}C$ values for the sheep/goat species vary by approximately 2‰, *c.* -19 to -21‰, within the range indicative of the consumption of terrestrial C_3 resources. The $\delta^{15}N$ values vary by *c.* 3‰ (5‰ to 8‰). These values also reflect the consumption of C_3 grasses such as Poaceae and Gramineae species. The greater isotopic range for this group (both in terms of $\delta^{13}C$ and $\delta^{15}N$ values) possibly reflects differences between sheep and goats in terms of their feeding habits, and as the samples studied (with only one exception) were not separated by species it is not possibly to test this. Sheep are grazers and so have a penchant for the tender shoots of grasses, and goats, which are browsers, will consume the leaves, shrubs and twigs of the plants (as well as grazing on middens etc.). The isotopic variation between the different parts of a plant is discussed in chapter 3. The δ^{13}C for the pigs is consistent with the rest of the fauna at Aktopraklık, however, the δ^{15}N values are more interesting, with two samples at *c.* 4‰ and two samples at *c.* 7-8‰. This is quite a pronounced difference and potentially reflects the possibility that two of the pigs originate from outside of this settlement site, or that the pigs with the high δ^{15}N values might indicate feeding with slops from human cooking waste, i.e. domesticates. This idea is supported by the low δ^{15}N value of the wild boar sample. However, any conclusions based on only five samples are tentative. Whilst the cattle and sheep/goat also have examples of very high δ^{15}N values, the variance in the respective groups is considerably smaller, as is the overall range.

The red and fallow deer samples provide a useful baseline for the natural landscape surrounding Aktopraklık, with the δ^{13}C values falling between -22‰ and -20‰, reflecting the consumption of C_3 grasses. The δ^{15}N values (4.8±0.1‰) largely agree with this, and the single sample with a δ^{15}N value of 8.2‰ is most probably the misidentification of a juvenile sample.

5.3.2 Statistical testing

If we revisit the hypotheses set out in the introductory chapter, the first point of order is to establish whether isotopic differences exist between fauna values to investigate the possibility of animal management practices. δ^{13}C is often used to address aspects of livestock production, such as seasonal foddering, transhumance and land use practices (Balasse 2002, Balasse and Ambrose 2005, Finucane *et al.* 2006, Maskour

2003, Towers *et al.* 2011). These studies utilise tooth enamel to look at seasonality, or pronounced isotopic differences in wild *vs.* domestic plants (e.g. natural C_3 resources *vs.* purposely grown C_4 maize subsequently used as fodder). In the absence of tooth enamel for analysis from Aktopraklık, or evidence for C_4 crop cultivation, it possible to consider the isotopic variation between wild and domestic fauna. The underlying principle is that animal management practices would *potentially* result in narrower isotope ranges. The theory behind this is that practices such as penning or foddering (discussed in chapter 2) represent an anthropogenic restriction in the variety of food available to the livestock. Overall, a narrow isotope range for domestic animals (and conversely a wide range for their grazing wild counterparts) would point to animal management practices; however, the absence of a narrow isotopic range does *not* point to the *absence* of animal management practices – they are not necessarily identifiable using isotopic analysis of bone collagen.

ANOVA was performed on the fauna data to investigate whether the variation in isotope values is the same. Variation is tested rather than central tendencies (such as means and standard deviation), as a measure of variation will highlight the extent of different patterns between individuals in the group (where group equates to domestic or wild). ANOVA consolidates the data into one number (*F*), and it provides a *p* value for the null hypothesis.

The $\delta^{13}C$ data for the cattle samples is not normally distributed, so the Kruskal Wallis Test should be applied. ANOVA and Kruskal Wallis are applied to possible permutations of the datasets to see if the results were comparable (we would expect the ANOVA to be more likely to reject the null hypothesis because it is a more powerful test). Four groups were utilised for the variance tests: cattle, sheep/goat, pig, and wild fauna (wild boar, red and fallow deer). The 'wild fauna' group is an applicable analogue for the domestic fauna as deer species are ruminants, like cattle and sheep/goat, and wild boar are non-ruminants, like their domestic pig counterparts.

Isotope	*ANOVA*		*KRUSKAL WALLIS*	
	p-value	*F*-value	*p*-value	KW chi-squared value (*H*)
$\delta^{13}C$ all fauna	0.260	1.422	0.3901	3.01
$\delta^{15}N$ all fauna	0.063	2.770	0.0626	7.31
$\delta^{13}C$ domestic fauna	0.236	1.345	0.2579	2.71
$\delta^{15}N$ domestic fauna	0.694	0.372	0.788	0.5

Table 5.2 ANOVA and Kruskal Wallis variance test results for Aktopraklık fauna collagen isotope values.

(performed in R).

For ANOVA, the comparison between the actual observed variation between groups and the expected variation between groups is expressed as the *F* ratio (where *F* = (found variation of the group averages)/(expected variation of the group averages) (Roberts and Russo 1999). If the null hypothesis is correct (e.g. the expected variation of the group averages is observed), then we would expect the *F* value to be about 1. If the F value is larger, then this indicates a location effect. The *p*-value is generated from the *F* ratio, which gives the confidence level at which we should reject the null hypothesis. The Kruskal Wallis test is a non-parametric analogue of the *F*-test in ANOVA, and is less sensitive to outliers in the dataset. For the Kruskal Wallis test, a large *H* value points to a large discrepancy in the variability between groups. For ANOVA, the significant *F* ratios are the $\delta^{13}C$ and $\delta^{15}N$ values for all fauna analysed (with the *F-crit* value at 1.077 and 1.901 respectively, see Roberts and Russo (1999), Field *et al.* (2012) and Wright (2013), for further details on interpreting ANOVA).

These results (table 5.2) highlight that there are no significant differences in δ^{13}C and δ^{15}N variance between all of the fauna groups, this disappears for the δ^{15}N when the wild fauna data are removed. This can be tested statistically with post hoc tests, Tukey for ANOVA or a Dunn's test for Kruskal Wallis, but as multi-level modelling will be applied later, testing is not undertaken here.

5.3.3 Barçin Höyük

A total of 50 faunal samples were processed from Barçin Höyük, these include 21 cattle samples, 18 sheep/goat, and 1 pig sample (table 5.3 and figure 5.3). These samples are currently chronologically assigned the Neolithic period.

Species	**n**	**d^{13}C Min**	**d^{13}C Max**	**d^{13}C Ave**	**1 s.d**	**d^{15}N Min**	**d^{15}N Max**	**d^{15}N Ave**	**1 s.d**
Cattle	21	-22	-19	-20.2	0.9	5.9	9.2	6.5	1.0
Sheep/Goat	18	-20.8	-18.5	-19.7	0.6	4.9	8.9	7	0.7
Pig	1	-	-	-20.6	-	-	-	7.6	-
Fox	1	-	-	-19.2	-	-	-	8.1	-
Wild Boar	1	-	-	-19.9	-	-	-	5.1	-
Roe Deer	1	-	-	-21.6	-	-	-	4.6	-

Table 5.3 Summary statistics for Barçin Höyük.

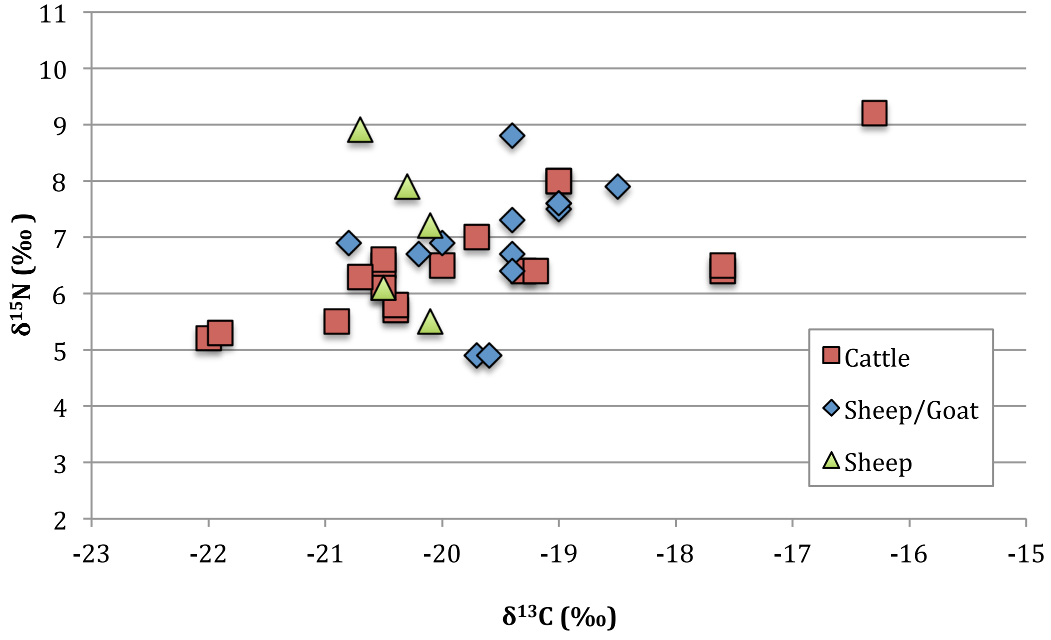

Figure 5.3 δ^{13}C and δ^{15}N for the main fauna present at Barçin Höyük.

The δ^{13}C values of the cattle samples exhibit a considerable range at -22‰ to -16.3‰, a difference of *c.* 6‰. The majority of the δ^{13}C values, e.g. -20.2±0.9‰, indicate the consumption of C_3 grasses, and as at Aktopraklık, the most likely species are Poaceae and Graminae (Bottema and Woldring 1995).

The mean δ^{13}C value for the sheep/goat samples is -20.8‰±0.6. The δ^{15}N values for the sheep/goat samples average at 7‰±0.7. The sheep samples from Barçin Höyük plot within the same range as the sheep/goat samples, although the distributions are significantly different for δ^{13}C ($p = 0.008$), but not for δ^{15}N values ($p = 0.7$) (student's t-test).

5.3.4 Statistical Testing

ANOVA and Kruskal Wallis testing is applied to the Barçin Höyük dataset (table 5.8). For Barçin Höyük the groups are cattle, sheep/goat, and wild fauna (which include fox, wild boar, aurochs and roe deer). It is acknowledged that grouping different types of wild fauna together is not ideal (they have different species effects, and digestive systems etc.), but in the absence of any other available data it is the best comparative option. Domestic pig cannot be used as a group as there is only one sample, as a result of this the Mann Whitney U test (two-tailed, with the alpha at 0.05) will be used to examine differences between the cattle and sheep/goat datasets.

Isotope	*ANOVA*		*KRUSKAL WALLIS*	
	p-value	*F*-value	*p*-value	KW chi-squared value (*H*)
$\delta^{13}C$ all fauna	0.161	1.811	0.5827	1.08
$\delta^{15}N$ all fauna	0.132	1.984	0.1979	3.24

Table 5.4 ANOVA and Kruskal Wallis test results for all Barçin Höyük fauna collagen isotope values.

The ANOVA and Kruskal Wallis test statistics in table 5.4 demonstrate that there is no difference in $\delta^{13}C$ and $\delta^{15}N$ between any of the wild or domestic fauna at Barçin Höyük. The difference in $\delta^{13}C$ between the cattle and sheep/goat data is not significant (Z-ratio = 0.33, p=0.7414, U = 142.5), as the critical value of U at $p \leq 0.05$ is 93. The difference in $\delta^{15}N$ for the cattle and sheep/goat data at Barçin Höyük is also not significant (Z-ratio = 1.4522, p=0.14706, U=108.5) – the critical value of U at $p \leq 0.05$ is 93. The ANOVA, Kruskal Wallis, and Mann Whitney U tests highlight that there are no differences in $\delta^{13}C$ and $\delta^{15}N$ in the faunal datasets.

5.3.5 Osłonki 1

In total 130 faunal samples were analysed from Osłonki 1. Table 5.5 provides the summary statistics for the fauna.

Species	**n**	**^{13}C min**	**^{13}C max**	**^{13}C ave**	**^{13}C s.d.**	**^{15}N min**	**^{15}N max**	**^{15}N ave**	**^{15}N s.d.**
Cattle	45	-22.4	-20.0	-20.6	0.4	4.2	7.4	5.9	0.7
Sheep/Goat	30	-21.1	-19.0	-20.1	0.4	4.5	7.8	5.7	0.8
Pig	20	-23.0	-19.7	-20.8	0.7	5.8	9.2	7.3	1.0
Wild boar	6	-21.4	-20.5	-21.0	0.3	4.7	6.5	5.5	0.7
Roe Deer	7	-21.6	-19.3	-20.7	0.8	4.1	6.3	5.0	0.7
Red Deer	10	-22.1	-20.1	-20.8	0.7	2.5	7.4	4.7	1.4
Horse	1	-	-	-22.3	-	-	-	3.9	-
Dog	2	-19.6	-18.3	-18.9	0.9	7.8	8.6	8.2	0.7
Beaver	1	-	-	-20.5	-	-	-	8.5	-
Turtle	5	-25.5	-23.2	-24.4	0.9	6.3	7.5	6.8	0.5
Auroch	1	-	-	-20.4	-	-	-	7.8	-

Table 5.5 Summary of fauna isotope values at Osłonki 1.

The faunal assemblage from Osłonki 1 is largely composed of domestic fauna, e.g. cattle, sheep/goat and pig, but it also includes some wild species, such as red and roe deer and aurochs. Figures 5.4 - 5.7 highlight the isotopic differences between wild and domestic species. Figure 5.4 shows the δ^{13}C and δ^{15}N red and roe deer from Osłonki 1.

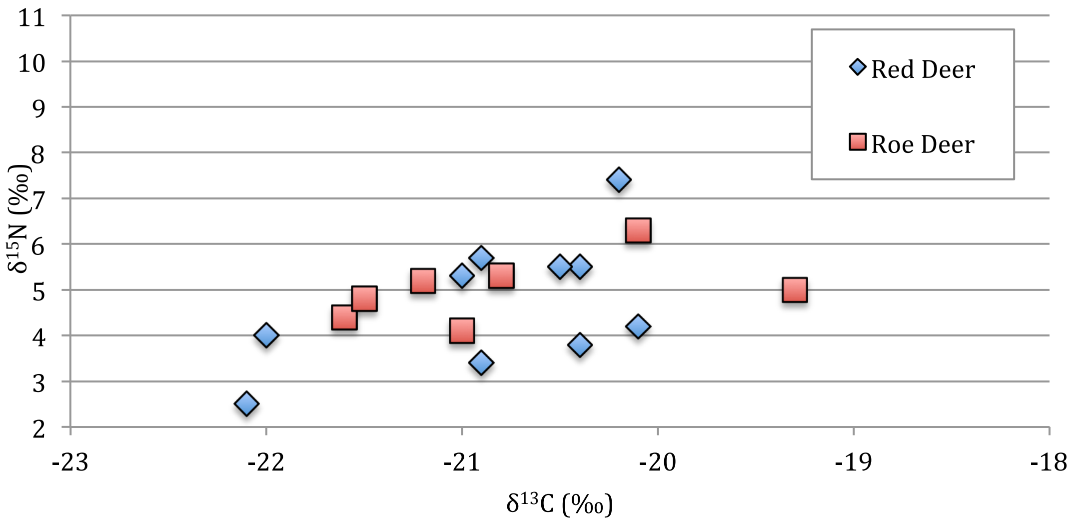

Figure 5.4 δ^{13}C and δ^{15}N for Osłonki 1 for Red and Roe deer.

The δ^{13}C values for the roe deer average at -20.8‰±0.8, and the red deer cluster at -20.8‰±0.7. The average δ^{15}N for the roe deer samples is 5.0‰±0.7, and 4.7‰±1.4 for the red deer samples. The difference between the distributions of data for δ^{13}C and δ^{15}N is not significant using a 2 tailed Mann Whitney U, with an alpha of 0.05 (For δ^{13}C: *Z*-ratio= 0.1464, *p*=0.88076, *U-crit* = 33 .For δ^{15}N: *Z*-ratio = -0.2928, *p*=0.77182, *U-crit*= 14). Despite the fact that roe deer are primarily browsers, whilst red deer are mixed feeders (Gordon and Prins 2008:161), their isotope values are not different. This range of δ^{13}C values provides an indication of the range of plant values present in the area surrounding Osłonki 1. Figure 5.5 shows the δ^{13}C and δ^{15}N for the domestic cattle and the single auroch sample, the cattle date to both the Classic (n= 28) and Late (n= 15) phases.

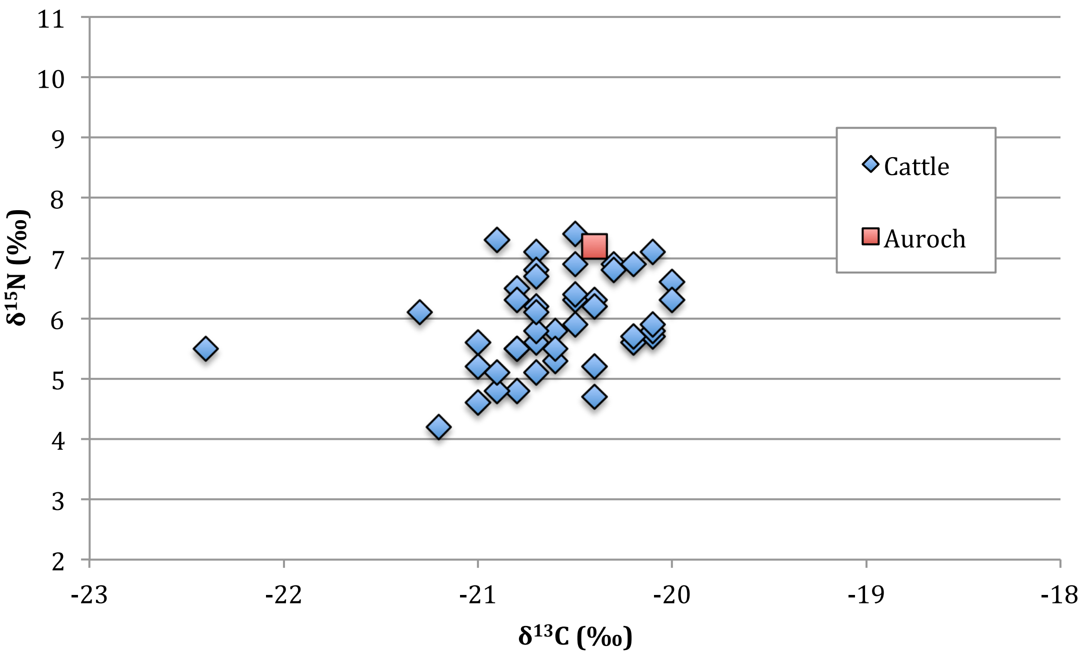

Figure 5.5 δ^{13}**C and** δ^{15}**N for Osłonki 1 cattle and auroch samples.**

The average δ^{13}C value for the cattle (and auroch) is -20.6‰±0.4, the 1‰ range for over 45 cattle samples is very constrained. The single outlier, with a δ^{13}C value of -22.4‰ has no obvious associated evidence to explain its location outside the main distribution of the group. It is possible that the outlier is a misidentified auroch sample, as comparative studies have shown that aurochs samples are consistently depleted when compared to their domestic cattle counterparts (Noe-Nygaard *et al.* (2005), Hamilton *et al.* (2008)). Two of the cattle at Barçin Höyük also exhibited depleted δ^{13}C ratios, at -21.9‰ and -22‰, and this may potentially reflect the presence of misidentified auroch samples, as auroch samples have been recovered from Central and North-West Anatolia (Arbuckle *et al.* 2014). Equally, we cannot discount the possibility that the depleted $\delta^{13}C$ values may reflect specific grazing patterns of individual animals (Gordon and Prins 2008).

The $\delta^{15}N$ values for the cattle average at 6‰±0.8, which initially seems like a wide range, but on comparison is in line with the variation observed in the North-West Anatolian sites. The single auroch sample plots within the distribution of the cattle, and may indicate that this sample is a misidentified cattle bone. Figure 5.6 highlights the $\delta^{13}C$ and $\delta^{15}N$ for domestic pigs and wild boar from the Classic and Late phases.

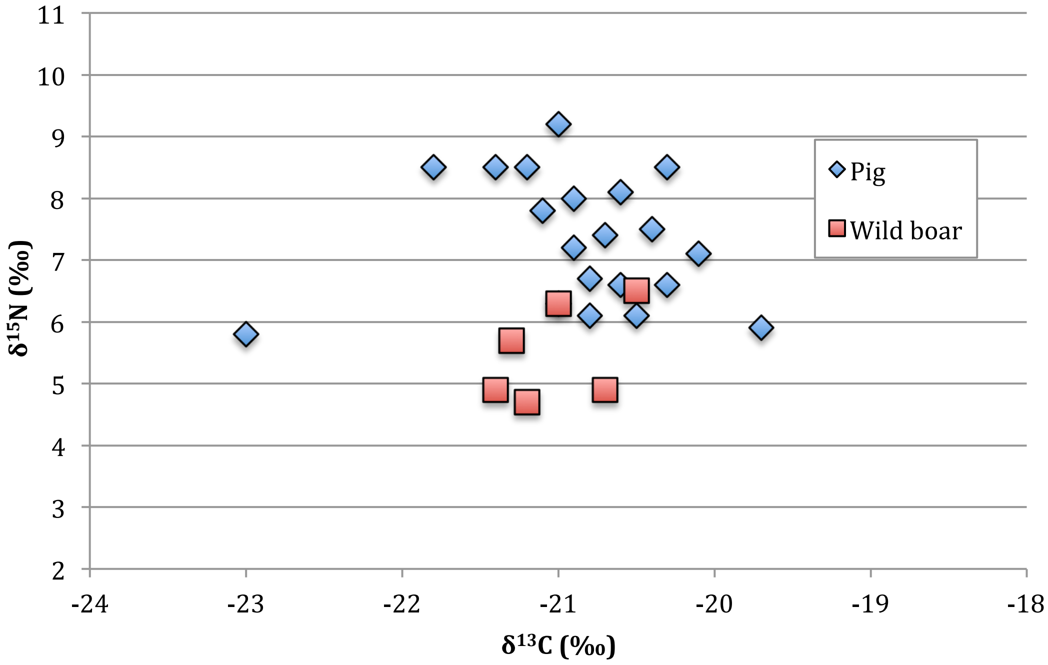

Figure 5.6 $\delta^{13}C$ (‰) and $\delta^{15}N$ (‰) for wild boar and domestic pigs.

The average $\delta^{13}C$ value for the wild boar samples is -21‰±0.4, with -20.9‰±0.7 for the domestic pigs. The difference in the distribution of $\delta^{13}C$ values between the domestic pig samples and the wild boar samples is not significant (*p*=0.2). The wild boar $\delta^{13}C$ values are more constrained than the domestic pigs, and this might be an artefact of the different sample sizes (wild boar = 6, domestic pig = 20).

The average $\delta^{15}N$ value for the domestic pigs is 7.3‰±1, a range that is more isotopically enriched than their cattle counterparts, suggesting a different diet. The wild boar $\delta^{15}N$ values range between 5.5‰±0.8. The difference in the $\delta^{15}N$ values between the wild boar and the domestic pigs is statistically significant ($p = <0.001$). Figure 5.7 shows the isotopic distribution of cattle, sheep/goat and pigs.

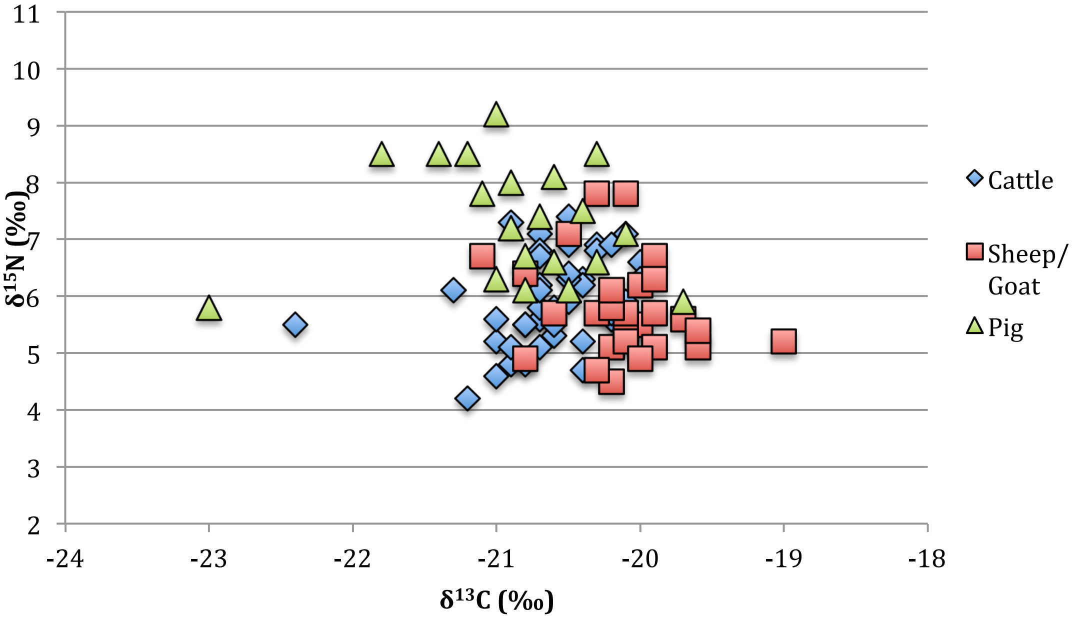

Figure 5.7 $\delta^{13}C$ (‰) and $\delta^{15}N$ (‰) of cattle, sheep/goat and pig from Classic and Late phases.

The difference of the distribution of $\delta^{13}C$ values of the cattle and sheep/goat samples is statistically significant ($p<00.1$), as are the differences between pigs and cattle ($p=0.08$), or pigs and sheep/goat are significant ($p<0.001$). ANOVA testing of the $\delta^{13}C$ values found the distributions to be significantly different ($p<0.001$). Due to the non-parametric distribution of the cattle $\delta^{15}N$ values, the Kruskal Wallis test was used to test for variance between the $\delta^{15}N$ values three groups. ANOVA testing was also undertaken and was found to be in agreement (table 5.7). The species distributions were tested for homogeneity of variance prior to the significance testing and were found to be in agreement.

Isotope	*ANOVA*		*KRUSKAL WALLIS*	
	p-value	*F*-value	*p*-value	KW chi-squared value (*H*)
δ^{13}C all fauna	0.000	15.4	<0.0001	28.97
δ^{15}N all fauna	0.000	27.47	<0.0001	26.59
δ^{13}C Wild, Classic, and Late	0.02	3.7	-	-
δ^{15}N Wild, Classic, and Late	<0.001	14.78	-	-

Table 5.6 ANOVA and Kruskal Wallis test results for all Osłonki 1 fauna.

Osłonki 1 is divided into three phases of occupation; Early (4,700-4,500 cal BC), Classic (4,500-4,300 cal BC) and Late (4,300-4,100 cal BC). In total, 73 faunal samples date to the Classic phase, and of these 19 were wild species (red deer, roe deer, wild boar and the auroch). 42 fauna samples were retrieved from the Late phase, and only one of these samples was from a wild animal (red deer). Figure 5.8 plots the fauna by phase. The wild fauna is included to provide a comparison (assuming the wild fauna will not reflect changes in management practices between phases).

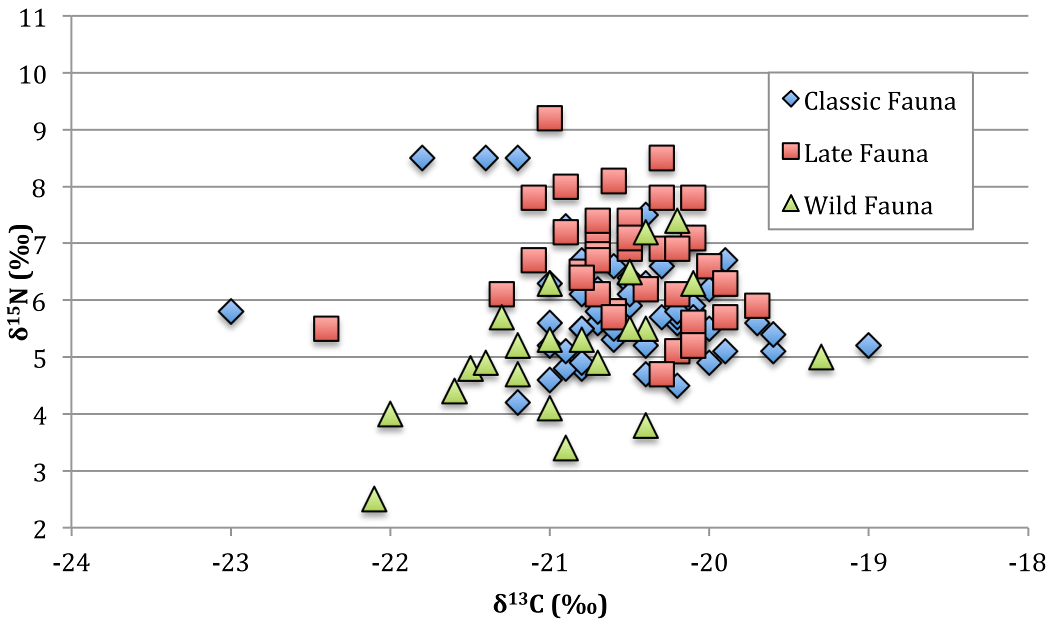

Figure 5.8 δ^{13}C (‰) and δ^{15}N (‰) for Classic, Late and Wild fauna at Osłonki 1.

The difference in the distribution of the δ^{13}C values of the Classic, Late and Wild fauna is significant (at *p*=0.02, F value = 3.7), as are the differences in the δ^{15}N values in the datasets (*p*=<0.001, F value = 14.78) (table 5.6). The reason for the significance between the δ^{13}C values is largely the result of the range carbon isotope values obtained on the wild fauna. Post hoc analysis (Tukey's HSD at σ 0.05) of group means demonstrates that the difference between the cattle δ^{13}C and sheep/goat δ^{13}C is not significant (*p*-adjusted = 0.9). The difference between the δ^{15}N values remains significant, with a Classic-Late *p*-adjusted value = 0.004. The cattle, sheep/goat and pig isotope values were combined for the ANOVA testing (table 5.6). The individual species are considered independently below in order to examine the possibility of a change in one species skewing the statistical tests.

Figure 5.9 highlights the δ^{13}C and δ^{15}N values for Classic and Late cattle. The difference in the distributions of δ^{13}C values between cattle in the Classic and Late phases is not significant (*p*=0.3). The difference in the $\delta^{15}N$ distributions is significant (*p*=<0.000), and this is commensurate with the ANOVA carried out above.

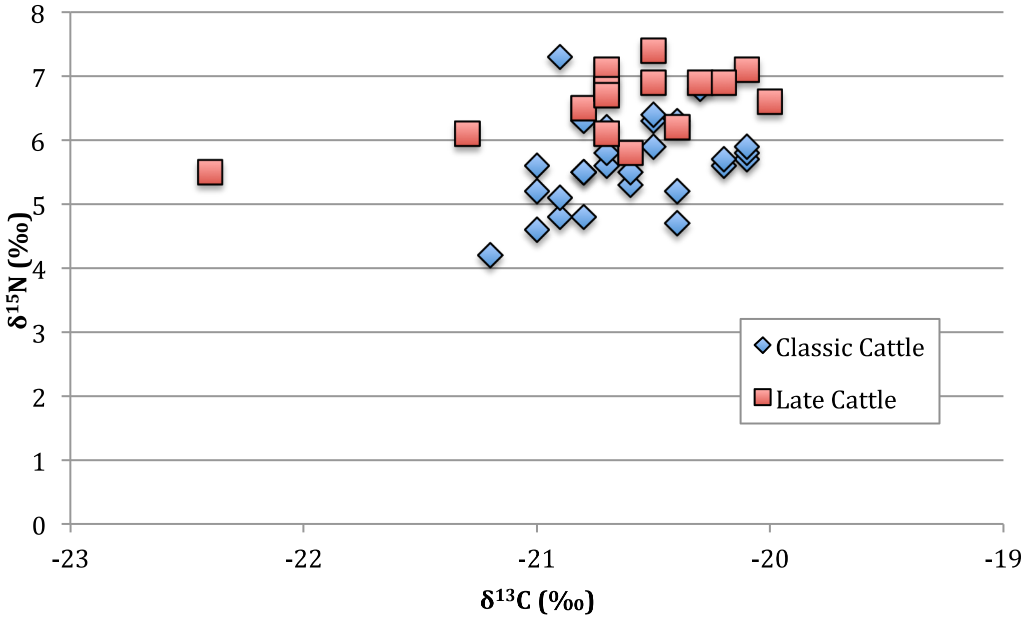

Figure 5.9 $\delta^{13}C$ (‰) and $\delta^{15}N$ (‰) of Classic and Late cattle samples.

Figure 5.10 illustrates the $\delta^{13}C$ and $\delta^{15}N$ for the Classic and Late sheep/goat samples. The distributions of the sheep/goat species are non-parametric, table and so the Mann Whitney U test is applied. The $\delta^{13}C$ values of the sheep/goat samples are significantly different (*p*=0.03). The difference in the $\delta^{15}N$ distributions is not significant (*p*=0.10). This result is not commensurate with the overall ANOVA testing.

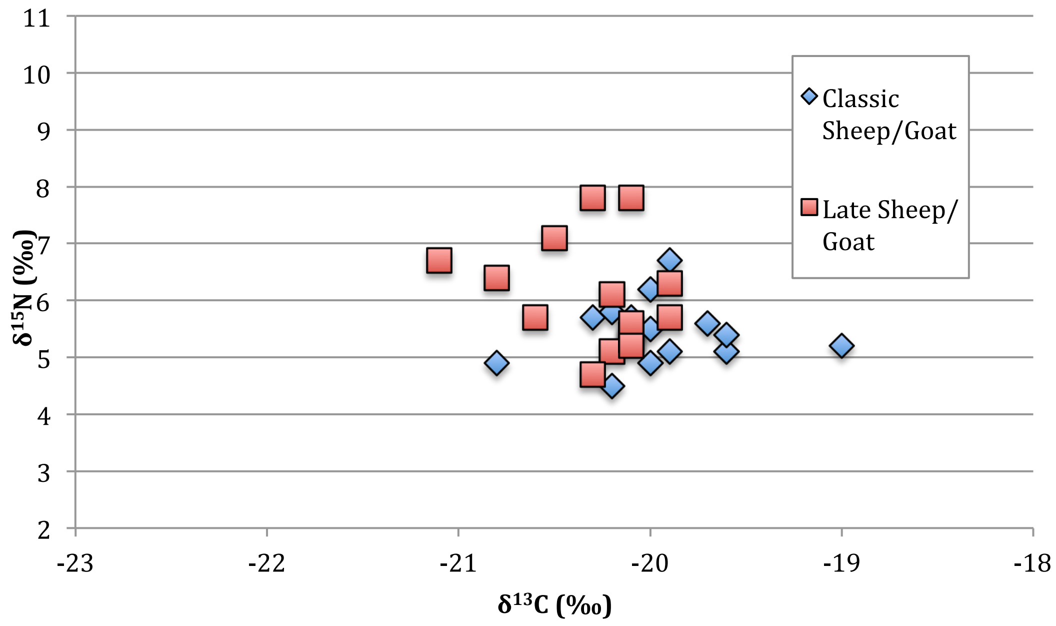

Figure 5.10 δ^{13}C (‰) and δ^{15}N (‰) for Classic and Late sheep/goat samples.

Figure 5.11 plots δ^{13}C and δ^{15}N results for the Classic and Late pig samples. The differences in variance of δ^{13}C and δ^{15}N values were found not to be significant (p=0.80 and p=0.10, respectively). Overall, if we compare the output of the ANOVA to the output of the independent tests (e.g. Mann Whitney U), it may be that the difference in the cattle δ^{15}N values in the Late phase is enough to sway the significance of the test.

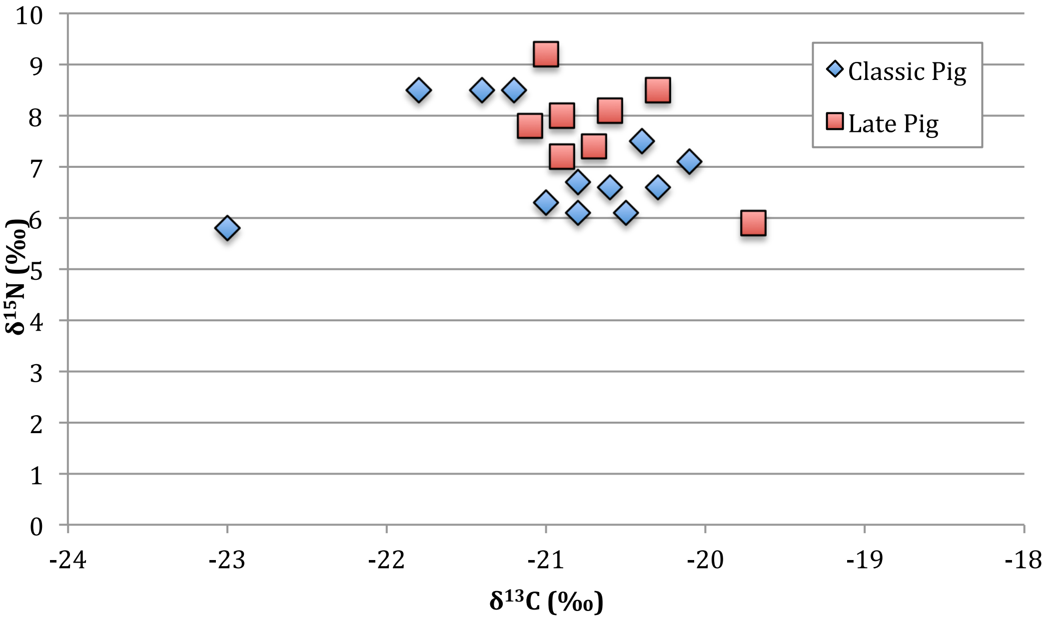

Figure 5.11 $\delta^{13}C$ (‰) and $\delta^{15}N$ (‰) for Classic and Late pigs.

The humans interred at Osłonki 1 mostly span the Classic and Late Phases with a single individual, burial 35, dating to the Early period. Tables 5.7-5.8 highlight the basic statistics for the Classic and Late Phases at Osłonki 1. The discussion of the human isotope values will initially focus on general trends in dietary reconstruction, and then will progress to investigate potential isotopic differences in sex and burial status.

Species	**n**	**^{13}C min**	**^{13}C max**	**^{13}C ave**	**^{13}C s.d.**	**^{15}N min**	**^{15}N max**	**^{15}N ave**	**^{15}N s.d.**
Cattle	28	-21.2	-20.1	-20.6	0.3	4.2	7.3	5.6	0.7
Sheep/Goat	14	-20.8	-19.0	-20.0	0.4	4.5	6.7	5.5	0.6
Pig	12	-23.0	-20.1	-20.9	0.8	5.8	8.5	7.0	1.0

Table 5.7 Classic Phase summary statistics.

Species	**n**	**^{13}C min**	**^{13}C max**	**^{13}C ave**	**^{13}C s.d.**	**^{15}N min**	**^{15}N max**	**^{15}N ave**	**^{15}N s.d.**
Cattle	15	-22.4	-20.0	-20.6	0.6	5.5	7.4	6.6	0.5
Sheep/Goat	16	-21.1	-19.9	-20.2	0.3	4.7	7.8	6.0	0.9
Pig	8	-21.1	-19.7	-20.6	0.4	5.9	9.2	7.7	1.0

Table 5.8 Late Phase summary statistics.

The average cattle δ^{15}N values between the Classic and the Late samples is 1‰ apart at 5.6‰±0.7 and 6.6‰±0.5 respectively. The difference between the Classic δ^{15}N and Late δ^{15}N cattle values is significant (p=<0.0001). Overall, the most important point that is evident from the dataset is that the cattle and sheep/goat isotopic distributions significantly changed from one phase to the next.

5.4 Factors Affecting Isotope Values

There are a number of factors affecting carbon and nitrogen values (chapter 2). The secondary mechanistic factors that affect, and vary between, the study regions are seasonality, canopy effects, latitude, elevation, light intensity, temperature, humidity, and water stress/moisture availability. Seasonality influences isotopic variations, but as bone collagen ratios are an average value of the last *c.* 10 years of a human's life, this is not testable with our dataset (but could be investigated using serial sampling of teeth). The canopy effect relates to isotopic variation in woodland areas. There is very limited evidence for woodland areas in North West Anatolia; whilst they occur in higher mountainous regions and the study sites are not located in close proximity to these. Similarly, there is no evidence for woodland areas on the Central Anatolian Plateau. By contrast, Osłonki 1, in the Polish plain, is located in a clearing surrounded by woodland, and as such the canopy effect is conceivably an issue. However, after a review of the relevant literature (chapter 3) it seems likely that only pigs would have (potentially) been kept and fed in woodland areas.

Latitude and elevation were tested against carbon and nitrogen isotopes values using regression analysis, and no correlation was found. To provide a context for the faunal data from Aktopraklık and Barçin Höyük, the isotope data from the sites of Çatalhöyük, Aşıklı Höyük and Nevali Çori are also included. The site of Çayönü Tepesi, located in south-eastern Anatolia, south-west of Nevali Çori, was considered for inclusion but discarded. The initial research at Nevali Çori was a weaning study that provided only $\delta^{15}N$ values (Pearson *et al.* 2010), and the second study, at Aşıklı Höyük included averages and standard errors (Pearson *et al.* 2013, Hongo *et al.* 2009), but no raw data was included, and as a consequence individual datum points could not be obtained. For Osłonki 1, isotope data from the sites of Blatne, Rutzing, Lerchenleid and Heilbronn are used for comparison. Table 5.9 displays the summary statistics for all of the sites used in the environmental regression analysis.

Site	*n*	*$\delta^{13}C$ average*	*s.d.*	*$\delta^{15}N$ average*	*s.d.*	*Data Source*
Aktopraklık	28	-20.3	0.6	5.7	1.2	This project
Barçin Höyük	37	-20	0.8	6.7	1.1	This project.
Osłonki 1	127*	-20.6	0.6	6	1.1	This project.
Çatalhöyük	60	-18.1	0.9	9.5	1.1	Pearson *et al.* 2007, Richards *et al.* 2005.
Aşıklı Höyük	64	-18.9	0.4	8.5	0.9	van Zeist *et al.* 2013.
Nevali Çori	47	-20.2	0.9	7	1.5	Grupe and Peters 2008.
Rutzing	19	-21.5	1	5.8	1.2	Bickle 2013
Blatne	24	-20.5	0.4	7.8	1.2	Bickle 2013
Lerchenleid	28	-21	0.8	5.9	1.3	Bickle 2013
Heilbronn	14	-21	1	8.6	0.8	Bickle 2013

Table 5.9 Summary statistics for the faunal $\delta^{13}C$ and $\delta^{15}N$ data.

*The beaver and tortoise samples, and the juvenile domestic samples are excluded.

These sites are chosen as they are largely contemporary with the primary study sites, and have large amount of fauna isotope data results.

5.4.1 Testable Environmental Variations: Rainfall, Temperature, Evapotranspiration, Humidity and Sunlight Regressions – All Sites

In this section the faunal isotope data from all of the study sites are combined, and compared to modern climate variables. The term fauna refers to both the wild and domesticated species. The faunal datasets are compared to climatic variables (e.g. $\delta^{13}C$ fauna *vs.* temperature) using regression analysis, followed by step-wise multiple regressions. There are a number of caveats associated with using modern climatic variables [(i.e. periods of warming and cooling during the Holocene), and obviously, modern industry affecting climate in ways not present in the past] (Bickle 2013). However, modern data provides a higher resolution of specific data points, and we can use this data to reconstruct changing conditions at a higher resolution (e.g. a daily basis, or an hourly basis etc.). By contrast, palaeoenvironmental records (particularly those available from the study regions) only highlight broad scale changes over longer timeframes. Details of the AquaStat and CRU datasets, alongside explanations of how variables such as temperature and precipitation are calculated, are outlined in Chapter 4: Samples and Methods.

In this section regression analysis of stable isotope data is performed against precipitation, temperature, evapotranspiration, humidity and sunshine (table 5.10).

Environmental Factor	*Unit Measurement*	*Source*
Precipitation	Mean Annual Precipitation (mm)	AquaStat Climate Tool
Temperature	Mean Annual Temperature (°C)	AquaStat Climate Tool
Reference Evapotranspiration	Mean Annual Ref Evap (mm)	CRU CL 2.0 data set
Humidity	Percentage of water vapour in the atmosphere (mean annual value)	AquaStat Climate Tool
Sunshine	Percentage of sunshine per day (mean annual value).	AquaStat Climate Tool

Table 5.10 Environmental factors selected for data testing, and explanation of unit of measurement.

The variables in table 5.10 have been selected after consultation of the literature (chapter 3), which indicates that these parameters are important variables in isotopic analysis at the pan-regional/European level (Shearer *et al.* 1978, Mariotti *et al.* 1980, O'Leary and Berry 1982, Sealy *et al.* 1986, Ehleringer and Cooper 1988, Ehleringer and Hubrick 1989, Broadmeadow and Griffiths 1993, Ehleringer, Hall and Farquhar 1993, Bogaard *et al.* 2007, Hidy *et al.* 2009, Fraser *et al.* 2011,2013, Bonafini *et al.* 2013, Cernusak *et al.* 2013, Styring *et al.* 2013, Wallace *et al.* 2013). Table 5.11 displays the environmental parameter values used in the regression analysis.

Related Site	*MAP*	*Average temperature (°C)*	*% Sunshine*	*Ref evap**	*% Humidity*
Aktopraklık	698	14.2	63.2	1059	75
Barçin Höyük	698	13.8	61.4	1022	75
Osłonki 1	525	8.1	31.8	644	78
Çatalhöyük	334	11.4	65.9	1127	60.3
Aşıklı Höyük	334	9.9	61.4	1116	60.3
Nevali Çori	536	17.2	70.7	1487	56
Rutzing	971	8.5	34.4	674	77.4
Blatne	572	9.8	37	803	74.4
Lerchenleid	783	8.5	34.3	674	77.4
Heilbronn	666	9.5	35.4	678	77.4

Table 5.11 Environmental parameter values used in the regression analysis
(Source: AquaStat and CRU dataset). * Reference evapotranspiration (see chapter 4 for details)).

For each regression (e.g. $\delta^{13}C$ values *vs.* humidity) there are two graphs, one to highlight intra- and inter-site variability and one plotting the regression line for the overall dataset.

5.4.2 Regression Results

Figures 5.12 and 5.13 present mean annual precipitation levels against $\delta^{13}C$ and $\delta^{15}N$. The corresponding graphs for these regressions (e.g. where the data is plotted by site and not as a single data series) are in appendix 1, figures A1.1 –A1.10.

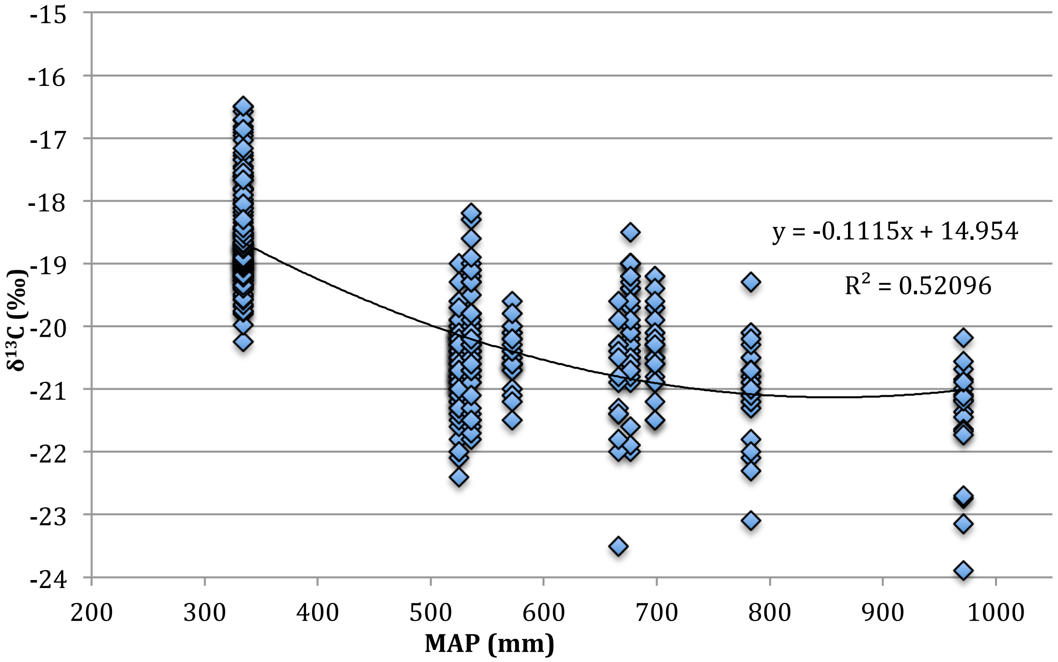

Figure 5.12 Mean Annual Precipitation and δ^{13}C of fauna.
Precipitation data is the average value per month for a 10 year span (2002-2012) Data from AquaStat.

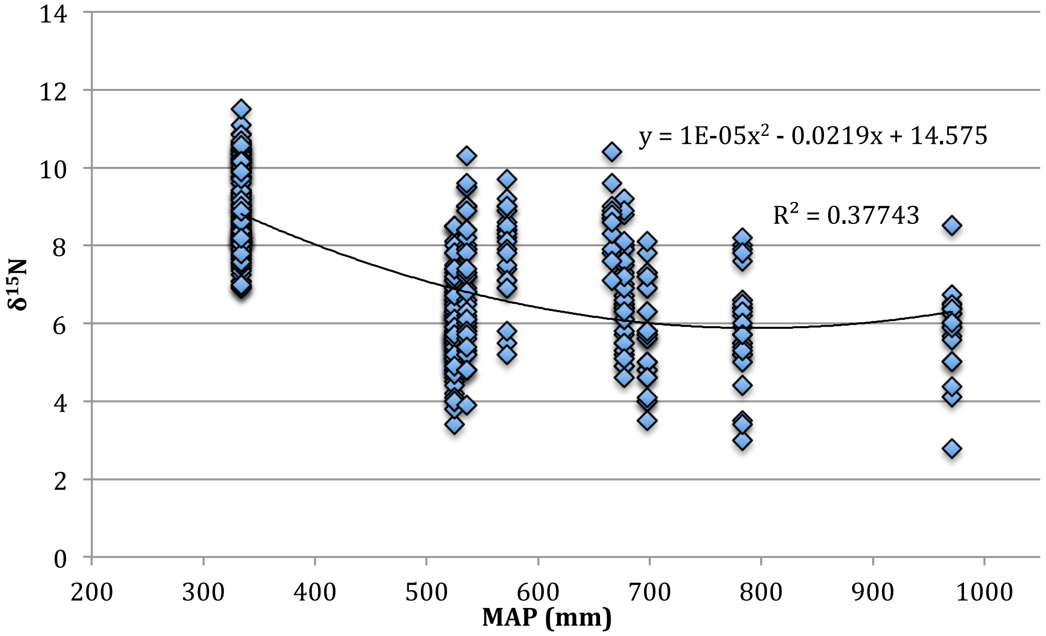

Figure 5.13 Fauna δ^{15}N and Mean Annual Precipitation (mm).
(Data: AquaStat).

