The history of the European aurochs (Bos primigenius) from the Middle Pleistocene to its extinction: an archaeological investigation of its evolution, morphological variability and response to human exploitation

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A thesis submitted for the degree of
Doctor of Philosophy

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December 2013

Abstract

The aurochs (*Bos primigenius*) was an important animal to humans, during prehistory when it was widely hunted, and in some areas also during historical periods. It is generally agreed to be the wild ancestor of domestic cattle (*Bos taurus*) and therefore an in-depth knowledge of this animal is key to research exploring human-cattle interactions, and the origins and spread of cattle domestication.

Domestic cattle are smaller than their wild ancestors, but there is also a degree of overlap between the two species, which means that distinguishing them can be problematic. However, previous analyses of aurochs morphology have generally been patchy, and do not provide a picture of aurochs variation across Europe according to environment, climate and geography. We also do not have a good chronological overview for any specific area of Europe. As a consequence, zooarchaeologists often refer to comparative biometrical data from geographical areas and time periods which may not be suitable for identifying remains from their study area.

This thesis provides the widest ranging review of aurochs material in Europe to date, bringing together aurochs bone and tooth biometrical information from a number of European geographical areas and time periods, in order to gain a better understanding of the morphological variation of this animal, and provide a data resource which can be used in future for more geographically and temporally relevant identifications.

A number of patterns of body size and shape variation were identified including a south-north cline in body size during the Pleistocene and Early Holocene, and hints of a west-east cline during later periods. An increase in the body size of the aurochs during the Chalcolithic period in Iberia is particularly intriguing as it fits with similar patterns previously identified for other animals. A general slendering of certain postcranial bones over time has also been identified; this begins during the Pleistocene and therefore cannot be solely linked with domestication. Possible interpretations of these findings, and others, are discussed.

Acknowledgements

This project would not have been possible without the help of a number of generous and patient people, who have provided advice about the most suitable datasets for inclusion, provided references and/or unpublished raw data, participated in fruitful discussions on relevant topics, or more generally through providing encouragement and support.

First and foremost my deepest gratitude goes to Umberto Albarella, who has offered constant support, encouragement and advice throughout my project. I could not have asked for a more hard working (and tolerant) supervisor. Umberto also provided a number of pig datasets that were incredibly useful for comparison. Thanks also go to Andrew Chamberlain and Paul Halstead who have both been advisors at different points, and who have offered useful advice.

Many people at a number of institutions across Europe arranged access to faunal material, and also made my visits truly enjoyable:

In Denmark, thanks go to Kim Aaris-Sørensen and Kristian Murphy Gregersen, who provided access to material at the Zoology Museum in Copenhagen, and continued to provide lots of information after I returned home. Nanna Noe-Nygaard also made available material at the Department of Geology, at the University of Copenhagen.

In Britain, thanks go to Richard Sabin and Roberto Portela-Miguez who provided access to the material held by the Zoology Collections, and Andy Currant and Roula Pappa who provided access to the material held in the Palaeontology Collections at the Natural History Museum, London. Thanks also to Elizabeth Walker who provided access to the material held at the National Museum of Wales, Cardiff.

In Poland, thanks to Daniel Makowiecki who provided access to a large number of Polish papers, and provided many measurements from his unpublished database.

In Italy, thanks go to Antonio Tagliacozzo, who provided access to collections at the Pigorini National Museum of Prehistory and Ethnography; Paulo Boscato, who made available material held at the Department of Archaeological Science at the University of Siena; Elisabetta Cioppi, who made available material at the Geology and Paleontology Museum in Florence; Daniela Sacca, who provided access to material held at the Department of Archaeological Science at the University of Pisa, and Simone Farina, who provided access to material at the Natural History Museum in Calci, and who also provided me with lots of relevant literature (and a tour of the museum!).

In Portugal, Cleia Detry arranged access to the material held at the Geology Museum in Lisbon and the Natural History Museum in Porto. Thanks also to Maria José Cunha at the Natural History Museum in Porto who was so welcoming and helpful.

In France, thanks to Jean-Denis Vigne and Karyne Debue who provided me with access to material held by the Zooarchaeology Lab at the Natural History Museum in Paris, and Stéphanie Renault, who provided access to material held by the Palaeontology department of the same museum.