If we consider figure 5.12 it is evident that there is a correlation (r^2=0.520, $p \leq 0.000$) between the mean annual precipitation and δ^{13}C. The general [non-linear] trend is that lower precipitation is correlated with higher $\delta^{13}C$ values in fauna bone collagen. The distribution of the data appears non-linear (particularly as the r^2 value assuming a linear relationship is 0.447), and a second-order polynomial model better describes curvilinear relationships. As such, this model is used here.

There are however studies which both disagree and agree with this trend. A study by Schulze *et al.* (1996) found no correlation between mean annual precipitation (MAP) and $\delta^{13}C$ in Namibia, whilst conversely a study by Guo and Xie (2006) on the Tibetan Plateau found a positive correlation between MAP and $\delta^{13}C$. Recent work by Kohn (2010) has incorporated $\delta^{13}C$ from C_3 plants on a global scale (>528 sites), alongside MAP, latitude and altitude. This research has demonstrated that $\delta^{13}C$ ratios for temperate plants are consistently over-estimated by 2‰, and this is largely the result of a distinct bias in the literature towards plant samples from dry ecosystems. The overall conclusion from this study is that the global average $\delta^{13}C$ for C_3 species is -28.3‰, and that there is a distinct non-linear increase in $\delta^{13}C$ with decreasing MAP. Interestingly Kohn (2010) states that $\delta^{13}C$ values above -25.5‰ are reserved for areas that receive less than 500 mm MAP. If we refer back to table 2.1 (chapter 2), we can see that a number of the study regions receive MAP <500mm.

Appendix 1 highlights the $\delta^{13}C$ values for the faunal collagen analysed from the study sites, with the average values ranging between -20‰ to -18‰. If we assume that the $\delta^{13}C$ shift between plants and consumer's meat values (herbivores) is 1 to 2‰ (with a 5‰ meat to collagen difference between fauna and humans), this value does approach the expected carbon isotope value of -25.5‰. Fung *et al.* (1997) have shown that seasonal variations in $\delta^{13}C_{atm}$ depend on biomass ratios, and that variations in C_3/C_4 biomass discrimination can have a distinct affect on the values produced. Research by Ferrio *et al.* (2005) has produced AIRCO2_LOESS, a program by which you can obtain an approximate value for the $\delta^{13}C_{atm}$ during a given study period. Using the date range of 7000 – 5000 cal BC, (based on radiocarbon dates on human bone collagen from a number of the study sites), the $\delta^{13}C_{atm}$ is -6.39‰. This value is higher than the $\delta^{13}C_{atm}$ often used in regressions in the literature (-8‰). There is a correlation between $\delta^{15}N$ values and mean annual precipitation averages (with $r^2 = 0.377$, $p \leq 0.000$) at the sites studied (fig. 5.13). In a similar fashion to the $\delta^{13}C$ data, the general [non-linear] trend is that lower precipitation is correlated with higher $\delta^{15}N$ values in fauna bone collagen.

The evaluation of $\delta^{15}N$ values is more problematic than carbon as $\delta^{13}C$ values in herbivores are generally dictated by plant values, and the variations in fractionation rates occur during photosynthesis. With $\delta^{15}N$ (as with $\delta^{13}C$), variations occur at the plant level (e.g. climatic factors or human management), and also at the herbivore level (animal management, physiological adaptions). Plant $\delta^{15}N$ values are largely controlled by variations in temperature and soil dryness, which dictate N_2 fixation rates (Delwiche and Steryn 1970, Shearer and Kohl 1986). Higher MAP is often associated with lower $\delta^{15}N$ values, and this partially evident in the current dataset. In terms of herbivore $\delta^{15}N$, the regression in figure 5.13 is in agreement with the majority of the published literature, as a variety of studies have observed a negative correlation between $\delta^{15}N$ of herbivore collagen and MAP (Sealy *et al.* 1987, Gröcke, Bocherens & Mariotti 1997, Murphy and Bowman 2006, Pate & Anson 2008), and this is evident in our dataset.).

The regression analysis for δ^{13}C and average temperature (°C) shows no relationship, with $r^2=0.026$ ($p \leq 0.583$) (figure 5.14). If we consider the fact that high temperatures paired with low MAP for the study regions causes decreased water availability (and therefore enriched δ^{13}C) we might anticipate a pronounced shift towards higher δ^{13}C values in the dataset considered here (multiple regression of these variables is present in a later section). This trend is not apparent in the dataset (figure 5.14), as we would expect Nevali Çori to have the highest δ^{13}C values, and not Çatalhöyük and Aşıklı Höyük. This disparity in δ^{13}C values maybe explained by different rates of evapotranspiration at sites (discussed in Chapter 3 Isotopes: Environment and Diet), as Çatalhöyük and Aşıklı Höyük have higher evapotranspiration rates than Nevali Çori. This is investigated below. Figure 5.15 illustrate the relationship between δ^{15}N and temperature (°C) average.

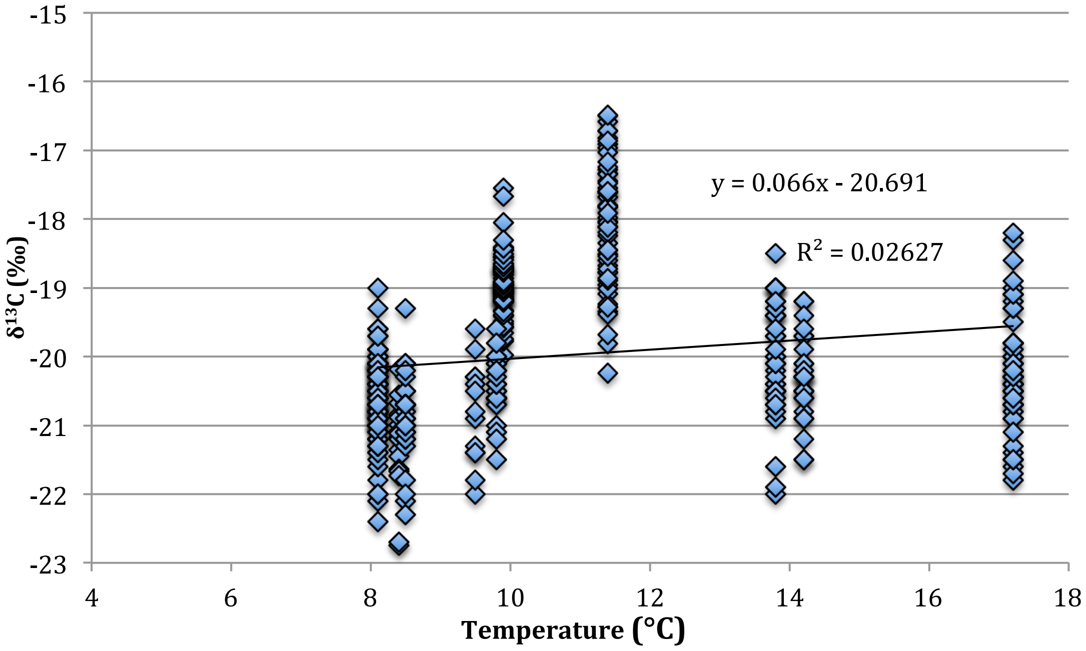

Figure 5.14 Fauna δ^{13}C values and mean annual temperature (°C).
(Data: AquaStat).

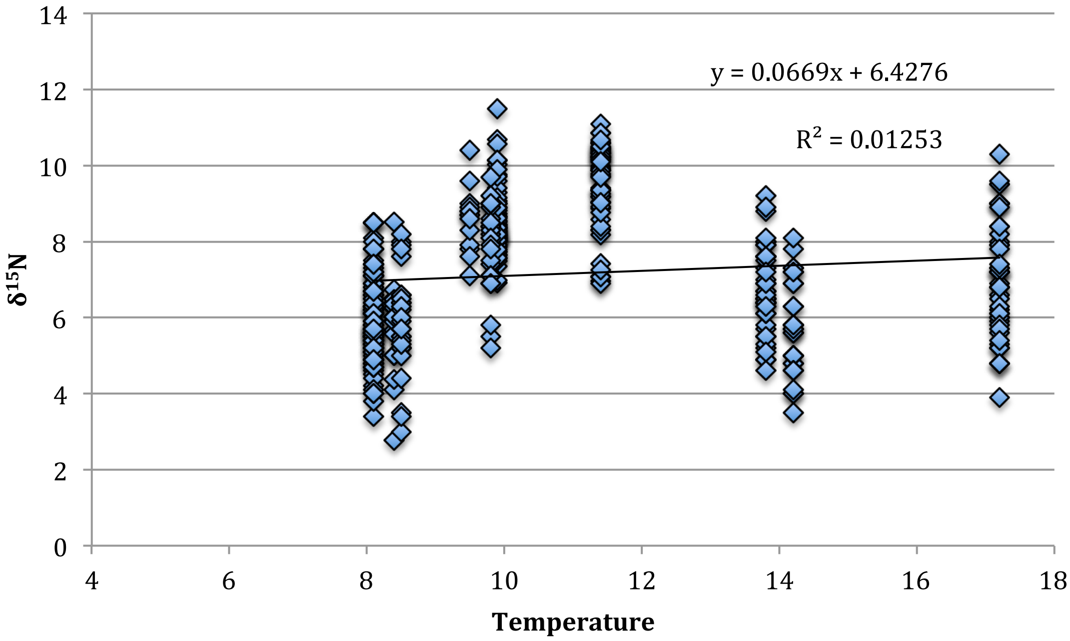

Figure 5.15 Fauna δ^{15}N and temperature (°C).
(Data: AquaStat).

It is evident from figure 5.15 that there is no statistical correlation ($r^2 = 0.012$, $p \leq 0.79$) between δ^{15}N and temperature, although δ^{15}N does generally increase with increasing temperature. Temperature could potentially have affected the amount of moisture availability in the environment (as highlighted in the literature, see chapter 3), although no strong effects are evident in the dataset. The effects of evapotranspiration (e.g. how much precipitation is lost due to evaporation before it really enters the soil/environmental landscape) is considered below in order to assess whether this factor its acts as a better proxy for moisture availability (figures 5.16 and 5.17). The FAO (publishers of the AquaStat dataset) defines reference evapotranspiration as 'the evapotranspiration from disease-free, well-fertilized crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions' (with evapotranspiration rates representing a combination of evaporative losses from the soil surface and transpiration from the plant surface) (http://www.fao.org/nr/water/aquastat/data/glossary). Evapotranspiration rates therefore are directly related to the extent of moisture availability in a given growing environment. In the absence of direct measurements of evapotranspiration rates (from the Neolithic period), the optimum evapotranspiration rates will be used (e.g. the reference evapotranspiration, see fao.org.nr/water/aquastat for more details on how this is calculated by region).

The fauna $\delta^{13}C$ values show a limited correlation with evapotranspiration rates at $r^2=0.201$ ($p\leq0.000$), but the relationship is not as strong as MAP. This would appear to suggest that evapotranspiration rates are not a strong determining factor in $\delta^{13}C$ values. As is evident in figure A1.5 (appendix 1) Nevali Çori plots contrary to expectation (we would expect it to plot similarly to Çatalhöyük and Aşıklı Höyük), and with the Nevali Çori dataset removed the r^2 value is 0.5.

Figure 5.17 the relationship between $\delta^{15}N$ and evapotranspiration. The value of $r^2=0.147$ ($p=0.002$) shows a very low correlation between $\delta^{15}N$ and evapotranspiration.

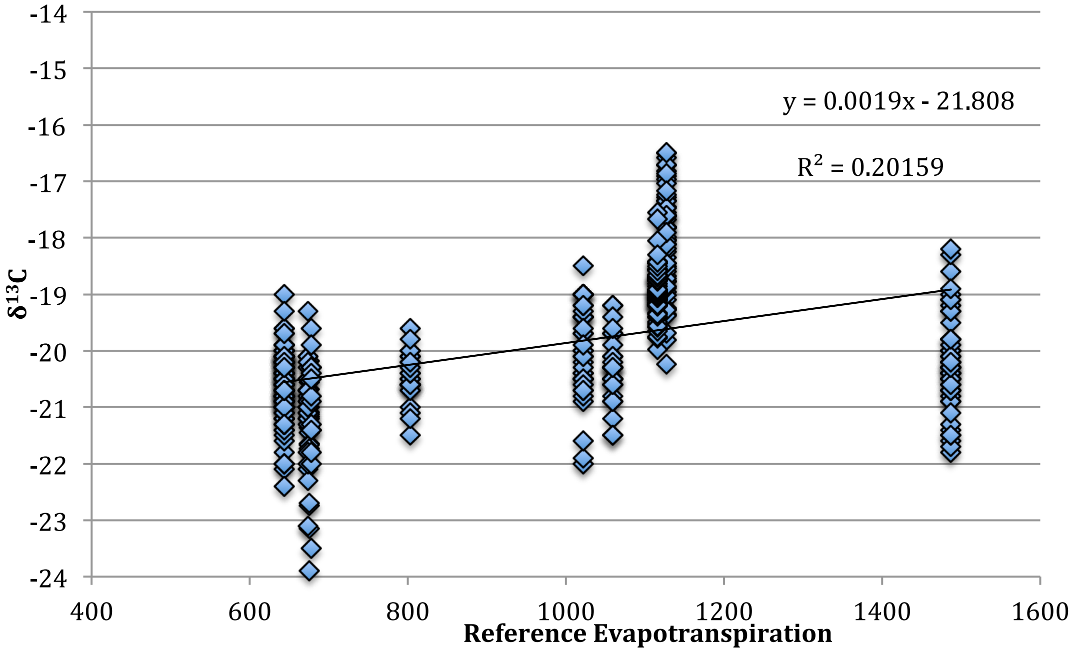

Figure 5.16 Fauna δ^{13}C fauna values and reference evapotranspiration.
(Data: New *et al.* (2002)).

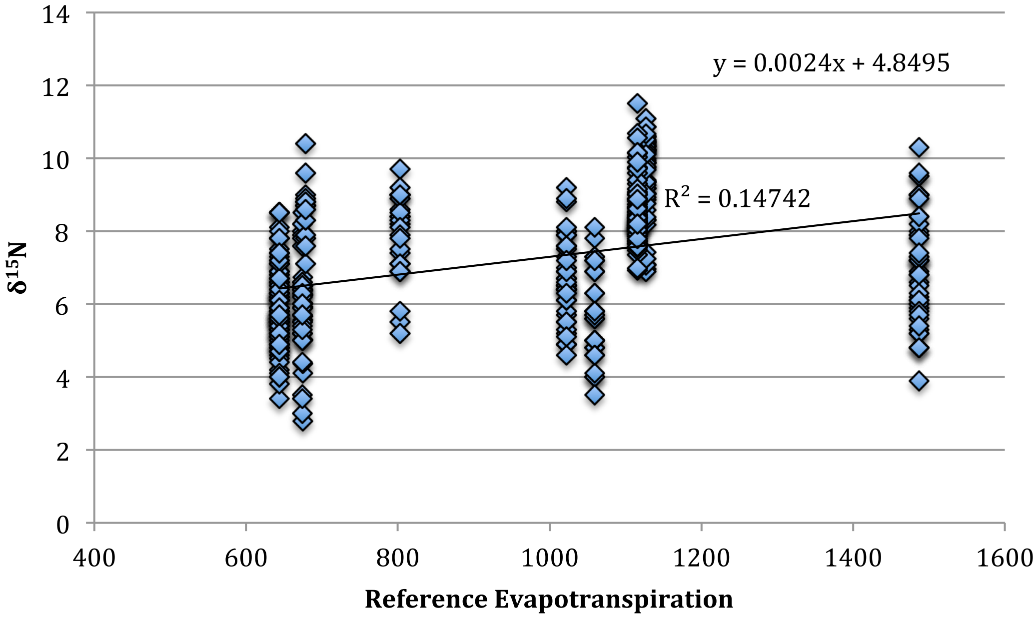

Figure 5.17 Fauna δ^{15}N and reference evapotranspiration.
(Data: New *et al.* (2000)).

Humidity is measured as the percentage of water vapour in the air, which is controlled by precipitation and temperature. Figure 5.18 shows there is a linear correlation between δ^{13}C and humidity (%), with an r^2 value of 0.349 ($p \leq 0.000$). The correlation between humidity and δ^{13}C is perhaps not surprising given that this parameter is inextricably linked with sunshine and precipitation, however what is interesting is that the sites of Osłonki 1, Aktopraklık, and Barçin plot together in terms of humidity (and δ^{13}C), which demonstrates that the precipitation gradient increases as you move further West. Figure 5.19 shows the fauna δ^{15}N fauna collagen values and percentage humidity levels.

From figure 5.19 it is evident that there is a strong correlation ($r^2 = 0.306$; $p \leq 0.000$) between δ^{15}N and percentage humidity. The humidity percentages correlate well with the precipitation gradient and the geographical locations of the sites, i.e. the further East you travel the less humid it becomes.

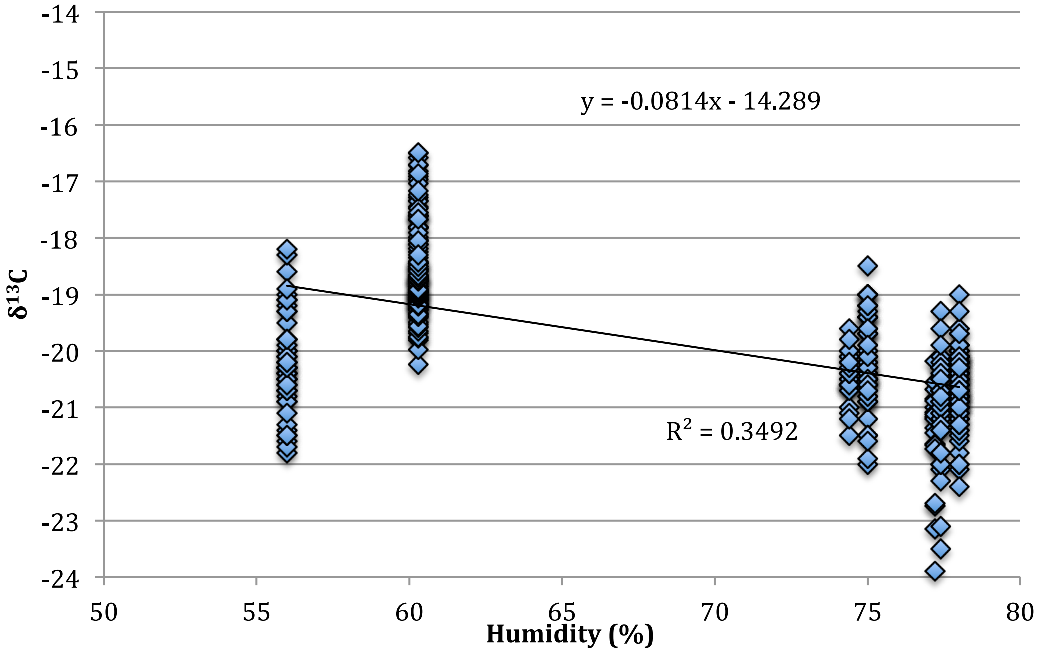

Figure 5.18 Fauna δ^{13}C and humidity.
(Data: AquaStat).

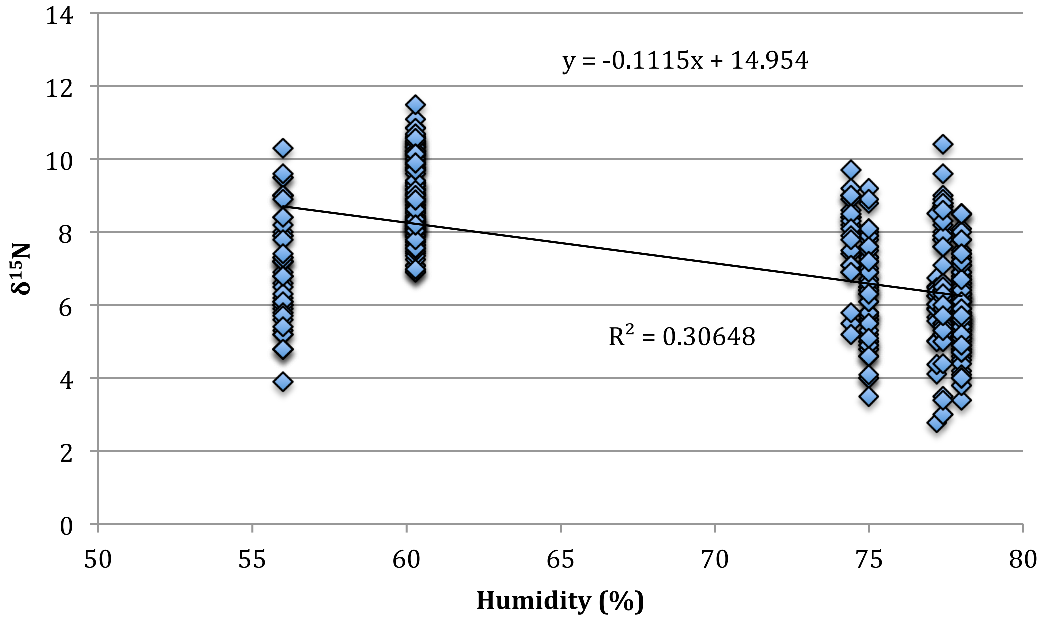

Figure 5.19 Fauna δ^{15}N and humidity (%).
(Data: AquaStat).

Figure 5.20 shows the δ^{13}C fauna values and percentage of sunlight hours per day. The amount of sunshine hours per day varies considerably between sites, ranging from *c*.30% to *c*.70%, and the amount of sunshine received per day only explains 30% of the variation in the data.

Finally figure 5.21 shows the relationship between δ^{13}C and average hours of sunlight per day. There is a low correlation (at r^2=0.198, *p*=0.002) between these variables, indicating that a greater number of sunlight hours equates (to some degree) to more enriched δ^{13}C ratios at the sites studied.

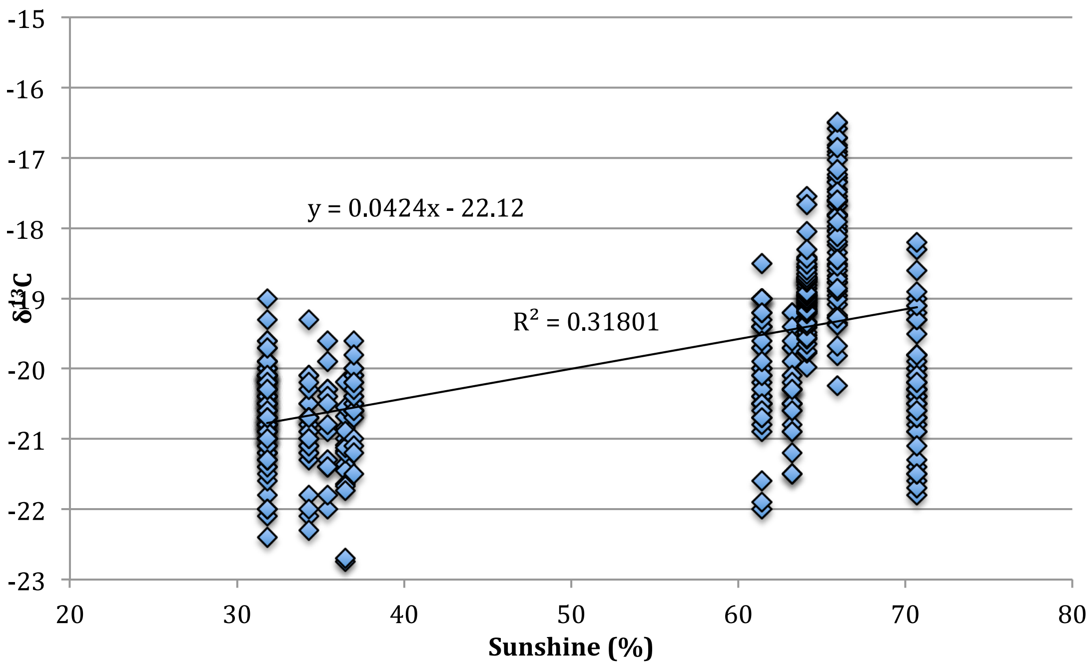

Figure 5.20 Fauna δ^{13}C and sunshine (%).
(Data: AquaStat).

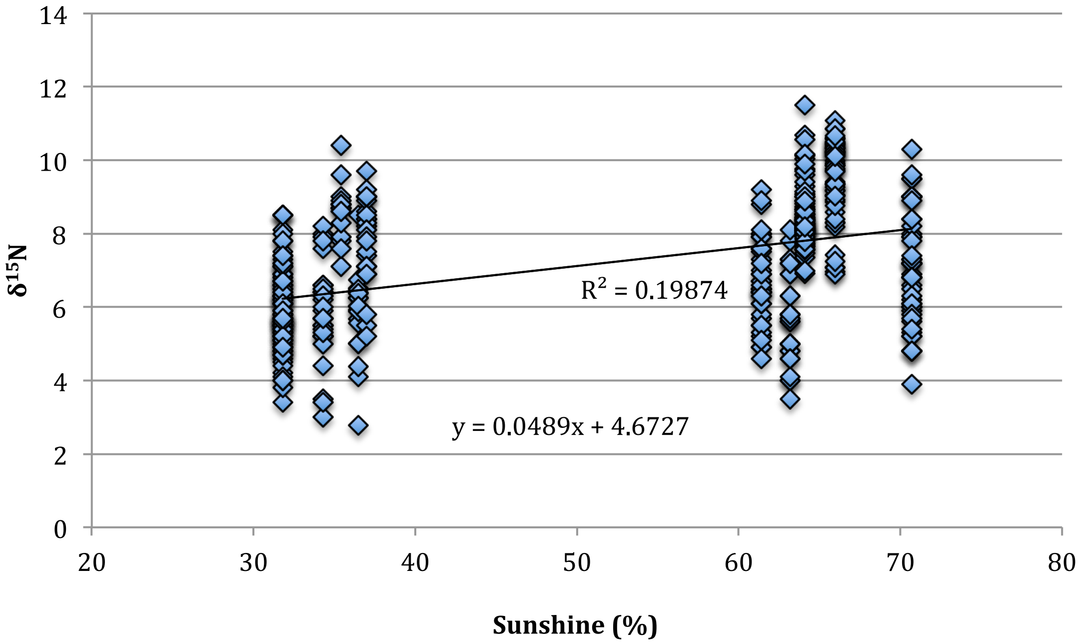

Figure 5.21 Fauna δ^{15}N and sunshine (%).
(Data: AquaStat).

This is perhaps not surprising, as one would expect that the amount of sunlight that an area will receive is related to its temperature (e.g. an arid environment would be sunny for greater periods of time, when compared to a temperate environment that would be cloudy/rainy). The variability in sunlight hours for the Anatolian sites is limited, and this may explain why the trend in the dataset is weak. However, this trend is at odds with the rest of the dataset, considering the high amount of sunlight Eastern Anatolia receives. The site of Nevali Çori appears to (consistently) be an anomaly in the dataset (see appendix 1).

5.4.3 Summary

Table 5.12 details the r^2 & *p*-values for the fauna isotope values.

Variables	$\delta^{13}C$		$\delta^{15}N$	
	r^2value	*p*-value	r^2 value	*p*-value
Precipitation	0.520	0.000≥	0.377	0.000≥
Temperature	0.026	0.583	0.012	0.79
Humidity	0.349	0.000≥	0.306	0.000≥
Sunlight	0.318	0.000≥	0.198	0.02
Evapotranspiration	0.201	0.000≥	0.147	0.02

Table 5.12 r^2 & *p*-values for individual and multiple regressions for the fauna isotope values.

The variable *p*-values are all sufficiently low to reject the null hypothesis, and so all of the climatic variables do have an effect on the $\delta^{13}C$ and $\delta^{15}N$ (even for temperature, which is surprising given the gradient of the regression). If all of the climatic variables are included in a general linear model (e.g. d13C~precipitation+humidity+sunshine+evapotranspiration+temperature), then the variables account for approximately 60% of the variation observed (multiple r^2 = 0.638, adjusted r^2 = 0.634, $p \leq 0.00$). One of the significant factors that can influence $\delta^{13}C$ and $\delta^{15}N$ in bone collagen is the species effect (Chapter 2: Isotopes: Environment and Diet). To mitigate for this, single linear regressions were performed by species, and no significant differences were recorded. In fact, weaker correlations were generally observed (e.g. cattle $\delta^{13}C$ and MAP has a r^2 value of 0.360).

If we consider all of the climate regression graphs and the basic statistics undertaken on the dataset, a number of observations can be made:

- $\delta^{13}C$ shows the stronger correlations with climatic variables than $\delta^{15}N$, and this is consistent with the literature reviewed.
- All of the *p*-values for the regressions are statistically significant.
- The r^2 values were more variable. The strongest correlations observed for both $\delta^{13}C$ and $\delta^{15}N$ are MAP and humidity.
- Nevali Çori does not fit in with any of the trends present in the dataset.

With regards to Nevali Çori, the ‘poor fit’ of the isotope values may reflect the fauna composition at the site; such as gazelles and antelopes and badgers, so species differences may be influencing the effects in evidence. However, Nevali Çori is located in the hilly landscape of the Anti-Taurus, approximately 3km south of the Euphrates on one of its tributaries, the Kantara Çay (Lösch *et al.* 2004:183). If the crops and animals were cultivated and kept in areas close to the tributary, the tributary may be introducing a secondary source of water to the soil (and so moisture availability) that is evident from consulting the climate variables.

Overall the initial comparison of the isotope data and climatic variables has highlighted a number of interesting points, namely that MAP and humidity demonstrate the strongest relationships with $\delta^{13}C$ and $\delta^{15}N$. Additional statistical testing, using more complex models are required to further tease out differences between the variables. One aspect that has not yet been integrated with the output from these tests and regressions is how the archaeological evidence at the sites compares to the results. Anthropogenic factors such as foddering practices or the application of manure to crops, could all influence the final isotope values recorded from the samples.

5.5 Multi-Level Regression Models

The relationship between the carbon and nitrogen isotope data and the climatic variables has been tested using multilevel modelling techniques. A stepwise approach is used to fit the data, with the model dropping variables to minimise the AIC value (the akaike information criterion) of the model. This is achieved by removing factors within the model that have the lowest AIC (Snijders and Bosker 1999, Gelman and Hill 2006). The overall AIC for the model should be as close to zero as possible. The modelling is performed using the `lme` and `nlme` packages in `R` (see chapter 4). Initially, a pairs graph of all the variables is created to examine the relationships (e.g. auto-collinearity) between the climate variables (appendix 1, figure A1.11).

It is evident from the plot that, unsurprisingly, the variables of sunshine and evapotranspiration are very highly correlated. As a consequence of this correlation, only one of these variables can be included in each iteration of the model (e.g. one set of models will include sunlight, and the other model will include evapotranspiration, in order to see which variable best fits the data).

5.5.1 Modelling the $\delta^{13}C$ Data

The first model tested for the δ^{13}C data is as follows;

```
Lme1c = d13C ~ MAP + Humidity + Evap + Species + Site
```

where MAP is mean annual precipitation, and Evap is evapotranspiration rate. The variable ‘site’ is included as a random effect, and the category of ‘species’ is a fixed effect (this is consistent for all of the models). The models are ‘fitted’ using the “maximum likelihood” method at this stage (chapter 4). The AIC value for model `Lme1c` is 917.55. The model will remove the variable that explains the least variation in the dataset (using the ‘`drop1`’ function in `nlme`). The output for the model is presented in table 5.13. The full statistical outputs of the model `Lme1c` (and all of the relevant models that appear in this section) are located in appendix 1 (figures A1.12 – A1.15).

Variable	df	AIC
<none>	0	917.55
MAP	1	923.26
Humidity	1	915.57
Evap	1	915.66
Species	15	985.70

Table 5.13 AIC for `Lme1c`

From the table it is evident that humidity has the lowest AIC value, and as such this variable is removed from the model. The next model therefore is the same as above, but with humidity removed (where ‘site’ remains a random effect, and species a fixed effect):

`Lme2c = d13C ~ MAP + Evap + Species + Site`

If we assess how well this new model fits the data (table 5.14), it is evident that the overall AIC value has changed marginally to 917.57.

Variable	df	AIC
<none>	0	917.57
MAP	1	924.39
Evap	1	914.24
Species	15	983.77

Table 5.14 AIC for `Lme2c`

In the second model (`Lme2c`), evapotranspiration generates the smallest AIC value, and so this is removed from the model. A third model is run.

`Lme3c = d13C ~ MAP + Species + Site`

The new AIC for this model (`Lme3c`) is 914.23, which is the best fit for all of the variations tested. The AIC's for model `Lme3c` are 925.97 for MAP and 983.07 for species. The model is then converted to REML for the final fit, to estimate standard errors and coefficients. Using this model (e.g. `Lme4c`), it is evident that for every unit of change in MAP (e.g. every mm of precipitation), the $\delta^{13}C$ values shift by -0.0040 (e.g. ‰) (SE=0.00085, *p*=0.0015).

The $\delta^{13}C$ values are now be modelled using sunshine as a variable instead of evapotranspiration. The first model is:

```
Lme5c = d13C ~ MAP + Humidity + Sun + Species + Site
```

The AIC value for `Lme5c` is 914.22. Table 5.15 shows the AIC criterion values for the individual variables.

Variable	df	AIC
<none>	0	914.22
MAP	1	922.70
Humidity	1	912.82
Sun	1	925.66
Species	15	982.14

Table 5.15 AIC for `Lme5c`.

Humidity has the lowest AIC value, and is consequently removed from the model. `Lme6c` is the next iteration of the model.

```
Lme6c = d13C ~ MAP + Sun + Species + Site
```

`Lme6c`'s overall AIC value is 912.81, which is an improvement on the previous iterations (table 5.16). If sunlight is removed from this model, the AIC rises to 914.23, which indicates that Lme6c is the best fit of these models (e.g. MAP and sunshine are the variables which best explain the data).

Variable	df	AIC
<none>	0	912.81
MAP	1	922.09
Sun	1	914.24
Species	15	980.47

Table 5.16 AIC for `Lme6c`.

Finally, a REML fit is applied to `Lme6c`. Using this model it is evident that for every unit change in MAP (mm) and Sun (hours per day), the δ^{13}C values shift by -0.003 (e.g. ‰) (SE = 0.008, *p*=0.06). However, the *p* value for `Lme6c` is less convincing than the *p* value for `Lme4c` (*p*=0.0015), therefore `Lme4c` is determined as the model of best fit.

5.5.2 *Modelling the δ^{15}N Data*

The first model for δ^{15}N incorporates evapotranspiration and omits sunshine.

```
Lme1n = d15N ~ MAP + Humidity + Evap + Species + Site
```

where species remains a fixed effect and site is a random effect. The AIC value is 1345.5. Table 5.17 shows the individual AIC values for the model variables.

Variable	df	AIC
<none>	0	1345.5
MAP	1	1347.5
Humidity	1	1344.5
Evap	1	1345.2
Species	15	1407.9

Table 5.17 AIC for `Lme1n`.

Humidity is consequently dropped from the model as it has the lowest AIC value. The second model, `Lme2n`, is as follows:

```
Lme2n = d15N ~ MAP + Evap + Species + Site.
```

The AIC value for this model (`Lme2n`) is 1344.4. Table 5.18 displays the individual AIC values.

Variable	df	AIC
<none>	0	1344.5
MAP	1	1350.0
Evap	1	1343.2
Species	15	1407.6

Table 5.18 AIC for `Lme2n`.

Evapotranspiration has the lowest AIC value in this model and so is dropped from the model. `Lme3n` is the final iteration of the model:

```
Lme3n = d15N ~ MAP + Species + Site.
```

The AIC value is 1343.2, and this model is clearly the best fit of the variables. As such the model is run as a REML fit. Using this model, it is evident that for every unit change in MAP, there is a δ^{15}N values shift by -0.005 (e.g. ‰) (SE=0.001, *p*=0.01). Finally, the δ^{15}N values are modelled using the variable sunshine and omitting the variable evapotranspiration.

```
Lme4n = d15N + MAP + Humidity + Sun + Species + Site
```

The initial AIC value for the model (`Lme4n`) is 1346.9. When the 'drop' function is applied, the model removes humidity, as it has the lowest AIC value (table 5.19).

Variable	df	AIC
<none>	0	1346.9
MAP	1	1349.5
Humidity	1	1345.0
Sun	1	1345.2
Species	15	1409.1

Table 5.19 AIC for `Lme4n`.

`Lme5n` is the model run without the humidity parameter;

`Lme5n = d15N ~ MAP + Sun + Species + Site.`

The AIC for this model is 1344.9. Table 5.20 displays the output of the drop function, which highlights sunlight as the variable that contributes the least to the model.

Variable	df	AIC
<none>	0	1345.0
MAP	1	1349.7
Sun	1	1343.2
Species	15	1407.7

Table 5.20 AIC for Lme5n.

As sunlight contributes the least to the model this parameter is removed for Lme6n. Consequently, `Lme6n` produces the best fit, with an AIC value of 1343.2. If the drop function is applied, `nlme` highlights the intercept as having the lowest AIC, so this model is the best fit. The model is then run as a REML (e.g. `Lme7n`, not shown), so that the coefficients and standard errors can be produced.

It is evident from model `Lme7n` that with every unit change of MAP, the nitrogen values shift by -0.005 (e.g. ‰) (SE=0.001, *p*=0.01). The final iterations of the nitrogen models are identical (e.g. both evapotranspiration and sunshine are removed from each string of fitted models), and as such the outcome is the same.

5.5.3 Summary

The individual linear regressions have highlighted relationships between both $\delta^{13}C$ and $\delta^{15}N$ with precipitation and humidity. However, it is evident that the variables of MAP (mean annual precipitation) and species best explain the distribution of the $\delta^{13}C$ and $\delta^{15}N$ data analysed here. For $\delta^{13}C$, there is a -0.004‰ shift per millimetre of rainfall, so we would expect to see a -0.4‰ shift in $\delta^{13}C$ values for every 100mm of precipitation at the study site. For $\delta^{15}N$, there is a -0.005‰ shift per millimetre of rain, so we would expect to see a -0.5‰ shift in $\delta^{15}N$ values for every 100mm of precipitation at the study site. The next logical step for the multi-level modelling approach, would be to perform 'species specific' models (e.g. just perform the iteration using the cattle data), but this is unfortunately beyond the remit of this research project due to word constraints.

Chapter 6: Human Stable Isotope Results

6.1 Introduction and Overview of Analysis

This chapter details the human $\delta^{13}C$ and $\delta^{15}N$ values for the study sites. The biological state of preservation of the samples is assessed, and failed samples are removed. The datasets generated are subjected to statistical testing, both to check for outliers and to examine the nature of their distributions. Finally, the $\delta^{13}C$ and $\delta^{15}N$ isotope data for each site are evaluated in relation to the values obtained for faunal and fish remains with a view to determining the potential inputs to human diets at the sites considered.

6.2 Sample Preservation

The human bone collagen $\delta^{13}C$ (‰) and $\delta^{15}N$ (‰) values for Aktopraklık, Barçin Höyük, and Osłonki 1 are summarised in appendix 1, table A1.1 (these are the averages of the duplicate measurements). A number of quality control parameters are in place at RLAHA to ensure the accuracy of the data produced, these include a collagen yield of 1% or above, a C:N ratio of between 2.9 and 3.6, and an collagen yield of 5mg (DeNiro and Epstein 1978, Brock *et al.* 2010). The purpose of these parameters is to ensure that sufficient organic material (e.g. mainly collagenous protein) was preserved, and that this material remains uncontaminated in the bone sample (as assessed by the C:N ratio).

6.3 Dietary Reconstruction

6.3.1 Aktopraklık

In total 48 human samples were processed from the Late Neolithic/Chalcolithic site of Aktopraklık. One human sample failed the quality control parameters, producing a poor C:N ratio (KA 8). This individual was re-sampled and subjected to pre-treatment, and subsequently passed the quality control parameter. Table 6.1 provides the summary statistics for the isotope values.

Species	**n**	**$\delta^{13}C$ Min**	**$\delta^{13}C$ Max**	**$\delta^{13}C$ Ave**	**1 s.d**	**$\delta^{15}N$ Min**	**$\delta^{15}N$ Max**	**$\delta^{15}N$ Ave**	**1 s.d**
Human	48	-20.7	-20.1	-20.3	0.3	7.7	12.1	9.4	0.8
Females	16	-20.4	-19.7	-20.1	0.2	8.4	11.1	9.3	0.7
Males	17	-20.7	-19.8	-20.2	0.2	8.4	10.6	9.3	0.7
Un. Ident.	15	-20.6	-19.6	-20.2	0.3	7.7	10.3	9.2	0.8
Child	4	-20.2	-19.4	-19.9	0.4	8.1	12.1	9.8	1.7

Table 6.1 Summary statistics for the $\delta^{13}C$ and $\delta^{15}N$ human data from Aktopraklık.

Figure 6.1 displays the human $\delta^{13}C$ and $\delta^{15}N$ values for Aktopraklık, alongside the $\delta^{13}C$ and $\delta^{15}N$ values for the faunal samples (detailed in chapter 5).

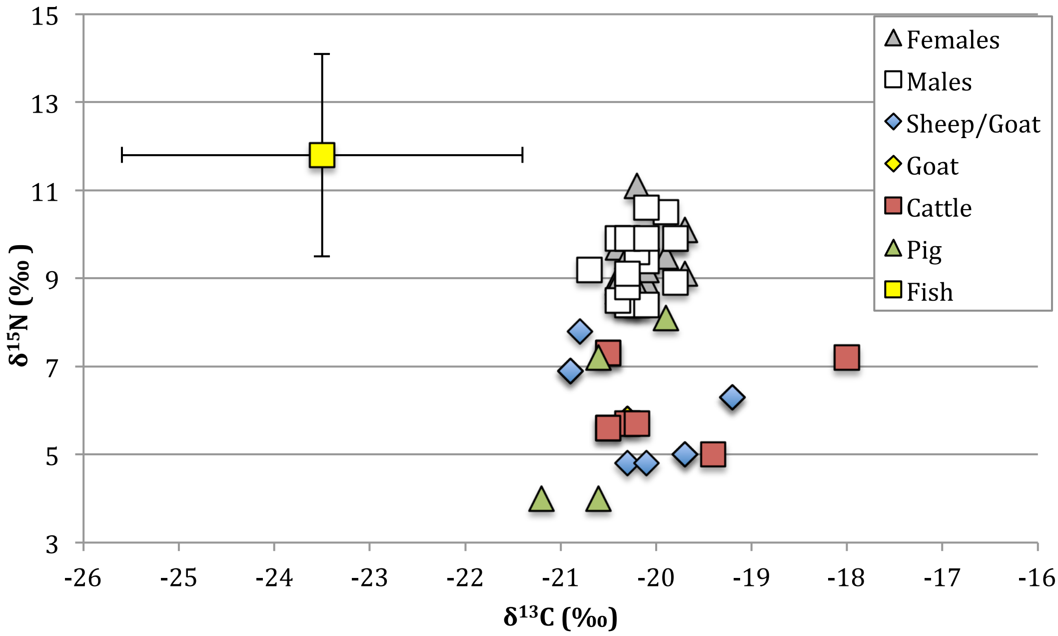

Figure 6.1 δ^{13}C and δ^{15}N human and faunal values for Aktopraklık, alongside the average fish δ^{13}C and δ^{15}N values.
Fish values represent five samples and five different species (chapter 5).

Overall the adult human δ^{13}C isotope data, for both the Neolithic and Chalcolithic periods, averages at -20.1‰±0.2. The nitrogen isotope data at Aktopraklık displays greater variation at 9.2‰±0.7. If we compare the human and faunal δ^{13}C and δ^{15}N values, the isotope data suggests a major reliance on terrestrial proteins. Despite the sites proximity to a freshwater lake, it is evident from both the δ^{13}C and δ^{15}N values that freshwater fish resources did not comprise a large proportion of the diet.

Of course, there is the caveat that a number of burials have yet to be securely attributed (chronologically) to either phase. Figure 6.2 presents the human isotope data separated by sex, alongside the main fauna analysed. The burials that have not yet been securely sexed are not included. There appears to be no clear difference in carbon and nitrogen isotope values between males and females (table 6.2 presents significance testing).

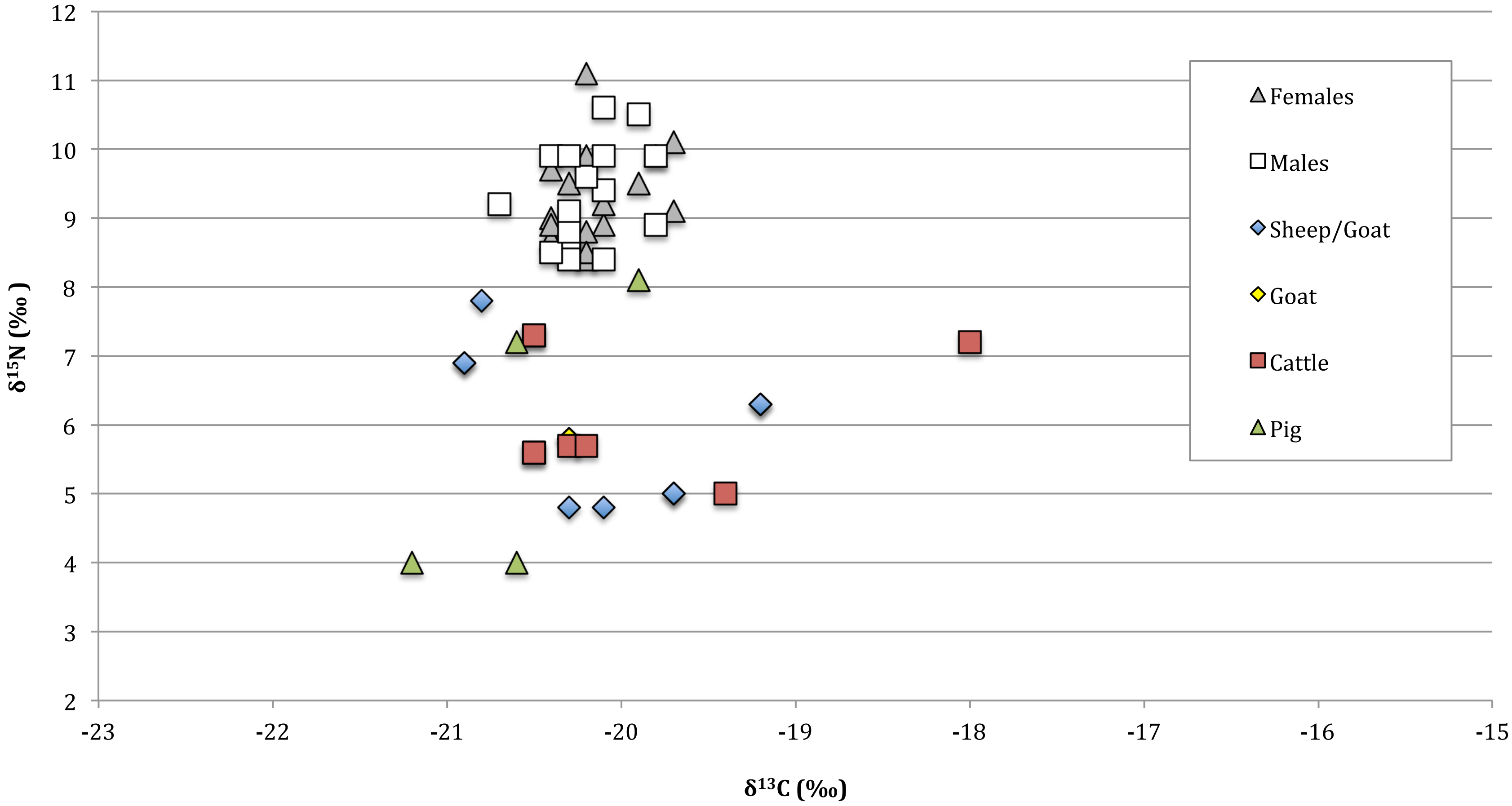

Figure 6.2 $\delta^{13}C$ and $\delta^{15}N$ for securely sexed human samples and main fauna at Aktopraklık (Data: this project, and Budd *et al.* (2013)).

At Aktopraklık, the isotopic range of the human data is such that it is difficult to ascertain whether animal or plant resources formed the mainstay of the diet. One categorical factor however, is that terrestrial resources, and not freshwater resources, formed the main component of the diet. Figure 6.3 plots additional data from Aktopraklık published by the author (Budd *et al.* 2013).

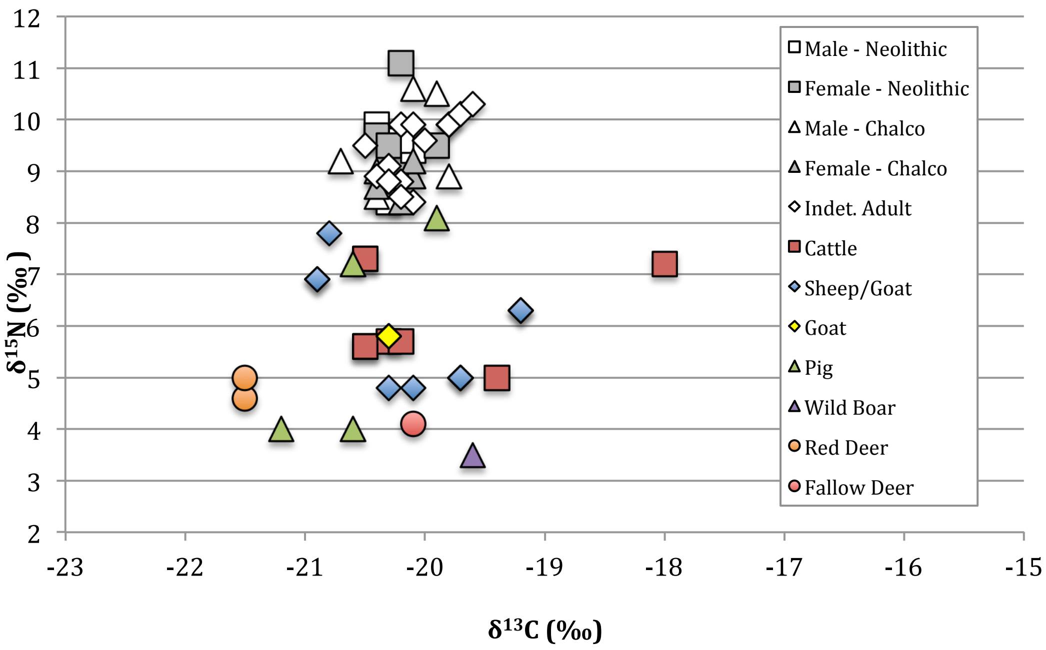

Figure 6.3 δ^{13}C and δ^{15}N for all humans and main fauna at Aktopraklık
(Data: this project, and Budd *et al.* (2013)).