During my data collection trips a number of people also helped to make my stays so much more enjoyable:

In Poland, Daniel Makowiecki and Marzena Makowiecka hosted me in their house for a week, and were incredibly welcoming and understanding during a difficult time for me, and Mik Lisowski took me to see the sights of Poznan. In Italy, Claudia Minniti provided accommodation at her house in Rome, and Carla D'Andrassi was a wonderful host; taking me to see the sights despite the language barrier. Francesco Boschin provided a warm welcome to Siena (as well as number of papers and other useful information after my trip) and Daniela Sacca looked after me for a few days in Pisa. Cleia Detry was a great host in Lisbon; providing food, accommodation, transport and great conversation. Barbara Castelo Branco also hosted me in Porto, and took me to see the city. My trip to Paris was greatly enhanced by Ardern Hulme-Beaman and Roz Gillis, who took me out for some great food (and drinks!).

A number of people have also provided data and advice from afar. In Germany, Norbert Benecke provided information about aurochs remains on German sites, and sent many papers to Sheffield from Berlin; Aikaterini Glykou kindly provided raw data from the site of Neustadt LA 156; Martin Street generously provided raw data from Bedburg-Königshoven and Karlheinz Steppan provided unpublished data from Bruchsal-Scheelkopf. In Spain, Maria Saña provided raw unpublished data from the site of La Draga, and Arturo Morales and Nayeli Jimenez provided me with a number of useful papers on Spanish sites. In Portugal, Simon Davis provided me with lots of papers, and some interesting discussions about some of my results, and Catarina Ginja provided lots of information and useful discussions about cattle genetics. In France, Jean-Phillipe Brugal provided some raw unpublished data from the site of La Borde. In Sweden Ola Magnell provided some biometrical and dating information and a number of useful papers. Kurt Grøn provided some unpublished data from the Danish site of Havnø. In Britain Peter Rowley-Conwy gave permission for the use of some Danish pig data, and Tim Allen, Gillian Jones and Sarah Crump provided access to primary records of measurements from the British site of Eton Rowing Lake. Thanks also to Jose Carvajal Lopez who provided some useful papers and also some vital translations.

Thanks go to the whole team at the Department of Archaeology and Palaeoecology at the University of Algarve who have welcomed me into their group on a number of occasions, and especially to Rita Dias and João Marreiros who have hosted me many times, and have always been so generous and fun to spend time with.

Many thanks go to past and present members of the Zooarchaeology Lab at the Department of Archaeology, University of Sheffield, who welcomed me into their group and have provided constant encouragement and also practical help. These include Claudia Minniti, Marian Galindo, Silvia Valenzuela Llamas, Kim Vickers, Giorgos Kazantzis and Lenny Salvagno. Angelos Hadjikoumis kindly re-measured some bones for me in Paris; Sarah Viner-Daniels provided data from her PhD research and from Durrington Walls, as well as some great discussions and advice; Mik Lisowski provided a number of Polish papers, and checked my Polish spelling; Beatrice Bertini Vacca brightened up every day with her smile and positivity, and Hannah Russ was a constant source of encouragement (and fun!). Special thanks go to Angela Trentacoste, who has travelled the Masters and PhD journey with me, and who has facilitated a number of much needed beer-drinking and pizza-eating sessions. Thanks also go to David Griffiths for his encouragement, especially during the last few months of the thesis.

It would not have been thinkable for me to undertake a PhD in Archaeology if it had not been for the support of my parents Fiona and John, who have always encouraged me to study what I have found most interesting, and who have provided emotional and financial support throughout my university career.

A special mention must go to Kate Hooley, Michael Mallon and Alex Young, who have been wonderful friends over the past few years; always on the end of the phone when I need them.

And finally, to Nick I owe my deepest gratitude for believing in me throughout this whole process, and supporting me, both emotionally and materially, through the most challenging parts of this experience.

This project was made possible through a Faculty of Arts and Humanities studentship from the University of Sheffield. In addition a number of smaller grants assisted with the costs of my data collection trips; A Santander Mobility Award (through the University of Sheffield), A Petrie Watson exhibition (also through the University of Sheffield), and a Richard Stapley Educational Award.