With the inclusion of the published data, it is possible to compare male and females isotope values across the Neolithic and Chalcolithic periods (figure 6.3). The isotope data shows consistency between males and females across the periods studied (i.e. the Neolithic and Chalcolithic periods), and also between them. Finally, figure 6.4 shows the δ^{13}C and δ^{15}N averages for the humans and main fauna for Aktopraklık.

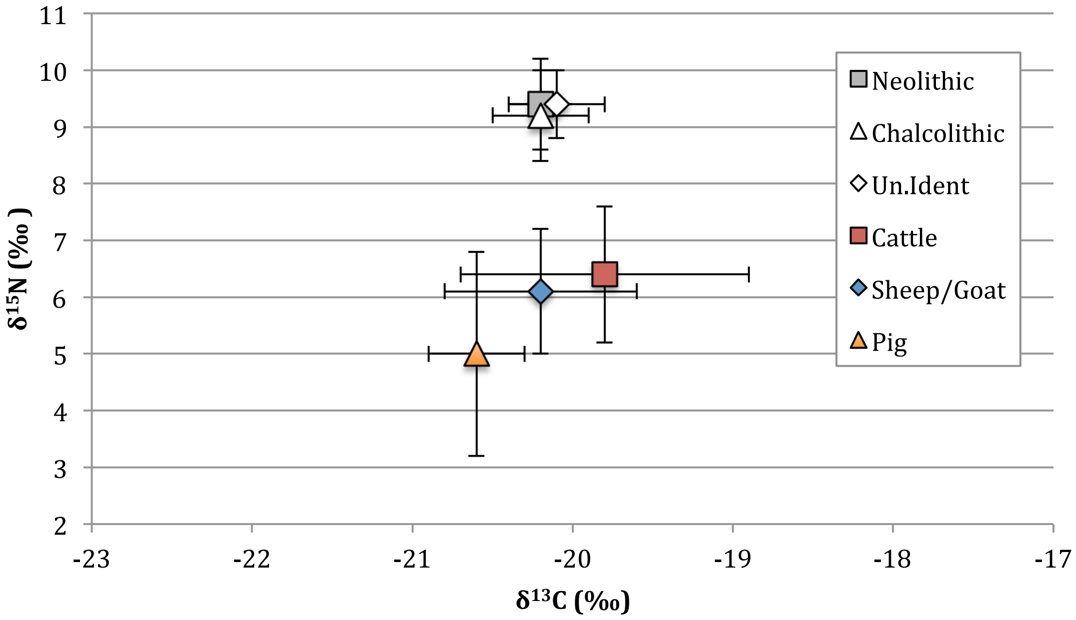

Figure 6.4 δ^{13}C and δ^{15}N averages for all humans and main fauna at Aktopraklık.
Error bars show one standard deviation (Data: this project, and Budd *et al.* (2013)).

It is apparent from figure 6.4 that the human values are much more constrained than the associated fauna, which in part reflects the fact that adult human bone collagen reflects a longer-term averaged diet (e.g. over a period of *c.* 10 years), whereas domestic animals are often when still immature and so reflecting a shorter period of diet, potentially introducing greater inter-animal variation.

6.3.2 Statistical testing

Table 6.2 presents the statistical tests for the human isotope data. The purpose of these tests is to identify whether any of the groups (Neolithic males, Neolithic females, Chalcolithic males, Chalcolithic females) are significantly different. This is achieved by testing means and variance. Medians will indicate whether there is an overall difference in diet between two groups, whereas variance will indicate how isotopically diverse the diet was (e.g. two groups might have the same δ^{13}C mean, such as -20‰, but one group may have a standard deviation of 0.2 and another group a standard deviation of 1.5, which could point to different food production strategies).

Isotope	*MANN WHITNEY U**			*KRUSKAL WALLIS*	
	U-value	*Z*-value	*p*-value	*p*-value	KW chi-squared value (*H*)
δ^{13}C Neo *vs.* Chalco	-	-	-	0.934 (df=3)	0.43
δ^{15}N Neo *vs.* Chalco	-	-	-	0.1288 (df=3)	5.67
δ^{13}C Males *vs.* Females	132	0.6766	0.4965	-	-
δ^{15}N Males *vs.* Females	151	-0.4995	0.96012	-	-

Table 6.2 Mann Whitney U and Kruskal Wallis tests for the Neolithic and Chalcolithic humans at Aktopraklık.
**Also referred to as the Wilcoxon-Mann Whitney test.*

The Mann Whitney U test is an analogue of the student's t-test for non-parametric distributions. It compares unpaired groups by assigning ranks to the data points regardless of group allocation, and then compares the means of the ranks (Hart 2001, Field *et al.* 2012). The *U* value is the calculated test statistic, and its distribution under the null hypothesis is known (see Hart 2001 for calculation equation). The *Z* value (also referred to as the *Z* ratio) is the value of an observation expressed in standard deviation units (Field *et al.* 2012:928). A large *U* value and a significant *p*-value (e.g. less than the stated alpha, 0.01 or 0.05 etc.) indicate a significant difference between groups. The confidence level for this Mann Whitney U test is set at $p \leq 0.05$, and the test is two tailed (as we do not know which group is expected to be higher or lower). As is evident from table 6.2 neither the difference between δ^{13}C, or the difference between δ^{15}N is significant between males and females from Aktopraklık.

The Kruskal Wallis test for the $\delta^{13}C$ values at Aktopraklik has a small *H* value at 0.43, showing that there is little difference in the carbon isotope values between any of the groups (e.g. Neolithic males, Neolithic females, Chalcolithic males or Chalcolithic females). The *H* value for the $\delta^{15}N$ values is considerably higher at 5.67, but the *p* value is not significant (*p*=0.13). In summary, the statistical testing of the humans at Aktopraklık shows isotopic consistency in diet between the Neolithic and Chalcolithic.

6.3.3 Barçin Höyük

A total of 18 adult samples were processed from Barçin Höyük (table 6.3).

Species	**n**	**$\delta^{13}C$ Min**	**$\delta^{13}C$ Max**	**$\delta^{13}C$ Ave**	**1 s.d.**	**$\delta^{15}N$ Min**	**$\delta^{15}N$ Max**	**$\delta^{15}N$ Ave**	**1 s.d.**
Human	18	-20.0	-18.3	-19.3	0.6	9.1	10.5	9.9	0.4
Females	5	-20.0	-18.8	-19.4	0.4	9.4	10.4	10.0	0.4
Males	2	-19.2	-19.0	-19.1	0.1	9.9	9.9	9.9	0
Indet.	3	-20.0	-19.9	-20.0	0.0	9.1	9.7	9.4	0.4
Sub-Adults	8	-19.9	-17.4	-18.3	0.8	10	12	11	0.7

Table 6.3 Summary statistics for Barçin Höyük.

The $\delta^{13}C$ values of the cattle samples exhibit a considerable range at -22‰ to -16.3‰, a difference of *c.* 6‰. The majority of the $\delta^{13}C$ values, e.g. -20.2±0.9‰, indicate the consumption of C_3 grasses, and as at Aktopraklık, the most likely species are Poaceae and Graminae (Bottema and Woldring 1995). Figure 6.5 shows all of the fauna (both wild and domesticated) and human isotope values from Barçin Höyük, with figure 6.6 showing the human values alongside the values of the main domestic fauna recovered from the site.

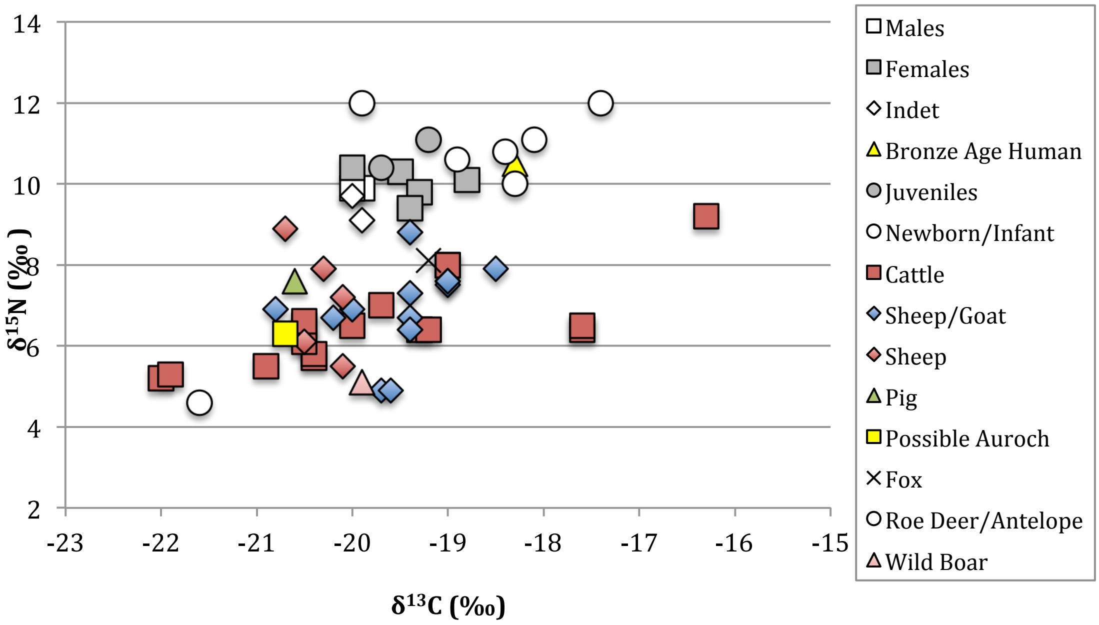

Figure 6.5 $\delta^{13}C$ and $\delta^{15}N$ for all human and fauna from Barçin Höyük.

The $\delta^{13}C$ values for the newborn and infant human samples average -18.3‰±0.8 and these are largely commensurate with a 1‰ trophic shift from the human adults (e.g. mother's milk). The mean $\delta^{15}N$ value for the sub-adults at Barçin Höyük is 11±0.7‰, which when compared to the average adult female $\delta^{15}N$ value of 10.0±0.4‰ is a small trophic shift. There are only two juvenile samples. Individual M10-166a was 7-8 years at death and plots in with the adult isotope values, whilst the second individual, M10-166, is simply described as 'juvenile', and plots in with the newborn and infant isotope values.

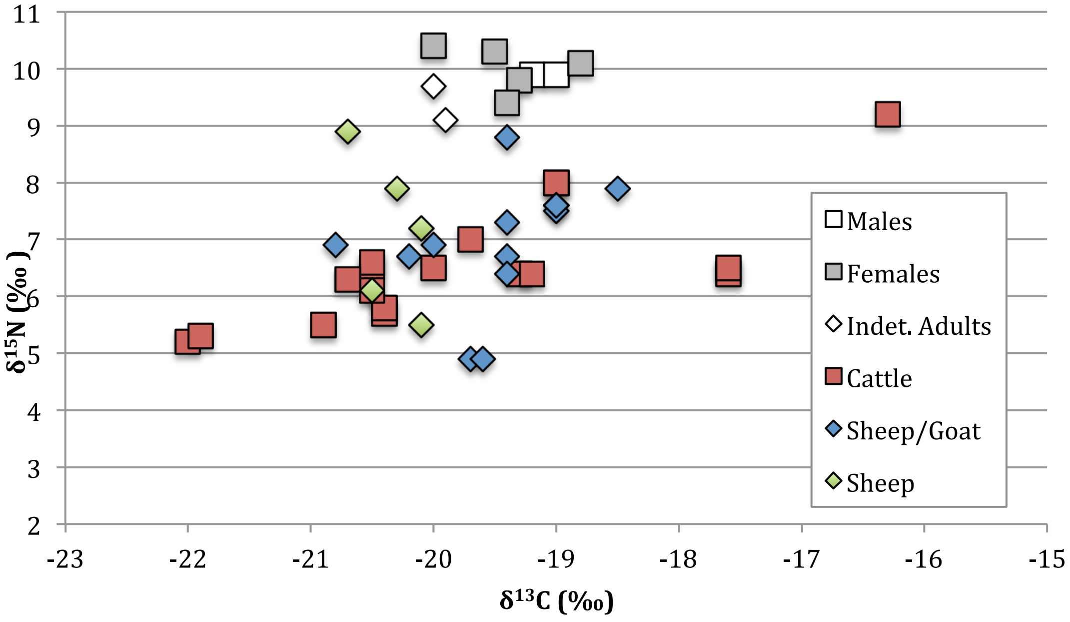

Figure 6.6 $\delta^{13}C$ and $\delta^{15}N$ for the main fauna and adult humans at Barçin Höyük.

The adult humans from Barçin Höyük have an average $\delta^{13}C$ value of 19.3‰±0.5. The $\delta^{15}N$ values range from 9.9‰±0.4, which is largely in line with a 3‰ trophic shift from the average cattle (6.5‰) and sheep/goat (6.9‰) $\delta^{15}N$ value.

6.3.4 Statistical Testing

The human isotope data set is in reality too small to provide reliable statistical analysis of isotopic differences between genders (males = 2, and females = 5). However, with the acknowledged caveat that these tests are not necessarily reliable (given that the test statistics are calculated from means and standard deviations, see de Winter (2013)), the two groups were t-tested for significance. The difference between the human males and females is not significant for $\delta^{13}C$ ($p = 0.39$) or $\delta^{15}N$ ($p = 0.75$).

6.3.5 Osłonki 1

In total 31 human samples were analysed from Osłonki 1. All of the humans analysed were adults at the time of death: twelve are female, thirteen are male, and the sex of six individuals was undetermined (chapter 4, table 4.2.3). Table 6.4 provides the statistical analysis of the human remains.

Ident.	**n**	**^{13}C min**	**^{13}C max**	**^{13}C ave**	**^{13}C s.d.**	**^{15}N min**	**^{15}N max**	**^{15}N ave**	**^{15}N s.d.**
Female	14*	-20.8	-19.7	-20.1	0.4	7.5	9.3	8.5	0.6
Male	16	-20.6	-19.5	-20.3	0.3	7.9	9.2	8.5	0.4
Un.Idet.	1	-	-	-20.2	-	-	-	8.8	-

Table 6.4 Summary of human isotope values at Osłonki 1
(*includes the two female burials that have not been assigned to a chronological phase (chapter 4, section 4.2.3). The unidentified ('Un.Idet') sample is burial 59, which has no sex or phase.

Osłonki 1 is divided into three phases of occupation; Early (4,700-4,500 cal BC), Classic (4,500-4,300 cal BC) and Late (4,300-4,100 cal BC). The δ^{13}C and δ^{15}N values for the main domestic fauna excavated from Osłonki 1 (discussed in detail in chapter 5), demonstrate average values of -20‰ and 5.7‰ respectively, which reflects the available C_3 plant resources in the landscapes surrounding the settlement site.

The humans interred at Osłonki 1 mostly span the Classic and Late Phases with a single individual, burial 35, dating to the Early period. The discussion of the human isotope values will initially focus on general trends in dietary reconstruction, and then will progress to investigate potential isotopic differences in sex and burial status. Figure 6.7 provides the averages (and ranges to one standard deviation) of the humans and main fauna isotope results from Osłonki 1.

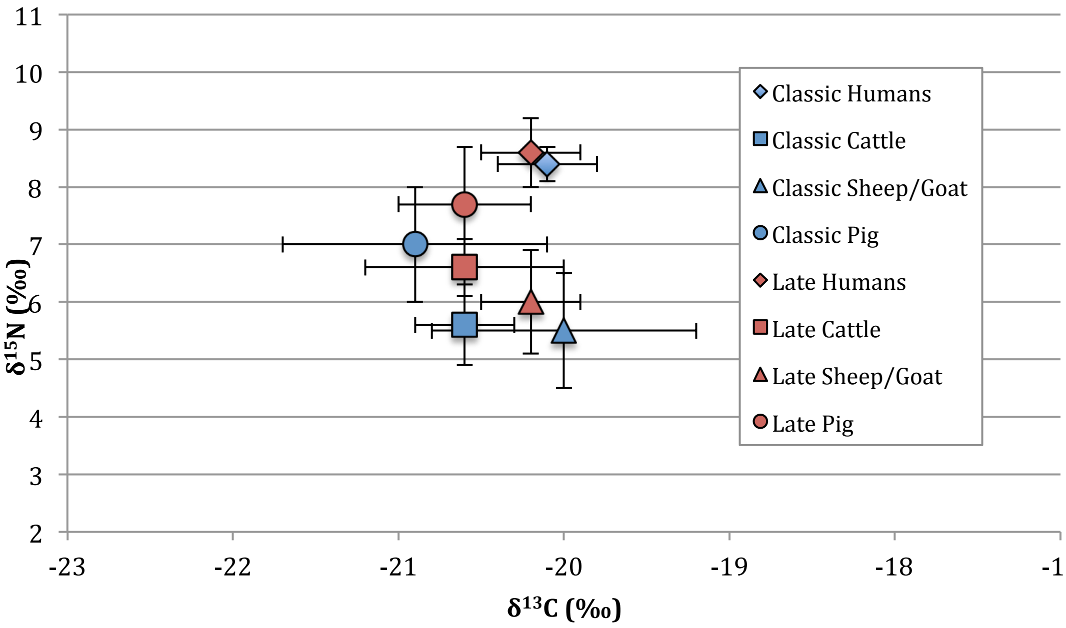

Figure 6.7 δ^{13}C (‰) and δ^{15}N (‰) averages for the humans and main fauna recovered from Osłonki 1.

The average δ^{15}N value for Classic phase humans in 8.6‰±0.3 and for Late humans is 8.9‰±0.3 (the difference is significant at *p* = 0.001). The average cattle δ^{15}N values between the Classic and the Late samples is 1‰ apart at 5.6‰±0.7 and 6.6‰±0.5 respectively. The difference between the Classic δ^{15}N and Late δ^{15}N cattle values is significant (*p*=<0.0001). Overall, the most important point that is evident from the dataset is that the cattle and sheep/goat isotopic distributions significantly changed from one phase to the next, but this shift is not seen in the human isotopic dataset. Figure 6.8 illustrates the human isotope data delineated by phase and sex.

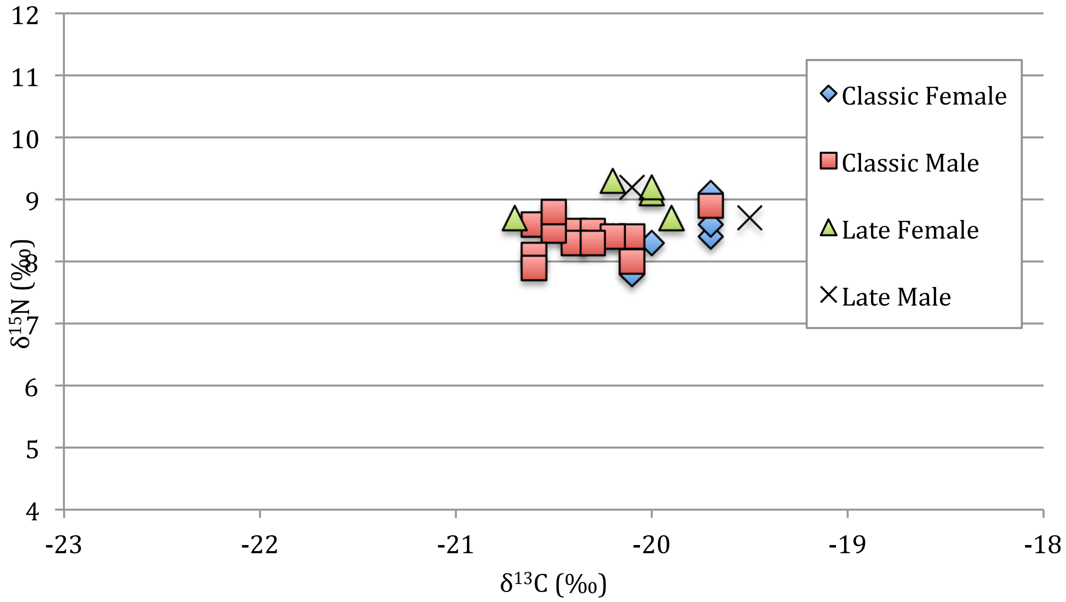

Figure 6.8 $\delta^{13}C$ (‰) and $\delta^{15}N$ (‰) of Classic and Late Phase humans.

In the Classic phase, male and female $\delta^{13}C$ averages differ significantly (*p*=0.002). The difference in $\delta^{15}N$ values however is not significant (*p*=0.8). In the Late phase, the isotopic difference between males and females is not significant for either $\delta^{13}C$ (*p*=0.2) or $\delta^{15}N$ (*p*=0.8). It should be noted however that the sample size for Late phase humans, particularly for the males (n=2), is small, and the validity of such significance testing may be questioned (due to the power of the test, and frequency of type II errors (de Winter 2013)).

A further aspect to be examined is the relationship between diet and burial rites. Overall, wealthy burials in the Classic phase are characterised by the inclusion of copper artefacts (but not always – burial 26 was buried with huge amounts of bone tools, flint blades, boar tusks and an antler T-axe, but no copper). In the Late phase, ‘wealthy’ burials are simply characterised by the presence of *any* grave goods. Figure 6.9 highlights the isotopic differences between copper and non-copper burials.

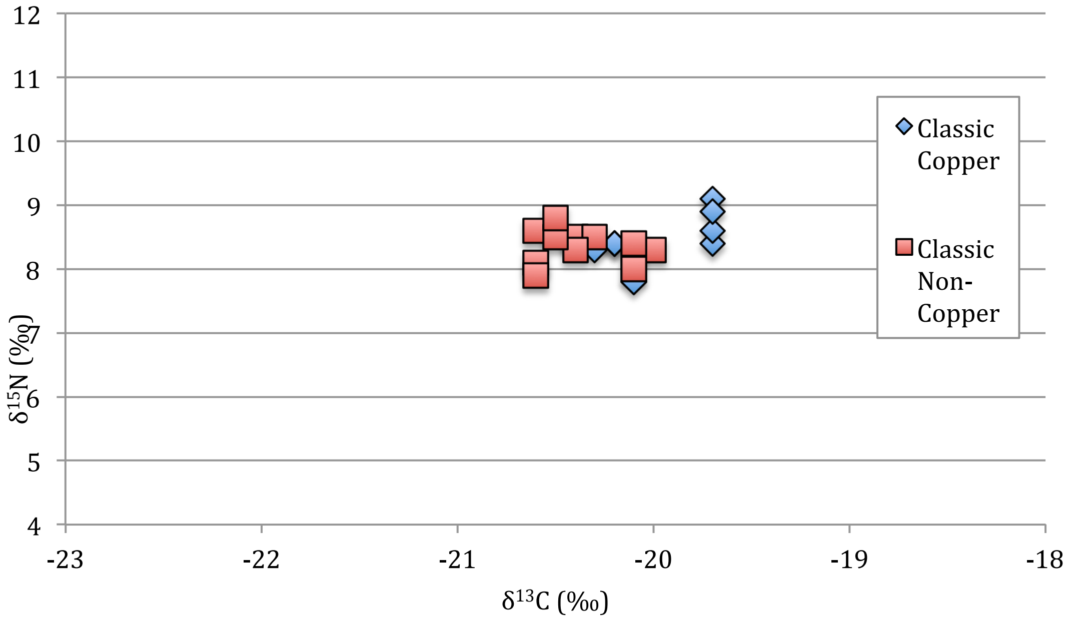

Figure 6.9 $\delta^{13}C$ (‰) and $\delta^{15}N$ (‰) for Classic Copper and Classic Non-Copper artefact associations in human burials.

There is a division in the distribution of $\delta^{13}C$ values between ‘copper’ individuals and ‘non-copper’ individuals. Burials with copper are more likely to have enriched $\delta^{13}C$ values compared to their non-copper counterparts. The difference between the distributions for $\delta^{13}C$ is significant ($p<0.001$). However, the difference in $\delta^{15}N$ is not significant ($p=0.4$). Figure 6.10 illustrates the isotopic distribution of burials from the Late phase.

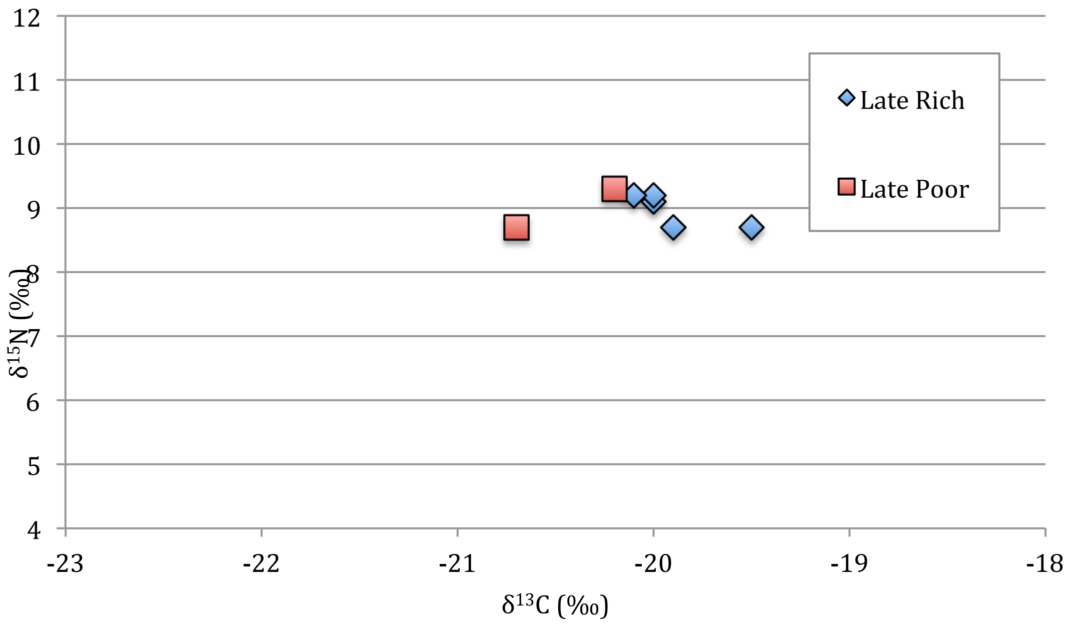

Figure 6.10 δ^{13}C (‰) and δ^{15}N (‰) Late Rich and Late Poor humans.

The difference in the δ^{13}C values between the late 'rich' and late 'poor' humans is significant (*p*=0.05). However, as noted previously, the sample size for the Late phase is very small and so this has to be interpreted with a degree of caution. The difference between the δ^{15}N values is not significant (*p*=0.9). In both the Classic and Late phases, the wealthy burials have more enriched δ^{13}C than their 'poorer' counterparts.

ANOVA testing of humans has been undertaken, entering δ^{13}C as the variable and burial rites and sex as dependent factors,

`model <- aov (d13C~Burial+Sex+Phase)`, with a = 0.05 (table 6.5).

Variable	**Df**	**Sum Sq.**	**Mean Sq.**	**F value**	***p*-value**
Burial	1	1.3388	1.3388	22.093	0.000109
Sex	1	0.0297	0.0297	0.490	0.491122
Phase	1	0.0017	0.0017	0.028	0.869607
Residuals	22	1.3332	0.0606	-	-

Table 6.5 ANOVA of Classic and Late human δ^{13}C values.

The difference in Classic and Late δ^{13}C values is highly significant by burial rite, but loses its significance when tested by sex. The difference in δ^{13}C by phase remains insignificant. Post hoc testing was undertaken on the model (table 6.6), and the adjusted *p*-values are in agreement with the original model.

Variable	**Difference**	**Lower**	**Upper**	**Adjusted *p*-value**
Burial Copper *vs.* Non Copper	0.4538462	0.2535989	0.6540934	0.0001091
Sex Male *vs.* Female	-0.0630303	-0.2656903	0.1396297	0.5255933
Phase Late *vs.* Classic	-0.01671321	-0.2424405	0.2090141	0.8793621

Table 6.6 Post-Hoc testing for Classic and Late δ^{13}C, with Copper *vs.* Non-Copper burials.

Interestingly, the difference in δ^{13}C between all ‘rich’ burials (e.g. from the Classic and Late phase) is significant, $p \leq 0.000$, but the difference in δ^{15}N is not ($p=0.183$). Overall, the difference in δ^{13}C between burial rites remains highly significant throughout testing, but the sex differences lose their significance. This suggests that status exerted the strongest influence on diet at Osłonki 1.

6.4 Source Partitioning: SIAR Models

The Çatalhöyük, Aktopraklık, Barçin Höyük, and Osłonki 1 isotope data were entered into the SIAR programme (chapter 4) in an attempt to estimate the proportions of dietary resources consumed.

The purpose of applying source-partitioning algorithms (SIAR) to the $\delta^{13}C$ and $\delta^{15}N$ dataset produced for this project is to investigate whether we can use these models to gain more dietary information about past human populations, when compared to the standard graphs used in palaeodietary reconstruction (e.g. figures 6.3 and 6.4).

The use of the SIAR source partitioning model, and others like it (e.g. IsoSource and FRUITS), comes with a long list of caveats and assumptions. These caveats range from the nature of isotopic fractionation in consumer/source tissues, to the way in which the model performs the statistical analyses. For example, from a biological perspective the SIAR model assumes homogenization of dietary resources in the consumer's body prior to tissue synthesis, and doesn't account for preferential routing of dietary proteins and lipids (Newsome *et al.* 2004). From a statistical standpoint, the model will always try to fit the data even if it is nonsensical. However, despite the stated caveats and assumptions these models are still useful for palaeodietary reconstruction because they provide a method for constraining the isotope data, even if the method is not perfect. The models should not be considered as stand-alone outputs, and a consideration of the accompanying archaeological evidence, such as faunal assemblages and evidence for dietary resource procurement (e.g. the presence of fishing weirs/equipment) is essential.

6.4.2 Data Input

A more detailed explanation of the application of the SIAR model is present in chapter 4. As a reminder, to begin with the SIAR package requires that four files are input into SIAR before the model will run;

- `Consumers` -> a list of the individual human isotope values
- `Sources` -> a list of the potential dietary sources (e.g. cattle, C_3 plants) and the mean and standard deviations of $\delta^{15}N$ and $\delta^{13}C$ of these
- `Tef` -> a trophic enrichment factor file
- `Conc` -> an elemental concentration dependence file

The consumer and sources files are self-explanatory, and the majority of the data input is evident from appendix 1 (table 'A1.1'). The `tef` file represents the likely trophic enrichment shift between source isotope tissue values and consumer *diet* values (not bone collagen values). For example the `tef` file used for the Aktopraklık example (table 6.7), has $\delta^{13}C$ enrichment at 5±1‰ and $\delta^{15}N$ at 4± 1‰ (figure 6.11).

Source	*mean$\delta^{15}N$*	*sd$\delta^{15}N$*	*mean$\delta^{13}C$*	*sd$\delta^{13}C$*
Cattle	4	1	5	1
Ovicaprid	4	1	5	1
Pig	4	1	5	1
C_3 Plants	4	1	1	1

Table 6.7 SIAR `tef` file for Aktopraklık.

This is because the study is not simply tracking the change from collagen to collagen, but also the change from animal (and plant) living tissues values to human diet (as well as metabolic fraction), but using human collagen values to calculate the variation. The $\delta^{13}C$ '`tef`' (5±1‰) represents the 4‰ negative shift between diet and collagen and the 1‰ metabolic fractionation of the consumer (figure 6.11). The fractionation factor for the $\delta^{13}C$ values from C_3 plants is 1‰ (representing trophic enrichment), as the $\delta^{13}C$ values for plants are obtained directly from the seed or grain. The $\delta^{15}N$ `tef` of 4±1‰ represents the trophic shift between sources and consumers, and this value does not have to be altered as there are thought to be no systematic differences in $\delta^{15}N$ between tissues.

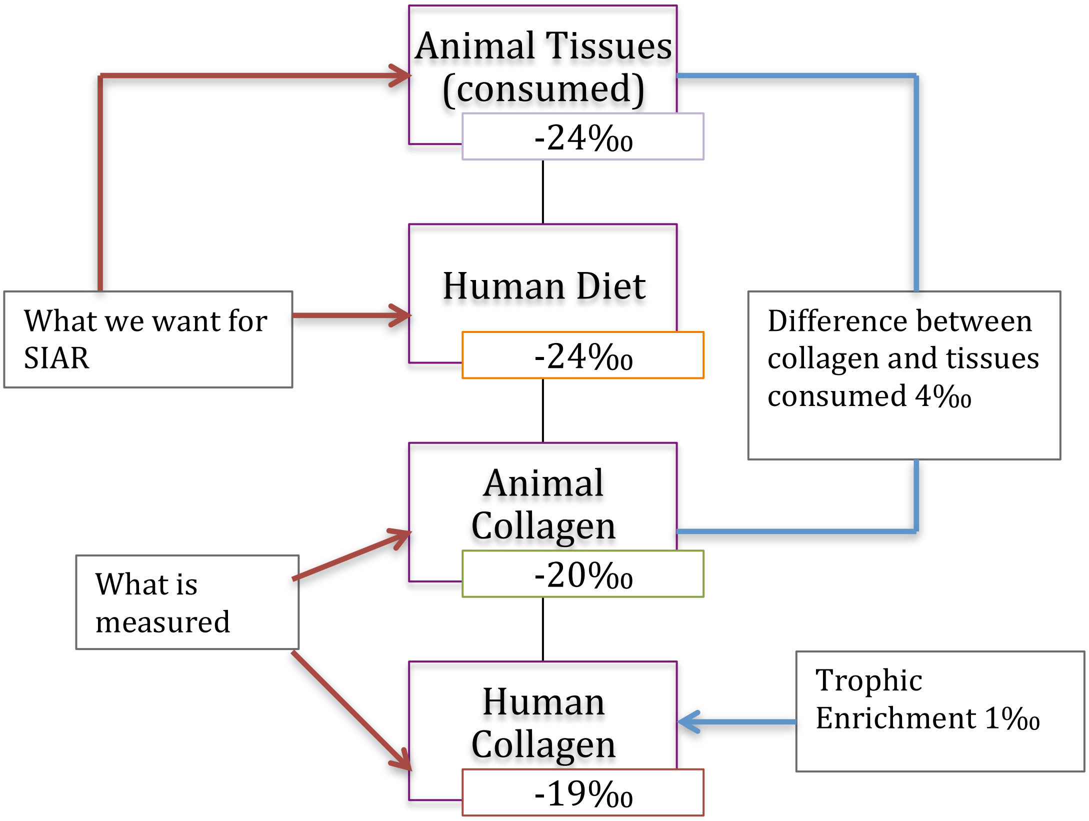

Figure 6.11 Image to illustrate the necessity of the 5±1‰ '`tef`' for $\delta^{13}C$.

The concentration dependence file (table 6.8) represents the difference between elemental concentrations of carbon and nitrogen in food sources. Research by Koch and Phillips (2002) has highlighted the difference in availability of digestible carbon and digestible nitrogen.

Source	N concentration	N standard deviation	C concentration	C standard deviation
Cattle	14.1	1	56.1	1
Sheep/Goat	14.1	1	56.1	1
Pig	14.1	1	56.1	1
C_3 plants	2.3	1	47.8	1

Table 6.8 Elemental concentration dependence of the sources.
(Data: Newsome *et al.* 2004:1106).

For example, terrestrial plants have low nitrogen concentrations and high carbon concentrations when compared to animal flesh, and as a result of this they provide lower proportions of nitrogen for the same weight of food consumed. It is assumed that animal products (both fat and protein) are 100% digestible (Newsome *et al.* 2004:1106). The relative concentration ratios for animal and plant proteins are entered into the SIAR programme using information from Newsome *et al.* (2004:1106).

6.4.3 Calculating NISP Values

For each site, three different models are produced using three difference source files (see 6.4.1 Data Input). The source file used in the first iteration of the model is 'NO NISP' this means that the only information available to the model is the average (± 1 s.d.) δ^{13}C and δ^{15}N value per species. It has no information about the proportion of species recovered from the site (e.g. whether a site's fauna assemblage was comprised of 9% cattle or 90% cattle – it does not have that information).

The *siarelicit* function allows prior information (in this case existing data from the faunal assemblage) to be incorporated into the model. To further constrain the model, a NISP % source file and 'weighted' NISP % for the fauna was utilised (table 6.9 for **Çatalhöyük** example):

- **NISP** <- the model is run with the *siar elicit* function using the face values of the NISP at a site
- **WEIGHTED NISP** <- the model is run with the *siar elicit* function using the weighted NISP calculated from the meat weight ratio and NISP.

Whilst the NISP provides important information about the species recovered from a site, it does not provide direct information about the ratio's of total 'dietary weight' of the fauna. The weighted NISP will use the ratio 1:10:4:1 for cows: sheep/goat: pigs: red deer (e.g. the weight of one cow is approximately equal to the weight of 10 sheep/goat, or four pigs), alongside the NISP percentages at a site, to calculate 'meat-weight faunal assemblage' (as opposed to number of identified bones calculation) (Lyman 1979). A further issue is the inclusion of C_3 plant values. We know from botanical assemblages at the four sites studied that plant protein contributed to human diet, it is unclear however, what proportion plants contributed to the diet. A baseline 'NISP' value of 50% plants was used as a reasonable starting point (Bogaard 2014: *pers comm*), with iterations of 30% and 70% also run (30% and 70% graphs not shown). The $\delta^{13}C$ values for the plants are obtained from archaeological plant isotope analysis either from the site, or from a nearby, climatically similar, contemporary site. The $\delta^{15}N$ values were estimated at 6‰ to account for the aridity affect (see Chapter 3: Isotopes: Environment and Diet), but models were also run at 3‰ and 9‰ (graphs not shown).

Finally, it is important to note that entering NISP values does not tell the model what the actual % contribution of the species consumed is, and if the model is unable to differentiate statistically between faunal or plant values it will preferentially emphasise one animal species, or another, depending on how many are present in the assemblage.

6.4.4 Çatalhöyük

Table 6.9 presents the summary $\delta^{13}C$ and $\delta^{15}N$ statistics for the fauna at Çatalhöyük**.** The isotope values for the C_3 plant component are included for comparison. The $\delta^{13}C$ bone collagen values are depleted by 5‰ prior to calculation as this reflects the flesh values. The table also presents NISP and weighted NISP values. Table 6.10 shows a composite faunal value, calculated from NISP and weighted NISP respectively. The NISP had to be rounded up to equal 100% for the likely animals consumed (pig, cows, sheep/goat), as it is necessary for the model to function. It is acknowledged that other species were recovered from the site, such as *Canis* and *Equuids*, but these are present in small numbers and are unlikely to have contributed significantly to human diet.

Species	*Flesh $\delta^{13}C$ ave.*	*Flesh $\delta^{13}C$ st.dev*	*Flesh $\delta^{15}N$ ave.*	*Flesh $\delta^{15}N$ st. dev*	*NISP*	*Weighted NISP*
Sheep/Goat	-23	1	9.3	1.5	70%	22%
Cattle	-23.4	0.8	9.7	1.6	20%	70%
Pig	-24.5	0.5	7.5	1.3	10%	8%
C_3	-22.7	1.3	6	1	n/a	n/a

Table 6.9 $\delta^{13}C$ and $\delta^{15}N$ flesh values, NISP and weighted NISP figures.

Species	*NISP Comp $\delta^{13}C$*	*NISP Comp $\delta^{15}N$*	*NISP Weighted Comp $\delta^{13}C$*	*NISP Weighted Comp $\delta^{15}N$*
Composite Value	-23.2	9.2	-24.2	9.4

Table 6.10 Composite isotope values for the fauna at Çatalhöyük.

6.4.5 NO NISP ~ No Prior Information in Model

Figure 6.12 depicts proportional consumption of the main faunal species and C_3 plants (cereals) for adults at Çatalhöyük**,** with no priors (e.g. no prior information). The model suggests that the cattle form the dominant part of the diet, with ovicaprids also providing a significant amount of protein (figure 6.12).

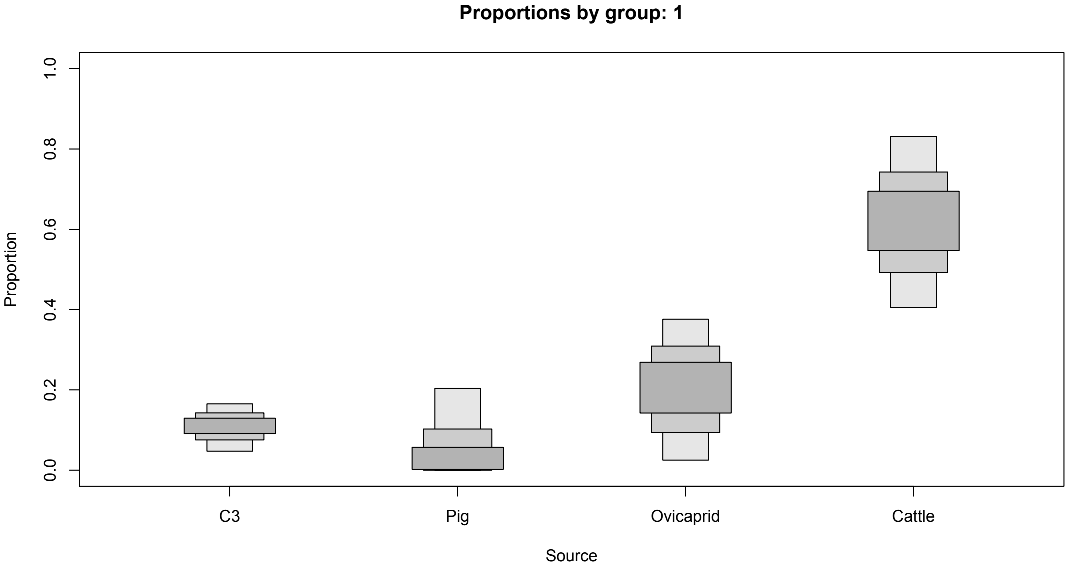

Figure 6.12 Boxplot showing proportional densities of protein consumption by human adults (Çatalhöyük**).**

6.4.6 NISP –Face value priors

The next model was run using NISP (figures 6.12), the values of which are present in table 6.9.

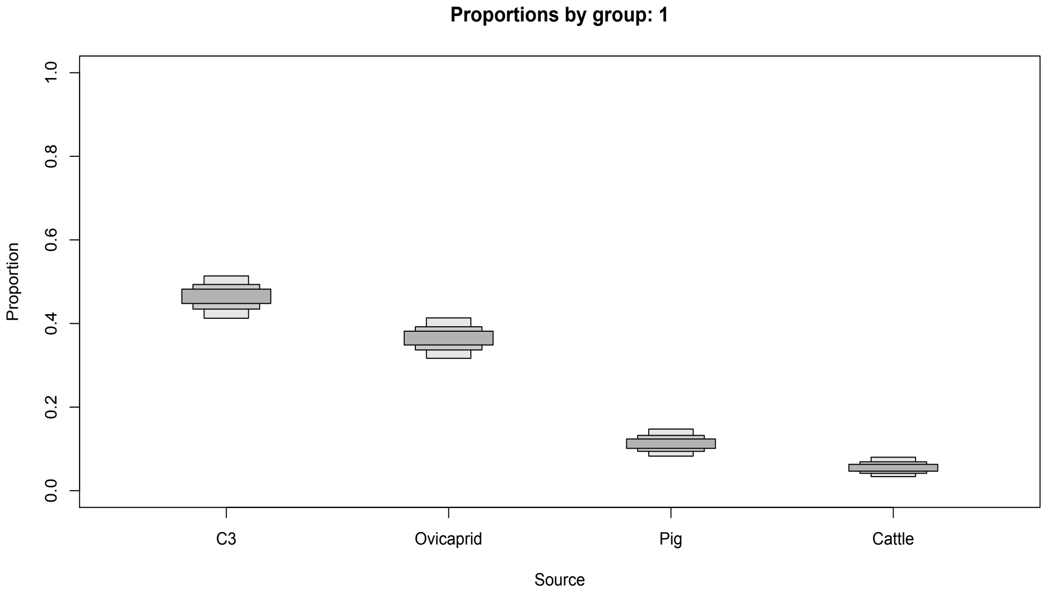

Figure 6.13 Proportion densities for adult protein consumption incorporating NISP values (Çatalhöyük**).**

It is clear from figure 6.12 that two factors are highlighted from these plots. Firstly, the model has shifted protein resources dramatically, with C_3 plant species and ovicaprids making up the dominant proportion of dietary protein, rather than cattle. This is largely the result of sheep/goat bones making up 70% of the faunal assemblage at Çatalhöyük. As a consequence**,** when an isotope value is mid-way between the cattle isotope range and the sheep/goat isotope range the model has a weighted tendency to identify sheep/goat as the likely source. Secondly, the margin for error for the source partitioning has decreased dramatically (as evidenced by the reduction in size of the grey boxes); suggesting that the prior info input function is heavily 'weighted' within the model. This is evident in both the histogram and boxplot.

6.4.7 Weighted NISP

Figure 6.13 shows the proportional densities of human protein consumption if the weighted NISP is used (values present in table 6.9).

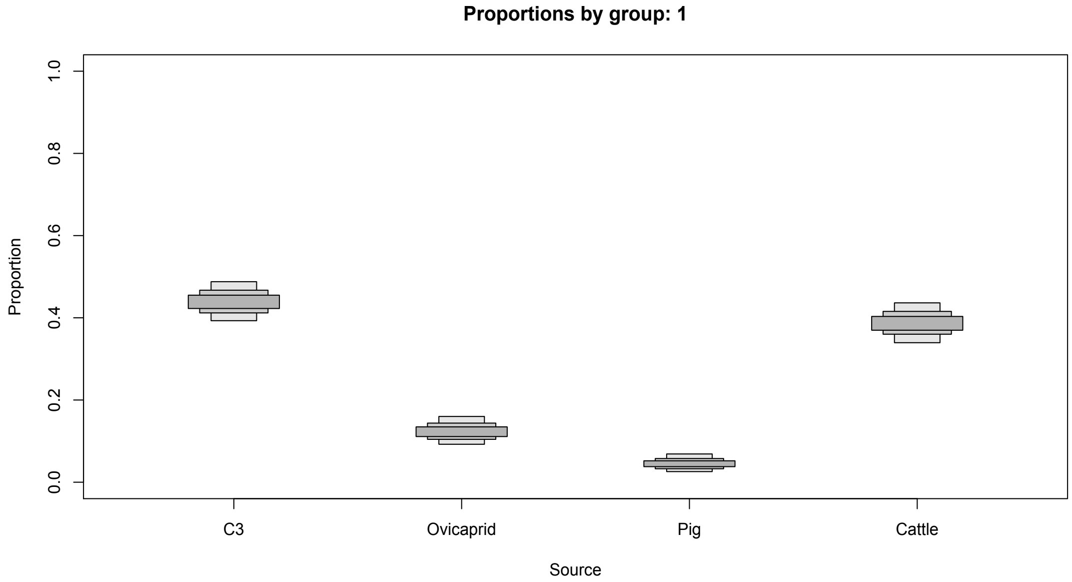

Figure 6.14 Proportion densities for adult protein consumption incorporating weighted NISP values (Çatalhöyük**).**

The result graphs demonstrate that weighting the NISP figures results in ovicaprids being reduced in significance in favour of cattle, and for C_3 plant resources to remain a significant factor in human diets at **Çatalhöyük.**

6.4.8 Aktopraklık

Table 6.11 highlights the δ^{13}C and δ^{15}N flesh values, NISP and weighted NISP figures for Aktopraklık. The isotope values for the C_3 component are included for comparison. The δ^{13}C fauna values have been enriched by 5% prior to calculation to reflect the flesh values. For C_3 plants, as no samples from Aktopraklık were available for isotope analysis, a δ^{13}C value of -26% (±1%) was used. This value was calculated using the average fauna 'flesh' δ^{13}C value, minus the 1% trophic enrichment between consumer and resource (figure 6.11).

Species	*Flesh δ^{13}C ave.*	*Collagen δ^{13}C st.dev.*	*Collagen δ^{15}N ave.*	*Collagen δ^{15}N st.dev.*	*NISP*	*Weighted NISP*
Cattle	-25.5	0.8	6.2	1.3	20%	58%
Ovicaprid	-24	0.5	5.8	1.1	65%	19%
Pig	-24.9	0.4	4	1	10%	8%
Red Deer	-25.5	0	4.6	1	5%	15%
C_3 plants	-26.0	1	6	1	n/a	n/a
Humans	-19.9	1.5	9.3	0.8	n/a	n/a

Table 6.11 δ^{13}C and δ^{15}N flesh values, NISP and weighted NISP figures.

Figure 6.15 clearly illustrates the overlap of sources at Aktopraklık, it is evident that cattle and ovicaprid comprise *c.* 10-15% of the total protein. It is clear from figure 6.15 that the model is not readily distinguishing between the faunal resources, because they are isotopically similar.