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Chapter 1: Introduction and Background

1.1 Introduction: research questions and outline of the thesis

The aurochs, *(Bos primigenius* Bojanus 1827), is generally accepted to be the extinct ancestor of modern domesticated cattle (Chaix 1994; Clutton-Brock 1999), and was one of the most widely hunted animals in European prehistory. The study of this animal is integral to the exploration of the origins of cattle domestication, in terms of when and where it took place, and the reasons for this. Domestic cattle are considerably smaller than their wild ancestors (Degerbøl and Fredskild 1970; Grigson 1978) and you would therefore expect that morphometry would be extremely useful for investigating the origins of cattle domestication. There is, however, a size overlap between wild and domestic forms, which in combination with a dearth of biometrical studies, has made it difficult to distinguish aurochs and domestic cattle, as well as understand the dynamics of the origin of domesticated forms. Palaeogenetic works on the subject of cattle domestication, which have proliferated in the last twenty years or so (e.g. Loftus *et al.* 1994; Edwards *et al.* 2007; Bollongino *et al.* 2008; Scheu *et al.* 2008; Mona *et al.* 2010), are valuable, but because they are dependent on the correct identification of cattle remains, they suffer from the uncertainty associated with our understanding of the morphometric characteristics of the aurochs and even the early forms of domesticated cattle. There is therefore an urgent need to address the issue of aurochs morphology.

Previous analyses of aurochs morphology have generally been brief and patchy, with biometrical studies rarely dealing with abundant material and often focused on just one anatomical element or a small geographical range. This work is unable to provide a picture of aurochs variation across Europe depending on differing environmental conditions in different geographical areas, nor is it able to provide a picture of changes over time in any specific area of Europe (with the exception of the study undertaken by Degerbøl and Fredskild 1970) on Danish material.

The purpose of this study is to provide a wider ranging review of aurochs biometry across Europe, which takes into account geographical variation and environmental change over time, as well as human impact such as hunting pressure, and the initial processes of domestication. This will provide a resource that can be used by researchers in order to make aurochs identifications relevant to geographical area or time period. Using zooarchaeological techniques, this project aims:

1. To explore the morphometric variability of the aurochs across its European range.
2. To explore the morphometric variability of the aurochs in time, from the Middle Pleistocene to its extinction.
3. To relate any morphometric variation to regional patterns, whether determined by environmental (e.g. forest coverage, altitude) and/or cultural factors (e.g. hunting pressure, nature of the human settlement).
4. To assess the extent of morphometric variation existing between aurochs populations that lived in glacial, inter-glacial and post-glacial times.

5. To relate aurochs morphometric variation to later Holocene climatic fluctuations, assessing in particular the hypothesis of a post-Mesolithic size increase, as already identified in wild boar and red deer.
6. To provide the foundations for a more reliable morphometric identification of wild and domestic cattle from the Neolithic onwards.
7. As a consequence of the points above, to provide palaeogenetic analysis with more reliable criteria for the interpretation of aurochs remains.

This chapter will include introductory sections on what is currently known about the taxonomy and geographical distribution of the aurochs, as well as the factors responsible for the determination of body size in mammals, including previous work dealing with aurochs material. An overview of the climatic and environmental context of the material dealt with in this project is also provided, as well as a review of the literature regarding aurochs morphology, and genetic studies. Finally, issues of the distinction between *Bos* and *Bison* are also outlined in this chapter. This project will **not** attempt to solve this problem although the presence of this issue will need to be taken into account throughout every stage of this work.

A note on dates: A number of sites included in this thesis from the Pleistocene were only dated according to Marine Isotope Stage, or to cultural layer. Wherever possible dates have been presented in calibrated calendar years BP, or if C14 dates were available these were converted to cal BC. Holocene dates are presented as cal BC where possible. Calibrations were performed using Calib 6.0 (after Stuiver *et al.* 1993).