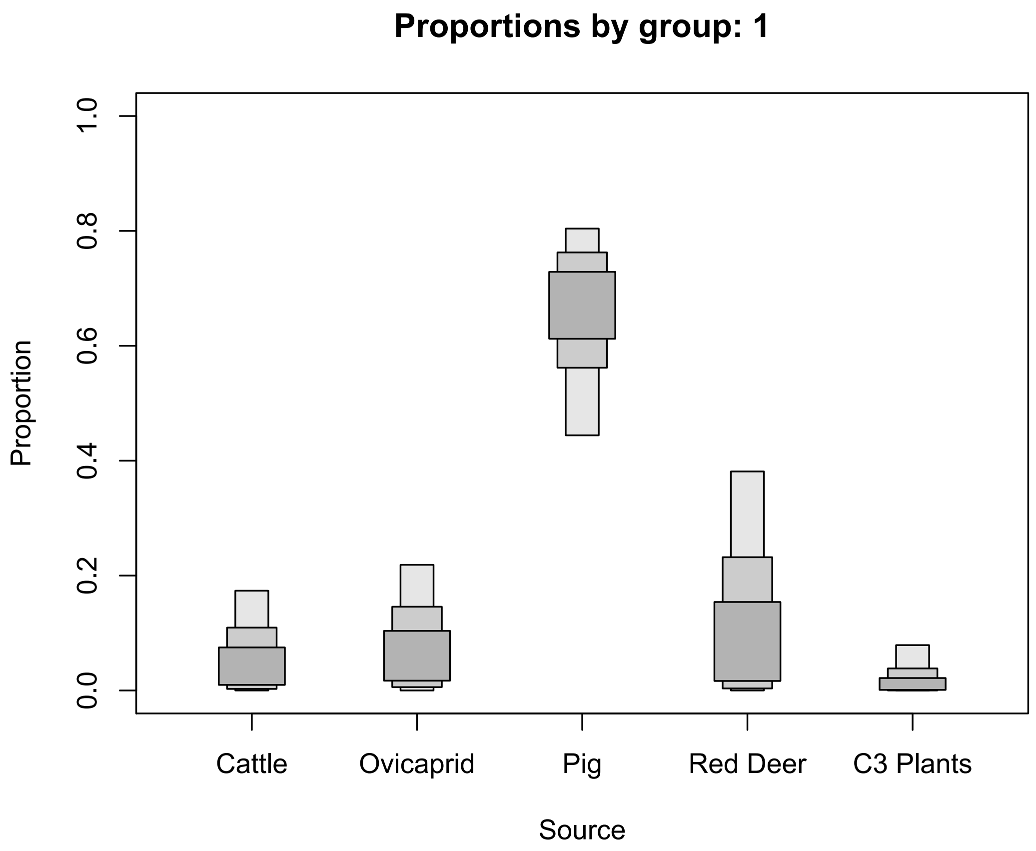

Figure 6.15 SIAR boxplot to display output for source partitioning at Aktopraklık.

The siarelicit function requests proportion estimates for the sources at a site, as such, the NISP values are entered and the function gives you dirichlet priors to enter into the next model. The NISP priors for Aktopraklık are 72.6, 235.95, 36.3, 18.15, 0. The model is run incorporating these priors –

```
model1a <-
siarmcmcdirichletv4(consumers,sources,tef,concdep,prior=c(72.6,
235.95, 36.3, 18.15, 0)).
```

Figure 6.16 highlights the results from the inclusion of the NISP values. The high percentages of ovicaprids in the fauna assemblage are now evident in the model.

Finally the weighted NISP values (table 6.11) are entered into the model (prior parameters 95.2476, 31.2018, 13.1376, 24.633, 164.22) (figures 6.17).

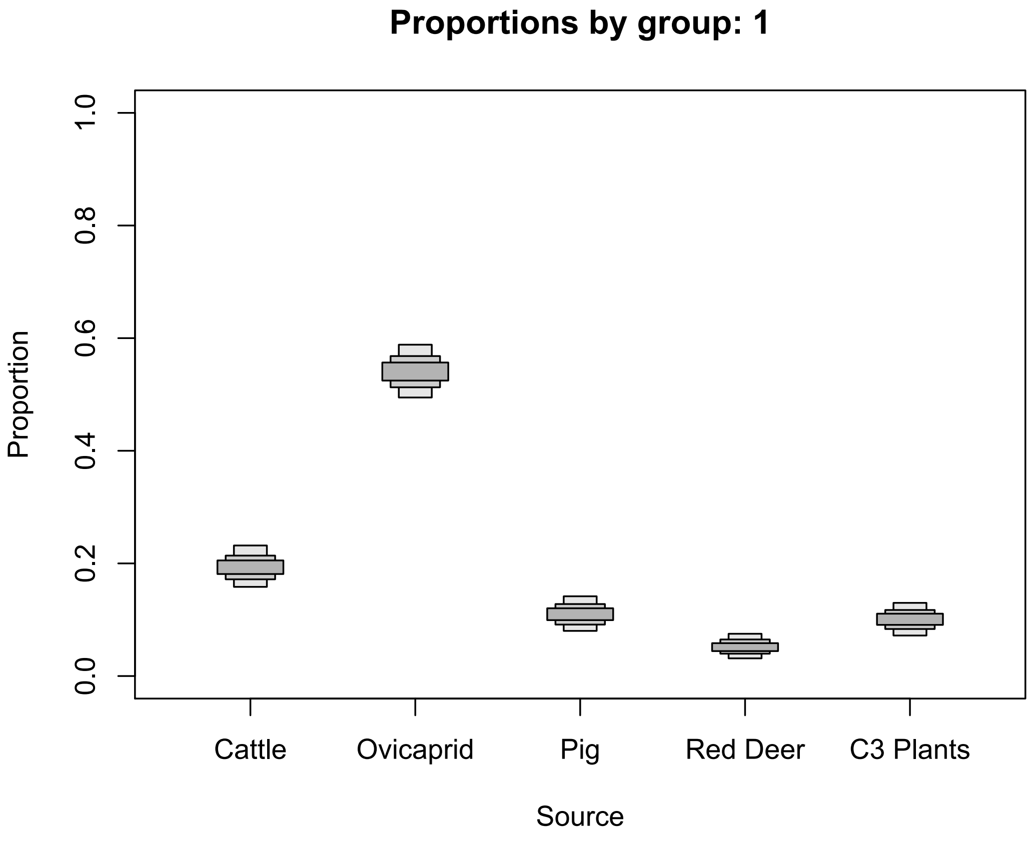

Figure 6.16 Source partitioning of adult diet at Aktopraklık using NISP values.

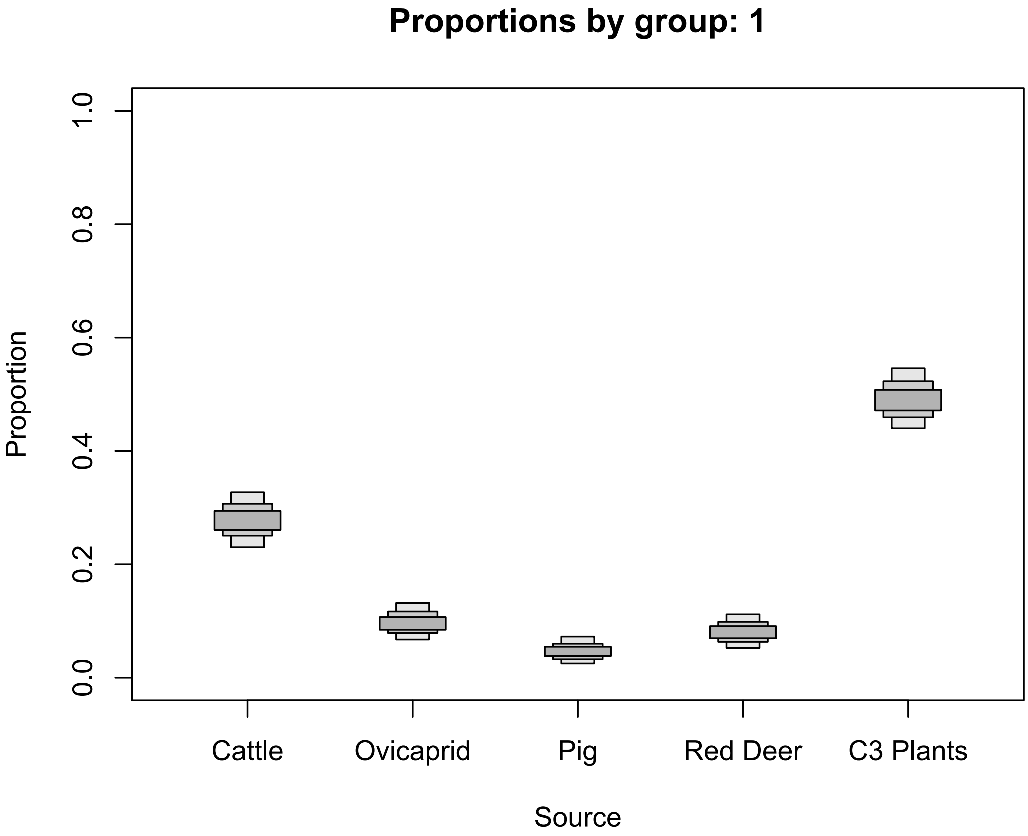

Figure 6.17 Source partitioning of adult diet at Aktopraklık using weighted NISP values.

The inclusion of the weighted NISP priors into the model (figure 6.17) suggests a continued reliance on C_3 plant species in the diet, but the outputs also indicate that cattle protein, rather than ovicaprid protein sources, comprised the second major component of the diet at Aktopraklık. The major caveat associated with using the weighted NISP value in the model is that it only reflects meat weight, and cannot provide insights into the exploitation of secondary products such as milk and dairy products.

6.4.9 Barçin Höyük

Table 6.12 details the average $\delta^{13}C$ and $\delta^{15}N$ and standard deviations for the fauna at Barçin Hoyuk. No plant samples were available from Barçin Hoyuk, so the $\delta^{13}C$ value for C_3 plants was calculated using the faunal $\delta^{13}C$ values from the site (see section 6.4.4). The $\delta^{13}C$ fauna values have been enriched by 5% prior to calculation to reflect the flesh values. The table also highlights the face value NISP, the weighted NISP. Table 6.13 highlights the faunal composite value (again calculated from NISP and weighted NISP).

Species	*Flesh $\delta^{13}C$ ave.*	*Flesh $\delta^{13}C$ st.dev.*	*Flesh $\delta^{15}N$ ave.*	*Flesh $\delta^{15}N$ st.dev.*	*NISP*	*Weighted NISP*
Cattle	-24.4	1.8	6.8	1.37	30%	84%
Ovicaprid	-24.6	0.8	6.7	1.21	60%	9%
Pig	-25.9	0.42	4	1	10%	7%
C_3	-26.0	1	6	1	n/a	n/a

Table 6.12 $\delta^{13}C$ and $\delta^{15}N$ flesh values, NISP and weighted NISP figures.

Species	*NISP Comp $\delta^{13}C$*	*NISP Comp $\delta^{15}N$*	*NISP Weighted Comp $\delta^{13}C$*	*NISP Weighted Comp $\delta^{15}N$*
Composite Value	-24.7	6.5	-24.5	6.6

Table Error! No text of specified style in document.**.1 Composite isotope values for the fauna at Barçin** Höyük.

6.4.10 No NISP – No Priors

Figure 6.18 displays the suggested proportion consumption of protein resources at Barçin Höyük, where no NISP information is incorporated into the model.

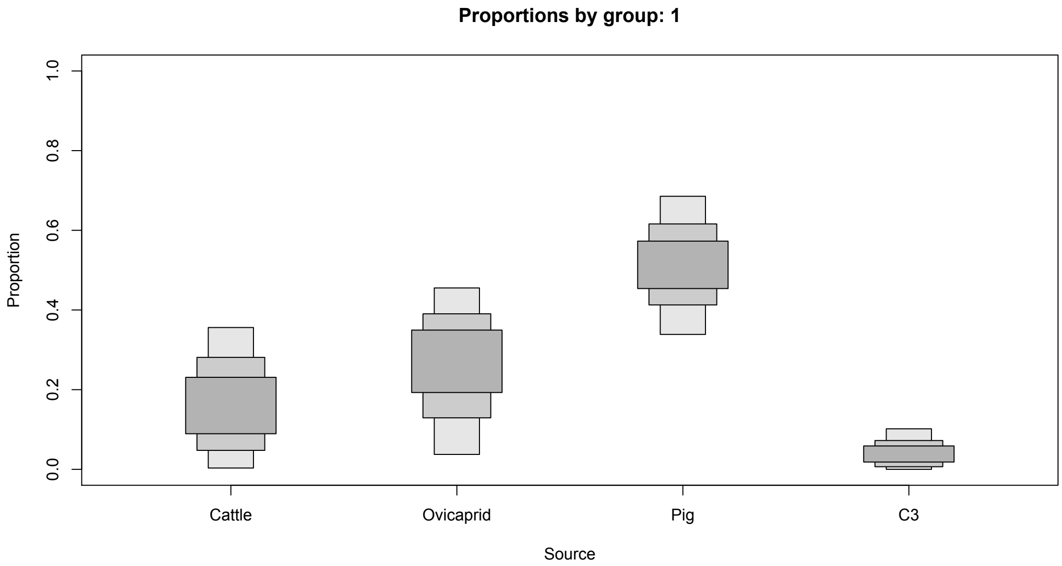

Figure 6.18 Proportion densities for adult protein consumption incorporating no priors (Barçin Höyük**).**

When no priors are entered in to the model, the posterior estimates suggest that pig protein was the main dietary component, with ovicaprid and cattle protein contributing slightly less to the overall composition of the adult diet. In light of the fact that pig bones only comprise 25% of the faunal assemblage at Barçin Höyük, this model output would appear unreliable**.**

6.4.11 NISP

Figure 6.19 illustrates the protein consumption estimates, incorporating face value NISP values as priors into the SIAR model.

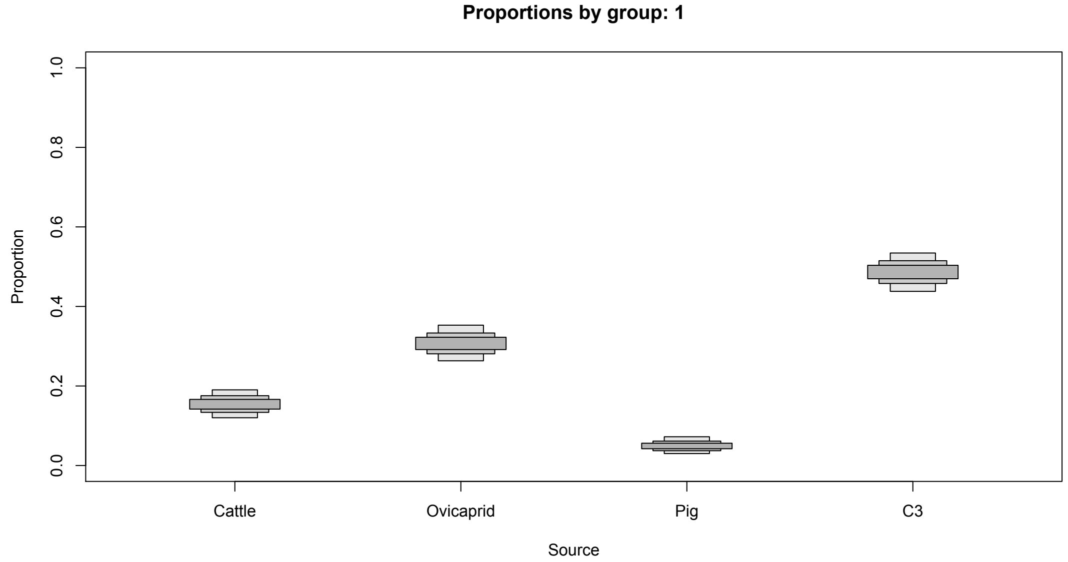

Figure 6.19 Proportion densities for adult protein consumption incorporating NISP priors (Barçin Höyük).

When the model is run with NISP priors, the posterior estimates suggest that C_3 plant proteins form the main basis of the adult at Barçin Höyük with ovicaprid protein resources also contributing a significant proportion of the dietary protein intakes at this location.

6.4.12 Weighted NISP

Figure 6.20 highlights the estimated protein outputs for adult diet at Barçin Höyük when weighted NISP are added into the model.

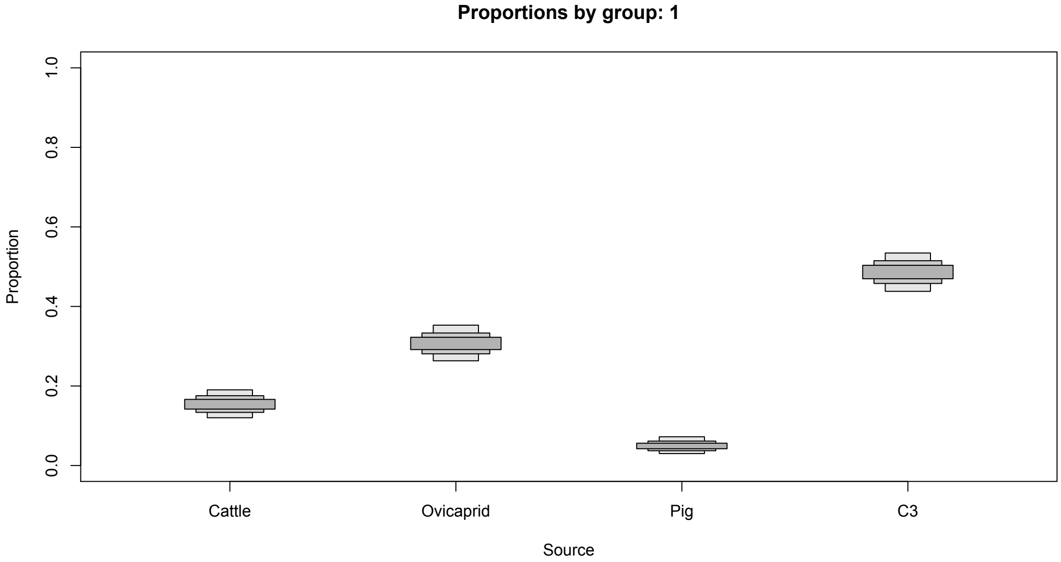

Figure 6.20 Proportion densities for adult protein consumption incorporating weighted NISP priors (Barçin Höyük).

The introduction of weighted NISP into the model sees a shift towards a suggested reliance on cattle and C_3 plant proteins at Barçin Höyük. The same shift is evident in Çatalhöyük and Aktopraklık when weighted NISP priors are included. The reason for this shift is that the 'meat weight' of the cattle vastly outweighs the ovicaprid (1:10) and this causes the model to have a preference for cattle protein contribution.

6.4.13 Osłonki 1

Table 6.14 details the average $\delta^{13}C$ and $\delta^{15}N$ and standard deviations for the fauna at Osłonki 1. The isotope values for the C_3 component are included for comparison. The $\delta^{13}C$ fauna values have been enriched by 5% prior to calculation to reflect the flesh values. The table also highlights the face value NISP and the weighted NISP. Table 6.15 highlights the faunal composite value (again calculated from NISP and weighted NISP). The $\delta^{13}C$ values for the C_3 component is set a -23‰ and the $\delta^{15}N$ value is set a 3‰ (rather than 6‰), as this nitrogen value is commensurate with published studies for this region of Central Europe (Reitsema *et al.* 2011), and is implied by the faunal δ^{15}N values from the site (e.g. 6‰).

Species	*Flesh δ^{13}C ave.*	*Flesh δ^{13}C st.dev.*	*Flesh δ^{15}N ave.*	*Flesh δ^{15}N st.dev.*	*NISP*	*Weighted NISP*
Cattle	-25.6	0.38	5.4	0.5	34%	68%
Ovicaprid	-25.2	0.2	5.8	0.8	33%	7%
Pig	-25.6	0.4	6.6	0.4	25%	5%
Red Deer	-26.2	0.8	4.2	1.5	5%	20%
C_3	-23	1	3	1	n/a	n/a

Table 6.14 δ^{13}C and δ^{15}N flesh values, NISP and weighted NISP figures.

Species	*NISP Comp δ^{13}C*	*NISP Comp δ^{15}N*	*NISP Weighted Comp δ^{13}C*	*NISP Weighted Comp δ^{15}N*
Composite Value	-25	5.6	-25.7	5.2

Table 6.15 Composite isotope values for the fauna at Osłonki 1.

6.4.14 NO NISP – No prior information in the model

Figure 6.21 displays the consumption estimates for adult diet at Osłonki 1.

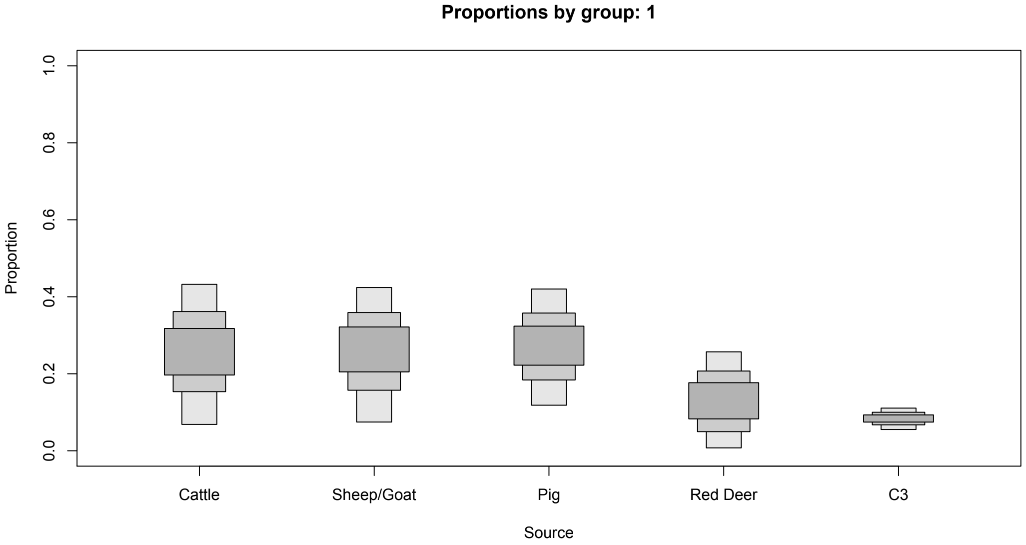

Figure 6.21 Proportion densities for adult protein consumption incorporating no priors (Osłonki 1).

Figure 6.22 indicates that the SIAR model has significant difficulty distinguishing between dietary resources.

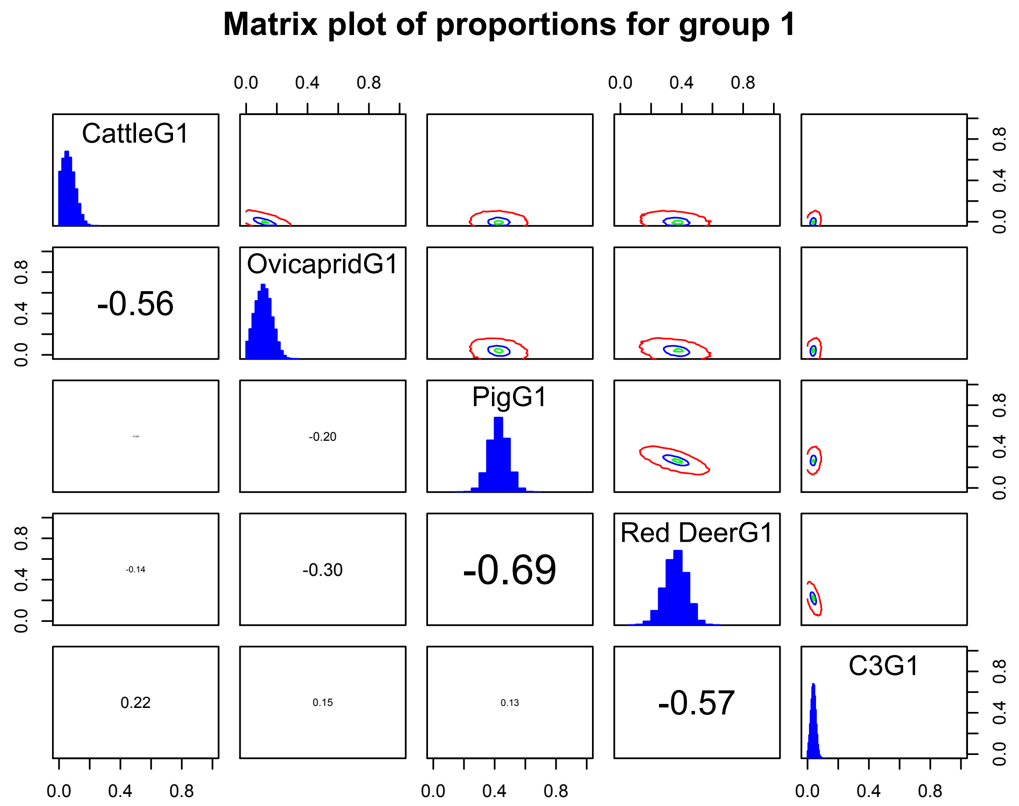

Figure 6.22 SIAR matrix plot for Osłonki 1, dirichlet priors not incorporated.
The numeric values in the lower left triangle of plots are the correlation coefficients. The upper right triangle is a graphical representation of the correlation coefficient.

The matrix plots and correlation coefficients were consulted for each model created. Figure 6.22 is included as it highlights the particular difficulty this model had with fitting the data. The correlation plots are generated by pairing simulated values of the dietary proportions drawn by iteration of the mcmc process (Parnell *et al.* 2010). The higher the numbers (which are conveniently scaled to demonstrate importance) the less the model fits.

6.4.15 *NISP – Face value priors*

Figure 6.23 highlights the proportion estimates for Osłonki 1 with face value NISP priors included in the model.

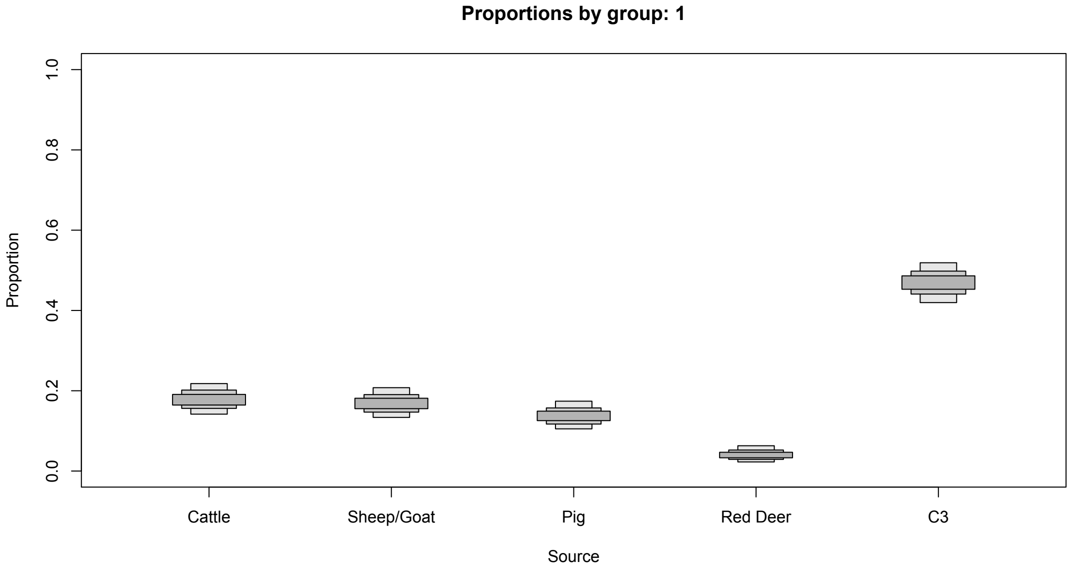

Figure 6.23 Proportion densities for adult protein consumption incorporating NISP priors (Osłonki 1).

The inclusion of the NISP % has caused the model to estimate that C_3 is the main component of the diet, and again the faunal values are not showing much separation in terms of their relative importance. The faunal NISP from Osłonki 1 shows a fairly even division between cattle, sheep/goat and pig species, and as such these priors do not help the model to distinguish between resources.

6.4.16 *Weighted NISP*

Figure 6.24 detail the estimates for adult protein consumption at Osłonki 1 utilizing weighted NISP priors in the model.

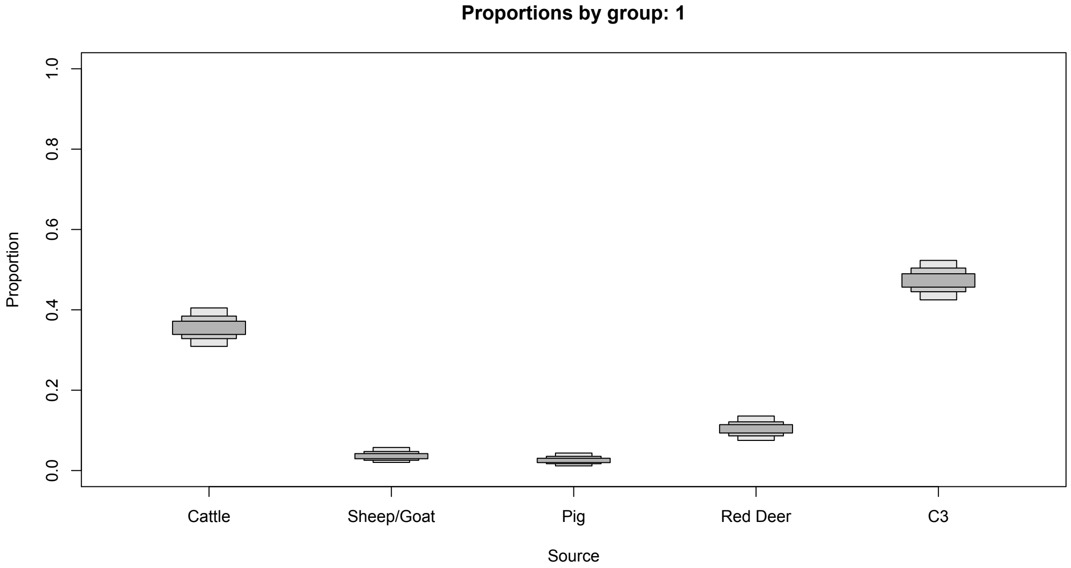

Figure 6.24 Proportion densities for adult protein consumption incorporating weighted NISP priors (Osłonki 1).

The addition of weighted NISP priors for the Osłonki 1 prior has allowed the model to identify cattle and C_3 as the main components of diet for the adult population at the site. It is also evident from the weighted NISP models that red deer is suggested to have contributed a higher proportion of dietary protein than pigs and sheep/goats. This outcome is surprising, as the wild fauna only comprises *c.*10% of the faunal assemblage. The most probable reason for this modelled outcome is that red deer have a higher meat weight than pigs and sheep/goat, and this fact coupled with the issue of the range of red deer $\delta^{13}C$ and $\delta^{15}N$ values (e.g. the range is so broad that it overlaps with the pig and sheep/goat isotope values) is sufficient to influence the model.

6.4.17 Dairying at Osłonki 1

Salque *et al.* (2012) have clearly demonstrated the presence of dairying *and* cheese making at Osłonki 1 during the LBK phases of occupation. From this research it is necessary to consider the possibility that dairy products also contributed to diet during the Lengyel phases of occupation. Chapters 2 and 3 (sections 2.6.5 and 3.7.4

respectively) detail the issue of dairying (e.g. milking and cheese making), in addition to the amount of protein dairy products contribute to human diet. It is clear from USDA database that the amount of protein per 100g is different for cow milk (3.4g), cow cheese (6g) and cow meat (20g when raw and 27g when cooked). The SIAR programme was used to attempt to model the contribution of milk, cheese and meat to human diet at Osłonki 1. This approach to modelling the dairy input at Osłonki 1 is purely a heuristic exercise, as it is not (currently) possible to adequately model all of the potential food sources in prehistoric human diet.

A number of issues are acknowledged when attempting to model the contribution of meat *vs.* milk *vs.* cheese to diet using this approach. Firstly, as the number of possible protein sources in the model are increased (e.g. cow milk, cow meat, cow cheese), the less precise the output of the model (see Phillips and Gregg 2005, Parnell *et al.* 2010, and Phillips and Newsome 2005 for a detailed consideration of this issue). The difficult issue of combining too many sources is particularly pronounced when the potential protein sources have similar δ^{13}C and δ^{15}N values (as is the case with Osłonki 1).

If we consider table 3.1 (chapter 3), it is evident that the differences between species in protein content (per 100g of milk and meat) are not high, e.g. cow milk is 3.4g and sheep milk is 5.5g, with goat somewhat higher at 9.9g. The differences in protein for (cooked) meat (per 100g) are again fairly small; cattle (27g), goat (27g), and sheep (23g). Therefore, if we run the model with the intent of distinguishing between meat and milk contribution to diet, using the protein content (table 3.3, Chapter 3) as prior information, it should provide *broad scale* information about the importance of meat *vs.* milk. The caveat of this approach is that it would not be able to differentiate between cow milk and goat milk (etc.).

A potential obstacle to this approach, is that the differences in protein content of *cheese* (per 100g) between species however are quite pronounced; sheep (17g), goat (18g) and cow (6g). Of course, this data reflect modern cattle, sheep and goat cheese values, but the *relative* differences between the species should hold firm. The consequence of this is that protein content cheese of sheep and goat would affect the model differently to cow cheese, and so would not be comparable. However, Salque *et al.* (2012:4) highlight the high amount of cattle bones in the Kuyavia region (68%-80%) to suggest that the cattle would be the likely producers of dairy products. The problem with this is that the research undertaken by Salque *et al.* focused on Linear Pottery (LBK) phases of occupation, and that by the Lengyel period (e.g. the chronological research period for Osłonki), the faunal assemblages had diversified to include (among other species) cattle at 34%, sheep/goat at 33% and pigs at 25% (NISP values, Bogucki 2008:1608). Therefore, a number of different approaches are utilised to attempt to produce a meaningful source-partitioning model. Firstly, a simplified version of the model is undertaken, where the potential protein sources entered are “meat”, “milk”, “cheese” and “C3 plants”. This model uses the average values for the species (e.g. cow, sheep and goat) for both the δ^{13}C and δ^{15}N values, and the concentration dependence values (e.g. the average δ^{13}C value of the goat, sheep and cattle combined is -20.2‰, the average protein value of sheep, goat and cattle milk combined is 6g (per 100g)). SIAR was unable to fit a meaningful output for this model, each of the protein sources was suggested as contributing an equal proportion to the diet.

Figure 6.24 shows the SIAR output when all of the potential sources are included in the model individually. The protein amount (n/100g) is included as a concentration dependence file (see chapter 3, table 3.3). From the boxplot (figure 6.24) it is evident that the cattle meat is modelled as contributing the largest proportion to human diet, closely followed by cattle milk and cheese, sheep and goat milk, and C_3 plants. This output is largely in agreement with the previous research into diet at Osłonki (chapter 2, section 2.5).

Figure 6.25 shows the proportion density outputs for the human burials at Osłonki 1 that have higher status burials (e.g. copper containing burials during the Classic phase and burials containing grave goods during the Late phase, see section 6.3.3). Figure 6.26 shows the density proportions for non-copper burials from the Classic phase combined with burials with no grave goods from the Late phase. This approach is adopted as during both the Classic and Late phases the 'status' burials (for definitions of 'status' and 'non-status' see section 2.6.2, chapter 2) exhibit more enriched $\delta^{13}C$ values than the 'non-status' burials, and so is consistent through time. This approach also *partially* sidesteps the issue that a number of the burials may have to be re-assigned to a chronological period in light of the new radiocarbon determinations (chapter 6, section 6.5) - as the model differentiates on 'status', rather than by chronological phase. However, as the identification of status in the Late phase is characterized by the presence of any grave goods, there is a clear issue that a non-copper Classic burial (e.g. has grave goods with no copper inclusions) could be misidentified as a status burial in the Late phase.

The density distribution for boxplots 6.26 and 6.27 display more overlap than figure 6.25 as a smaller number of consumer values was run in the model. Figures 6.26 and 6.27 show that individuals with higher status burials consume diets than were predominantly composed of cattle meat, whereas individuals with 'lower status' consumed higher quantities of C_3 plant species. However, the final radiocarbon chronology of the Osłonki burials is yet to be considered (chapter 6, section 6.5), and its integration into the isotope dataset may necessitate a refinement of the source partition modelling.

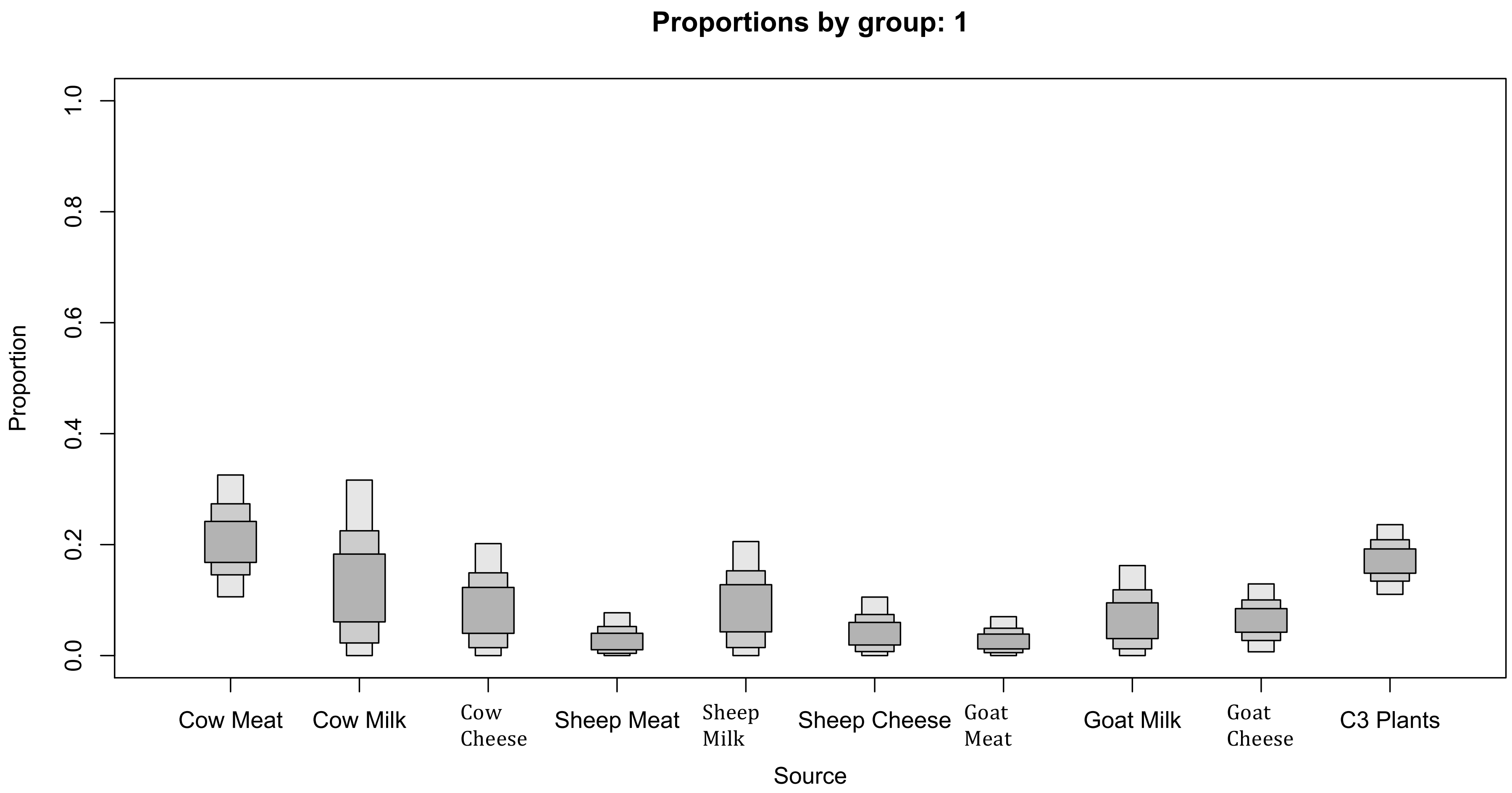

Figure 6.25 Proportion densities for major protein sources for all adults at Osłonki 1.

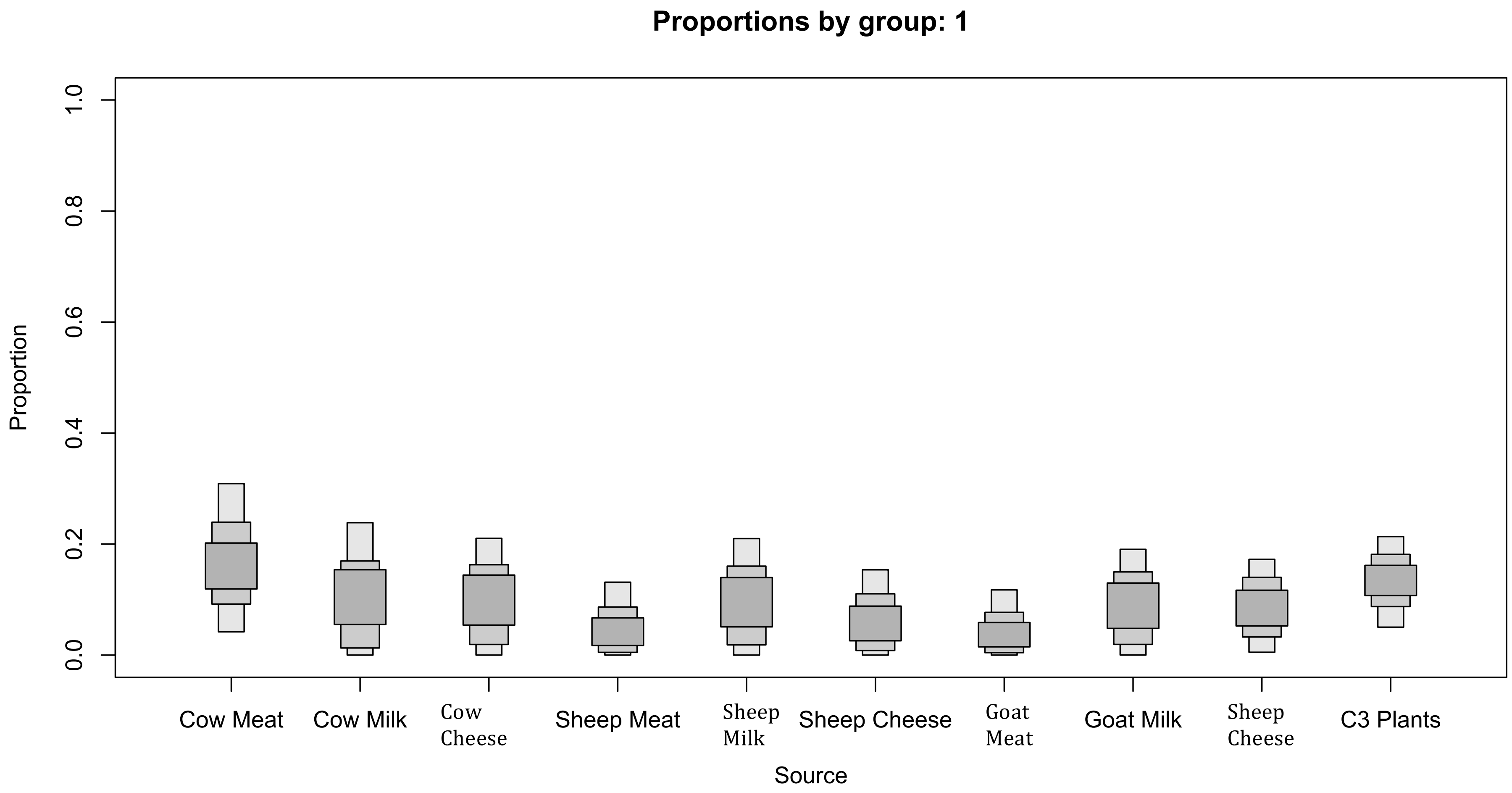

Figure 6.26 Proportion densities for Classic Copper burials and Late burials with grave goods at Osłonki 1.

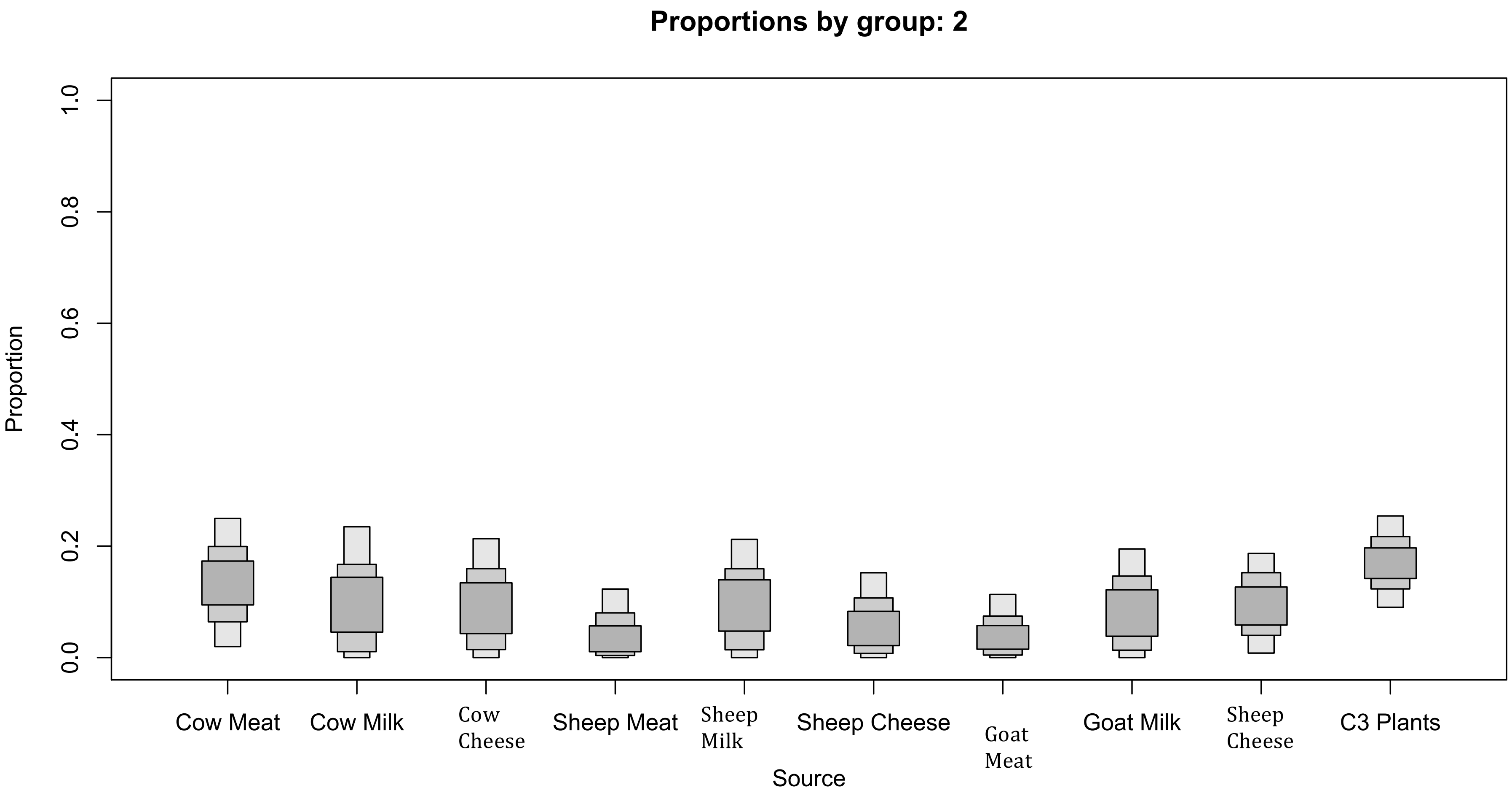

Figure 6.27 Proportion densities for Classic non-copper burials and Late burials with no grave goods at Osłonki 1.

In an attempt to further refine the model, the protein sources that contribute limited proportions to diet were dropped to remove excess noise from the model (e.g. sheep meat, sheep cheese, and goat meat were removed from the model). The purpose of this was to show broad-scale proportion estimates for the probable major food groups for adult human diet at Osłonki 1. However, the remaining protein sources (cattle meat, cattle milk, cattle cheese, sheep milk, goat milk, goat cheese and C_3 plants) are too similar isotopically, and the model could not meaningful fit the data (e.g. the model suggested that all protein sources contributed equally).

6.4.17 Summary

In summary, SIAR models add little (if anything) to existing methods of palaeodietary reconstruction, and any use of the models in similar contexts should be undertaken with great caution. The SIAR models for the Anatolian study sites show similar trends when NISP and Weighted NISP values are added to the models; table 6.16 provides a summary of the results.

Model	***Çatalhöyük** Diet*	*Aktopraklık Diet*	*Barçin **Höyük** Diet*
No NISP	Cattle	Pig/Red Deer	Pig/Ovicaprid
NISP	C_3/Ovicaprid	Ovicaprid/cattle	C_3/Ovicaprid
Weighted NISP	C_3/Cattle	C_3/Ovicaprid	C_3/Ovicaprid

Table 6.16 Summary data for the Anatolian study sites, with posterior protein estimates listed in order of magnitude.

It is apparent from the modelled data that if the no priors model is run (no NISP) the model cannot differentiate between protein resources at any of the sites studied, and this is demonstrated by high correlation coefficients. The no prior's model suggests different major protein components for each site, with the Aktopraklık posterior output of pig and red deer being the most unlikely fit when compared to the archaeological material. This suggests that the SIAR model is not a useful tool for palaeodietary reconstruction when the protein sources have similar isotope values, and indeed this is a point that the creators of SIAR highlight (Parnell *et al.* 2010).

The introduction of NISP/weighted NISP as dirichlet priors into the model has a uniform affect on the posterior protein distributions. All of the Anatolian sites demonstrate a shift towards a joint reliance on C_3 and ovicaprid resources when the NISP priors are added. This shift reflects the high component of ovicaprid remains with the faunal assemblages at the respective study sites. The introduction of weighted NISP brings a uniform change to a joint reliance on C_3 and cattle protein resources. This reflects the issue that the meat weight of one cow is equivalent to 10 sheep/goat, and this causes the % component of cattle (so % component of animals by weight) to increase dramatically.

6.5 Plotting Δ

The purpose of plotting the trophic 'spacing' Δ is to identify what dietary source provided the most (proportionally) protein to the diet. Spacing, noted as Δ in the literature, is the trophic space, isotopically speaking, that exists between diet resources and consumers (e.g. cattle with $\delta^{15}N$ values of 6‰ and humans with $\delta^{15}N$ values of 9‰, would reflect a trophic space of 3‰). The theory behind the plotting of the isotopic trophic spacing between consumers and prey is that if a faunal species is selected that is likely to have contributed the largest proportion of dietary protein to the human diet, a correlation in the data should be visible in the model outputs. If we consider the published literature on trophic enrichment (DeNiro and Epstein 1978, Ambrose 1991, Hedges and Reynard 2007) we would expect to see an enrichment (trophic shift) in $\delta^{13}C$ of *ca.* 1‰ and a $\delta^{15}N$ enrichment of between 3-5‰ between consumer and prey. The trophic spacing graphs (figures 6.28 – 6.31) take the average carbon and nitrogen value from the isotope values for the site studied (e.g. the average for all of the goats analysed from Aktopraklık), which is why some of the trophic enrichments in the graphs appear to shift in the wrong direction. One caveat to this approach to examining the dataset is that it does not take environmental effects on isotope values into account. Figure 6.28 illustrates the human-diet isotopic spacing at Aktopraklık for the two fauna species that appear most frequently in the faunal assemblage: ovicaprids and cattle. Table 6.17 displays the r^2 and p values. The shaded blocks represent the areas that human-fauna spacing values should fall between. For nitrogen 3-5‰ is used, and for carbon 0.8‰ to 1.3‰ is used to represent the 1‰ shift (based on research undertaken by Bocherens and Drucker 2003).