1.2 The Aurochs (*Bos primigenius*): taxonomy and geographical distribution

1.2.1 Taxonomy

The genus *Bos* falls within the tribe Bovini, the sub-family Bovinae, the family Bovidae, and the order Artiodactyla, the even toed ungulates. Other members of the tribe Bovini include the American Bison (*Bison bison*), the European Bison or Wisent (*Bison bonasus*), the Yak (*Poephagus mutus*), the Asian buffalo (*Bubalus*) the African buffalo (*Syncerus*) the Banteng (*Bos banteng*), the Gaur (*Bos gaurus*), and the Kouprey (*Bos sauveli).*

The aurochs *(Bos primigenius* Bojanus 1827) is generally accepted to be the extinct ancestor of modern domesticated cattle (Poplin 1983; Chaix 1994; Clutton-Brock 1999). There are two recognised forms of domesticated cattle, the humpless *taurine* cattle of Europe, West Africa and northern Asia (*Bos taurus*) and the humped *zebu* cattle of southern Asia and Africa (*Bos indicus*). The Latin nomenclature for domestic animals used in this dissertation will follow the recommendations of Gentry *et al.* (2004).

The exact origins of *Bos primigenius* are not clear, although it is thought to have Indian ancestry, and is possibly related to or descended from *Bos acutifrons*, which is dated back to 2 million years ago in the Siwalik Hills of northern India (Pilgrim 1947). *Bos primigenius* is also thought to be related to the two Asiatic species *Bos planifrons* and *Bos namadicus* (Zong 1984, Guintard 1999).

Some researchers recognise three sub-species of *Bos primigenius*: *Bos primigenius primigenius* found in Europe and the Middle East, *Bos primigenius namadicus* found in south Asia, and *Bos primigenius opisthonomous/mauretanicus*, the North African group (Payne 1970; Epstein and Mason 1984). The presence of these groups continues to be debated. A study by Grigson (1980) looking at cranial morphology, proposed that *Bos primigenius primigenius* and *Bos primigenius namadicus* should be classified as separate species. Others disagree with this view, stating that the differences between the three sub-groups, seen mainly in horn shape and body size, are down to environmental differences between the three geographic areas and that geographic range should not be the basis of phylogenetic classification (Zeuner 1963; Epstein and Mason 1984).

The phylogeny of the tribe Bovini continues to be a subject for debate, and a number of different types of evidence have been used to reconstruct it. Based on the sequence of nucleotides for the mitochondrial b gene, *Bos* and *Bison* are grouped together, but separately from Asian and African buffaloes such as *Bubalus* and *Syncerus* (Hassanin and Douzery 1999). According to amplified fragment length polymorphisms (AFPL), Bison and Yak species (*Bison bison*, *Bison bonasus* and *Poephagus*) on the one hand, and domesticated cattle (*Bos taurus, Bos indicus)* and Gaur *(Bos gaurus*) on the other are grouped separately. Both groups are also separate from both *Bubalus* and *Syncerus* (Buntjer *et al.* 2002). According to some morphological studies however, *Bos*, *Bison, Poephagus* and *Bibos* are considered as subgenera of the genus *Bos* (e.g. Gentry 1978; Groves 1981).

As is clear from above, the relationship between *Bos* and *Bison* is especially problematic. Depending on the type of evidence used, they are sometimes grouped together, and sometimes apart. The situation is confused further by the fact that bison and cattle are able to interbreed, and produce fertile female F1 hybrids, but sterile males (Krasinska 1971). This has led some to argue that they should be included as the same species (e.g. Gee 1993). Despite all of this, the divergence between the two species has been dated back to 1 million years ago (Bradley *et al.* 1996).

The close genetic relationship between *Bos* and *Bison* is reflected by their close morphology. Issues of identification stemming from this are discussed further in Section 1.6.

1.2.2 Geographical Distribution

The aurochs first appeared during the Pleistocene, and finally became extinct in Poland in 1627AD, the last surviving population being found in the Jaktorów forest near Warsaw (Kędzierska 1959; 1965 cited by van Vuure 2005). At the peak of its distribution it could be found across the Old World, from the Atlantic coasts of Europe to the Pacific coasts of China as well as in North Africa (see Figure 1.1). No aurochs remains have been found in Ireland, making the west coast of the Iberian Peninsula the western most extent of its range. In the east no aurochs seem to have crossed the Bering Strait and therefore the species did not spread into America. The rest of this section will mainly deal with the European distribution, as this represents the focus of this project.