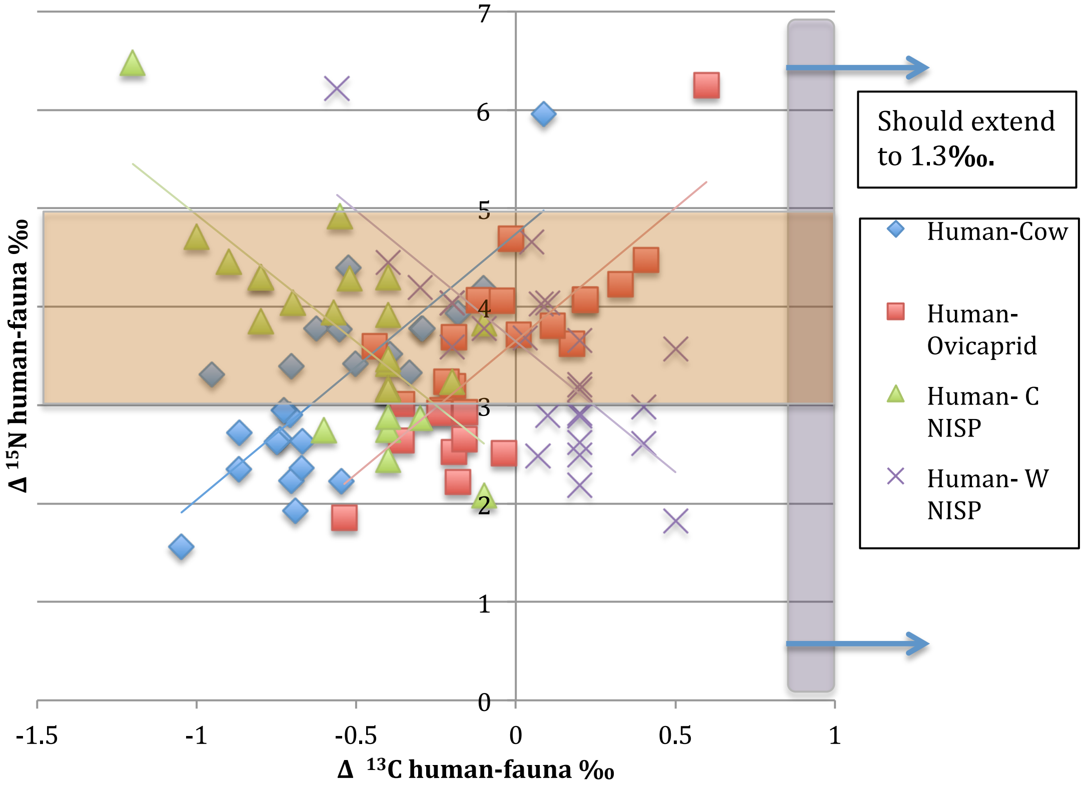

Figure 6.28 Human-fauna Δ (spacing) at Aktopraklık.
The shaded areas highlight the expected spacing values for human-fauna, e.g. 0.8 -1.3‰ for δ^{13}C (in purple) and 3-5‰ for δ^{15}N (in orange).

Spacing	*r^2 value*	*p-value*
Human-Goat	0.6	0.42
Human-Cow	0.6	0.42
Human-Composite NISP	0.41	0.37
Human-Composite Weighted NISP	0.41	0.37

Table 6.17 Human-fauna spacing regression values at Aktopraklık.

It is evident from figure 6.27, that there is a correlation between human-goat and human-cow spacing (r^2 = 0.41, *p*=0.37 for the cattle and goat data). The individual correlations for these groups (human-goat, human-cow) are both somewhat higher (r^2

=0.6, *p*=0.42). If we consider the carbon isotope spacing between the humans and the average cattle $\Delta^{13}C$ value (-19.5‰) it is evident the majority of the human values are depleted when compared to their faunal counterpart. This is contrary to expectation, as 1‰ enrichment shift should be observed in the human to fauna carbon isotope values. If we examine the human-goat spacing it is evident that a greater proportion of the human carbon values are enriched when compared to the mean goat isotope value (even when considering the variation around the goat carbon isotope mean). This would suggest that goat species did contribute a significant amount of protein to the diet of individuals at Aktopraklık during the Neolithic, which is also commensurate with the archaeological data discussed in chapter 2 (e.g. higher percentages of goats in the faunal assemblages, and the issue that goats are better adapted to arid and semi-arid areas than cattle (Dawson *et al.* 1975)).

If we compare the expected human carbon isotope values to the actual $\delta^{13}C$ values (figure 5.2, chapter 5), it is evident the main issue is that the actual values are more depleted than expected. The human-fauna $\delta^{13}C$ values are too depleted and do not show a trophic enrichment factor, this strongly suggests that C_3 plant species contributed a significant amount of protein to the human diets at Aktopraklık. The 'expected' and 'actual' human $\delta^{15}N$ values suggests that the amount of meat and milk protein *vs.* plant proteins consumed at Aktopraklık varied by individual, e.g. the individuals plotting within the orange box show a 3-5‰ enrichment in nitrogen are commensurate with animal produce. Individuals who do not show that shift (and fall outside of the the orange box) reflect diets of proportionally higher amounts of plant protein (as plant proteins have a more depleted $\delta^{15}N$ values than meat or milk). Figure 6.29 displays the human-fauna spacing at Barçin Höyük.

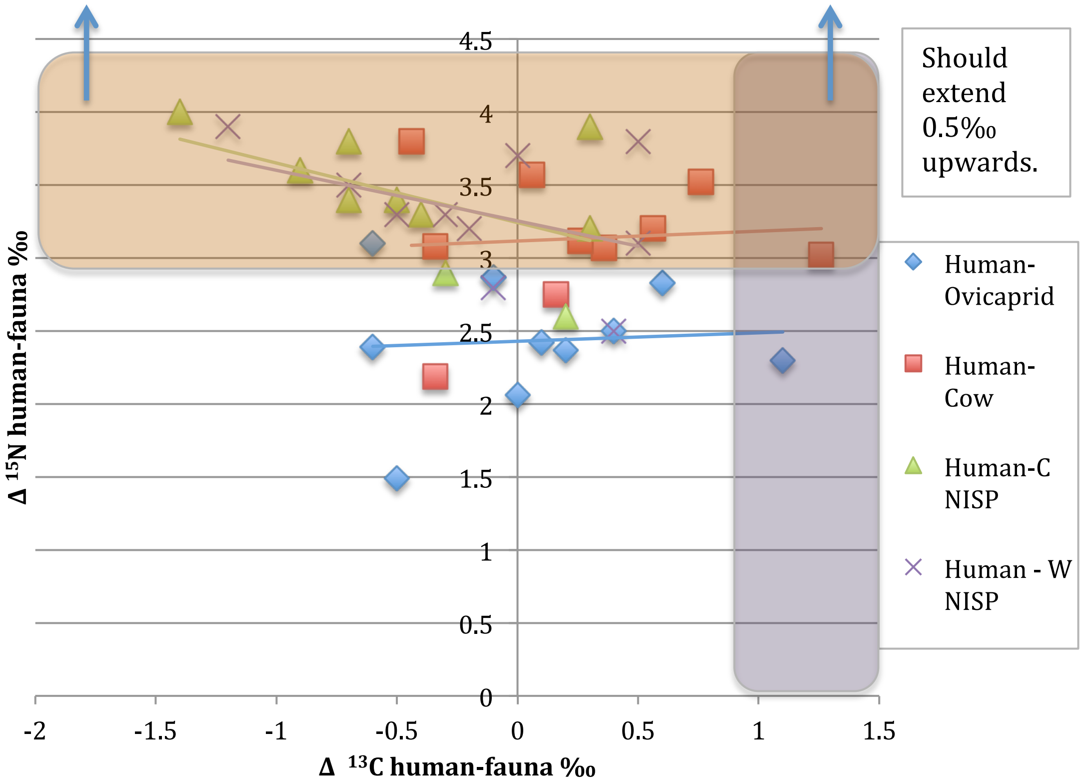

Figure 6.29 Human-fauna isotope Δ (spacing) at Barçin Höyük.
The shaded areas highlight the expected spacing values for human-fauna, e.g. 0.8 to 1.3‰ for δ^{13}C (in purple) and 3-5‰ for δ^{15}N (in orange).

It is evident from figure 6.29 that, unlike Aktopraklık, there is no correlation between human-fauna isotope spacing at Barçin Höyük (table 6.18).

Spacing	r^2 *value*	*p-value*
Human-Goat	0.004	0.8466
Human-Cow	0.006	0.8258
Human-Composite NISP	0.266	0.1271
Human-Composite Weighted NISP	0.187	0.2119

Table 6.18 Human-fauna spacing regression values at Barçin Höyük.

The overall r^2 is 0.02, and the human-goat and human-cattle correlations are both <0.000. The spacing distribution of goat and cattle values plot closer together here than at Aktopraklık. The spacing data is commensurate with the isotope data from figure 5.6 (chapter 5), suggesting a mixed reliance on cattle and sheep/goat protein. The ^{15}N spacing at Barçin Höyük seems lower overall than at Aktopraklık, ranging from approximately 2-4‰. Figure 6.30 shows the human-fauna spacing graph for Çatalhöyük.

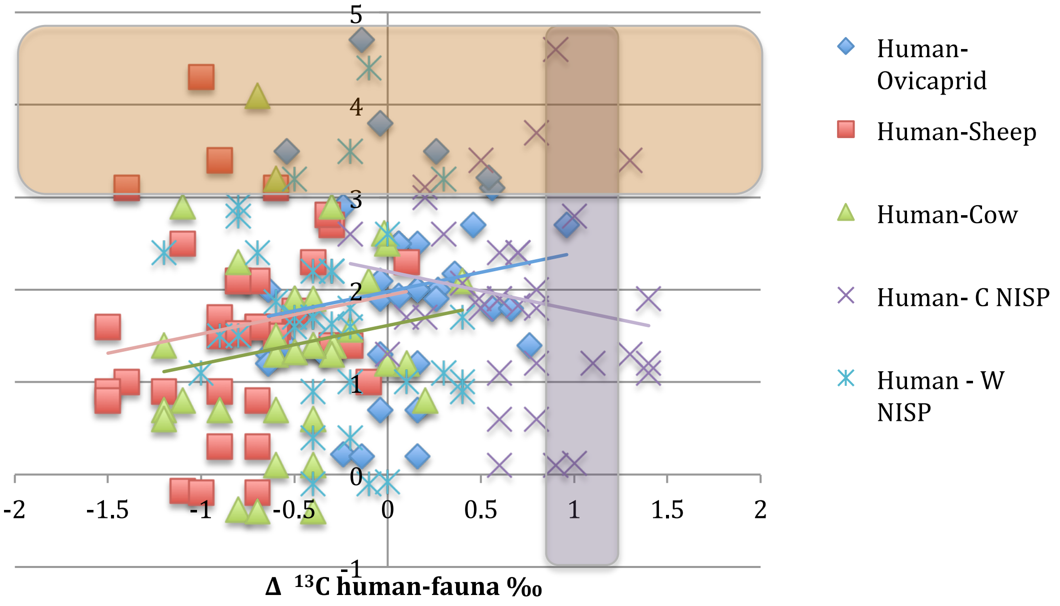

Figure 6.30 Human-fauna isotope Δ (spacing) at Çatalhöyük.
The shaded areas highlight the expected spacing values for human-fauna, e.g. 1 ‰ for δ^{13}C and 3-5‰ for δ^{15}N.

As seen with Barçin Höyük**,** the human-fauna isotope trophic enrichment spacing at Çatalhöyük shows no correlation (r^2 at <0.02) (figure 6.30 and table 6.19). The shaded areas of expectation at Çatalhöyük are interesting as the composite value for human-fauna carbon isotope values plot exactly where they should, and the human-fauna nitrogen values are far too depleted at 0-3**‰** when compared to where they should plot 3-5**‰.**

Spacing Parameter	r^2 *value*	*p-value*
Human-Ovicaprid	0.02577	0.3569
Human-Cattle	0.02596	0.3552
Human- Composite NISP	0.02622	0.3527
Human- Composite Weighted NISP	0.02615	0.3534

Table 6.19 Human-fauna spacing regression values at Çatalhöyük.

This pattern, between expected spacing values and observed spacing values, potentially suggests that the majority of the protein consumed at Çatalhöyük was from plants. This would also explain why the composite NISP human-fauna carbon value plots in the expected area (reflecting the range of carbon isotope values present in the local floristic composition of the area), but that the nitrogen human-fauna spacing values do not fit. Plant proteins would potentially plot between 0-3‰ (0‰ for leguminous species), a factor that would explain the nitrogen spacing observed in the humans at Çatalhöyük.

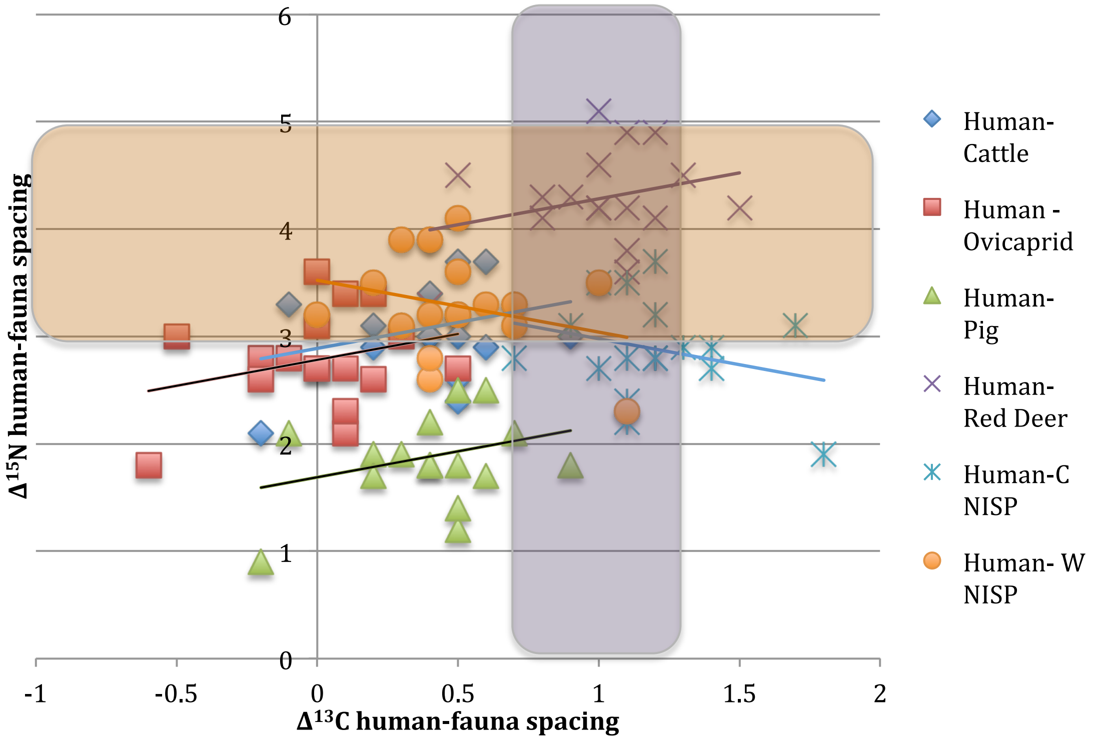

Figure 6.31 Plotting the isotopic Δ (spacing) at Osłonki 1, Kuyavia region, Poland.
The shaded areas highlight the expected spacing values for human-fauna, e.g. 1‰ for δ^{13}C and 3-5‰ for δ^{15}N.

Spacing Parameter	r^2 *value*	*p-value*
Human-Ovicaprid	0.07987	0.2717
Human-Cattle	0.07981	0.2713
Human-Pig	0.07989	0.2719
Human-Red Deer	0.07978	0.2715
Human- Composite NISP	0.07979	0.2714
Human-Composite NISP	0.07985	0.2718

Table 6.20 Human-fauna spacing regression values at Osłonki 1.

The graph of trophic enrichment for Osłonki 1 demonstrates a moderate correlation for trophic enrichment at r^2 =0.37, but this correlation becomes significantly less obvious if the red deer samples are removed (r^2= <0.22) (figure 6.31 and table 6.20). The nitrogen values for the human-pig scatter plots lower than the human-cattle/goat/sheep scatter, which potentially suggests that pig protein makes up proportionally less of the total diet at Osłonki 1 than cattle or sheep/goat. If we consider the shaded areas of expectation, it is evident that the composite mean of the faunal values fits into the carbon spacing area. The human-fauna nitrogen spacing values are lower than expected at 1.5‰ to 4‰, and as such this may well reflect a mixed diet of plant and animal proteins.

In summary, if we consider the trophic enrichment spacing information obtained from the isotope analysis, it is evident that there is a significant correlation at Aktopraklık, but no correlation whatsoever at Çatalhöyük, Barçin Höyük, or Osłonki 1. Whether Çatalhöyük or Aktopraklık is the most notable site (e.g. for exploring environmental effects at Çatalhöyük or narrow resource procurement at Aktopraklık) remains to be determined, but the inclusion of isotope data from more sites in the surrounding area, such as Nevali Çori in Anatolia, and the Lengyel sites in Poland, will hopefully prove useful in evaluating these patterns in the data.

Chapter 7: Radiocarbon Methodology and Results

7.1 Introduction

This chapter discusses the principles and methodology of the radiocarbon dating technique and proceeds to detail the radiocarbon ages obtained for this project. Whilst the chapter is largely self-contained (*i.e.* the principles, methodology and associated limitations are detailed in this chapter), the interpretation of the radiocarbon results, how the data integrates with the palaeodietary results, and existing archaeological frameworks is discussed in chapter 8. Radiocarbon ages were obtained from human skeletal collagen were processed from the study sites of Barçin Höyük and Osłonki 1 to aid the analysis of the palaeodietary $\delta^{13}C$ and $\delta^{15}N$ data processed for this project.

7.2 Radiocarbon Research Aims and Questions

Radiocarbon ages were obtained for the study sites of Barçin Höyük and Osłonki 1 to complement the existing resolution of chronological frameworks for the study regions. At Barçin Höyük, a comprehensive chronological framework for the earliest phases of the Neolithic (phases VId and VIe) has been obtained through the radiocarbon dating of plant macrofossil samples, undertaken by Gerritsen *et al.* (*pers.comm*). According to modelled (Bayesian) radiocarbon ages of the plant macro samples, the earliest phase of Neolithic occupation at Barçin Höyük dates to *c.*6,600 cal BC (n=4), with the following phase dating to *c.*6,400 cal BC to *c.*6,300 cal BC (n=7). To date, no human or faunal samples from the site had been submitted for radiocarbon dating. Three human samples (bone collagen) from Barçin Höyük were selected for dating analysis. The samples were chosen based on the chronological layer to which they had been assigned (e.g. VIe). The purpose of this approach is to compare the human radiocarbon ages to chronological framework constructed (in part) using the plant radiocarbon dates (see chapter 2, page 65). Barçin Höyük has experienced a certain degree of stratigraphic mixing due to voles tunnelling their way through the site (Gerritsen *et al.* 2010), and it is possible that this may have had an adverse affect on the chronological identification of human samples.

At Osłonki 1, no radiocarbon dating (or in fact absolute dating of any form) has previously been undertaken at the site. The existing chronological frameworks are predominantly based on changes in the material record, and are separated into Early (4700-4500 cal BC), Classic (4500-4300 cal BC), and Late (4300-4100 cal BC) (chapter 2, page 94). The beginnings of the Classic phase is characterised by the introduction of elaborate copper artefacts in the archaeological record, with the onset of the Late phase defined in part by the decline in the quantity and elaborate nature of the copper artefacts (Grygiel 2004).

Fifteen human skeletal samples were selected for analysis. The sampling approach was devised by the author and P.Bogucki (*pers.comm*, 2013). The aim of the sampling strategy was to select individuals that represented all three phases of occupation, with an additional focus of dating both the individuals that were interred with elaborate grave goods alongside those who were buried with no burial goods. This approach is used to examine the accuracy of the established chronology for the site, and to investigate any evidence for social stratification.

7.3 Principles of Radiocarbon Dating

Carbon has three naturally occurring isotopes, ^{12}C and ^{13}C, which are both stable, and ^{14}C which is radioactive, and decays at predictable rate. Carbon consists of 99% of ^{12}C, 1% of ^{13}C, and approximately one part in a million million of modern carbon is ^{14}C (Bowman 1990:10). ^{14}C is continually being formed in the upper atmosphere (specifically the lower stratosphere and the upper troposphere) as a result of the interaction of neutrons produced by cosmic rays with nitrogen atoms – ^{14}C is a cosmogenic nuclide (Taylor 1997). After the formation occurs, the ^{14}C atoms combine rapidly with oxygen, which leads to the formation of carbon dioxide (CO_2). This carbon dioxide is chemically indistinguishable from carbon dioxide that was formed with ^{12}C or ^{13}C atoms (Aitken 2014). The CO_2 then mixes throughout the atmosphere, dissolves in the oceans, and, as a result of the process of photosynthesis, enters the biosphere (e.g. plant and animal life) (Bowman 1990).

When a plant or an animal dies, it stops exchanging carbon with the biosphere, and it no longer takes in any ^{14}C. As ^{14}C is radioactive, the amount of ^{14}C in an organism (e.g. plant or animal) begins to decrease at a rate that is determined by the rate of radioactive decay. The law of radioactive decay is relates to the number of atoms A left after time t and the initial number of atoms A_0 at time zero. This rate of exponential decay is explained by the following equation (eq.5):

$$A = A_0 \, e^{-\lambda\tau}$$

Equation 5. Rate of exponential decay.

where λ represents the constant equal to the reciprocal of the meanlife τ. The process of radioactive decay is often described in relation to the half-life ($T_{1/2}$) of an radioactive atom. The relation of the meanlife to the half-life can be described as follows (eq.6):

$$T_{1/2} = (ln2)\tau$$

Equation 6. The relation of the meanlife to the half-life.

where *ln* is the natural logarithm to the base *e*. The half-life of ^{14}C was initially calculated as 5568 (±30) years by Libby (Willard and Frederick 1955). More recent research has placed the actual half-life for ^{14}C at 5730 (±40) years, referred to as the 'Cambridge Half Life', some 3% larger than the original figure quoted by Libby (Godwin 1962). Godwin (1962) recommended that the Libby half-life should still be used to calculate radiocarbon ages, to 'allow time for the development of a more reliable value'. The Libby half-life value is still used today. To determine the radiocarbon age of a given sample then, the following equation is used:

$$t = - \tau \ln(A/A_0).$$

Equation 7. Determining the radiocarbon age of a sample.

The radiocarbon dating method is based, therefore, on the fact that it is possible to calculate the amount of radioactive decay in organic material by measuring the amount of ^{14}C in a sample. The method and application of this technique, particularly in archaeology, is well established (Willard and Frederick 1955, Longin 1971, Bowman 1990, Ramsay 1995, Taylor 1997, van Klinken 1999, Higham *et al.* 2006, Williams 2012, Nalawade-Chavan *et al.* 2013, Aitken 2014).

7.3.1 Assumptions of the Method

The radiocarbon dating method is underpinned by a number of assumptions. Bowman (1990:14) provides a simplified overview of the assumptions linked to the method: i) the atmosphere has had the same amount of ^{14}C in the past as now (which in turn assumes constant rates of production, mixing, exchange and transfer rates, in addition to consistent reservoirs), ii) the biosphere is in equilibrium with the atmosphere, iii) the same ^{14}C concentration exists in all part so the biosphere, the death of a plant or animal is the point at which it ceases to exchange with environment, and iv) after the death of a plant or animal, the amount of ^{14}C within a sample is only affected by radioactive decay.

In reality, none of the assumptions listed are strictly correct, and discussing the geochemical and geophysical reasons that underlie these assumptions (and indeed how the associated issues they raise are dealt with) are far beyond the scope of this project (see Bowman 1990, Taylor 1997, Aitken 2014, for further details). Overall, the main issues that affect the assumptions of the method are: processes affecting the global ^{14}C concentration, source or reservoir effects, alteration effects, and contamination (Bowman 1990).

7.3.2 Limitations of the Method

There are a number of limitations associated with the application of radiocarbon dating to archaeological samples. With regards to the radiocarbon method, and indeed all of the archaeological dating methods, the two factors that dictate its usefulness are *accuracy* and *precision* (Pollard 2007). The factor of accuracy can be affected by a number of issues from the burial environment to the laboratory pre-treatment process. The preservation organic material in the archaeological record is controlled by the conditions present in the burial environment. Acidic and aerobic environments for example, are not favourable for the preservation of bone, leading to the decay of the datable organic fraction (e.g. collagen). If only a small fraction of the original organic content of a sample is dated, it can cause erroneous results (Schoeninger *et al.* 1989, Hedges and Millard 1995, van Klinken 1999, Nielsen-Marsh and Gernaey 2000, Nielsen-Marsh and Hedges 2000, Hedges 2002, Jans *et al.* 2004).

The contamination of a sample with modern ^{14}C is a problematic issue, and can occur from the site excavation, during the transit of the samples to laboratory, and in the laboratory during the pre-treatment process (Donahue *et al.* 1990, Hedges and van Klinken 1992, Ramsey *et al.* 2004, Higham *et al.* 2006, Higham 2011). Even a small amount of contamination can cause a significant effect on the final radiocarbon date of a sample, and in addition it is sometimes difficult to identify whether contamination has occurred.

Further problems include the fact that the ^{12}C to ^{14}C ratio does not remain constant in the atmosphere, and significant variation in the measurements of the ratio of these two isotopes has been observed. The method is based on the assumption that the ^{12}C:^{14}C has remained constant through time (this is how the decay rate is calculated), and this is shown to be variable (Southon 2011, Damon *et al.* 2013, Kourdriatsev *et al.* 2014).

In addition to naturally occurring variations in carbon in the atmosphere, there is the additional issue of man-made variations. The Suess (or fossil fuel) effect has been observed in tree-rings in the later half of the 20th century – the ^{14}C content was significantly lower than was expected, and this was shown to be a result of the burning of fuel such as coal (Suess 1955). The consequence of the Suess effect is that no recent organic material can be used as a modern standard (Bowman 1990).

A further man-made impact that causes variation in atmospheric concentrations of ^{14}C has been observed due to nuclear weapons testing (often referred to as the 'bomb effect') (de Vries 1958). The neutrons produced during testing produce ^{14}C by interaction with ^{14}N, which artificially stimulates the natural cosmogenic production of ^{14}C (Aitken 2014, Bowman 1990, de Vries 1958).

Moving on from man-made effects, there is the further issue of radiocarbon reservoir effects. When ^{14}C is stored (or 'trapped') in landscape reservoirs or sinks (such as freshwater lakes or marine water bodies), it does not exchange with atmospheric ^{14}C and so ages prematurely. When samples containing 'aged' ^{14}C are radiocarbon dated, they produce artificially 'old' radiocarbon dates. Marine and freshwater radiocarbon reservoir effects have been demonstrated in a number of archaeological contexts (Lanting and van der Plicht 1998, Cook *et al.* 2001, Yoneda *et al.* 2002, Ascough *et al.* 2006, 2007, 2011, 2012, Lillie *et al.* 2009, Keaveney and Reimer 2012).

Finally, the precision of a radiocarbon date is largely a function of the way in which the ^{14}C is measured. The 'conventional' method for radiocarbon dating measured the beta decay particles of the ^{14}C. The method currently used in radiocarbon laboratories is accelerator mass spectrometry (AMS) and is a direct measurement of the ^{14}C. The advantages of AMS are that it allows more rigorous pre-treatment of samples (down to the compound-specific level), the ability to select less contaminated fractions of inhomogeneous samples, and the option of performing repeat measurements on the same sample (Ramsey *et al.* 2004:16-17). The disadvantages of using AMS include the difficulty in achieving isotope ratio stability over the measurement period, the susceptibility of smaller sample sizes to contamination, and the danger of choosing unrepresentative fractions of inhomogeneous samples (Ramsey *et al.* 2004:16).

7.4 Radiocarbon Pre-Treatment

The radiocarbon samples were process at the Oxford Radiocarbon Accelerator Unit, Oxford, by the author. The ^{14}C pre-treatment process for bone collagen used at ORAU is set out in detail in Brock *et al.* (2010), and is not repeated in depth here. A simple overview is that it is a modification of Longin's (1971) approach to collagen extraction, e.g. an ABA (acid-base-acid) treatment, but with additional steps of ultrafiltration (after Brown *et al.* 1988). The ABA treatment is followed by gelatinization and freeze-drying, and the samples are then combusted on CF-IRMS system (e.g. a combustion elemental analyzer coupled to a gas source isotope ratio mass spectrometer). After this process, the samples are graphitized (see Dee and Bronk Ramsey 2000 for details), and finally dated on the ORAU HVEE AMS system (Bronk Ramsey *et al.* 2004).

7.5 Results

The radiocarbon results for Barçin Höyük and Osłonki 1 are presented in the proceeding sections. All of the dates are calibrated using INTCAL13 (Reimer *et al.* 2013).

7.5.1 *Barçin Höyük*

Three radiocarbon dates were obtained from humans at Barçin Höyük (table 7.1).

Sample (Burial No.)	**Excavation Layer**	**^{14}C Age**	**±**	**OxA**	**Cal BC (2 s.d.)**
L13-166	**VIe**	**7692**	**40**	**27,879**	**6606 - 6546**
M10-173	**VIc**	**7314**	**36**	**27,880**	**6236 - 6076**
L13-129	**VId**	**3461**	**29**	**28,003**	**1775 - 1630**

Table 7.1 Radiocarbon ages from Barçin Höyük.

The first two burials date to the Neolithic period, and are in line with previous Neolithic dates from this site. The first sample, L13-166, was excavated from layer VIe (c.6,600 – 6400 cal BC), the earliest Neolithic layer, and produced a radiocarbon age of 7692±40 (6,606-6,546 cal BC), which is in keeping with the chronological framework produced by the plant radiocarbon data. The second sample, M10-173, is assigned to occupation layer VIc (*c.*6,300 cal BC, early-middle Neolithic), and produced a radiocarbon age of 7314±36 (6,236 – 6,076 cal BC). This sample, whilst perhaps dating slightly later than expected, is still largely commensurate with the established chronology for the site.

The third burial, L13-129, was excavated from later VId (*c.*6,400 – 6,300 cal BC, early Neolithic), but produces a radiocarbon age of 3461±29 (1775-1630 cal BC) – which places it in the Bronze Age phase of occupation. This calls into the question the security of the chronological assignments of the humans interred at the site. The presence of chronologically younger layers of occupation at the site, is discussed by the sites directors (Gerritsen *et al.* 2013). Interestingly, the individual does not have stable isotopes values that are divergent from the Neolithic population, with a δ^{13}C of -19.2‰ and a δ^{15}N of 9‰, the latter value being is slightly lower than the site average of 10.5‰.

7.5.2 Osłonki 1

In total 15 AMS dates were obtained from human samples from Osłonki 1. The sampling strategy was based partly on the stable isotope data that had been obtained for the humans (see appendix 1, table A1.1). Table 7.2 highlights the individuals that were selected for dating, and reminds the reader of the associated anthropological and burial information (Grygiel 2004: 899-991, Bogucki 2014: *pers.comm*).

Phase	**Burial I.D**	**Sex**	**Age**	**Grave Goods**
Early	35	M	25-30	None.
Classic	1	F	17-25	Copper beads.
	6	M	40-50	Copper beads and plaques; perforated animal teeth; none tool
	18	F	17-25	Copper plaque; copper beads; shell beads.
	22	M	25-30	None.
	26	M	35-45	Antler T-axe; boar tusk, bone tools, flint blades.
	48	F	18-22	Copper binocular pendant and beads; shell bead belt.
	53	F	25-30	Double burial, left skeleton analyzed; copper plaque and beads, bone dagger, amber ornament.
	54	F	25-35	Huge amount of copper plaques, beads, shell bead belt.
	72	M	15-19	Copper plaques, bead; shell beads; flint blades.
	73	F	25-35	Woman in triple burial that died violently.
Late	24	F	25-35	Two whole ceramic vessels, copper beads; ceramic handle.
	55	M	40-50	None.
	61	F	30-40	None.
	80	M	17-25	Looks classic in orientation, Grygiel says late; antler, bone and flint tools, copper ornament.

Table 7.1 Anthropological and burial information for selected individuals from Osłonki 1.

Table 7.3 displays the radiocarbon ages and the calibrated radiocarbon dates. The dates are calibrated using the INTCAL13 curve (Reimer *et al.* 2013). Figure 7.1 is a graphical representation of this data.

Phase	**Burial I.D**	**14C Age**	**±**	**OxA**	**Cal. BC (2 s.d.)**
Early	35	5488	33	30,075	4445 - 4261
Classic	1	5260	30	30,345	4229 - 3985
	6	5241	29	30,344	4227 - 3972
	18	5416	29	30,346	4338 - 4236
	22	5246	32	30,072	4228 - 3973
	26	5332	32	30,074	4310 - 4040
	48	5393	32	30,076	4338 - 4076
	53	5329	31	30,077	4257 - 4049
	54	5402	30	30,347	4338 - 4175
	72	5313	33	30,080	4245 - 4043
	73	5288	31	30,081	4233 - 4001
Late	24	5440	33	30,073	4347 - 4244
	55	5446	32	30,078	4350 - 4247
	61	5287	32	30,079	4233 - 4000
	80	5317	32	30,082	4244 - 4045

Table 7.2 ^{14}C ages and calibrated dates for Osłonki 1.

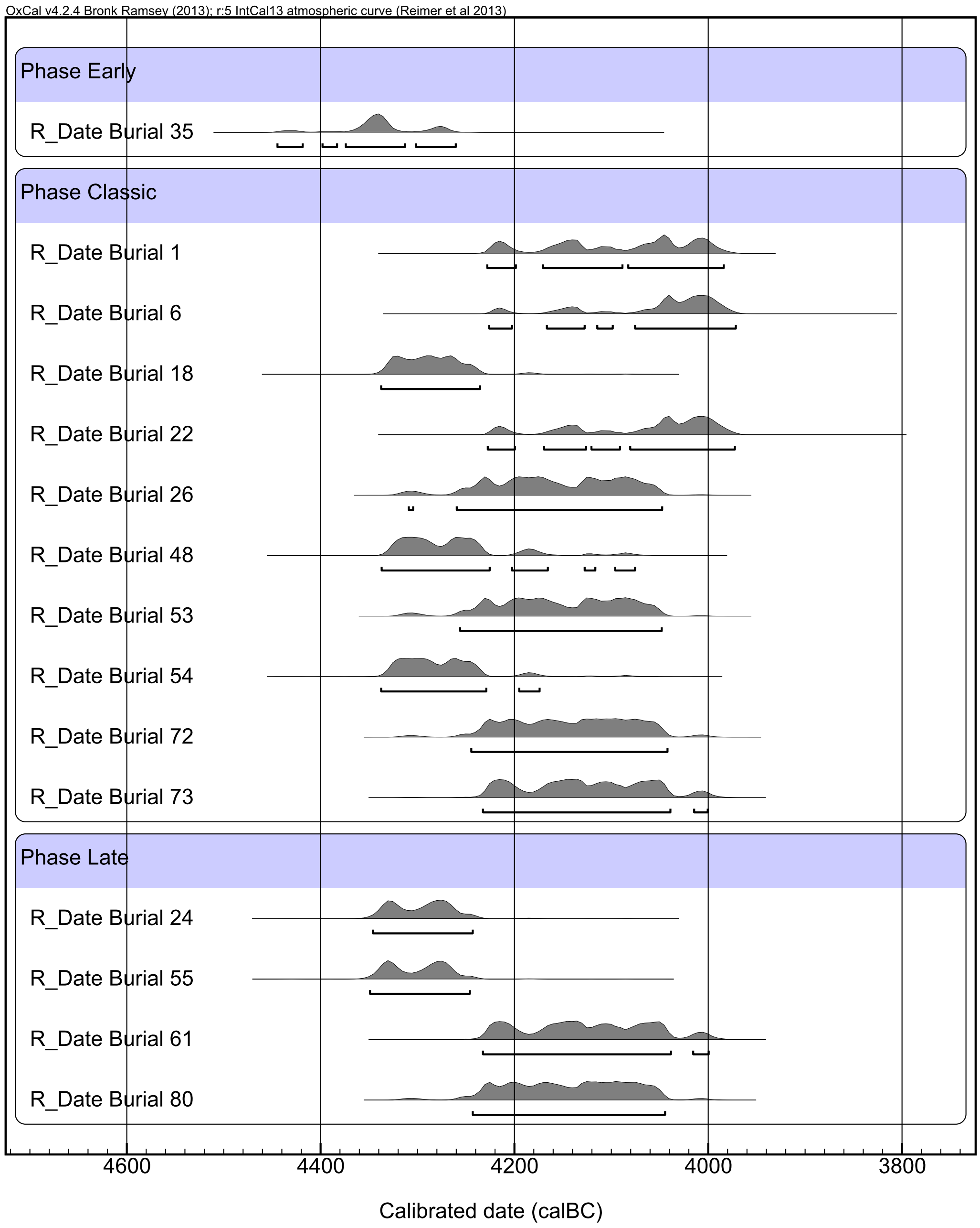

Figure 7.1 OxCal v4.2 plot of the Osłonki 1 calibrated dates.
The phases are based on cultural seriations suggested by Grygiel (2004).

From a practical standpoint, the biggest issue with radiocarbon dating *anything* from this chronological period is that it falls on a flat part of the calibration curve. This means that it is difficult to assign a calibrated date range to a radiocarbon age. Figure 7.2 displays a curve plot, with the Osłonki 1 ages to highlight the problem.

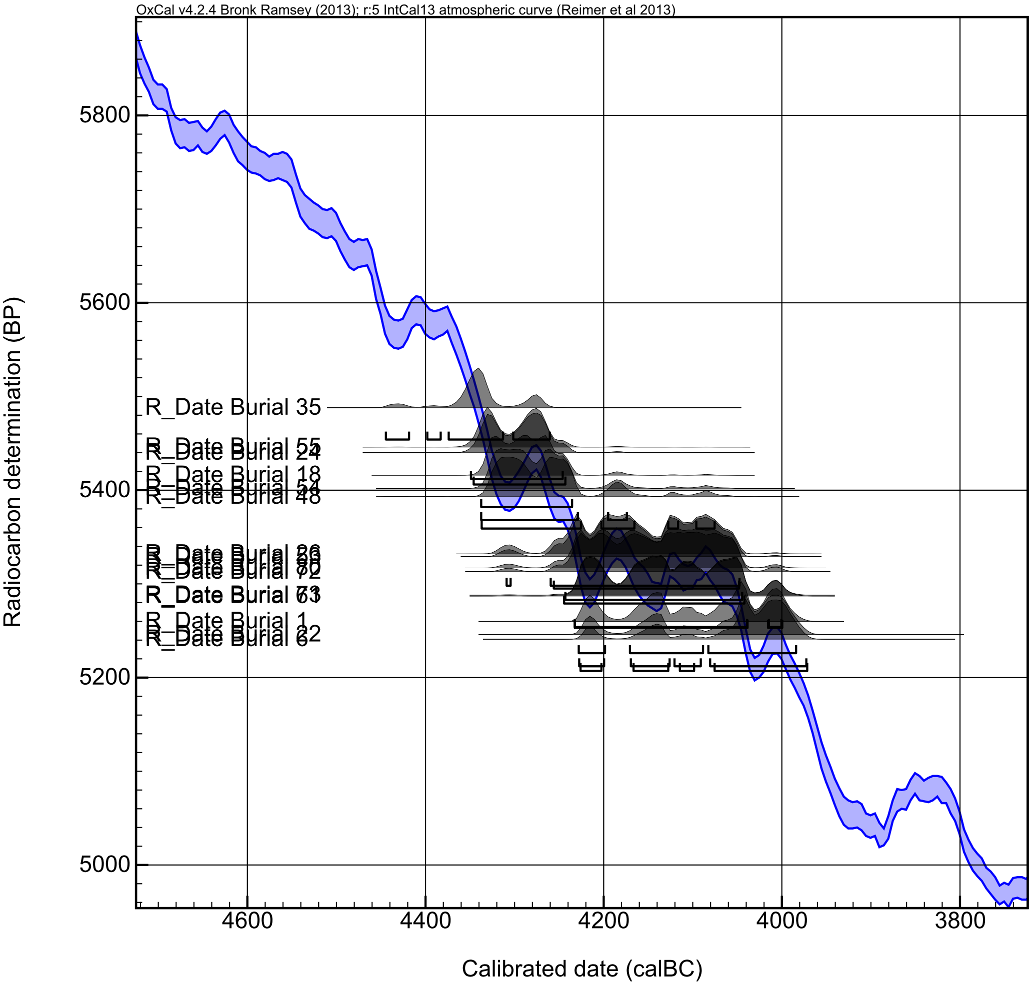

Figure 7.2 Graph to highlight the position of the Osłonki 1 radiocarbon dates against the INTCAL13 calibration curve.

The period between 4200 to 4000 cal. BC is particularly problematic, as evidence by the flatness of the curve, and the extent of the posterior destiny estimations (*i.e.* the radiocarbon calibrated estimates have a larger range of date estimation). Further details on the impacts of radiocarbon curves can be found in Reimer *et al.* (2009, 2013) and Ramsey (1995).

Whilst the issue of the calibration curve is an important aspect to note, it does not wholly affect the interpretation of Osłonki 1. The site has already been attributed to the Lengyel period (4700 – 4100 cal BC) based on the material culture, and the inability to chronologically refine this further is frustrating but perhaps not prohibitive. The radiocarbon ages still act as a chronological model of the sequence of deaths at Osłonki 1. The most interesting output from the radiocarbon dates is that the burial dates do not plot in their allotted, 'culturally assigned' chronological period (figure 7.3) (Grygiel 2004).

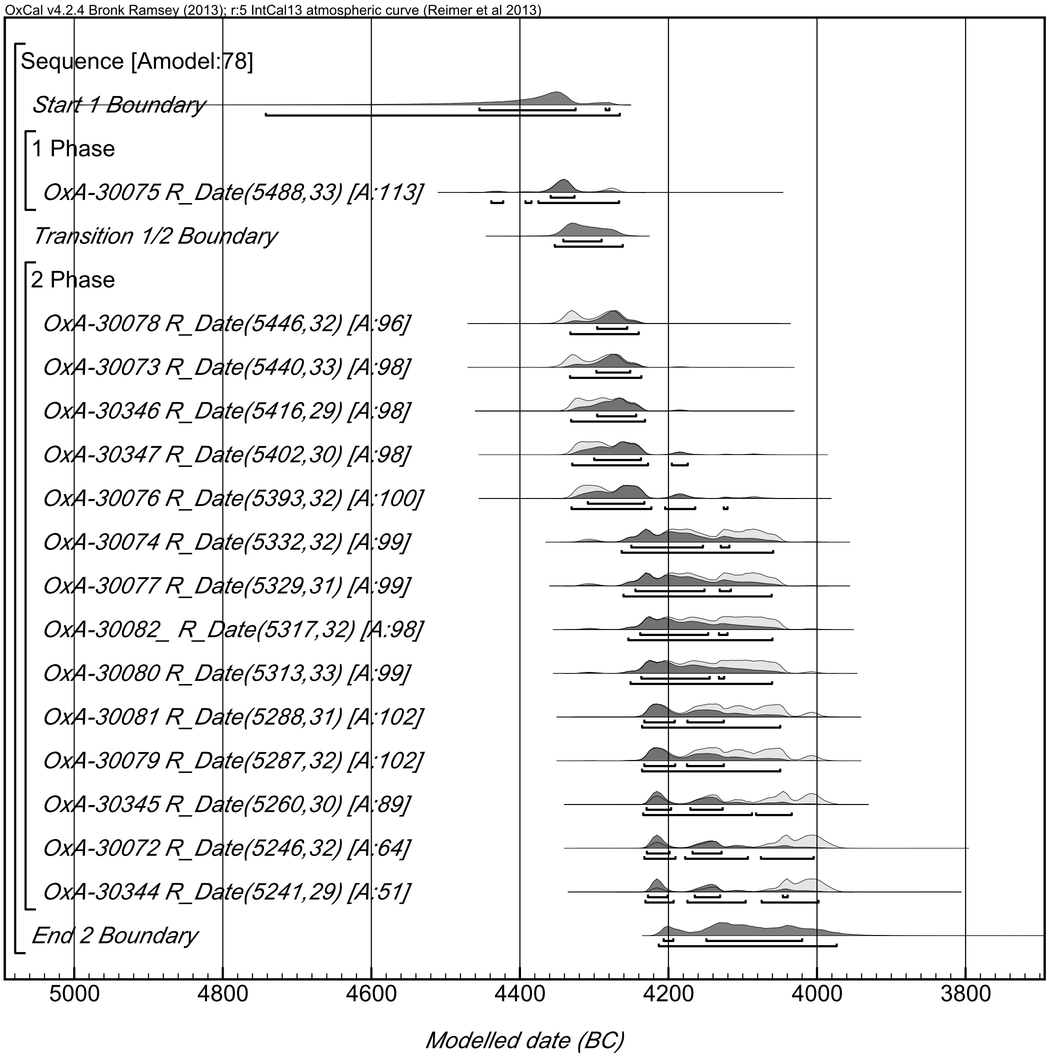

Figure 7.3 Bayesian model of the Osłonki 1 radiocarbon determinations (produced in OxCal).

From the *calibrated* plot, it is evident that burial 35 does date to one of the earliest phases of the occupation at the site (at 4445 – 4261 cal. BC), but burials 24 and 55, that are supposed to be part of the Late phase, also plot at a similar point to burial 35. The remaining burials from the Classic phase (and two burials from the Late phase), all have some area of overlap. This strongly suggests that the initial chronological attributions are not without problems. Figures 7.4 and 7.5 graph the radiocarbon ages against the $\delta^{13}C$ values and $\delta^{15}N$ values respectively.

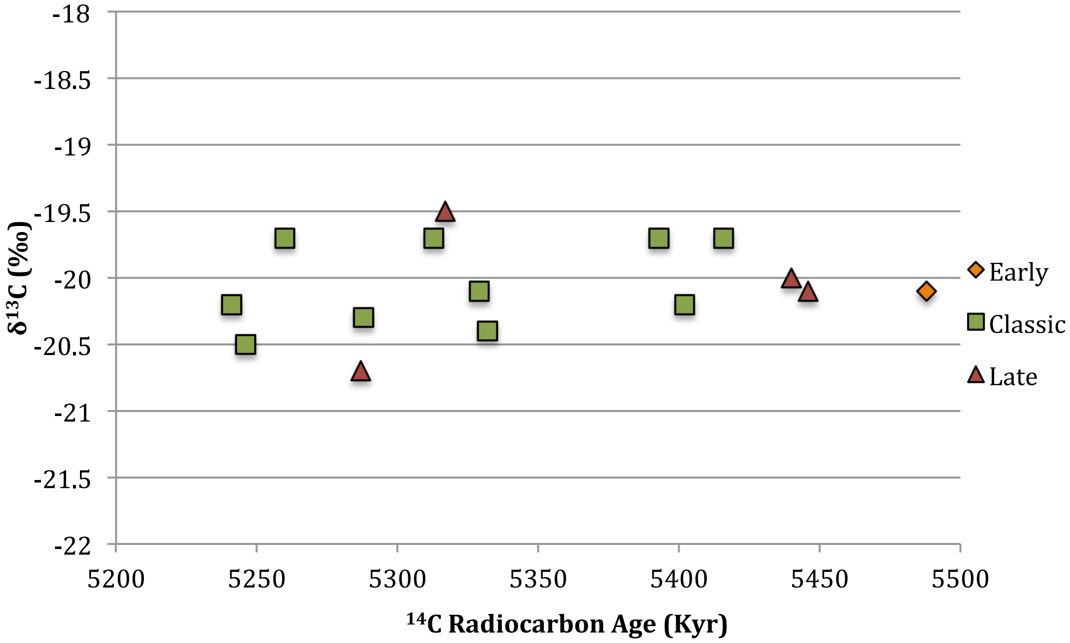

Figure 7.4 $\delta^{13}C$ (‰) and ^{14}C radiocarbon ages for Osłonki 1 humans.
(Isotope data: appendix 1, table A1.1).

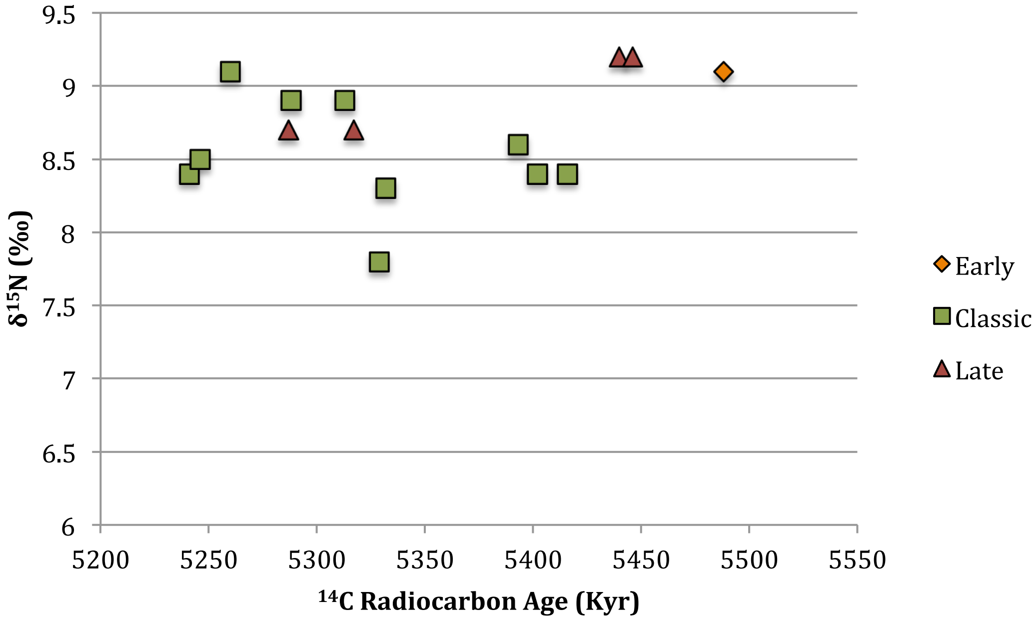

Figure 7.5 $\delta^{15}N$ values and ^{14}C radiocarbon ages for Osłonki 1 humans.
(Isotope data: appendix 1, table A1.1).

It is evident from the graphs that there is no clear overall trend through time for either $\delta^{13}C$ or $\delta^{15}N$. Arguably, there is a slight increase in $\delta^{15}N$, but it is not distinct. There is a slight gap in dates from 5350 to 5400 (kyr), but only 15 humans from a total of 80 are dated, so it may be an artifact of the sampling choice. In addition the error margin for the radiocarbon ages are approximately ±30 years (see table 7.3 for exact figures). If we consider the radiocarbon ages alongside the $\delta^{13}C$ and $\delta^{15}N$ values to look for trends, it is clear that burials 35, 24, and 55 do plot in close proximity to one another (figure 7.6). The image was created using scatterplot3D in R (Ligges and Maechler 2014).

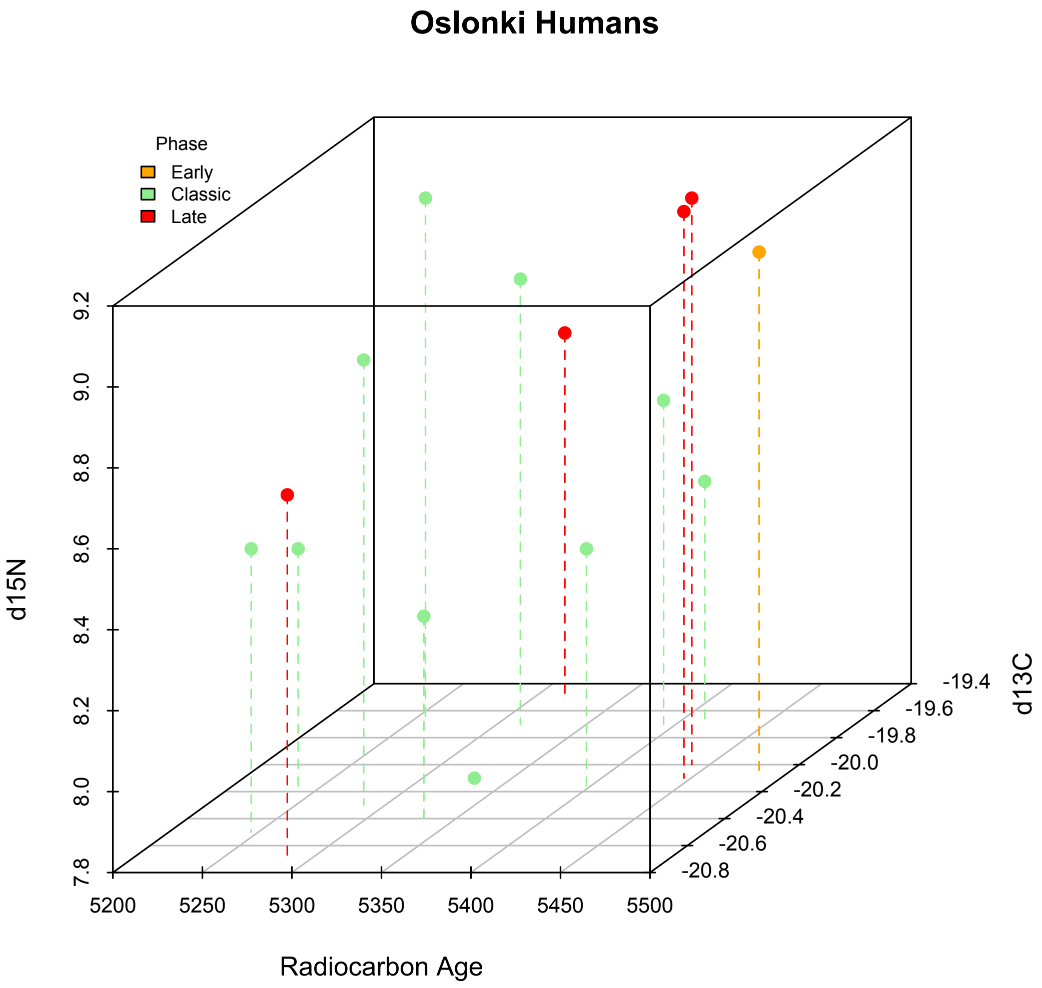

Figure 7.6 3D scatterplot of the ^{14}C radiocarbon ages, δ^{13}C and δ^{15}N in Osłonki humans.

However, whether these are similar enough to call them a *bona fide* separate group is difficult to determine. Two of the burials (35 and 55) have no grave goods, whilst burial 24 has a number of items, including copper beads and a copper handle (table 7.2). Indeed, we do not observe a difference in the δ^{13}C and δ^{15}N values based on sex (chapter 6). Overall it is evident that these radiocarbon dates do not fit perfectly into the cultural seriations set out by Grygiel and Bogucki (1998), further radiocarbon dates are required to refine the chronology. The implications of the new radiocarbon dates are discussed in chapter 8.

Chapter 8: Discussion

8.1 Introduction

This project has focused on a number of aspects of carbon and nitrogen isotope research; i) intra-site level dietary reconstruction, and associated site level social implications, ii) regional trends in diet, utilizing isotope signals to consider differences in farming practice where possible, and iii) environmental impacts on stable carbon and nitrogen isotopes in bone collagen, disentangling environment signals from diet signals. The aim of this chapter is to synthesize the results within the framework of Neolithic Anatolia and North-Central Europe. It begins with a review of the environmental data (8.2), and a consideration of the how the data produced for this study, and the secondary data sources considered, compare with the published literature. Section 8.3 provides summaries of the diet isotope results for the Anatolian study sites, and section 8.4 considers how the isotopic data at Osłonki 1 compare to other information from the site (e.g. sex differences, burial rites, and familial groups). Section 8.5 considers whether the SIAR models and spacing plots adequately explain the isotope data. The new radiocarbon dates for Barçin Höyük and Osłonki 1 are considered next to previous radiocarbon dates for the sites in section 8.6. Sections 8.7 and 8.8 consider the $\delta^{13}C$ and $\delta^{15}N$ data within their regional and environmental research contexts. Finally, section 8.9 is a synthesis of all the material considered in this project.

8.2 Environmental Factors

The multi-level models fitted in chapter 6 have highlighted that mean annual precipitation (MAP) is the variable which best explains the data for both $\delta^{13}C$ and

$\delta^{15}N$. The model demonstrated a 0.4‰ decrease in $\delta^{13}C$ for every 100mm of MAP, and a 0.5‰ shift in $\delta^{15}N$ for every 100mm. This model is comparable with plant values from the literature, which estimates 1-2‰ for every 500-1000mm change in precipitation levels (e.g. 0.2‰ to 0.4‰ per 100mm) (Van Klinken *et al.* 1994, Hartman and Danin 2010, Hedges *et al.* 2013). Figures 8.1 and 8.2 show the $\delta^{13}C$ and $\delta^{15}N$ average values of the wild and domestic fauna that were used in the environmental analysis.

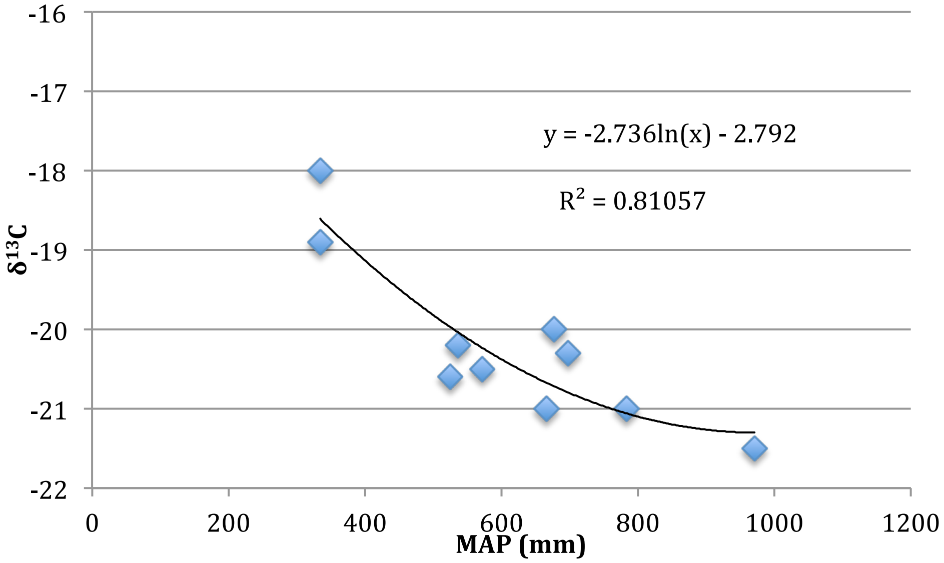

Figure 8.1 MAP and $\delta^{13}C$ averages for faunal bone collagen of the study sites. Individual data points presented in appendix 1 (table A1.1).

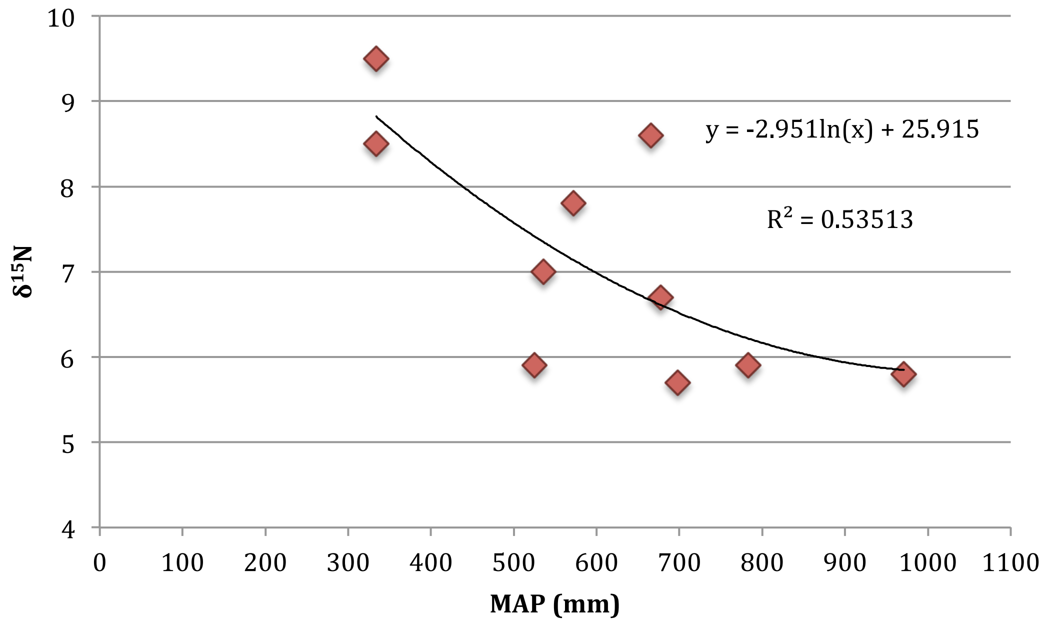

Figure 8.2 MAP and δ^{15}N averages for faunal bone collagen of the study sites. Individual data points presented in appendix 1 (table A1.1).

From these figures it is clear that the 0.4‰ and 0.5‰ shift for δ^{13}C and δ^{15}N values is largely evident from the averages, e.g. for every 100mm change in MAP, the isotope values shift by 0.4‰ and 0.5‰ (and this is to be expected given that the AIC models (see chapter 5, section 5.5) are based on this dataset). The general trend is that lower precipitation is correlated with higher δ^{13}C and δ^{15}N values in faunal bone collagen. This trend is largely mirrored in the literature for δ^{13}C in plant samples (Van Klinken *et al.* 1994, O'Leary 1995, Schleser 1995, Stewart *et al.* 1995, Heaton 1999, Hartman and Danin 2010, Hedges *et al.* 2013). Comparatively large studies for δ^{13}C and fauna collagen are limited. However, a large dataset exists that investigates the relationship between MAP and δ^{15}N in faunal bone collagen. Figure 8.3 illustrates Murphy and Bowman's (2006) kangaroo bone collagen data (redrawn from the original data). The study focused on larger members of the kangaroo genus *Macropus*, a group that are largely grazers, with a penchant for consuming small amounts of dicotyledonous plant material (Dawson 1989, Sanson 1989, Murphy and

Bowman 2007). A total of 779 bone collagen (road-kill) kangaroo samples were measured; however, not all of these kangaroos were adult in age. The age at death of the samples ranged from approximately 12 months old to 18.5 years old. Red kangaroos (*Macropus rufus*) remain as nursing joeys until they reach 12 months age, for grey kangaroos (*Macropus giganteus*) weaning age is around 18 months (Burt 2000, Jango-Cohen 2005). The inclusion of nursing young in the study therefore complicates the analysis of environmental impacts on the $\delta^{13}C$ and $\delta^{15}N$ isotope values. Despite this, Murphy and Bowman's (2006) $\delta^{15}N$ data demonstrates a very similar negative correlation, at $r^2 = 0.56$, $p = 0.000$.

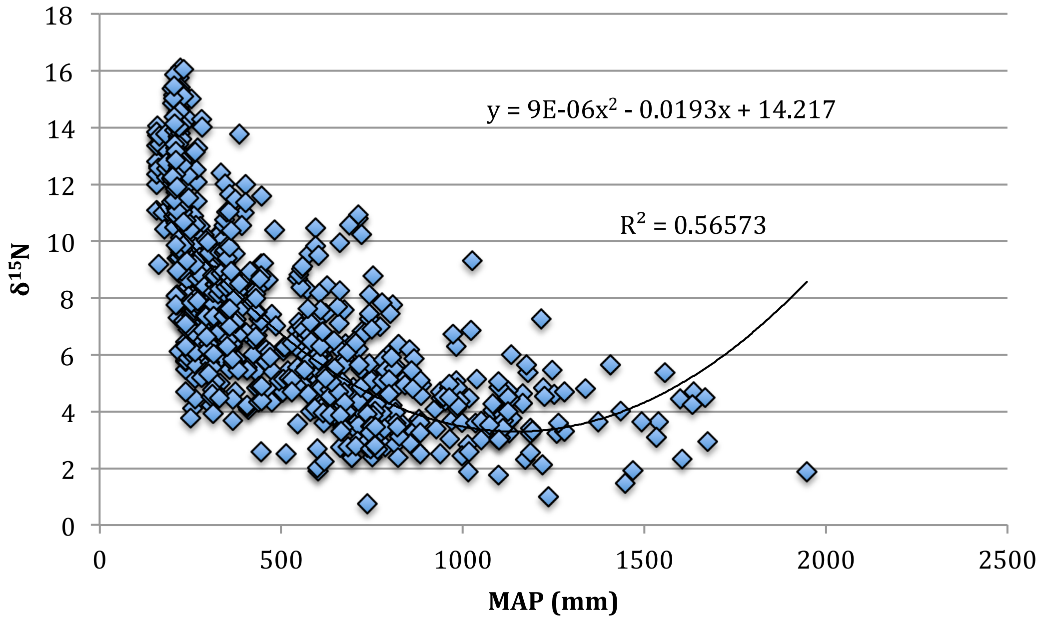

Figure 8.3 Modern Australian kangaroo $\delta^{15}N$ bone collagen values and mean annual precipitation (mm)
(redrawn from Murphy and Bowman 2006:1066, Fig. 2).

If the Murphy and Bowman (2007) data is run through the same stepwise AIC test as the data used for this study (e.g. d15N~MAP+….), the outcome is very similar - every unit shift of MAP (mm) corresponds to a -0.006‰ shift in $\delta^{15}N$ values (SE=<0.000

$p<0.000$), e.g. 0.6‰ per 100mm. Interestingly, δ^{13}C values were also measured from the kangaroo samples, which displayed no trends with MAP ($r^2=0.01$) – a conclusion that is at odds with our δ^{13}C dataset.

A number of other researchers have highlighted evidence to suggest that δ^{13}C variability in *Macropus rufus* (red kangaroo) is the result of differences in age. Witt and Aycliffe (2001) performed a study on 13 bone collagen samples of macropods aged from 10 months to 15 years and demonstrated that older individuals display a 4‰ enrichment in δ^{13}C values when compared to pouch young. Murphy *et al.* (2007) observed an enrichment of 3.5‰ in δ^{13}C values between adults and pouch young. This strongly suggests that the inclusion of sub-adult macropods in the Murphy and Bowman dataset is skewing the trend in δ^{13}C values. Figure 8.4 plots the data from this project together with the kangaroo data from Murphy and Bowman (2006).

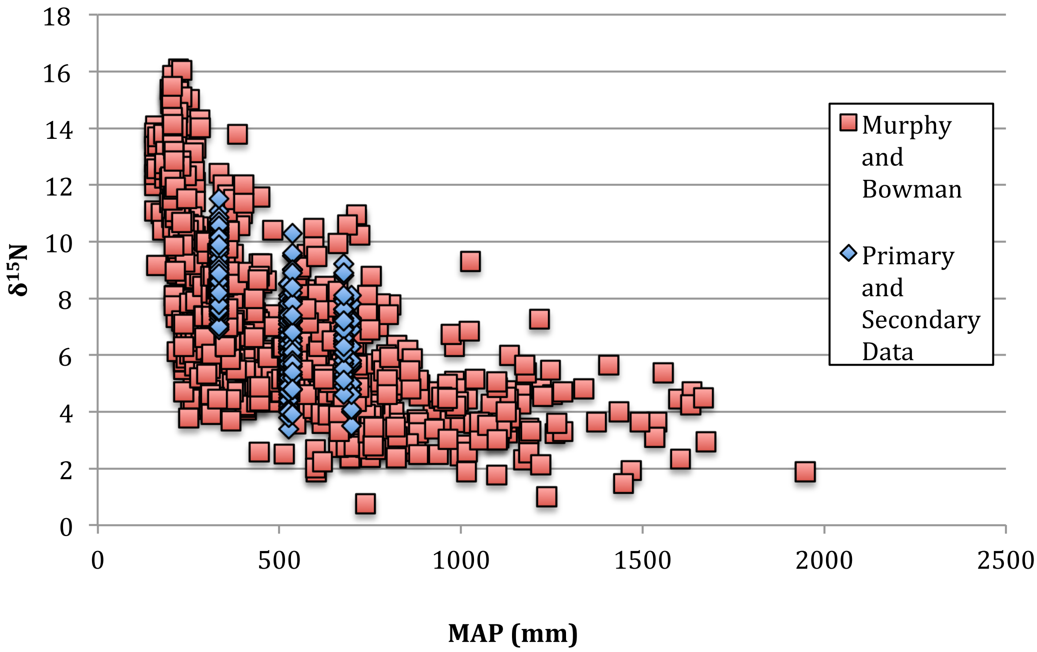

Figure 8.4 Fauna δ^{15}N values and MAP.
(Murphy and Bowman (2006), 'Primary and Secondary Data' refers to the data produced by this project, in addition to the Neolithic Central Europe and Anatolia isotope data produced by other researchers (see chapter 5)).

It is evident the fauna data from this project fits comfortably within Murphy and Bowman's study, the addition of the data points from this project (and the work of Pearson *et al.* 2007, Hedges *et al.* 2010 etc.), had a negligible impact on the regression (r^2=0.44). Examining these results, it is tempting to state that that there is a clear affect on bone collagen $\delta^{15}N$ with the amount of MAP received (and therefore the rate of soil microbial activity). However, there are a number of issues that may cloud this conclusion. Firstly, the biodiversity of species present at each site varies, and as such natural isotopic variation between species may be affecting the distribution of $\delta^{15}N$ values, and secondly there are a number of other factors that could be responsible for the trend in this projects' dataset (animal management practices, etc.). However, the fact that the isotope data (largely domestic fauna) for this project is in keeping with the kangaroo data (wild fauna) is encouraging, and does suggest that the local environmental baseline conditions in a given region are explaining at least 50% of the variation in herbivore bone collagen $\delta^{15}N$ values (assuming no confounding factors). Murphy and Bowman's study may have been flawed with regards to its analysis of the $\delta^{13}C$ data (e.g. including the $\delta^{13}C$ values of pouch young in the dataset), but there are a number of other studies that demonstrate increasing $\delta^{13}C$ values with aridity (chapter 3).

8.3 Site-Level Analysis at Anatolia: Aktopraklık and Barçin Höyük

Human diet at Aktopraklık in North-West Anatolia shows remarkable isotopic consistency between the Neolithic and Chalcolithic periods. Despite its proximity to a sizeable lake, there is no isotopic or archaeological evidence for the consumption of freshwater fish. The $\delta^{13}C$ values of the modern fish samples from Lake Ulubat are generally depleted (e.g. -26‰ to -21‰) in comparison to the fauna $\delta^{13}C$ values from the site, perhaps with the exception of the red deer samples, which are similarly depleted to the catfish and atherina fish samples. Of course, we cannot be certain what species of fish were present in Lake Ulubat during the Neolithic period, but the modern fish samples provide an idea of the potential range of $\delta^{13}C$ values (and $\delta^{15}N$ values) from the lake. The $\delta^{15}N$ values from the modern fish species at Lake Ulubat are considerably more elevated than their faunal counterparts (whether domestic or wild) at *c*.9- 14‰ – if fish protein had contributed significantly to diet at the site, we would expect human $\delta^{15}N$ values of approximately 12‰ and higher (up to c.17‰) (using the modern values as an analogue). None of the human $\delta^{15}N$ values (or $\delta^{13}C$ values) at Aktopraklık suggest the consumption of freshwater protein in significant quantities despite its proximity to the lake. The absence of a freshwater contribution to the diet appears to be in direct contrast to a number of contemporary Neolithic to the north of Aktopraklık. The archaeozoological remains from the sites of Fikirtepe, Menteşe, and Pendik highlight the presence of freshwater species (wel catfish, roach, pike and perch), marine species (jackfish, tuna and stingray), and estuarine species such as seabream and mullet (Cakirlar 2013). In addition to the fish species present in the Fikirtepe cluster, there is considerable evidence for the consumption of shellfish, particularly molluscs, and European oysters.

Interestingly, the site of Menteşe is located within close proximity to Lake Iznik, nestled in between the sites of Barçin Höyük and Ilıpınar (the sites of Fikirtepe and Pendik are located further north, bracketed between the Marmara and Black Sea, figure 2.18, chapter 2). The sites of Barçin Höyük and Ilıpınar have archaeozoological remains that suggest fully formed agricultural economies – no archaeological evidence for aquatic resources has been recovered at these sites - and indeed there is no isotopic evidence for aquatic protein consumption at Barçin Höyük either (see chapter 6 and below). This shows that there were contemporary Neolithic communities in the Marmara region, in close proximity to each other, which were utilising different approaches to subsistence (e.g. agriculture *vs.* agriculture/fishing and foraging).

At Aktopraklık, the major dietary components for humans were C_3 terrestrial plants and the herbivores that feed on them. A small inclusion of C_4 plant species is not beyond the realms of possibility for a few cattle samples, which had $\delta^{13}C$ values of around *c.* -18‰, but the evidence for this is limited. There is no evidence for change in either $\delta^{13}C$ or $\delta^{15}N$ between the Neolithic and Chalcolithic periods. Equally, no differences are observed between the domestic fauna, either delineated by species or by chronological period. It is plausible that all of the animal species were managed in the same way - e.g. all kept on the same type of pasture, leading to no isotopic differences between species.

At Barçin Höyük, the isotopic story is slightly different. Firstly, the adult cattle examined from the site have a range in $\delta^{13}C$ values, of approximately 6‰, which likely suggests the inclusion in the diet of both C_3 and C_4 plants from the surrounding landscape. The $\delta^{15}N$ values vary by 4‰, which could arise from the inclusion of C_4 plants, potentially reflecting an aridity effect), or grazing of animals on pastured fields. The sheep/goat and pig $\delta^{13}C$ and $\delta^{15}N$ values however, are consistent with those observed at Aktopraklık. The difference in isotope values between Aktopraklık and Barçin Höyük cattle suggests that these communities employed different management strategies for cattle. Despite the sites proximity to Lake Iznik, and indeed the site of Menteşe, there is no isotopic evidence for the consumption of aquatic protein resources.

Eight of the 18 humans analysed from Barçin Höyük were infants or sub-adults (see chapter 4 table 4.3 for anthropological information, and appendix 1 (table A1.1) for individual $\delta^{13}C$ and $\delta^{15}N$ values). Two of the samples are identified as 'newborn', three as 'infant', one as 6 months, one as 7-8 years of age, and finally one individual is identified as 'juvenile' (Songul-Alpaslaan-Roodenberg 2013). If we compare the infant (and '6 months') $\delta^{15}N$ values to the adult female $\delta^{15}N$ values, there is no clear isotopic evidence for an elevated nursing signal. The newborns, infants, and '6 months' samples $\delta^{15}N$ values average 11.1±0.8‰. The adult female $\delta^{15}N$ values average at 10±0.4‰. The newborn samples (n=2) have values of 11.1‰ and 10.8‰, and as these individuals died before nursing, one would not expect to see isotopic evidence for a nursing signal. The other infant samples (n=4) have an average $\delta^{15}N$ of 11.5±1‰, which demonstrates an 1.5‰ enrichment between the infants and adult females. We would expect an enrichment of at least *c*.3‰ for a pure nursing signal. However at 6 months of age we would anticipate the $\delta^{15}N$ values to reflect a mix of a pre-natal and nursing signal (e.g. not the full 3‰ enrichment). The $\delta^{15}N$ values of the infants at Barçin Höyük are commensurate with this, exhibiting a 1.5‰ shift from the adult females. The difference between the newborn $\delta^{15}N$ values and the infant and '6 months' $\delta^{15}N$ values however, are not statistically significant (p=0.8).

It is tempting to infer from this data that the children were weaned too early, leading to malnutrition, and therefore increased to exposure disease, leading ultimately to their early death. However, as only three of the adult burials are securely identified as female, cautioned is clearly warranted when making bold conclusions about the mechanisms driving infant mortality rates at Barçin Höyük.

There are only 10 adult samples from Barçin Höyük, so it is difficult to construct meaningful inferences between male and female diet (particularly as two of the adults cannot be identified as male or female), or to compare the diet there to that of the Aktopraklık adults. The data (see chapter 6) show that C_3 plants and herbivores provided the mainstay for diet at the site, and there is no statistical difference between the human $\delta^{13}C$ and $\delta^{15}N$ values at Barçin Höyük and those from Aktopraklık.

8.4 Osłonki 1: Diet, Burial Rites and Familial Animal Management in the Neolithic?

Considerably more samples were available for $\delta^{13}C$ and $\delta^{15}N$ analysis from the site of Osłonki 1 than for North-West Anatolia. In total, 130 fauna samples were analysed and 31 adult humans. No sub-adults were analysed from the site. The larger range of species allowed higher resolution of investigation than at the other the two study sites (such as the differences between wild and domestic species, domestic species comparison, change over time).

8.4.1 Diet

Overall, a number of key conclusions are evident for the fauna and humans. Firstly, the cattle $\delta^{13}C$ values at Osłonki 1 are very constrained, with a smaller range observed than at Barçin Höyük and Aktopraklık, despite the fact that the Anatolian sites have smaller sample numbers. This suggests that the inhabitants at Osłonki 1 utilised intense animal management methods (e.g. penning on specific areas, or using specific plant species for fodder), and perhaps highlights the absence of C_4 grass species available for grazing in Central Europe. This assumes that the very small amounts of millet (cf. *Panicum millet*) samples that were recovered from the LBK phases in a different site of the Brzesc Kujawski cluster (Mueller-Bieniek 2007) do not reflect the availability of C_4 plants for cattle fodder. During the Classic and Late periods combined, the $\delta^{13}C$ values for the cattle, sheep/goat and pig samples cluster distinctly (although overlapping), and are statistically different from one another. This potentially suggests species-specific animal management practices at Osłonki 1. A significant difference in the $\delta^{15}N$ values is not observed.

If we consider the fauna by phase, it is clear there is a shift in isotopes for cattle and sheep/goat between phases. For cattle, the $\delta^{15}N$ values become enriched in the Late period. Higher $\delta^{15}N$ values are often seen at sites where manuring is introduced (see chapter 3 for discussion), so this shift in values may reflect the intensification of animal management at the site. During these periods, the environmental conditions were stable (chapter 2, Monaghan 2011), and the shift in $\delta^{15}N$ values is not the result of changing environmental conditions in the region.

In addition to the changing cattle $\delta^{15}N$ by phase, the sheep/goat $\delta^{13}C$ differs between phases, becoming more enriched in the later period. The sheep/goat $\delta^{15}N$ values also become more depleted in the Late phase, combined with the fact that the variance of $\delta^{13}C$ values decreases significantly (chapter 5, section 5.3.3). It is difficult to ascertain whether this change reflects a move towards increased animal management (e.g. a narrowing of $\delta^{13}C$ values due to penning or foddering), or whether the depleted $\delta^{15}N$

values potentially reflect a greater emphasis on natural grazing/browsing (Drucker *et al.* 2003, Makarewicz and Tuross 2006, 2012).

Interestingly, the closest thing to a 'comparative' proxy at the site, the red and roe deer, are considerably variable in both $\delta^{13}C$ and $\delta^{15}N$, which tentatively suggests that the contraction in values does indeed suggest increased animal management. The contrasting issue to this interpretation is that deer species have a tendency to exhibit catholic dietary habitats when compared to sheep and cattle (e.g. deer will happily graze and browse, whereas cattle and sheep have a strong preference for grazing) (Clutton-Brock and Guinness 1982, Gerbert and Veheyden-Tixier 2001, Balasse *et al.* 2005).

The analysis of human collagen has provided some interesting insights on the diets consumed at Osłonki 1. The human $\delta^{15}N$ values during the Late phase appear to become significantly enriched when compared to the humans of the Classic phase, and this shift potentially tracks the $\delta^{15}N$ enrichment in cattle values observed between the phases. However, the new radiocarbon results for Osłonki 1, detailed in Chapter 7 (section 7.5.2), have shown that the original interpretation of the chronology at the site requires some refining, e.g. burials 24 and 55 which were thought to date to the Late phase actually date to the Early phase, alongside burial 35. However, in the absence of a revised (or final) chronology, the isotope values will be tentatively analysed within the current 'work in progress' chronology established for Osłonki 1 (e.g. the original chronological context (see chapter 2, section 2.6) with the new radiocarbon data integrated into the framework (chapter 7)).

The human $\delta^{13}C$ values do not show any variation by phase. During the Classic period the difference between male and female $\delta^{13}C$ values is significant, but the $\delta^{15}N$ is not. In the Late phase, there is no isotopic difference by sex. Overall, the most important point is that the $\delta^{13}C$ values for cattle and sheep/goat isotopic distributions significantly changed from one phase to the next, but the human isotopic distributions did not, which means the human diet must have changed composition between the Classic and Late phase. However, until the chronology of the phases at Osłonki 1 is refined, it is difficult to postulate meaningful conclusions about small-scale chronological shifts in human diet from the dataset.

8.4.2 Burial Rites and Diet at Osłonki 1

One of the most interesting outcomes of this project is the finding that status (as evidenced by burial rites) appears to exert the greatest control over human isotope values at Osłonki 1. In both the Classic and Late phases, there is a significant division in the distribution of $\delta^{13}C$ values based on the type of grave goods with which the individual was interred. In the Classic phase, burials with copper items are more likely to have enriched ^{13}C compared to their non-copper counterparts, which against the backdrop of the fauna isotope values would suggest a diet that was either richer in animal protein than their counterparts without copper, or suggests the possibility that they were consuming different plant species (or the same plant species grown in different conditions (see chapter 3)).

In the Late phase, humans with any type of grave goods have significantly enriched ^{13}C values compared to those without grave goods. Similarly to the Classic phase, $\delta^{15}N$ values do not vary by burial inclusions. A number of factors that may explain the isotopic variance, such as the potential impacts of extensive dairying/cheese making at the site, and the possibility of familial group ownership of certain areas of land affecting the isotope values. There is an issue with regard to the small sample size, particularly for the Late phase, but future isotopic work on the remaining 49 burials will aid the resolution of this problem. This study is particularly interesting in light of the recent research into an Iron Age site in Central Germany. Knipper *et al.* (2014) have demonstrated the presence of limited social differentiation as evidenced in diet at Glauberg, whose "prince burial" (interred with a wealth of bronze artefacts, *ibid.* 2014:821) exhibited significantly higher $\delta^{15}N$ values than the individuals with less extravagant burials. In contrast, Herxheim (an LBK site) and Trebur (a Middle Neolithic site), in Southern Germany, show no isotopic variation in diets as a result of status, despite the pronounced disparity in grave goods at the site, even though a sex-based dietary isotope difference is associated with Herxheim (Dűrrwächter *et al.* 2006).

Therefore, it would seem that Osłonki 1 exhibits some of the earliest evidence in Europe for social stratification exerting control over human diet. It is already established that the Brześć Kujawski has the earliest evidence for cheese-making in Europe (Salque *et al.* 2013), and it is possible that this reflects different social, as well as dietary approaches in practice. Given the size constraints of the research project it is simply not an option to explore this matter further here (the author is already pursuing this avenue of research outside of the doctoral studies). For now, the possibility of familial groups at Osłonki 1 will be investigated using the current data.

8.4.3 Osłonki 1: Human diet in context and the presence of familial groups?

Overall, whilst the mechanisms behind the change in isotopes values between phases may not currently be forthcoming, a shift is clearly observed. This is particularly interesting given the existing interpretation of context at Osłonki 1. The Classic phase is seen as 'golden period', when large settlement buildings are constructed, the fauna assemblage expands, copper artefacts are introduced to the material culture, and grave goods become both more frequent and more extravagant. In contrast, the Late phase is described as a period of mild decline, with a less extensive building program, and fewer burials that were often located within rubbish-filled pits (Bogucki and Grygiel 1997). The nature of the downturn, and what caused it is unclear, but it maybe that the shift in the cattle and sheep/goat isotopes is a human adaptive response to this decline. Again, the problem of the new radiocarbon results from Osłonki 1 may throw this conclusion into question, and additional refinement of the chronology is required to further address this issue.

The human populations at Osłonki 1 are characterised by the sole reliance on C_3 terrestrial plants and the herbivores that feed on them – despite the small inclusion of aquatic species in the faunal assemblage. The $\delta^{13}C$ and $\delta^{15}N$ variability in human diet during both phases is small, suggesting limited variation in consumption patterns (isotopically speaking). As discussed above, status exerted the greatest control over human diet at Osłonki 1. There is a significant difference in $\delta^{13}C$ values based on grave goods in both the Classic and Late phases. The 'poorest' burials (e.g. non-copper for the Classic period, or no grave goods for the Late period) for both periods display more depleted $\delta^{13}C$ values than their 'richer' counterparts. This difference is not mirrored in $\delta^{15}N$ values.

If the difference *was* mirrored in the $\delta^{15}N$ values the logical inference would be that individuals with copper in their burials had higher amounts of animal-based protein in their diets. However, it is less straightforward to interpret the shift in $\delta^{13}C$ values. The $\delta^{13}C$ values for the copper burials are more enriched, and given the almost complete absence of C_4 plants in the region, any explanation relying on their contribution is unlikely.

One other possible component of the diet was dairy based products. As mentioned previously, Salque *et al.* (2012) have conclusively shown evidence for cheese making during the LBK phases in the Brześć Kujawski cluster. The research into European Neolithic dairying through the application of analysis of fatty residues from pottery is well established (Evershed *et al.* 2008, Copley *et al.* 2003, 2005, Craig *et al.* 2005, Cramp *et al.* 2014, Dunne *et al.* 2005). The $\delta^{13}C_{18.0}$ values of ruminant adipose fats are approximately -2.3‰ more enriched than ruminant dairy fats (Copley *et al.* 2003, 2005, see chapter 3 for details). Therefore, individuals who ate a lot of meat would have higher $\delta^{13}C$ values than individuals who ate a lot of dairy products. This is because it is the protein consumed in a diet that predominantly dictates the $\delta^{13}C$ values in bone collagen (assuming that it is consumed in ample quantities). It is plausible that the human populations at Osłonki 1 could be consuming low protein diets, leading to the biosynthesis of non-essential amino acids from the general pool of dietary carbon (e.g. so the dairy fats would contribute to the $\delta^{13}C$ values measured from collagen).

Of course with regards to collagen (and therefore this study), it is the amount of protein in the diet that largely influences the $\delta^{13}C$ values of a sample (and $\delta^{15}N$ values solely reflect dietary protein). Whilst it is not possible to use the results of the dairying study to directly explain the carbon isotope values at Osłonki 1 (e.g. the issue of the contribution of fats *vs.* protein, as well the LBK date of the pottery sherds that were analysed) it clearly demonstrates the importance of dairy products in the region during the Neolithic, and provides an additional focal point for future dietary reconstruction in the region.

In chapter 6, source partition modelling was undertaken for Osłonki 1, using the $\delta^{13}C$ and $\delta^{15}N$ values of cattle, sheep/goat, and pig bones, alongside the estimated $\delta^{13}C$ and $\delta^{15}N$ values for C_3 plants species (based on previous research of nearby sites, see chapter 2) that were present in the plant assemblage. The overall output for these models was influenced by the prior information imported into the model, and this is perhaps not surprising. The (meat weight) NISP composition of Osłonki 1 favours cattle considerably, even though the fauna assemblage during the Lengyel phase is comprised *c.*30% of cattle, *c.*30% sheep/goat and *c.*25% pig.

Chapter 3 details the protein content for the main animal components of diet at Osłonki 1 (e.g. cow meat, cow cheese, cow milk, sheep meat, etc.). This dietary protein information was used to attempt to model dairy input in human diet at Osłonki 1, using the SIAR model (chapter 6), and it was found that the model could not adequately differentiate between animal products (and species), and a meaningful output could not be modelled. However, it is clear from the research undertaken by Salque *et al.* (2012) that populations during the LBK phases were consuming cheese and dairy products in Brześć Kujawski cluster. The introduction of cheese-making at sites does coincide with the decline of the LBK (and the subsequent phase of abandonment before the onset of the Lengyel period), but whether this chronological convergence of events is merely coincidence is difficult to ascertain. It *is* evident from the fauna assemblages that the LBK population exploited a narrower range of species than the subsequent Lengyel occupations. It is tempting to suggest that the diversification of dietary resources in the Lengyel period is a response to resource stress during the LBK phase (and hence the abandonment), although there is no clear evidence to support this possibility.

Whilst pottery sherds from the Lengyel phases at Osłonki 1 have not yet undergone the same residue analysis at those from the LBK phase, one pottery sieve has been recovered from the site (Grygiel 2004), which may point towards continuity in dairying. Following this argument, it would suggest that the individuals with copper burials at Osłonki 1 consumed more meat than their non-copper counterparts. This could explain why the δ^{13}C values are different and the δ^{15}N values are not – because (in terms of protein) milk and meat have the same δ^{15}N values.

The consequence of using cattle herds for dairying produce (instead of just meat) is that animals can be retained in times of economic downturn, whilst still supplementing the diet with the necessary proteins. If we refer back to the discussion of the archaeology at the Brześć Kujawski cluster in chapter 2, we are reminded that the onset of the Lengyel period is characterised a diversification in dietary breadth, as evidenced by the higher inclusion of wild fauna in the assemblage. Cattle comprise approximately *c.*34% of the fauna, sheep/goat *c.*33% and pig *c.*25% during the

Lengyel period (with wild fauna, including aquatic species, contributing 10%). Comparatively, the fauna from the earlier LBK levels in the region were dominated by cattle bones *c.*80%, with limited sheep/goat contribution. The high number of cattle recovered reflects the importance of dairy and meat in the diet, and the importance of dairy is highlighted further by the fact that 40% of the pottery sieves analysed yielded dairy fats (consistent with other Neolithic dairy processing sites, Salque *et al.* 2012) and 29%-59%[1] of the pottery contained adipose fats.

Overall, it is evident that status exerted the greatest control over adult diet at Osłonki 1. During the Classic period there is a significant difference in δ^{13}C values between the males and females, but as the chronology of the burials now requires further radiocarbon dating, this outcome maybe be questionable. Whether this difference was due to 'non-copper individuals' consuming proportionally higher levels of dairy protein, and 'copper individuals' consuming higher levels of meat protein is more speculative. One could argue that the difference in δ^{13}C values could arise from difference types of plant species (that are isotopically distinct) being consumed. If we first consider the possibility of wild plants, we have the useful proxy of the red and roe deer analysed from the site. Combined, they exhibit δ^{13}C values from approximately -22‰ to -19‰, but as the δ^{13}C values get higher the δ^{15}N values also become enriched (chapter 6) – so this explanation seems improbable.

For domestic plants, research by Bieniek (2007:335) has demonstrated that at Osłonki 1 *c.*80% of the botanical assemblage is wheat chaff, with *c.*20% cereal grains (with einkorn (*Triticum monococcum*) the most common found, alongside emmer

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[1] Variation is based on pot type, with cooking pots yielding 59%, cooking bowls yielding 29% and collared flasks yielding 33% (Salque *et al.* 2012:3).

(*Triticum dicoccum*), so species difference is unlikely. Of course, referring back to the isotopes discussion in chapter 3, we know from previous studies that $\delta^{13}C$ values in the same species of plant can vary due to moisture availability (see chapter 3, section 3.3.2.1 as well as: Ehleringer and Cooper 1988, Bonafini *et al.* 2013, Wallace *et al.* 2013, Cernusak *et al.* 2013, Ehleringer, Hall and Farquhar 1993 Farquhar, Ehleringer and Hubrick 1989, Farquhar, O'Leary and Berry 1982, Broadmeadow and Griffiths 1993, Hidy *et al.* 2009).

Wallace *et al.* (2013) demonstrated that $\delta^{13}C$ in experimentally grown crops that were subject to different levels of watering produced different results. The research highlighted that well- watered wheat grains on average had $\delta^{13}C$ values above 17‰, and poorly watered wheat grains had carbon isotope values typically below 16‰. Bonafini *et al.* (2013) have shown differences in light intensity can cause $\delta^{13}C$ values to vary by as much as 4‰.

The question therefore is, does the landscape surrounding Osłonki 1 fluctuate enough to cause pronounced variation in $\delta^{13}C$ of the species that have grown there? Dr. Aldona Mueller-Bieniek[2] has begun isotopically analysing plant remains from Brześć Kujawski to look for potential variance, though no data are yet available. In the absence of the direct $\delta^{13}C$ plant data, we can consider the next best thing, the isotope values from the domestic fauna, which provides a mixed signal of the C_3 plants values in the landscape (see chapter 3).

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[2] School of Archaeology, University of Oxford, Beaumont Street, Oxford.

The possibility of familial groups at Osłonki 1 (and the wider Brześć Kujawski cluster) has been previously suggested in the literature (Grygiel 2004, Pyzel 2013). If distinct familial groups existed at the site (which itself is 4,000m^2 (Bogucki and Grygiel 1997)) it is possible that they reared their livestock on separate areas around the settlement, or even employed different animal management techniques. A way of examining this is by plotting the fauna isotope data by the location in which the faunal material was found, e.g. pit 137 or gl9. Chapter 2 (figure 2.29) displays a layout of the site, including locations of the pits and features.

To accurately compare the isotope data of the different species, the distribution and confidence ellipses will be considered. The elliptical graphs are created in R using the car[3] package. Fauna were analysed from 13 different contexts, of which five features (rubbish pits, pits, etc.) contained more than five bone samples from one species (e.g. feature gl2 contained more than 5 cattle and 5 sheep/goat). Only features that have five samples from two or more species will be considered. It is worth noting that there are considerably more faunal samples in the contexts than were analysed here, but financial and time constraints prevented them from being included this project. In chapter 2, the location of the pits in relation to the rest of the site can be in figure 2.28. The 'gl' pits are clay pits that are significantly larger than their rubbish pit 'counterparts'. Table 8.1 displays the number of samples for site location used in the statistics testing. Pits 137 and 153 are potentially both associated with house 10. However, the new radiocarbon dates for this project have highlighted that the original chronology for the site requires revision. As a result of this, pits 137 and 153 are considered separately.

Site Loc.	Phase	Cattle	Sheep/Goat	Pig	Notes
gl 2	Classic	12	5	5	Associated with House 1.
gl 9	Classic	14	6	6	Associated with House 22-23.
pit 137	Late	5	-	-	Possible association with House 10.
pit 204	Late	5	6	-	Interior basin feature of House 14.
pit 153	Late	5	6	-	Possible association with House 10.

Table 8.1 Number of samples analysed from each site context at Osłonki 1.
Phase information is based on association with other features (Bogucki 2013, *pers. comm*).

Table 8.2 displays the *p* values for ANOVA tests undertaken on the fauna $\delta^{13}C$ and $\delta^{15}N$ values for the selected pits at Osłonki 1.

All fauna Groups (ANOVA)	**δ^{13}C *p-value***	**δ^{15}N *p-value***
All pit locations	0.3	0.5
Classic phase clay pits (gl9, gl2).	0.5	0.3
Late phase rubbish pits (123,153 and 204)	0.2	0.5
Classic clay pits *vs*. Late phase rubbish pits (listed above)	0.5	0.01

Table 8.2 ANOVA test *p-values* for *combined fauna* δ^{13}C and δ^{15}N values for the selected clay and rubbish pits at Osłonki 1.

ANOVA was applied (using R) to the 5 site locations, and the variation the δ^{13}C and δ^{15}N distributions was found to be not significant (*p*=0.3 and *p*=0.5 respectively). The distributions between the samples from the clay pits, gl 2 and gl 9, which are both Classic in date, are not significantly different, with *p*=0.5 for δ^{13}C and *p*=0.3 for δ^{15}N. ANOVA was also applied to the three rubbish pits, 123, 153 and 204, and the differences were again found to be not significant, with *p*=0.2 for δ^{13}C and *p*=0.5 for δ^{15}N. If we test the Classic clay pits (gl 2 and gl 9) against the Late rubbish pits (123, 153 and 204), the difference in the δ^{13}C in not significant at *p*=0.5, but *is* significant for δ^{15}N at *p*=0.01. This result is not surprising as this chronological increase in δ^{15}N is evident in the cattle populations, and they comprise a large component of the fauna assemblage.

However, grouping the all fauna species together may not be the ideal approach, as issue such as species effect, and species-specific animal management practices may confound any differences that are present.

Groups (ANOVA) Cattle	**δ^{13}C *p-values***	**δ^{15}N *p-values***
All pit locations	0.1	0.2
Classic phase clay pits (gl9, gl2).	0.7	0.2
Late phase rubbish pits (123,153 and 204).	0.003	0.8
Classic clay pits *vs.* Late phase rubbish pits (listed above)	0.4	$\leq$0.000

Table 8.3 ANOVA test *p-values* for cattle δ^{13}C and δ^{15}N values for the selected clay and rubbish pits at Osłonki 1.

Again, there appears to be no obvious difference between the isotopic distributions for the cattle by site location, and indeed this is reflected by the results of the ANOVA, p=0.1 and p=0.2 for carbon and nitrogen respectively. If we consider the Classic clay pits, the difference in the δ^{13}C or δ^{15}N is not significant (p=0.7 and p=0.2). ANOVA was subsequently applied to the three Late pits, and a significant difference was observed between the cattle δ^{13}C values, at p=0.003. However, the cattle δ^{15}N values from the Late phase rubbish pits show no significant difference (p=0.8). In addition, there is no difference in cattle δ^{13}C values between the Classic clay pits and the Late rubbish pits (at p=0.4), but as expected the difference in δ^{15}N values between chronological period is highly significant ($p\leq$0.000). Tukey's HSD post hoc testing (σ = 0.05) was undertaken (see chapter 5, for test details), and the p-adjusted values are in agreement with the ANOVA outputs.

Groups (ANOVA) Sheep/Goat	**δ^{13}C *p-values***	**δ^{15}N *p-values***
Pit locations (gl2, gl9, p153, p204).	0.9	0.5
Classic phase clay pits (gl9, gl2).	0.04	0.3
Late phase rubbish pits (153 and 204).	0.1	0.5
Classic clay pits *vs.* Late phase rubbish pits (listed above)	0.008	0.3

Table 8.4 ANOVA test *p-values* for sheep/goat δ^{13}C and δ^{15}N values for the selected clay and rubbish pits at Osłonki 1.

ANOVA was performed on sheep/goat samples from four site locations (pit 137 did not include enough sheep/goat samples to be used in the analysis). The difference between the pits is not significant, with δ^{13}C at p=0.9, and δ^{15}N at p=0.5. The difference in δ^{13}C between to two Classic clay pits (gl2 and gl9) is significant at p=0.04, but the variation in Classic sheep/goat δ^{15}N values is not, p=0.3. Pits 153 and 204 are dated to the Late phase, and the variation in δ^{13}C is not significant at p=0.1, and the Late sheep/goat δ^{15}N values are similarly showing no significant variation (p=0.5).

The difference in sheep/goat δ^{13}C values between the Classic pits (gl 2 and gl 9) and the Late pits (153 and 204), are significant, p=0.008 (see chapter 5, for summary statistics of Osłonki 1 fauna). For δ^{15}N, no significant difference in variation is observed (p=0.3). Tukey's HSD post hoc testing (σ = 0.05) was undertaken (see chapter 5, section 5.3.3 for test details), and the p-adjusted values are in agreement with the ANOVA outputs. Figures 8.11 and 8.12 show the confidence distribution and prediction ellipses for pig samples.

Only three pits had enough pig samples to be used as part of this analysis. Gl 2 and gl 9 which date to the Classic period, and pit 137 which is assigned to the Late period. Table 5.1 displays the results of the ANOVA tests for pig δ^{13}C and δ^{15}N values.

Groups (ANOVA) Pig	**δ^{13}C *p-values***	**δ^{15}N *p-values***
Pit locations (gl2, gl9, p137).	0.07	0.4
Classic phase clay pits (gl9, gl2).	0.06	0.2
Classic clay pits *vs.* Late phase rubbish pits (listed above)	0.3	0.6

Table 8.5 ANOVA test *p-values* for pig δ^{13}C and δ^{15}N values for the selected clay and rubbish pits at Osłonki 1.

ANOVA is performed on the three pits and the difference in variance between them is found to be not significant (δ^{13}C *p*=0.07 and δ^{15}N *p*=0.4). The variation in δ^{13}C between the pig samples from the two Classic clay pits is approaching significance at *p*=0.06 (with δ^{15}N at *p*=0.2). Finally, the pig samples from the two Classic pits are compared to the single Late pit. The δ^{13}C values are not different at *p*=0.3, and the δ^{15}N similarly show no difference (*p*=0.6). Tukey's HSD post hoc testing (σ = 0.05) was undertaken (see chapter 5, for test details), and the *p*-adjusted values are in agreement with the ANOVA outputs.

In summary, the distributions at Osłonki 1 do potentially suggest the presence of familial groups. The cattle δ^{13}C values from the Late pits are different from one another, and additionally, the δ^{13}C values for the Classic sheep/goat samples are significantly different. It is clear that further research is required to resolve this issue.

8.5 SIAR Modelling & Isotopic Spacing

The $\delta^{13}C$ and $\delta^{15}N$ values obtained for this study allows broad conclusions to be made about an *individual's* diet (chapters 3 and 6). SIAR modelling and plotting the isotopic 'spacing' (Δ) are two methods that intend to provide dietary information at a higher resolution, e.g. was an individual consuming a higher quantity of cow protein or goat protein?

8.5.1 SIAR Modelling

Overall, the SIAR package demonstrated a novel (but unsuccessful) way of modelling the palaeodietary isotope data. For each of the sites entered into the programme (Çatalhöyük**,** Aktopraklık, Barçin Höyük and Osłonki 1) the ultimate outcome (using the weighted NISP as model priors) is that cattle and C_3 plants comprised the majority of the diet (proportionally speaking) *for all sites*. Whilst it is not beyond the realms of possibility that all four sites (from arid, semi-arid, and temperate regions) utilised the same dietary resources (e.g. cattle and C_3 plants) in roughly the same proportions, it seems unlikely. If we consider the archaeological literature for the sites of Çatalhöyük**,** Aktopraklık, and Barçin Höyük**,** it is not commensurate with cattle as livestock being the main source of dietary protein. Whilst the earliest research into subsistence at Çatalhöyük suggested a reliance on cattle protein (Perkins 1969), this is no longer the case (Pearson *et al.* 2007). Recent research suggests that the phenotype and morphology of the cattle remains suggest that they are not domestic and retain the majority of characteristics from their wild progenitors (Arbuckle 2012). In addition the mortality profiles for the cattle are not in line with a population bred for meat consumption, as there are a high number of adult males present. This is has lead to suggestion of the use of cattle mainly for hunting and feasting (Twiss and Russell 2009). The research into the faunal assemblage at Barçin Höyük has produced broadly similar results with no real evidence for intensive cattle livestock breeding. Extensive work into the mortality profiles of cattle and ovicaprids at Aktopraklık is yet to be undertaken, and so a comparison cannot be made.

Conversely, the evidence for ovicaprid breeding at Çatalhöyük is plentiful. The mortality profile for ovicaprids at Çatalhöyük are commensurate with a mixed breeding population for milk and meat products (Russell *et al*. 2005, 2013), and this is further supported by the isotope studies undertaken at the site (Richards *et al.* 2003, Richards and Pearson 2005, Pearson *et al.* 2007). The same findings for milk exploitation of ovicaprids have been uncovered at Barçin Höyük**,** and at Mentese (a Neolithic site in close proximity to Aktopraklık and Barçin Höyük). This is attested by the slaughtering of milk lambs younger than 3 months of age and the slaughter of ewes aged 3-4 years, two approaches considered to be complementary strategies in flock management (Gourichon and Helmer 2008). In addition, lipid residue analysis of pottery has been undertaken at Çatalhöyük and Barçin Höyük**,** as well a large number of other contemporary sites in Anatolia, and the results have shown extensive evidence for dairying through the presence of milk fats (Evershed *et al.* 2008, Thissen *et al.* 2010, Türkekul Biyik and Özbal 2008, Sauter *et al.* 2003). The region of North-West Anatolia in particular demonstrated emphatic evidence for the intensive processing of dairy products (~70% of pottery contained dairy lipids), and furthermore, the proportion of cattle bones at these sites (note: specifically the sites analysed in the Evershed *et al.* 2008 study) is considerably higher than the cattle proportions observed at the other sites utilized in their study. This correlation is interpreted by Evershed *et al.* (2008:530) as reflecting higher rainfall quantities in the region, and therefore greener grazing resources.

8.5.2 Osłonki 1

The SIAR model had some difficulty distinguishing between the isotopic values of the dietary resources at Osłonki 1. The inclusion of weighted NISP caused the model to identify cattle and C_3 plant protein as forming the main basis for diet at Osłonki 1, although there is the issue that including a weighted NISP may have pre-determined the output of the model. The faunal assemblage from Osłonki 1 was fairly evenly divided between pig, cattle and sheep goat, so the mortality profiles of these species are consulted (figure 8.5). The cattle, sheep/goat and pig species that have been recovered from the site and included in the profile analysis are domestic. There are a few instances of aurochs and wild pigs, but these are very limited and not considered to be a major component of the diet (Bogucki 2008).

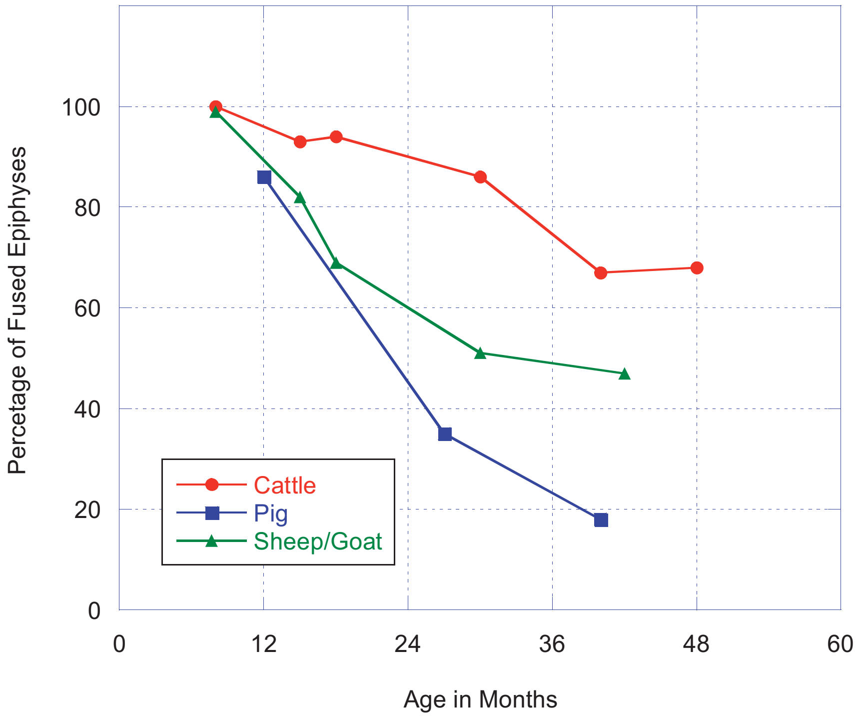

Figure 8.5 Osłonki 1 mortality profiles on grouped fusion date.
(Bogucki 2008:1641).

The mortality profile of the pigs is straightforward. They reach their maximum weight rapidly, with fewer than 20% surviving beyond 36 months. The profile is commensurate with domestic pigs that were fattened on settlement refuse and killed for meat (Bogucki 2008). The cattle and sheep/goat profiles are more ambiguous, as it seems that neither group were raised for meat products alone. Bogucki (2008:1642) states that approximately '60% of cattle survive beyond the attainment of their maximum meat weight at about 42 months, and since over 40% of sheep/goat survive their 42nd month as well, it seems that while some juveniles and sub-adults of these species were culled when young, there was clearly a purpose other than meat to their contributed economic value'. It is likely that both cattle and sheep/goat were used for milk products as well as meat. If this assertion is true, then calculating meat weight as a prior for protein consumption would be an ineffective measure of total contribution.

This work is further supported by a recent article in *Nature*, which argues for evidence for cheese production based on specific types of pottery present and the analysis of $\Delta^{13}C$ from dairy fat residues in said pottery types (Salque *et al.* 2013).

8.5.3 Plotting Δ

The purpose of plotting Δ between the human and fauna isotope values was a further attempt to understanding more precise compositions of human diet on an individual level. The same four sites were used for Δ models as for SIAR models (Çatalhöyük**,** Aktopraklık, Barçin Höyük, and Osłonki 1). For Aktopraklık, the Δ model showed that the cattle $\delta^{13}C$ values were more enriched than the humans, which is contrary to what we would expect if cattle formed the largest proportion of the human diet (i.e. the cattle $\delta^{13}C$ should be more depleted than the humans). The sheep/goat $\delta^{13}C$ values were more depleted than the human carbon isotope values, and this, combined with the $\delta^{15}N$ 'spacing' (Δ) (see chapter 6), suggested that sheep/goat proteins and plant proteins were the two major inputs into the protein component of diet at Aktopraklık. This outcome is clearly at odds with the SIAR output for Aktopraklık. At Barçin Höyük, the human-fauna **Δ** displays no strong correlation, but the $\delta^{13}C$ and $\delta^{15}N$ distributions are commensurate with cattle, sheep/goat and C_3 plants (which is to be expected, given the fauna and plant assemblage).

At Çatalhöyük there is again no clear correlation between the fauna $\delta^{13}C$ values and the human $\delta^{13}C$ values. The disconnect between the human $\delta^{15}N$ and the fauna $\delta^{15}N$, however, is clearly evident. Humans are lower in $\delta^{15}N$ than expected, which would suggest that the plant protein contributed as a major proponent of the human diet. Alternatively, the low $\delta^{15}N$ values maybe influenced by the consumption of leguminous plant species at the site (chapter 2), as these plants are N_2-fixing and often produce markedly low $\delta^{15}N$ values (chapter 3). The spacing graphs for Osłonki 1 are similarly indistinct, and overall the distribution of the majority of the human data is commensurate with the consumption of cattle and sheep/goat (again unsurprisingly in light of the fauna assemblage).

8.5.4 SIAR and Δ: Summary

In summary, whilst source partitioning models and spacing models offer a novel approach to understanding the use of dietary resources at an individual human level, it is doubtful that they have revealed a higher resolution of interpretation for the sites in this study. The purpose of its inclusion in the research project was not to 'test' whether the models are valid; rather, the project adapted an exploratory approach to using the models and analysing the isotope data. Overall it is evident that source-partitioning models (on this occasion SIAR) do not add any value to existing methods of palaeodietary reconstruction, and in fact they may produce erroneous results (section 8.5.1).

8.6 Radiocarbon dating

The radiocarbon dates undertaken on the samples Barçin Höyük are largely commensurate with the existing plant macrofossils dates, which were processed at Groningen University and Beta Analytical. Burial L13-166 produced a radiocarbon date of 7692±40 (6,606-6,546 cal BC), and burial M10-173 produced a radiocarbon age of 7314±36 (6,236 – 6,076 cal BC) - both of these dates fit well with the existing chronology for Barçin Höyük. Burial L13-129 produced a much later date than anticipated (1775-1630 cal BC), and this clearly raises questions about the degree of stratigraphic mixing at the site. However, Barçin Höyük remains one of the earliest Neolithic sites in Marmara Region. This early chronology, coupled with the distinct presence of milk residues from the pottery (Thissen *et al.* 2010), and the seemingly high infant mortality rate (higher than most of the sites, but still in line with the nearby sites of Ilıpınar and Menteşe (Alpaslan Roodenberg, 2008; 2001)), makes Barçin Höyük an interesting site within North-West Anatolia.

The radiocarbon program undertaken for Osłonki 1 has produced some interesting, albeit unexpected results. The original chronology for the humans that are buried at the site were divided into three phases of occupation Early (4700-4500 cal BC), Classic (4500-4300 cal BC), and Late (4300-4100 cal BC), with the phases largely characterised by the appearance, and subsequent decline, of copper artefacts. The actual chronological boundaries of these phases are based on their association with settlement structures that *had* been dated (as well as a consideration of burial goods with which the individuals had been interred).

The 15 radiocarbon dates obtained for this project however are not commensurate with the original chronology. Instead, the recent radiocarbon dates suggest two major phases of occupation (referred to forthwith as phases A and B to avoid confusion), with a single interment (burial 35), modelled in separate chronological phase prior to the onset of the other two phases (chapter 7, figure 7.3). Phase A is modelled to *c.* 4300-4225 cal BC, and five individuals that were radiocarbon dated are associated with this phase; burials 55, 24, 18, 54 and 48. Two of these burials (55 and 24) were thought to date to the Late phase, and the remaining burials were assigned to the Classic phase. The phase A group consists of four females, and one male. The females are all interred with copper based grave goods (with burial 54 exhibiting significant burial 'wealth'), and the single male burial was interred with no grave goods.

Phase B is modelled to *c.*4225 – 4100 cal BC, and the remaining 9 individuals (6 males, three females) that date to this phase were aligned to the either the Classic (n=8) or Late (n=2) period of occupation. Four of the burials dating to this phase were interred with copper artefacts (burials 6, 53, 72, 80), four were interred with no artefacts (burials 1, 22, 73, 61), and one individual was interred with non-copper artefacts (burial 26, male) – specifically an antler T axe and boar tusk, which bears striking resemblance to grave goods located further north in Baltic zone (Bogucki, 2013, *pers.comm*). Previously, the presence of copper artefacts in the archaeological record at Osłonki 1 was though to occur exclusively during the Classic phase (Bogucki and Grygiel 1997:172), but the new radiocarbon dates clearly demonstrate that copper artefacts were present in the burial record during both phases (e.g. phases A and B) of occupation. The $\delta^{13}C$ and $\delta^{15}N$ collagen values of the individuals from phases A and B were statistically tested to investigate for differences at both a intra- and inter- phase level and no differences were observed (e.g. no differences between phase A and B, males and females) - with the exception of copper *vs.* non-copper grave goods and $\delta^{13}C$ values (*t-value*=0.5, *p*=0.008).

8.7 Isotope Changes in Anatolia

In Anatolia, the differences in $\delta^{13}C$ and $\delta^{15}N$ collagen values between archaeological sites are distinct, but this reflects the large variation in moisture availability between sites. Figure 8.6 displays the $\delta^{13}C$ and $\delta^{15}N$ values for the sites located in the South-

East, North-West and Central Plateau of Anatolia of Nevali Çori, Çatalhöyük, Aktopraklık, Barçin Höyük, and Aşıklı Höyük.

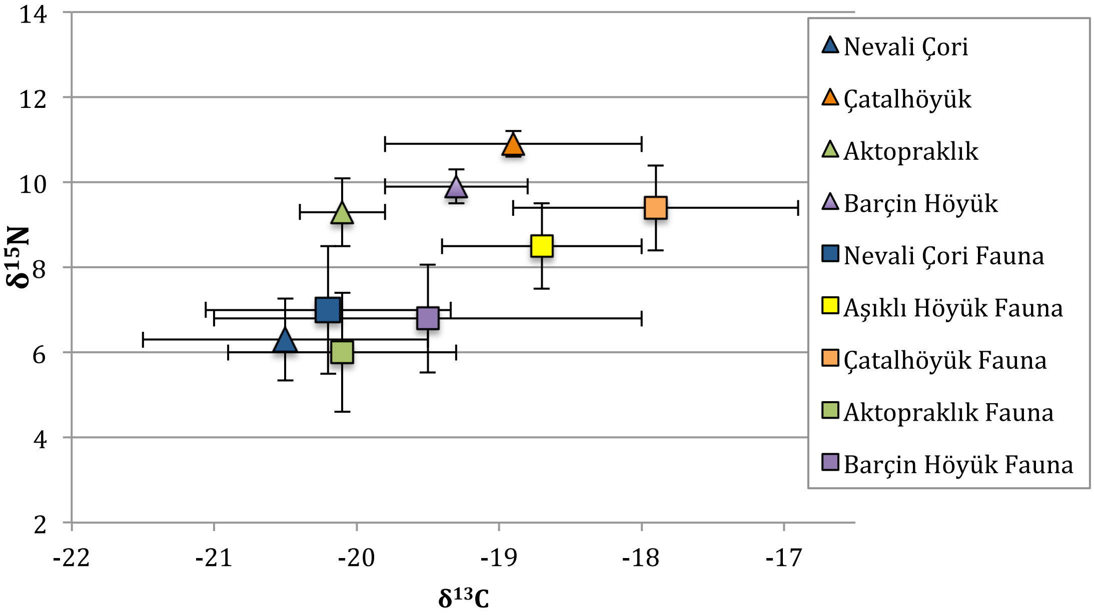

Figure 8.6 $\delta^{13}C$ and $\delta^{15}N$ collagen values from South-East, North-West, Central, and South East Anatolian Neolithic sites.
(averages and one standard deviation) (Data: see chapter 6 for details).

There is a clear enrichment in $\delta^{13}C$ and $\delta^{15}N$ values from West to East, and this increase in isotope values reflects an increasing aridity. For $\delta^{13}C$ the increasing aridity affects stomatal conductance, and drives an increase in C_4 plant species, while for $\delta^{15}N$ the aridity causes the denitrification of soils, alongside an increase in urea recycling in fauna. The difference in the standard deviations of the human $\delta^{13}C$ values when compared to the fauna (e.g. the humans exhibit smaller variation) is probably the result of the longer-term average represented by human bone collagen remodelling values, which averages out short-term differences. The incidence of C_4 grasses in these areas will have contributed to this isotopic variance in $\delta^{13}C$. The only exception to this trend is perhaps Çatalhöyük, where the human **$\delta^{13}C$** variance is equal to the fauna from the same site.

The site of Nevali Çori plots contrary to expectation. Given its location in South-East Anatolia (with associated high aridity and greater representation of C_4 plants), the human and fauna $\delta^{13}C$ and $\delta^{15}N$ values were expected to resemble the isotopic pattern of human and fauna samples at Çatalhöyük. The Nevali Çori human $\delta^{13}C$ and $\delta^{15}N$ values are in fact more comparable to the fauna $\delta^{13}C$ and $\delta^{15}N$ (of the other sites) than to any of the other human isotope datasets. This pattern indicates (alongside the low $\delta^{15}N$ values), that the human diet was primarily based on the consumption of mixed C_3 and C_4 plants (Lösch *et al.* 2006:185).

Furthermore, the human Nevali Çori $\delta^{15}N$ values plot lower than the corresponding fauna $\delta^{15}N$ from the site. This could reflect a number of factors, firstly, the humans at Nevali Çori could have been consuming proportionally high quantities of leguminous plants, which could have a $\delta^{15}N$ value of 0‰ (chapter 3). Secondly, the fauna assemblage at Nevali Çori is markedly different from the other Anatolian sites, including a number of wild animals species. Lösch *et al.* (2006) also cite the issue of urea depletion and the recycling of nitrogen by ruminant bacteria to explain the elevated $\delta^{15}N$ values (Richards *et al.* 2003, Fizet *et al.* 1995, Ambrose 1991). Finally, it is a distinct possibility that the modern climate data used to assess Nevali Çori was not an accurate analogue of the climate conditions present in the Neolithic period in the region. Nevali Çori is located on the hilly landscape of the Anti-Taurus, and it is possible that the local topography of the region affected the climatic conditions. Furthermore, the site of Nevali Çori was submerged underwater in 1992 as part of the Atatürk project, which oversaw the construction of the Atatürk dam to harness hydroelectric power and irrigate the plains in the region (Kaygusuz 2003), making it difficult to obtain more accurate climatic information about the region. Figure 8.7 displays a graph of the Anatolian sites with Nevali Çori removed.

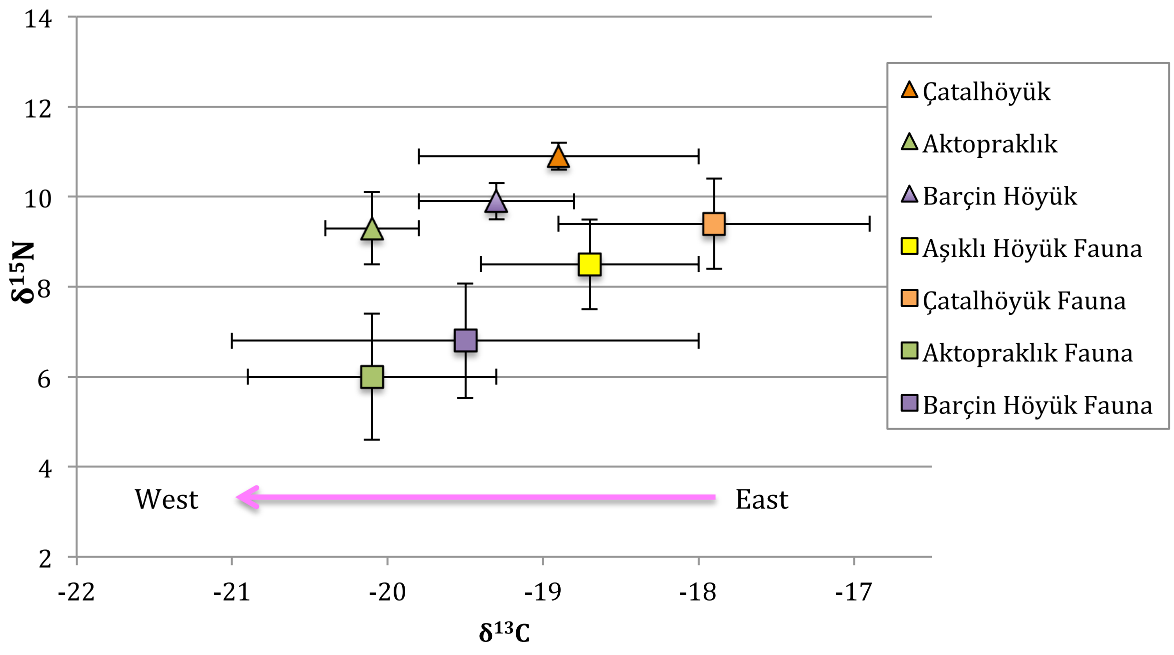

Figure 8.7 $\delta^{13}C$ and $\delta^{15}N$ collagen values from North-West and Central Anatolian Neolithic sites (averages and one standard deviation) (Data: see chapter 5 and chapter 6 for details).

With the data from Nevali Çori removed, it is evident that the Anatolian isotope values plot negatively in accordance with the East-West trajectory (with the over-simplified explanation that the climate becomes hotter and dryer the further East one travels). If we consider the human $\delta^{13}C$ and $\delta^{15}N$ distributions by region (North-West, Central, South-East) it is clear that the North-West sites of Aktopraklık and Barçin Höyük exhibit less variation in $\delta^{13}C$ values (i.e., the standard deviation is more constrained than the values from the Central and South-East sites). This difference in values reflects a higher proportion of meat consumption for human populations in the North-West region, because the faunal $\delta^{13}C$ values of the plants consumed, which are subsequently again averaged when humans consume meat or milk from the fauna.

An interesting question, is whether this difference in resource exploitation was a socio-cultural choice, or whether it was dictated by the environmental conditions present in the region? The further westwards toward Europe one goes, the colder it is, and so the more difficult it would be to cultivate plants species that are indigenous to the centres of domestication in the Near East, and that arrived in the North-West affiliated in part with the spread of the Neolithic 'package'.

In general, the δ^{13}C and δ^{15}N data that have been examined from Anatolian and European sites in this project (whether primary data produced by the author, or data cited from publications) demonstrates that the amount of meat proportionally consumed in human diets increases westwards. The issue of whether the change in climate is merely coincidental is difficult to approach. The critique of the concept that environmental determinism was the mechanism powering human adaptation and change in prehistory gained considerable traction during the 1980's (Astley and Van de Ven 1983, Peet 1985, Astley and Fombrun 1983), and this movement was largely mirrored in other academic disciplines (Hrebeniak and Joyce 1985). In more recent archaeological studies, the idea that environmental determinism may have something valuable to contribute to the narrative has gathered some speed (Nunn 2003, Coombes and Barber 2005, Erikson 1995) but it still remains something of an uncomfortable issue to discuss in the archaeological literature.

There are the further practicalities of actually attempting to disentangle environmental impacts from cultural impacts in the archaeological record. The Marmaran sites of Aktopraklık and Barçin Höyük are well placed for this examination. There are located in what is referred to as 'melting pot' of different cultural influences, with Central and East Anatolia from the East, and European influences from the West (Karul and Avci 2013). As discussed in chapter 2, the North-West region in Anatolia represents the integration of contrasting subsistence practices in the area. The Fikirtepean communities, located in close proximity to the Black Sea, were hunter-fisher-gatherers with a penchant for wattle and daub circular structures, likely linked to the indigenous populations of the region. The Central and Eastern Anatolian sites are fully formed agricultural economies with the same fondness for wattle daub structures, which alternatively would suggest the transmission of ideas from Central and Eastern Anatolia into the North-West region. The North-West sites (Aktopraklık and Barçin Höyük) are structurally similar to Central Anatolian sites, and employ agriculture as their main subsistence base, additionally large amounts of Fikirtepe pottery have been recovered from the sites. The southern Marmaran sites (not included in this project as the skeletal material could not be accessed) of Ilıpınar and Mentese have Fikirtepe pottery, but *rectangular* shaped architectural buildings, clearly demonstrating characteristics of both Eastern and Western influence.

A number of researchers (Karul and Avci 2013, Özdoğan 2011) suggest that the variability present in the material culture inventories of the sites in this region represent the conflation of "two distinct but contemporary Neolithic communities in the region, those with the rectangular massive constructions belonging to the immigrant farmers in the Anatolian plateau, and the wattle and daub huts belonging to the local hunter-gatherer-fishermen adopting Neolithic elements" (Karul and Avci 2013:52). This conflation of incoming farmers and local traditions and adaptations, produces a hybridized culture unlike those known in Central or Eastern Anatolia.

While the theory proposed by Karul and Avci (2013) may be valid, there appears to clear evidence for a hybridization of cultures from the East and West, as supported by the evidence for monochrome pottery, and the variation in structure shape. The usual approach in this situation would be to apply strontium isotope analysis to human and fauna tooth enamel in an effort to identify migrants to an area (Sealy *et al.* 1991, Price *et al.* 2002, 2011, Knudson *et al.* 2010, Boriç and Price 2011). However the geology of Turkey is composed of such an extensive number of geological deposits with differing isotopic signals (Okay 2008), the use of strontium for migration would be very difficult, if not impossible.

How then, does the discussion of the cultural assemblage relate to environmental determinism? The North-West Anatolian landscape, with its vast array of terrestrial and aquatic resources (both marine and freshwater) in easy reach for human populations at a number of Neolithic sites. The literature to date focuses on the obvious dichotomy between the subsistence practices of the hunter-fisher-gatherers from the sites surrounding Fikirtepe, alongside the fully formed agricultural economies of inland Marmara and further to the east. However, these 'distinct' subsistence practices simply represent the 'end points' of dietary linear model, less attention is attributed to the sites and populations that are in *transition* between the two. The site of Aktopraklık includes a number of storage pits that contain large numbers of red deer bone deposited in quick succession – clearly demonstrating a feasting event of wild species, and links back to previous dietary approaches. It is tempting to state that as the fishing-hunter-gathering and farming existed during the same chronological period in the region that 'obviously' environmental determinism did not dictate human choices about their economy. Neolithic communities could choose whether to hunt, fish or farm, and the environmental did not impact enough to affect these choices.

However, the site of Barçin Höyük may provide evidence contrary to this hypothesis. The site is one of the earliest in region, with its onset pre-dating Aktopraklık and Ilıpınar. The fauna assemblage at Barçin Höyük is unusual, as it comprises of very high proportions of cattle and sheep/goat – compared to the neighbouring sites of Aktopraklık and Ilıpınar it has a very narrow resource base. Additionally, the infant mortality rate at Barçin Höyük is noticeably higher than the other Neolithic sites in the area[4] (Alpaslan-Roodenberg 2013). These factors combined might suggest that an early indigenous group attempted to adopted farming subsistence 'wholesale' at a very quick rate (e.g. mostly domesticates, little wild species), and that this approach was unsuccessful. This hypothesis is admittedly undernourished. It is evident that the site of Aktopraklık had a much wider of resources present in the assemblage, and that the evidence for human nutrition and health is far more favourable, than the higher infant mortality rate at Barçin Höyük**.**

8.8 Summary: Answering the main research questions and aims of the study

Chapter 1 of this study provides a framework of research questions and aims, and it is evident from the results and discussion chapters (chapter 5, chapter 6, chapter 7, and this chapter) that these issues have not been wholly resolved. The first question to consider from chapter 1 is 'what influence do environmental factors have on the δ^{13}C and δ^{15}N collagen values of human and fauna samples'? It is evident from the

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[4] It is of note that the excavations at Barçin Höyük are still ongoing, and further burials may be uncovered.

environmental regressions in chapter 5 (sections 5.4 and 5.5) that environmental parameters do have a direct effect on the $\delta^{13}C$ and $\delta^{15}N$ observed in faunal (not human) collagen. After multi-level statistical modelling (chapter 5) it is clear that MAP (mean annual precipitation) functions as the best proxy to account for the effects of moisture availability (for $\delta^{13}C$) and soil microbial activity (for $\delta^{15}N$), which affect the plants consumed and this effect filters into the faunal collagen $\delta^{13}C$ and $\delta^{15}N$ values.

The second environmental question to consider from the original research aims is 'how do local environmental factors influence our interpretations and reconstruction of past dietary pathways'? The results of the multi-level modelling show a 0.4‰ shift in $\delta^{13}C$ for every 100m of MAP, and a 0.5‰ shift for $\delta^{15}N$ in faunal bone collagen. If we then consider the Anatolian study sites (Aktopraklık and Barçin Höyük**)** and the Polish site of Osłonki 1 the difference in modern MAP between the two regions is approximately 200mm, therefore based on the multi-level models the $\delta^{13}C$ values from the Anatolian sites should be 0.8‰ more enriched than the Osłonki 1 fauna values, and the $\delta^{15}N$ values should be 1‰ more enriched than the Osłonki 1 fauna. In reality, this shift is technically not apparent in $\delta^{13}C$, however these values are estimates that will *themselves* have associated error terms. Therefore attempting to analyse isotopic enrichments at such a small scale (e.g. <1‰) maybe misleading.

If we combine the overall all fauna values together for each site, the enrichment observed is only 0.3‰ for $\delta^{13}C$, but a 1‰ enrichment for $\delta^{15}N$ fauna values is evident. This tentatively suggests that the difference observed in $\delta^{15}N$ fauna values between regions is the result of environmental differences and *not* different animal management practices. It is acknowledged that evidence for animal management practices is observed at a number of sites (e.g. Osłonki 1), but whether these practices produced statistically observable isotopic differences at a inter-site level, remains a subject for debate. For $\delta^{13}C$, the fact that enrichment between regions is *slightly* evident (and that its enrichment and not depletion) is encouraging and is broadly commensurate with the environmental regressions.

If we consider the fauna isotope values by species (rather than a combined value), the results alter slightly. For cattle, the $\delta^{13}C$ enrichment increases slightly (to 0.6‰), but the $\delta^{15}N$ enrichment decreases to 0.6‰. For ovicaprids the $\delta^{13}C$ enrichment between sites is only 0.2‰ and the $\delta^{15}N$ enrichment is 0.8‰. Of course, the combined values listed initially include the wild fauna – so does the change in enrichment reflect the presence of animal management strategies, or do issues such as species differences (e.g. ruminants *vs.* non-ruminants) act as confounding factors, making it problematic to draw meaningful conclusions from the isotopic dataset? It is indeed a complex problem, and perhaps one that cannot be fully answered from the data produced and used in this study. Future research into this area would certainly benefit from sequential sampling of both domestic and wild fauna tooth samples, to investigate for the presence of seasonality and transhumance, as this has been demonstrated at a number of prehistoric sites (Balasse *et al.* 2002, 2006, Balasse and Tresset 2002).

Finally, the project aimed to reconstruct human diet in Central Poland and North-West Anatolia during the Neolithic period. The $\delta^{13}C$ and $\delta^{15}N$ values for the North-West Anatolian sites are the first isotopic studies for the Neolithic period in the region, and the values are largely commensurate with the dietary isotope studies from

Neolithic sites located on the Central Anatolian plateau, with the caveat that the North-West sites perhaps had a greater reliance on herbivore protein (instead of plant protein) than their plateau counterparts. This maybe a function of climate – the dryer climes of the plateau were likely more hospitable to cultivation of crops than the Marmara region.

Similarly, the extent of the isotopic work undertaken in the Kujavia region of Poland was the first of its kind for the Neolithic period. The dietary reconstruction of Osłonki 1 uncovered a rather unexpected outcome – namely that status exerted a degree of control over human diet. If this is indeed true it will be the early evidence in Europe of a distinct relationship between the socioeconomic status and diet of an individual. The caveat to this conclusion of course is that not all of the burials have been analysed, and additionally the inclusion of new radiocarbon dates undertaken as part of this study have highlighted that the chronology is in need of refinement.

Ultimately however, it is evident that a number of new, important, and interesting conclusions were derived as a result of this project.

Chapter 9: Conclusion

9.1 Overview

The purpose of this thesis was to investigate how farming practices evolve during the second phase of the Neolithic period in Anatolia and Central Poland, using new palaeodietary isotope data for the Neolithic period from regions that were hitherto understudied. In addition, the effects of environmental parameters on stable carbon and nitrogen isotope values in bone collagen are examined. These questions are addressed through a combination of carbon and nitrogen analysis of bone collagen and statistical modelling.

9.2 How do farming practices evolve during the second phased of the Neolithic?

The main research examined the isotopic evidence for evolving farming practices through time at sites that were undergoing their secondary phase of development. The aim for the project was use isotopic dietary information alongside discrete chronological indicators to allow for the investigation of change. One of the main challenges this project has encountered is the lack of secure dating information at a high enough resolution to adequately explore changes in diet between one phase and the next. This is particularly an issue for the faunal skeletal remains at Barçin Höyük and Osłonki 1.

On a site specific level, two hypotheses are considered for all sites; *'Is there isotopic evidence to suggest a change in diet through time at the study sites'?* and *'Is there isotopic evidence to suggest that adult males and females consumed different diets'?*

At Aktopraklık, there is no isotopic evidence for a shift in diet between the Neolithic (one burial dated to 6400 – 6235 cal BC) and Chalcolithic (one burial dated to 5736 – 5635 cal BC) phases. The average $\delta^{13}C$ value for both phases in -20.2±0.2‰ and the difference in average $\delta^{15}N$ values between the Neolithic and Chalcolithic phases is negligible (9.2±0.4‰ and 9.4±0.3‰ respectively). No isotopic difference was observed between males and females. If we consult the faunal assemblage at the site, it is evident that after the onset of the Chalcolithic period, there is a change in the composition of fauna; the percentage of sheep/goat species decreases in favour of cattle, and pig also becomes more prevalent. This period also observes an increase in wild fauna, particularly fallow deer (whose skeletal remains are recovered from 'feasting' pits at the settlement). Whilst the fauna assemblage may point to a slight modification of subsistence practices, this transition is not evident in the isotopic data.

There is the issue that a number of the individuals at Aktopraklık are yet to be chronologically assigned, however their carbon and nitrogen values cluster closely with the Neolithic and Chalcolithic individuals, so provisionally, it would seem unlikely that further dating would reveal a isotopic difference between the two phases. Of all the study sites, the problem of chronological resolution poses the least issues at Aktopraklık. There is no clear *isotopic* evidence for the evolution of farming practices from the Neolithic to the Chalcolithic at this site, but the faunal assemblage itself highlights a transition towards cattle husbandry and a greater inclusion of wild resources. During the Chalcolithic period, the faunal assemblage at Aktopraklık demonstrates closer affinities with the fauna at Osłonki 1 than the fauna at Barçin Höyük.

At Barçin Höyük, the issue of chronological resolution is pronounced, although this is to be expected for a site undergoing on-going excavations. The Neolithic period at the site is currently divided into 7 layers of occupation (VIe (oldest) to VIa), which span a chronological period of *c.*6600 – 6500 cal BC to *c.*6000 – 5900 cal BC. As the excavations and research continues it is possible that further sub-phases will be defined (Gerritsen *et al.* 2013:95), which may influence the interpretation of isotope data. The humans analysed from the site were recovered from layers VIe (burial I.D.'s with the suffix L13 and L14), VIb (burials with the suffix M10, M11, M13, L13) and layer VId and VIc (burials with the suffix M10 and L11). Layer VIe represents the oldest phase of occupation at the site. There is some overlap with burials and layers (e.g. burials with the M10 suffix might date to a number of different layers). When the human isotope values are examined layer by layer there is no evidence to suggest a difference in diet from one phase to the next. In addition, the males and females cluster tightly, with the average $\delta^{13}C$ values at -19±0.1‰ and -18.8±0.4‰ respectively, and 9.9±0.0‰ and 10±0.4‰ respectively for $\delta^{15}N$ values. No statistical difference is observed between the male and female isotope values.

The human isotope data is particularly interesting given that the isotopes values for the fauna show considerable range, particularly for $\delta^{13}C$ (the variation in cattle samples alone is 6‰). Whilst a considerable amount of this variation can be explained by the inclusion of C_4 protein (wild grasses) in the diet of the fauna, it would be interesting to refine the chronological assignment of the fauna samples to examine the evidence for any change in values from one phase to the next. It is possible that any observed changes in isotopic values could reflect changes in animal management (environmental impacts notwithstanding) and this would provide direct evidence for the evolution of farming practices at this site. There is no distinct change observed in biodiversity from the faunal assemblage throughout the phases.

At Osłonki 1, the issue of dating is again problematic. If we consider the human isotope dataset using the established chronology (e.g. the one in place prior to this project), the difference in $\delta^{15}N$ values between the Classic and Late phase is significant ($p=0.0001$, chapter 6), and the difference in the distribution of the $\delta^{13}C$ values is not significant. However, with the advent of the additional radiocarbon dates as part of this project, it would be unwise to assume that this conclusion is secure. Additionally, there are significant differences in Classic and Late faunal $\delta^{13}C$ *and* $\delta^{15}N$ values even with species types combined ($p=0.02$ and $p<0.001$ respectively, chapter 5), which would provisionally suggest a change in animal management. However, this interpretation of the isotope data is based on the previous chronological seriations. It is clear from this project that further work is required to refine the chronological resolution at the site. However, chronological issues aside, the cattle, sheep/goat, and pig $\delta^{13}C$ and $\delta^{15}N$ distributions are all significantly different from one another. If we compare this data to Aktopraklık and Barçin Höyük, where no isotopic difference is observed between species – despite the fact that there is greater overall isotopic variation in Anatolia – it is clear that the population at Osłonki 1 was utilising different animal management practices for different species at their site. Further research will reveal whether these differences evolved through time. Finally, the statistical difference in human $\delta^{13}C$ values between copper and non-copper burials remains significant ($p=0.008$), as chronological seriation is not a defining factor.

Previous environmental reconstruction of the study region of North-West Anatolia has suggested the presence of a distinct aridity spike during the Late Neolithic/Early Chalcolithic period in the Yenişehir Valley (Bottema and Woldring 1995, see chapter 2). If a spike in aridity did occur at this point, we would expect to observe the enrichment of both $\delta^{13}C$ and $\delta^{15}N$ isotope values of the faunal bone collagen. Due to the lack of a secure chronology for faunal samples at either of the study sites, it is difficult to positively identify the presence or absence of a shift in isotope values at the transition of the Late Neolithic/ Early Chalcolithic period. Whilst it is evident that a few of the cattle samples at Barçin Höyük exhibit enriched $\delta^{13}C$ values (<-18‰) which, assuming they date to the latter phases of the Neolithic, could speculatively reflect a shift towards more arid conditions, it would be problematic to disentangle the affects of climate from those of C_4 protein dietary inclusion using only bulk isotope analysis of bone collagen. An alternative approach would be to combine $\delta^{18}O$ values from faunal tooth enamel to investigate fluctuations in climate.

9.4 Additional hypotheses

In addition to the major research questions, a number of smaller hypotheses were also considered during the course of the project. Firstly, '*is there isotopic evidence to suggest the consumption of aquatic protein resources at the Anatolian study sites'?* The answer to this question is no, there is no archaeological evidence (isotopic or otherwise) to suggest the consumption of aquatic protein resources at either Aktopraklık or at Barçin Höyük – despite their proximity to lakes Ulubat and Iznik respectively. The lack of significant aquatic protein consumption during the Neolithic period is perhaps not surprising, as transitions towards agricultural subsistence methods (and away from hunting, fishing, and gathering practices) are defining characteristics of the period. The presence of freshwater species at contemporary sites in the region (e.g. Fikirtepe, Menteşe, and Pendik) is interesting, as it suggests that populations with hybridised subsistence practices (e.g. fishing and agriculture) existed alongside fully formed agricultural societies - despite the fact that they had access to the same resources. This information feeds into discussions regarding the transmission of agriculture as a technology, as well as the question of indigenous adoption *vs.* transition of populations. Whilst the transition of farming populations from the Near East into Anatolia is fairly well documented, there is a significant chronological hiatus between the appearance of Neolithic sites on the Anatolian plateau and the appearance of Neolithic sites in the North-West region (chapter 2). There are 10 known Palaeolithic and Epi-Palaeolithic sites in the North-West region (this period of Anatolian prehistory is poorly studied compared to its Neolithic counterparts), providing evidence that the region was occupied, even if only sparsely, prior to the advent of farming technologies in the region. Therefore, the presence of hybridized subsistence practices in the region may reflect the presence of both transition, and indigenous adoption, in North-West Anatolia.

The second hypotheses investigated for this project examined the relationship between social status and diet in Neolithic Poland; *'Is there a correlation between burial status and human isotope values at Osłonki 1'?* The short response is yes. There is a clear relationship between δ^{13}C values and the presence of copper artefacts as grave goods – this observed difference remains in place despite the fact that the new radiocarbon dates for Osłonki 1 have highlighted issues with the current chronology. The identification of a relationship between burial status and food consumption at this juncture in prehistory is uncommon, and this evidence contributes towards studies of the evolution of social complexity of human populations during (fairly) early phases of development.

If we consider the question of ‘physical’ access to food resources *vs.* ‘social’ access to food resources, it appears that social (more so than physical) factors dictate diet in both Poland and Anatolia. In Anatolia, despite the plentiful protein resources that surround the sites of Aktopraklık and Barçin Höyük (e.g. freshwater, terrestrial, with marine resources in reasonable proximity), the populations at these sites focused solely on terrestrial resources. At neighbouring sites, aquatic resources are in evidence, suggesting that any differences observed occur between sites (e.g. at an inter-site level). In the Polish study region the resolution changes, and social difference in diet is evident at the intra-site level.

9.5 Future directions

There are a number of future directions that would add significant value to this research area. All of the study sites would benefit from the sequential sampling of faunal dentinal collagen to examine potential evidence for seasonality and transhumance. Ideally, domestic fauna samples would be analysed to investigate for potential animal management practices, and this would be undertaken alongside the analysis of wild fauna dentinal collagen samples that could provide an analogue for changing seasonal conditions (e.g. fluctuations in moisture availability) in the region. This avenue of research could easily be pursued for the site of Osłonki 1, which has both domestic and wild faunal species in abundance. Aktopraklık is also promising, as a number of red deer remains were recovered from pits in the settlement area of the site (chapter 2, section 2.4.1), in addition to the domestic fauna. The site of Barçin

Höyük may present a greater problem, as the majority of the fauna recovered from the site are domestic.

From a regional perspective, the areas of North-West Anatolia and North-Central Poland could benefit from further isotopic and/or radiocarbon dating research. The area of North-West Anatolia is indeed interesting, as it comprised in part of sites similar to Aktopraklık and Barçin Höyük (e.g. apparently fully formed agricultural sites) and sites such as Fikirtepe and Pendik that are characterised by significant proportions of aquatic species (fish and mollusc) alongside domestic animals in their faunal assemblages. This mixed faunal assemblage has led to a number of researchers, including the author, to theorize about the possibility of a hybridization of subsistence methods in region (Ozdogan *et al.* 2005, 2011, Budd *et al.* 2013, Lillie *et al.* 2013). The opportunity to analyse skeletal collagen for $\delta^{13}C$ and $\delta^{15}N$ from these sites (Fikirtepe and Pendik etc., see chapter 2), could potentially change the way we perceive the transition of the Neolithic in this region.

In summary, it is evident from the study sites of Aktopraklık and Osłonki 1 that farming practices evolved via a transition towards a greater reliance on cattle protein, alongside the diversification, and increased inclusion of, wild fauna. At Aktopraklık, the difference between the domestic fauna isotope values are not significant, but at Osłonki 1 the differences in isotope values are significantly different. This speculatively suggests that at the point when the region of Poland was undergoing its secondary phase of Neolithic development, the available farming technologies had evolved to the extent where the focus was not on which species to select, but in fact, how to precisely manage each species within the landscape.

9.3 Climatic impacts on carbon and nitrogen isotope values in faunal bone collagen

The second major question for the research addresses the issue of climate conditions; *'Is there a correlation between climate conditions and isotope values in faunal collagen at the study sites'?* Yes, there is a clear and significant statistical relationship between mean annual precipitation (mm) and $\delta^{13}C$ and $\delta^{15}N$ values in faunal bone collagen at the study sites. The multi-level model (chapter 6) demonstrated a 0.4‰ decrease in $\delta^{13}C$ for every 100mm of MAP, and a 0.5‰ shift in $\delta^{15}N$ for every 100mm. The model is comparable with plant values from the literature, which estimates 1-2‰ for every 500-1000mm change in precipitation levels (Van Klinken *et al.* 1994, Hartman and Danin 2010, Hedges *et al.* 2013). Whilst a number of the other climate factors exhibited some relationship with isotope values (sunshine for $\delta^{13}C$, and evapotranspiration for $\delta^{15}N$), it is mean annual precipitation that demonstrates the strongest correlation.

Appendix 1

This appendix contains information pertaining to chapter 5 and chapter 6 faunal and human stable isotope results, and the statistical modelling of this data. Table A1.1 details all of the δ^{13}C and δ^{15}N data obtained for this project, alongside the quality control data.

Site	Sample I.D	Species	% collagen yield	% C	%N	δ^{13}C (‰)	δ^{15}N (‰)	C:N
Aktopraklık	AK 1	*Human*	15.6	42.1	14.3	-20.1	8.4	3.2
	AK 2		17.2	40.7	16.8	-20.5	9.5	3.1
	AK 3		11.2	40.9	15.5	-19.8	9.9	3.0
	AK 4		8.4	45.0	16.2	-20.2	9.9	2.9
	AK 5		7.9	42.4	12.2	-19.8	9.9	3.0
	AK 6		8.1	43.6	13.8	-20.2	8.4	3.2
	AK 7		4.7	43.0	16.6	-20.2	9.1	3.2
	AK 8		2.3	43.1	15.2	-20.2	8.1	3.3
	AK 9		3.7	44.2	14.8	-19.9	9.5	3.2
	AK 10		3.6	40.2	15.3	-20	9.6	3.3
	AK 11		7.9	45.8	17.0	-19.9	9.7	3.3
	AK 12		7.0	40.5	16.2	-19.7	10.1	3.5
	AK 13		6.4	46.4	15.4	-20.3	8.8	3.2
	AK 14		5.9	41.9	12.0	-20.3	9.1	3.1
	AK 15		8.4	43.7	14.7	-20.1	9.9	2.9
	AK 16		15.6	43.6	13.9	-20.6	7.7	3.0
	AK 17		12.4	41.9	16.4	-20.1	10.6	3.1
	AK 18		2.9	44.7	16.9	-20.4	8.5	3.1
	AK 19		3.1	45.4	12.6	-20.2	8.8	3.1
	KA 20		6.8	40.9	11.9	-20.2	8.5	3.2
	KA 7		4.9	41.3	15.5	-20.4	8.9	3.3
	KA 5		4.4	45.6	14.9	-19.4	12.1	3.2
	KA 2		6.1	43.2	13.8	-20.3	8.8	3.1
	KA12		9.7	44.0	14.2	-19.6	10.3	3.1
	AKFI 1	*Atherina hepsetus* (Atherina)	17.9	46.9	12.1	-21.2	10.3	3.4
	AKFI 2	*Esox masquinongy* (muskellunge)	16.8	47.9	13.9	-25.2	11.2	3.5
	AKFI 3	*Cyprinus carpio* (yellow carp)	17.1	47.6	15.1	-26	13.9	3.4
	AKFI 4	*Scardinius*	17.4	46.9	16.2	-23.6	11.1	3.4

		erythrophthalmus (Common rudd)						
	AKFI 5	*Silurus glanis* (wells catfish)	18.6	47.4	17.2	-21.7	8.6	3.4
	KA 1	OviCaprid (sheep/goat)	6.7	40.9	15.3	-20.8	14.1	3.1
	KA 3		5.8	42.6	16.2	-20.9	7.8	3.1
	KA 4		1.9	44.3	16.8	-20.3	6.9	3.2
	KA 6		2.7	41.8	14.3	-20.1	4.8	3.3
	KA 8		2.2	42.2	15.3	-19.7	4.8	3.2
	KA 9		4.9	44.6	15.0	-19.2	5.0	3.1
	KA 10		4.1	45.3	17.1	-20.3	6.3	2.9
	KA 11		6.9	45.8	13.5	-20.3	5.8	3.1
	KA 13		4.1	40.2	12.6	-19.7	5.0	3.0
	KA 14		9.6	41.7	14.1	-19.2	6.3	3.2
	KA 15		4.9	44.5	15.2	-20.3	5.8	3.2
	KA 16		2.1	48.0	16.4	-20.8	7.9	3.2
	KA 17		4.5	43.1	17.1	-20.9	6.9	3.3
	KA 18	Goat	5.5	44.4	14.5	-20.3	5.8	3.3
	KA 19	*Bos taurus* (cattle)	7.2	42.6	14.3	-20.5	7.3	3.1
	KA 20		6.8	42.8	14.9	-20.5	5.6	3.2
	KA 21		1.9	42.6	13.8	-18.0	7.2	3.2
	KA 22		2.3	46.9	12.6	-18.5	8.8	3.2
	KA 23		3.8	44.2	16.3	-19.4	5.0	3.2
	KA 24		4.1	46.1	15.8	-20.3	5.7	3.3
	KA 25		7.8	43.8	13.1	-20.5	7.3	3.3
	KA 26		4.7	44.2	16.9	-20.5	5.6	3.3
	KA 27		10.3	41.7	15.3	-20.2	5.7	3.4
	KA 28	*Sus domestus* (domestic pig)	12.1	46.5	14.7	-20.6	4.0	3.2
	KA 29		14.5	45.1	15.0	-21.2	4.0	3.1
	KA 30		12.8	42.8	17.0	-20.6	7.2	3.2
	KA 31		11.9	45.6	14.3	-19.9	8.1	3.2
	KA 32	*Sus scrofa* (wild boar)	7.1	43.7	12.1	-19.6	3.5	3.2
	KA 33	*Cervus elaphus* (red deer)	2.9	46.7	13.2	-21.5	4.6	3.3
	KA 34		9.1	43.1	13.3	-21.5	5.0	3.1
	KA 35	*Dama dama* (Fallow deer)	9.3	43.3	15.7	-20.1	4.1	3.2
Barçin Höyük	BA 1	*Human*	10.1	45.0	13.9	-20	10.4	3.2
	BA 2		11.4	43.2	15.4	-18.8	10.1	3.2
	BA 3		7.8	45.6	15.8	-19.5	10.3	3.1
	BA 4		9.1	44.7	14.6	-19.3	9.8	3.4
	BA 5		8.4	43.9	13.6	-19.4	9.4	3.3

	BA 6		8.7	44.5	13.2	-19.2	9.9	3.1
	BA 6		3.2	43.1	13.5	-19.0	9.9	3.0
	BA 7		7.6	43.2	13.9	-19.9	9.1	3.2
	BA 8		3.9	40.8	14.8	-20.0	9.7	3.2
	BA 9		10.1	41.2	15.6	-18.3	10.5	3.3
	BA 10		11.4	43.6	17.1	-18.1	11.1	3.3
	BA 11		5.1	42.8	14.3	-18.4	10.8	3.3
	BA 12		6.8	43.0	14.2	-19.9	12.0	3.2
	BA 13		2.4	46.0	14.7	-18.3	10.0	3.2
	BA 14		9.5	45.6	14.1	-18.9	10.6	3.2
	BA 15		9.2	41.4	15.8	-19.9	12.0	3.3
	BA 16		7.4	47.0	15.0	-18.3	10.0	3.3
	BA 17		6.8	42.2	14.7	-18.9	10.6	3.1
	BA 18		6.9	48.0	15.2	-17.4	12.0	3.3
	BA 19		6.0	43.2	16.8	-19.2	11.1	3.3
	BA 20		3.1	43.1	17.2	-19.7	10.4	3.2
	BA 21	OviCaprid (sheep/goat)	9.8	46.8	16.3	-19.0	7.6	3.0
	BA 22		7.5	46.7	13.2	-19.4	7.3	3.2
	BA 23		3.1	40.4	13.7	-19.7	4.9	3.2
	BA 24		2.9	44.1	12.9	-20.0	6.9	3.3
	BA 25		9.3	43.6	15.3	-20.2	6.7	3.2
	BA 26		8.0	45.8	16.4	-19.4	6.7	3.3
	BA 27		8.1	46.2	12.0	-19.0	7.5	3.3
	BA 28		9.4	47.3	12.6	-19.4	6.4	3.3
	BA 29		7.4	42.6	14.2	-19.4	8.8	3.2
	BA 30		5.9	43.5	15.4	-18.5	7.9	3.3
	BA 31		5.9	43.0	16.3	-19.0	7.6	3.2
	BA 32		5.0	41.4	15.2	-19.6	4.9	3.3
	BA 33		3.0	42.9	16.2	-20.8	6.9	3.3
	BA 34	Sheep	4.8	45.8	15.3	-20.7	8.9	3.2
	BA 35		3.4	46.5	14.7	-20.1	5.5	3.1
	BA 36		2.9	45.7	13.4	-20.3	7.9	3.3
	BA 37		8.1	44.5	16.3	-20.5	6.1	3.3
	BA 38		9.1	41.2	16.1	-20.1	7.2	3.3
	BA 39	*Bos Taurus* (cattle)	10.1	40.8	15.5	-16.3	9.2	3.2
	BA 40		9.3	42.0	16.4	-19.0	8.0	3.4
	BA 41		8.7	45.5	17.2	-20.4	5.7	3.2
	BA 42		8.4	43.6	15.3	-17.6	6.4	3.2
	BA 43		9.0	42.5	16.0	-19.3	6.4	3.2
	BA 44		4.8	47.2	14.8	-20.9	5.5	3.3
	BA 45		5.6	44.1	15.1	-22.0	5.2	3.2
	BA 46		4.9	46.4	15.7	-20.5	6.5	3.3
	BA 47		6.7	43.1	14.3	-20.0	6.5	3.1
	BA 48		5.9	45.3	14.0	-19.0	8.0	3.3
	BA 49		6.3	45.9	16.6	-20.4	5.8	3.3
	BA 50		6.2	45.7	17.2	-17.6	6.5	3.3
	BA 51		9.1	42.2	17.9	-19.2	6.4	3.2
	BA 52		8.0	47.0	15.8	-20.5	6.1	3.3

	BA 53		8.4	42.3	15.3	-21.9	5.3	3.2
	BA 54		2.9	44.6	14.0	-20.5	6.6	3.2
	BA 55		6.6	45.4	12.4	-19.7	7.0	3.2
	BA 56	*Bos primigenius* (auroch)	5.1	45.7	12.9	-20.7	6.3	3.3
	BA 57	*Sus domestus* (domestic pig)	5.5	44.4	13.1	-20.6	7.6	3.2
	BA 58	*Sus scrofa* (wild boar)	5.9	43.2	16.4	-19.9	5.1	3.3
	BA 59	*Vuples vulpes* (Fox)	6.4	44.2	14.5	-19.2	8.1	3.2
	BA 60	*Cervus elaphus/Alc elaphinae* sp. (Red deer sp.)	6.7	45.8	13.2	-21.6	4.6	3.3
Osłonki 1	OSH 1	*Human*	9.2	42.5	15.2	-20.1	8.4	3.3
	OSH 2		10.5	42.7	14.9	-20.4	8.5	3.3
	OSH 3		11.2	43.1	13.8	-20.1	7.8	3.3
	OSH 4		13.1	42.0	14.2	-20.1	9.1	3.2
	OSH 5		12.7	44.9	17.1	-20.0	9.1	3.2
	OSH 6		9.1	41.8	16.0	-19.9	8.7	3.3
	OSH 7		8.2	44.3	16.6	-20.0	8.3	3.2
	OSH 8		8.0	45.7	11.8	-20.1	8.0	3.2
	OSH 9		9.9	42.9	12.7	-20.2	8.4	3.2
	OSH 10		10.3	42.8	14.5	-20.7	8.7	3.3
	OSH 11		14.0	41.5	16.7	-20.3	8.5	3.3
	OSH 12		13.9	42.0	15.2	-19.7	8.4	3.3
	OSH 13		9.3	43.9	13.9	-20.8	7.5	3.2
	OSH 14		9.5	42.8	12.2	-20.4	8.3	3.1
	OSH 15		7.2	43.1	14.8	-20.2	9.3	3.3
	OSH 16		6.8	46.0	14.2	-20.2	8.4	3.3
	OSH 17		4.7	47.2	15.0	-20.2	8.8	3.3
	SO 1		3.0	43.9	14.8	-19.7	8.6	3.2
	SO 2		4.6	44.5	13.2	-20.7	7.8	3.3
	SO 3		5.4	42.8	11.6	-20.6	8.6	3.4
	SO 4		6.2	41.9	12.7	-20.3	8.3	3.3

	SO 5		6.8	40.8	12.9	-19.7	8.9	3.3
	SO 6		5.7	45.1	13.1	-20.5	8.5	3.3
	SO 7		11.2	47.0	14.3	-20.0	9.2	3.3
	SO 8		9.6	43.2	14.7	-19.7	9.1	3.3
	SO 9		7.1	46.3	14.6	-20.6	8.1	3.3
	SO 10		6.8	44.7	16.3	-19.5	8.7	3.3
	SO 11		9.4	43.4	15.8	-20.6	7.9	3.3
	SO 12		8.4	41.5	14.2	-20.1	9.2	3.3
	SO 13		8.0	44.6	17.0	-20.5	8.8	3.2
	OS 32	*Emys orbicularis* (European pond tortoise)	2.3	45.8	13.6	-24.1	7.5	3.3
	OS 64		7.3	44.8	12.8	-25.5	7.1	3.3
	OS 77		9.1	40.6	13.4	-25.1	6.3	3.2
	OS 111		5.2	41.0	17.5	-24.2	7.0	3.2
	OS 2	*Bos Taurus* (cattle)	11.1	46.2	14.3	-21.0	4.6	3.2
	OS 3		12.5	47.1	15.2	-20.8	4.8	3.2
	OS 5		9.3	46.9	16.8	-21.0	5.2	3.3
	OS 15		8.8	45.0	16.7	-20.9	4.8	3.3
	OS 16		7.9	42.8	14.6	-20.1	5.7	3.3
	OS 17		4.9	43.7	13.6	-20.4	6.3	3.2
	OS 18		5.6	46.7	12.3	-20.7	5.6	3.3
	OS 19		3.9	48.2	12.8	-20.6	5.3	3.3
	OS 20		6.4	47.1	16.0	-20.2	5.6	3.3
	OS 21		7.0	45.2	16.1	-20.2	5.7	3.3
	OS 36		4.1	46.1	13.2	-20.0	6.6	3.2
	OS 37		5.2	45.4	14.6	-20.1	7.1	3.3
	OS 38		9.4	46.8	14.4	-20.4	6.2	3.3
	OS 51		4.7	40.7	16.5	-20.5	7.4	3.2
	OS 56		2.8	41.2	16.1	-20.7	7.1	3.2
	OS 57		8.7	42.2	14.2	-20.5	6.9	3.2
	OS 58		5.2	40.7	13.8	-20.6	5.8	3.2
	OS 59		10.1	45.3	17.0	-20.8	6.5	3.3
	OS 60		3.8	46.9	16.4	-20.5	6.3	3.3
	OS 61		5.2	44.4	16.2	-20.7	6.2	3.2
	OS 62		8.5	42.5	15.3	-20.9	7.3	3.3
	OS 63		9.5	41.8	14.6	-20.8	5.5	3.3
	OS 65		6.3	46.2	11.9	-20.8	5.5	3.3
	OS 67		8.9	41.7	14.2	-20.5	6.4	3.3
	OS 70		2.8	43.2	15.8	-21.2	4.2	3.2
	OS 73		3.8	42.5	15.9	-20.9	5.1	3.1
	OS 76		4.7	44.9	12.3	-20.3	6.8	3.3
	OS 78		5.9	47.1	13.7	-20.6	5.5	3.3
	OS 79		5.1	43.8	15.5	-20.1	5.8	3.3
	OS 89		8.5	44.9	15.3	-21.0	5.6	3.3
	OS 90		7.9	43.2	14.2	-20.4	4.7	3.2
	OS 91		8.1	45.1	15.4	-20.5	5.9	3.2
	OS 66		12.1	42.6	16.7	-20.7	5.8	3.3
	OS 72		11.2	41.1	12.9	-20.8	6.3	3.2

	OS 88		11.9	48.1	13.2	-20.7	5.1	3.2
	OS 98		3.9	48.0	14.0	-20.4	5.2	3.2
	OS 101		4.1	44.1	16.4	-21.3	6.1	3.2
	OS 102		3.6	43.2	17.3	-20.7	6.8	3.2
	OS 123		5.4	40.8	14.9	-20.0	6.3	3.3
	OS 124		5.2	41.5	12.5	-20.1	5.9	3.3
	OS 125		13.1	42.1	13.8	-20.7	6.1	3.3
	OS 126		5.8	46.5	14.1	-20.2	6.9	3.2
	OS 127		3.4	46.6	16.4	-22.4	5.5	3.3
	OS 130		9.3	40.2	15.8	-20.7	6.7	3.3
	OS 113	*Bos primigenius* (auroch)	3.3	43.3	13.1	-20.4	7.2	3.3
	OS 1	Ovicaprid (sheep/goat)	7.2	44.7	13.0	-19.9	6.7	3.3
	OS 11		7.1	45.9	14.9	-20.3	5.7	3.3
	OS 13		9.5	47.1	13.5	-20.2	4.5	3.3
	OS 23		4.7	44.5	14.9	-20.0	5.5	3.3
	OS 31		4.6	46.2	15.2	-20.0	6.2	3.2
	OS 40		7.4	41.5	15.6	-20.6	5.7	3.1
	OS 41		6.8	42.8	14.2	-20.1	5.4	3.3
	OS 42		9.3	40.9	15.6	-19.9	5.7	3.3
	OS 47		4.5	46.7	15.3	-20.3	7.8	3.3
	OS 48		5.5	42.0	12.8	-20.1	7.8	3.3
	OS 52		3.9	43.5	12.4	-20.2	5.1	3.2
	OS 53		4.1	46.6	13.4	-20.1	5.3	3.3
	OS 54		8.0	47.1	16.8	-20.1	5.6	3.3
	OS 55		10.3	42.7	14.6	-20.1	5.7	3.3
	OS 68		10.7	48.0	12.1	-20.1	5.7	3.3
	OS 81		14.8	45.8	13.9	-19.7	5.6	3.3
	OS 82		8.4	44.7	14.7	-19.9	5.1	3.3
	OS 85		7.5	42.6	14.9	-19.6	5.1	3.2
	OS 86		7.6	43.0	11.9	-19.0	5.2	3.3
	OS 87		8.9	44.1	12.6	-19.6	5.4	3.3
	OS 99		9.3	43.6	13.5	-19.9	5.4	3.3
	OS 100		4.9	45.8	14.6	-20.2	5.8	3.3
	OS 103		6.3	42.7	13.9	-20.1	5.2	3.3
	OS 104		3.1	44.2	15.8	-20.8	6.4	3.3
	OS 107		4.4	47.2	16.7	-20.5	7.1	3.3
	OS 109		9.4	44.3	15.2	-21.1	6.7	3.3
	OS 112		5.7	45.6	13.8	-20.0	4.9	3.3
	OS 117		5.7	47.0	14.6	-20.8	4.9	3.3
	OS 119		4.9	43.9	14.9	-20.3	4.7	3.3
	OS 129		5.1	44.1	12.5	-20.2	6.1	3.2
	OS 4	*Sus domestus* (domestic pig)	7.9	46.2	13.1	-20.1	7.1	3.3
	OS 6		8.3	46.9	13.4	-20.3	6.6	3.3
	OS 22		9.5	41.0	14.1	-20.6	6.6	3.3
	OS 26		3.9	43.6	15.3	-20.8	6.1	3.3
	OS 30		4.3	44.8	16.7	-21.0	6.3	3.2

	OS 43		5.2	40.8	14.5	-20.9	7.2	3.3
	OS 44		8.5	43.2	14.8	-20.6	8.1	3.3
	OS 45		8.9	45.8	13.2	-19.7	5.9	3.3
	OS 46		7.6	46.7	12.0	-20.9	8.0	3.3
	OS 49		2.9	43.1	13.2	-21.1	7.8	3.3
	OS 50		6.4	44.9	14.2	-21.0	9.2	3.2
	OS 69		6.0	48.5	15.4	-21.8	8.5	3.3
	OS 71		5.9	45.1	16.8	-21.2	8.5	3.3
	OS 74		3.9	44.1	15.6	-23.0	5.8	3.3
	OS 83		6.4	42.4	13.0	-20.5	6.1	3.3
	OS 84		9.7	41.3	11.9	-20.8	6.7	3.3
	OS 93		7.3	44.7	11.4	-21.4	8.5	3.3
	OS 105		9.5	46.2	13.4	-20.4	7.5	3.2
	OS 120		9.2	42.4	15.0	-20.7	7.4	3.3
	OS 128		10.5	43.6	16.3	-20.3	8.5	3.2
	OS 8	*Sus scrofa* (wild boar)	8.5	44.0	17.0	-20.5	6.5	3.2
	OS 34		9.1	45.2	14.6	-21.3	5.7	3.2
	OS 75		7.4	42.6	13.5	-21.2	4.7	3.2
	OS 92		9.0	45.9	15.4	-21.0	6.3	3.2
	OS 96		15.1	46.0	13.2	-21.4	4.9	3.3
	OS 118		12.3	46.2	12.8	-20.7	4.9	3.3
	OS 7	*Cervus elaphus* (red deer)	4.0	46.7	16.5	-22.1	2.5	3.3
	OS 10		7.4	40.5	16.2	-20.4	5.5	3.3
	OS 25		8.6	41.8	14.9	-20.9	3.4	3.2
	OS 33		9.4	45.3	15.1	-20.9	5.7	3.3
	OS 94		9.0	46.1	16.3	-20.2	7.4	3.3
	OS 95		3.8	44.4	11.8	-20.5	5.5	3.3
	OS 110		5.2	43.4	13.3	-22.0	4.0	3.3
	OS 116		12.3	46.0	14.7	-20.4	3.8	3.2
	OS 122		9.4	43.2	14.0	-20.1	4.0	3.2
	OS 27	*Capreolus capreolus* (Roe deer)	8.1	46.9	13.6	-21.6	4.4	3.2
	OS 28		9.5	44.1	12.7	-21.2	5.2	3.2
	OS 29		10.4	42.2	13.7	-21.5	4.8	3.2
	OS 80		8.5	42.6	15.8	-21.0	4.1	3.3
	OS 106		9.3	45.9	16.2	-20.1	6.3	3.3
	OS 114		8.5	40.8	13.0	-19.3	5.0	3.2
	OS 121		7.4	44.3	14.9	-20.8	5.3	3.3
	OS 97	*Equus* sp. (horse)	12.7	46.2	12.6	-22.3	3.9	3.2
	OS 9	*Castor fiber* (Eurasian beaver)	3.8	45.4	13.7	-20.5	8.5	3.3
	OS 108	*Canis* sp. (dog)	8.4	42.8	12.4	-19.6	7.8	3.3
	OS 115		8.1	43.1	12.9	-18.3	8.6	3.2

Table A1.1. Quality control markers alongside δ ^{13}C and δ ^{15}N for collagen samples processed.

The graphs show the linear regressions for faunal δ ^{13}C and δ ^{15}N values against environmental variables.

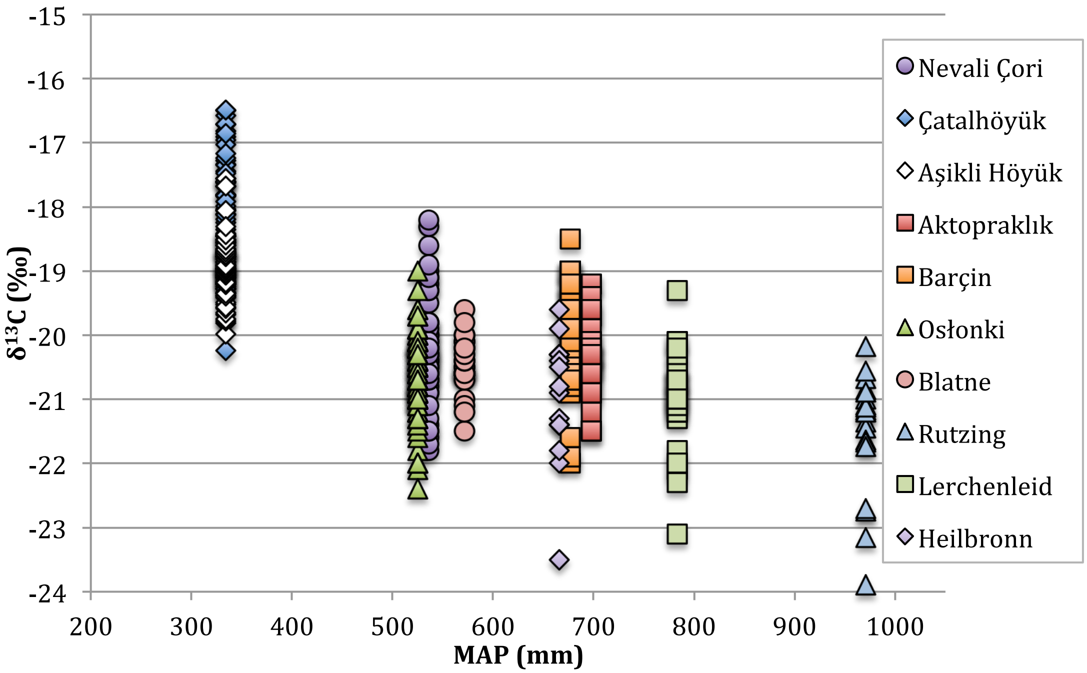

Figure A1.1. Mean Annual Precipitation and δ^{13}C of herbivore fauna bone collagen. Precipitation data is the average value per year for a 10 year span (2002-2012) Data from AquaStat.

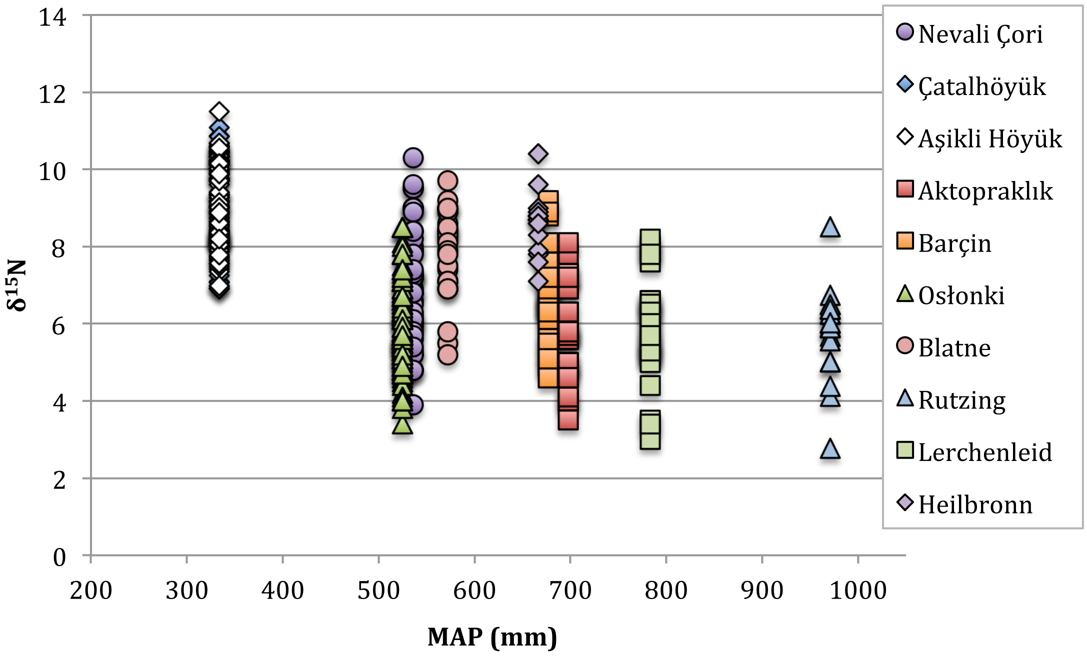

Figure A1.2. Fauna δ^{15}N and Mean Annual Precipitation (mm). Fauna δ^{15}N (Data: from AquaStat).

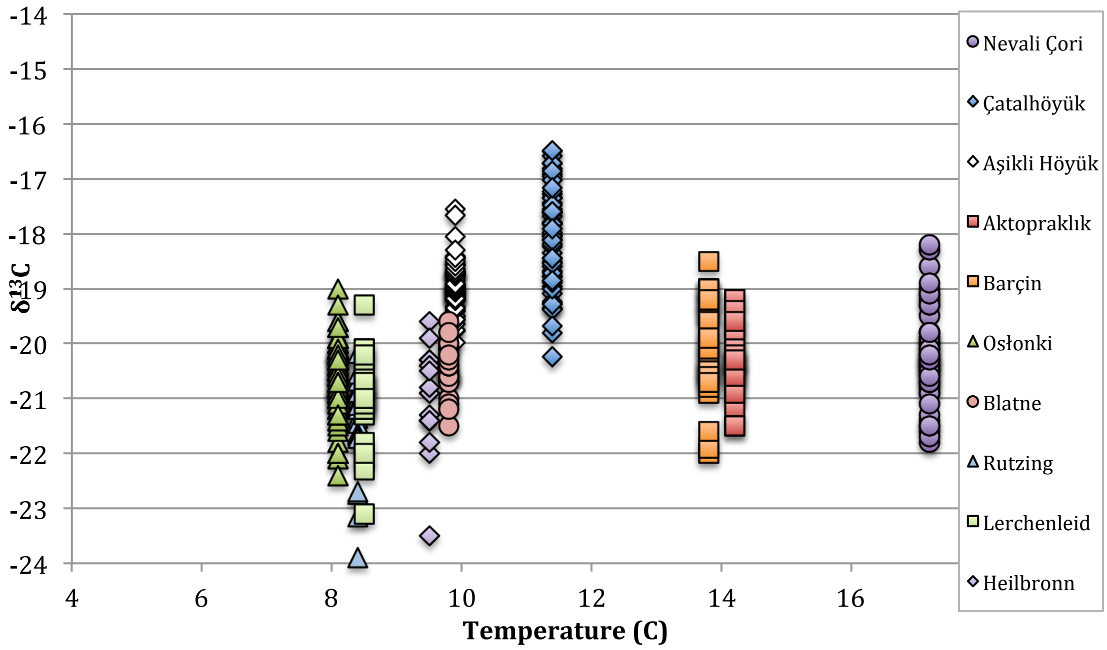

Figure A1.3. Fauna δ^{13}C values in fauna bone collagen and mean annual temperature (MAT) (°C) (Data: AquaStat).

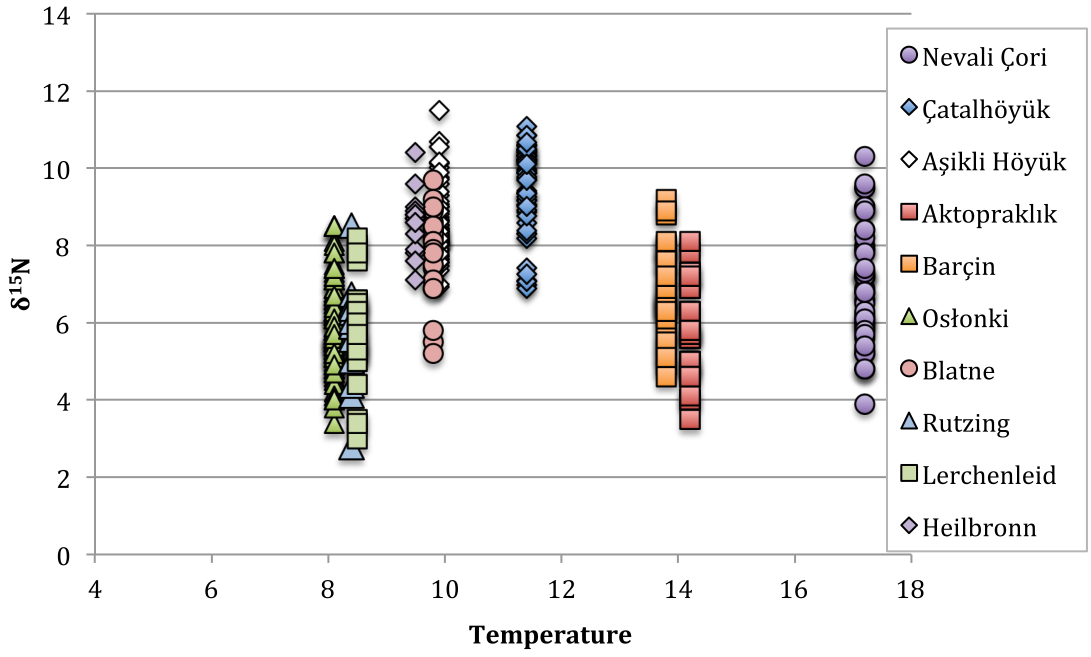

Figure A1.4. Fauna δ^{15}N and mean annual temperature (°C) (Data: AquaStat).

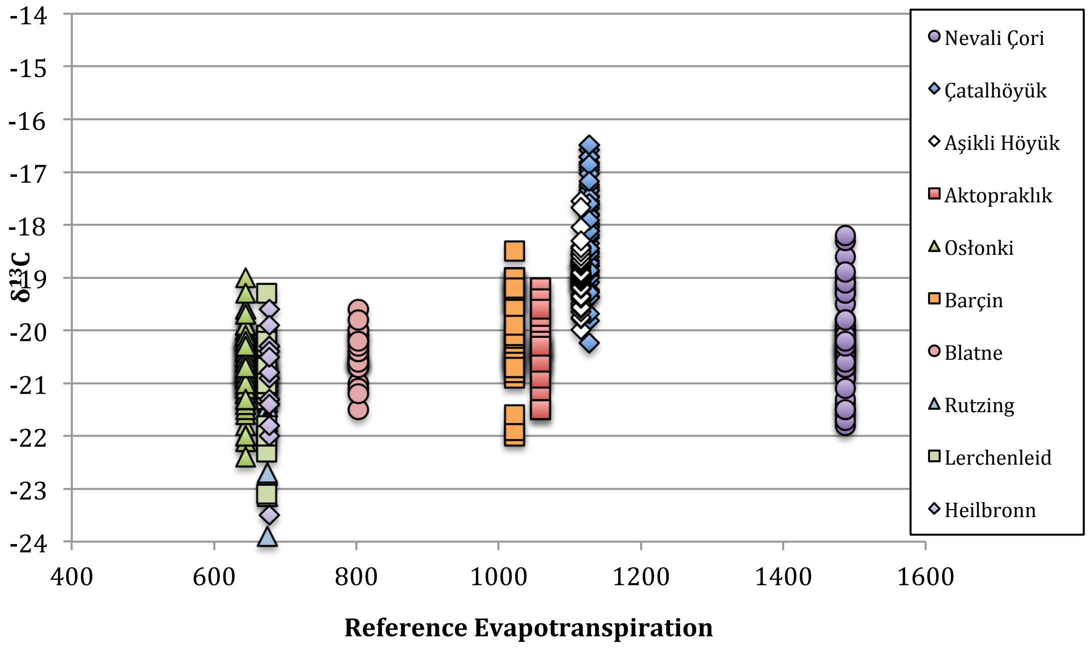

Figure A1.5. Fauna δ^{13}C fauna values and reference evapotranspiration.

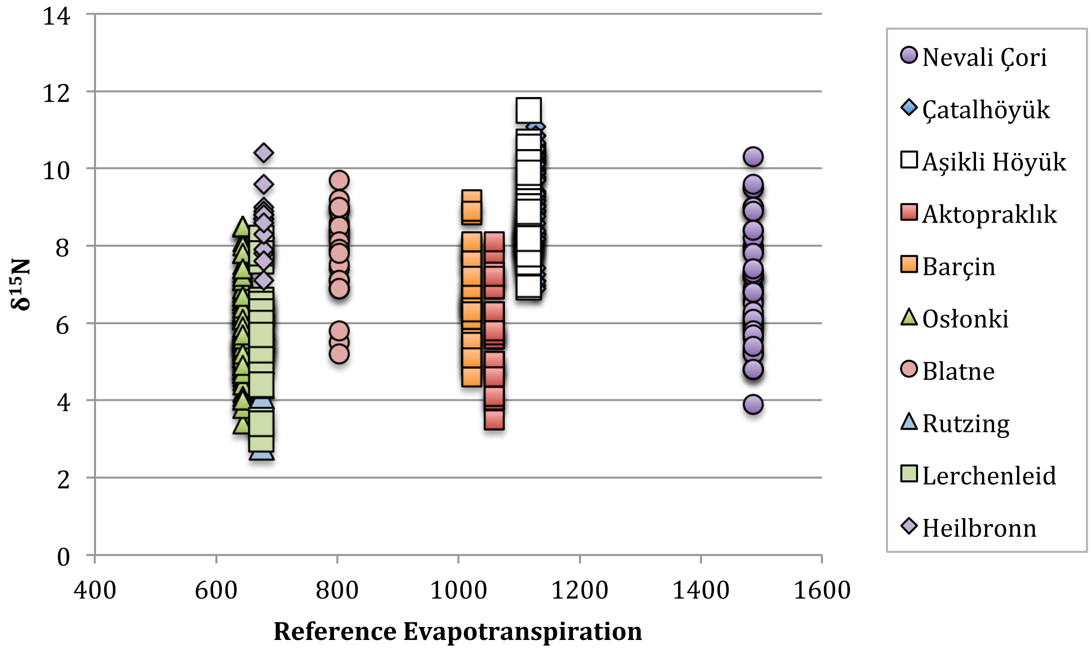

Figure A1.6. Fauna δ^{15}N and reference evapotranspiration.

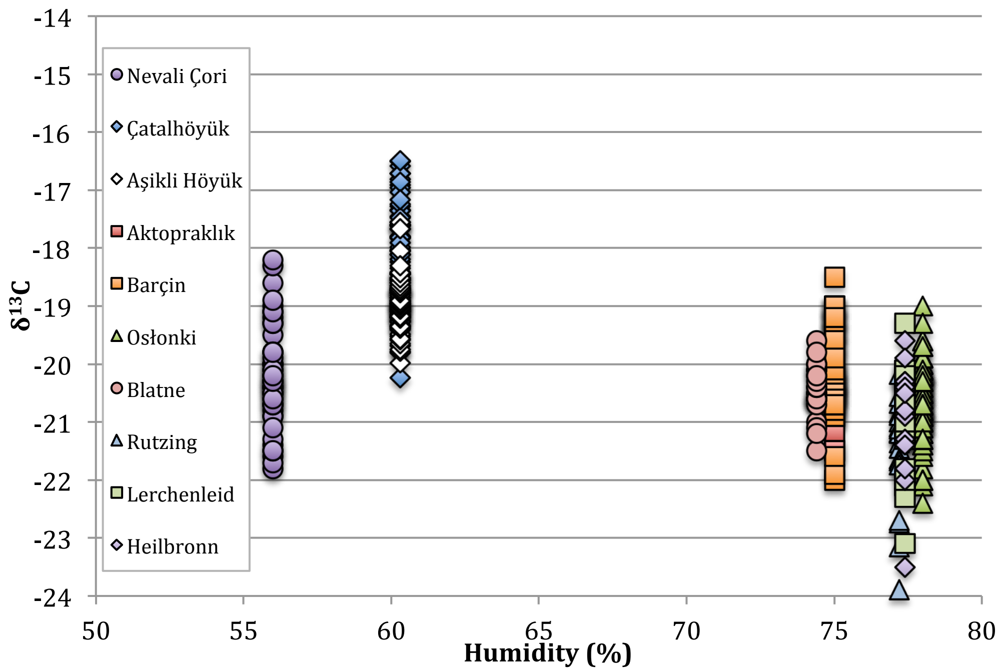

Figure A1.7. Fauna $\delta^{13}C$ and humidity.

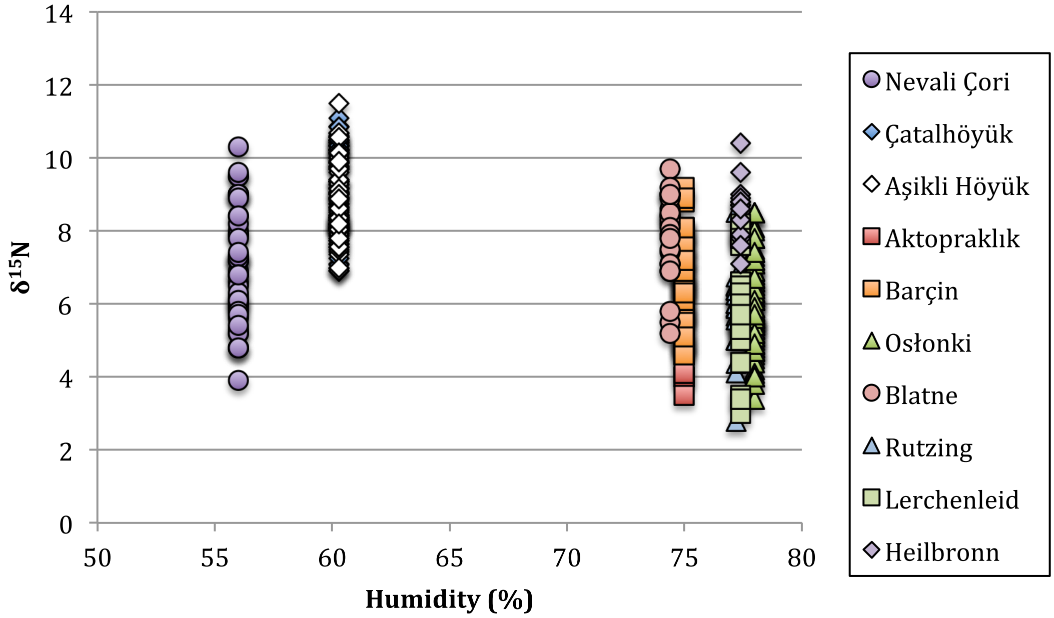

Figure A1.8. Fauna $\delta^{15}N$ values and humidity (%).

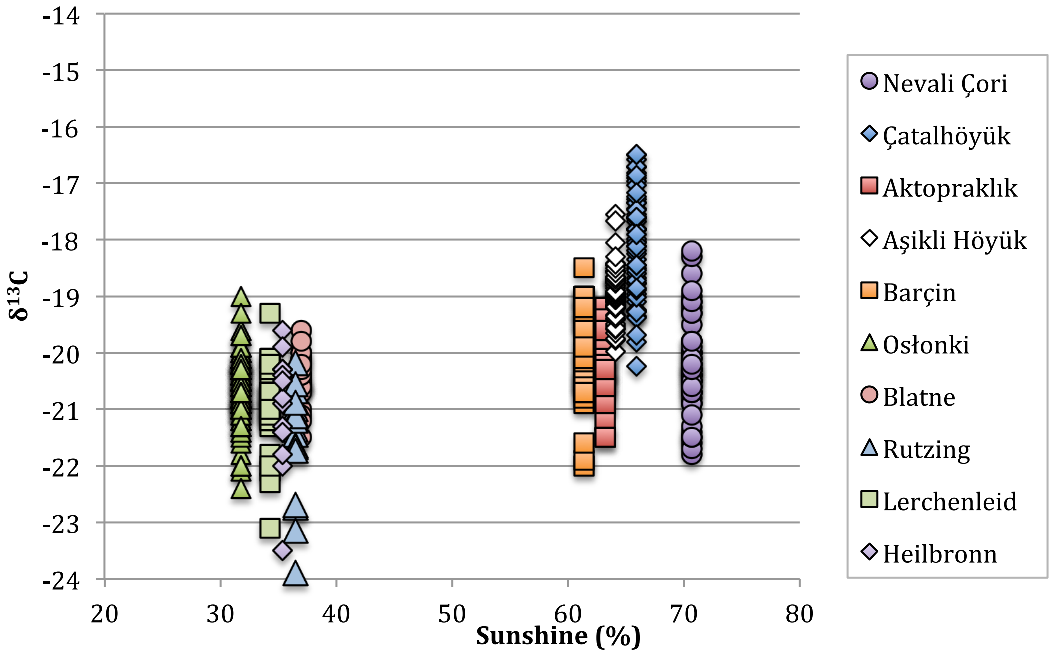

Figure A1.9. Fauna δ^{13}C and sunshine (%) (Data: AquaStat).

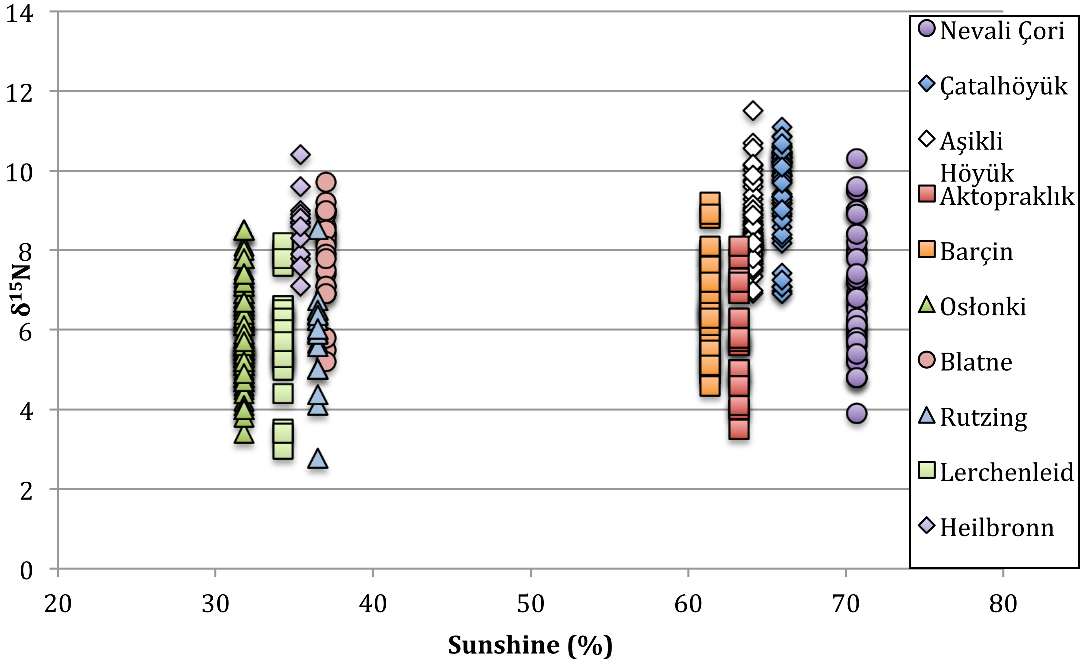

Figure A1.10. Fauna δ^{15}N and sunshine (%) (Data: AquaStat).

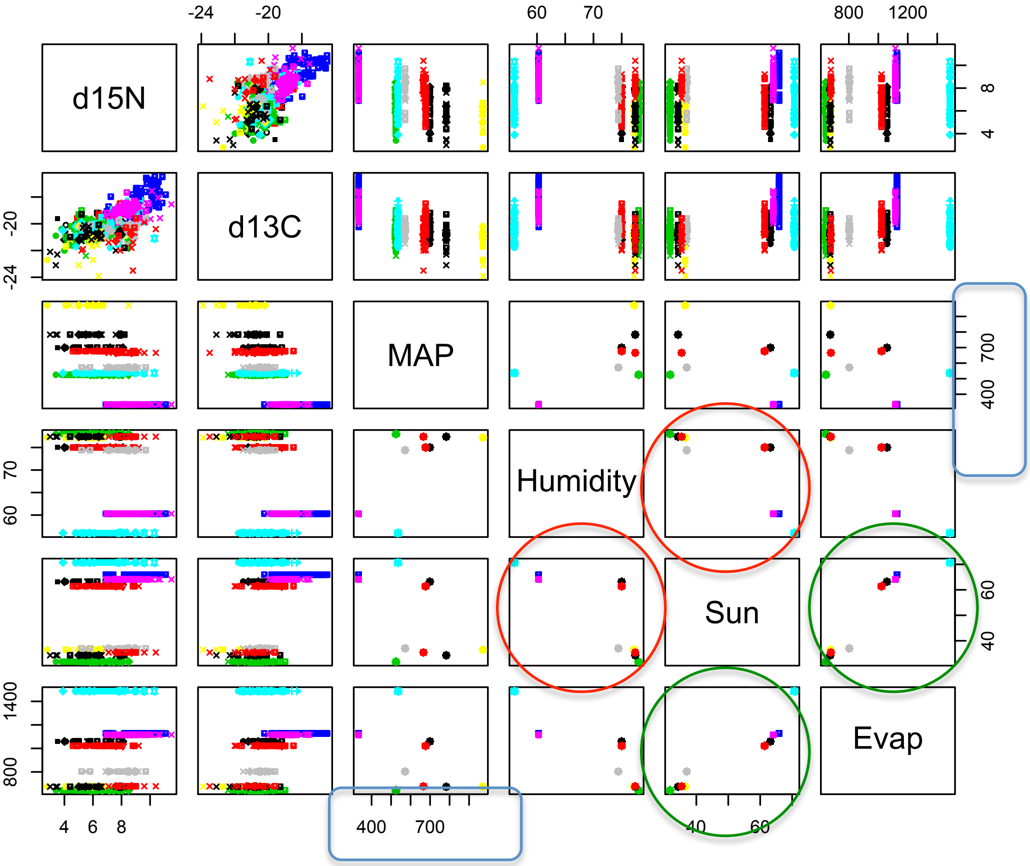

Figure A1.11. Pairs plot of the $\delta^{13}C$ and $\delta^{15}N$ values, alongside climatic variables. The *xy* axes for environmental parameters are listed in chapter 5 (e.g. MAP is measured in mm, and the *xy* axes reflect these values (blue rectangles)).

Figure A1.11 is pairs graph used to identify auto-collinearity between variables in multi-level regressions. The variables of sunshine and evapotranspiration are very highly correlated (green circles) as is evident from the linear regression (e.g. its in a straight line). As a result we cannot use sunshine and evapotranspiration in the same model. Conversely, the variables of humidity and sunshine are not highly correlated (red circles), so both of these variables can be used in the same model.

Figures A1.12 –A1.15 are examples of how the multi-level models (specifically for δ^{13}C values) are constructed.

```
Model A <- lmer(d13C~precipitation+humidity+sun+(1|Site))

Linear mixed model fit by maximum likelihood  ['lmerMod']
Formula: d13C ~ MAP + Humidity + Sun + Evap + (1 | Site)
   Data: data1

AIC  = 974.3  BIC = 1002.8  logLik = -480.1  deviance =960.3   df.resid =431

Scaled residuals:
Min =  -3.6854     1Q = -0.5562 Median = -0.0071     3Q  = 0.6243    Max =  2.8061

Random effects:
Groups         Name       Variance   Std.Dev.
Site         (Intercept)  0.04243    0.2060
Residual                  0.50759    0.7125
Number of obs: 438, groups:  Site, 10

Fixed effects:
                 Estimate        Std. Error     t value    p.z
(Intercept)       -1.436e+01     2.114e+00    -6.793      1.101741e-11
MAP               -2.914e-03     6.425e-04    -4.536      5.742022e-06
Humidity          -5.304e-02     2.535e-02    -2.093      3.637989e-02
Sun                8.269e-02     1.529e-02     5.410      6.311604e-08
Evap              -4.782e-03     1.150e-03    -4.157      3.229284e-05

Correlation of Fixed Effects:
             (Intr)     MAP    Humdty  Sun
MAP          0.501
Humidity    -0.970   -0.672
Sun          0.262    0.278  -0.293
Evap        -0.710   -0.418   0.688   -0.842
```

Figure A1.12. LME1C. Multi-level model for δ^{13}C faunal data and environmental parameters.

```
Model B
lmer(d13C~precipitation+humidity+sunshine+evapotranspiration+(1|Site
) +(1|Species), data=data, REML=FALSE)
```

```
AIC = 940.8    BIC = 973.4    logLik = -462.4 deviance = 924.8 df.resid =430

Scaled residuals:
   Min =  -3.6278    1Q =-0.5361   Median = -0.0058      3Q = 0.5925   Max
=2.6397

Random effects:
Groups          Name          Variance   Std.Dev.
Species        (Intercept)    0.44292     0.6655
Site           (Intercept)    0.1463     0.3825
Residual                      0.4249     0.6519

Random effects:
 Groups   Name         Variance    Std.Dev.
 Species  (Intercept)  0.44292    0.6655
 Site     (Intercept)  0.03874    0.1968
 Residual              0.42450     0.6515

Number of obs: 438, groups:  Species:Site, 47; Site, 10

Fixed effects:
                  Estimate       Std. Error  t value  p value (p.z)
(Intercept)      -26.357032   7.164837  -3.679     0.0002344585
MAP               -0.003194    0.001053  -3.034     0.0024095099
Humidity           0.086254    0.079349   1.087     0.2770290675
Temp             -0.316225    0.234787  -1.347     0.1780266940
Evap              0.006044    0.004301   1.405      0.1599485105

Correlation of Fixed Effects:
               (Intr)     MAP      Humidity   Sun
MAP            -0.044
Humidity     -0.9991   -0.069
Sun             0.882    -0.267     -0.864
Evap          -0.961     0.190      0.940     -0.971
```

Figure A1.13. LME2C. Multi-level model for δ^{13}C faunal data and environmental parameters.

```
Model C
Linear mixed model fit by maximum likelihood  ['lmerMod']
Formula: d13C ~ MAP + Humidity + Sun + Evap + (1 | Species) + (1 | Site) +     (1
| Group)
 Data: data1

 AIC  = 932.3    BIC = 969.0    logLik =   -457.1    deviance= 914.3     df.resid =429

Scaled residuals:
Min   =  -3.8167  1Q = -0.5298  Median  = 0.0178    3Q = 0.5702    Max = 2.6458

Random effects:
 Groups        Name          Variance     Std.Dev.
 Species      (Intercept)    0.44292      0.6655
 Site         (Intercept)    0.03874       0.1968
 Group        (Intercept)     0.00000       0.0000
 Residual                    0.42450       0.6515
Number of obs: 438, groups:  Species, 15; Site, 10; Group, 4

Fixed effects:
                  Estimate      Std. Error        t value    p.z
(Intercept)    -1.502e+01  2.027e+00      -7.411      1.254552e-13
MAP            -2.800e-03  6.092e-04      -4.596      4.305682e-06
Humidity       -4.227e-02  2.404e-02      -1.758      7.866618e-02
Sun             7.440e-02  1.499e-02       4.964      6.911395e-07
Evap           -4.345e-03  1.128e-03      -3.851       1.175659e-04

Correlation of Fixed Effects:
                  (Intr)    MAP   Humdty    Sun
MAP              0.482
Humidity        -0.963  -0.662
Sun              0.283   0.247   -0.296
Evap            -0.709  -0.382   0.673    -0.852
```

Figure A1.14. LME5C. Multi-level model for $\delta^{13}C$ faunal data and environmental parameters.

```
Model D
Linear mixed model fit by maximum likelihood  ['lmerMod']
Formula: d13C ~ MAP + Humidity + Sun + Evap + Species + (1 | Site)

 AIC =  973.8  BIC = 1006.5  logLik = -478.9  deviance = 957.8   df.resid = 430

Scaled residuals:
   Min = -3.6690    1Q= -0.5428   Median=0.0183   3Q= 0.6244   Max =2.5282

Random effects:
Groups      Name           Variance    Std.Dev.
Site        (Intercept)    0.04407     0.2099
Residual                   0.50442      0.7102
Number of obs: 438, groups:  Site, 10

Fixed effects:
                   Estimate      Std. Error    t value      p.z
(Intercept)        -1.415e+01     2.146e+00    -6.593      4.324230e-11
MAP                -2.943e-03     6.509e-04    -4.522       6.116380e-06
Humidity           -5.451e-02     2.570e-02    -2.121       3.391413e-02
Sun                 8.804e-02     1.589e-02     5.542       2.986398e-08
Evap               -5.242e-03     1.204e-03    -4.355      1.333263e-05
Species             2.905e-02     1.866e-02     1.557       1.194306e-01

Correlation of Fixed Effects:
           (Intr)    MAP   Humdty   Sun   Evap
MAP        0.496
Humidity -0.970  -0.669
Sun        0.270   0.265  -0.295
Evap      -0.702  -0.397  0.675   -0.850
Species    0.063  -0.027  -0.037    0.218  -0.248
```

Figure A1.15. LME5C. Multi-level model for δ^{13}C faunal data and environmental parameters.

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