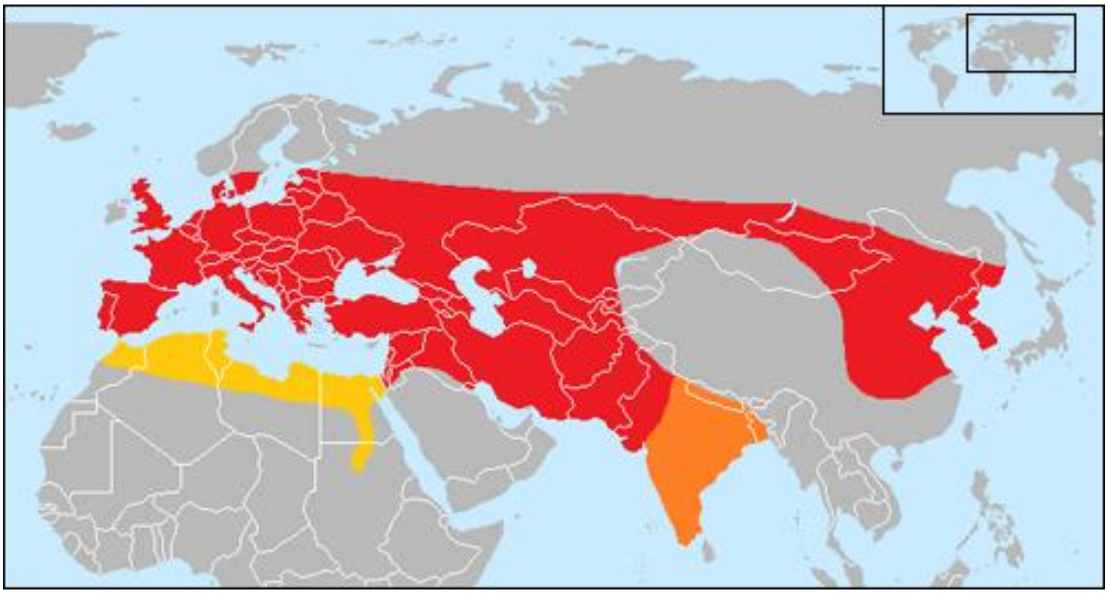


Figure 1.1: The former distribution range of the aurochs. The possible former range of the *primigenius*-subspecies is coloured in red, that of the *opisthonomous/mauretanicus* subspecies is coloured in yellow, and that of the *namadicus*-subspecies in orange. This map was created by Peter Maas for the The Extinction Website. Based on an image by C.T. van Vuure (2002). This image has been released under the Creative Commons Attribution Non-commercial No Derivatives 3.0 Licence.

Aurochs finds are less numerous during the Pleistocene than during the Holocene, but a large distribution area is represented nonetheless. During the early Holocene (Mesolithic and Neolithic cultural phases in Europe) the species seems to have increased in number, probably due to increasingly favourable mild and wet conditions after the end of the last Ice Age (van Vuure 2005). As it stands, the exact difference in abundance and distribution between the Pleistocene and Holocene is unclear. Van Vuure (2005), who has done the most wide ranging review of the literature to date, is quite vague on this matter. The process of data collection for this project has indicated that Pleistocene assemblages with aurochs remains may be more sporadic than in the Holocene, potentially due in part to the reduction of its range during the numerous Pleistocene glacial periods, but when aurochsen are present at Pleistocene sites they tend to be present in relatively large numbers. The largest samples included in this project are from Pleistocene sites such as Castel di Guido (Italy) and Ilford (UK), and other smaller Pleistocene samples actually represent very large assemblages which unfortunately are quite fragmented and do not provide much biometrical data (such as that from La Borde, France).

1.2.2.1 The Pleistocene

During the Pleistocene the aurochs spread from India to Europe, where it was first identified in the Tiber estuary (Cerilli and Petronio 1991). The aurochs arrived in Southern Europe much earlier than in Central Europe, which it probably reached from Russia. Its first appearance in Spain dates back to 700,000 years ago (ka) (Estévez and Saña 1999), whereas in Germany it is represented by a skull from Steinheim an der Murr (Württemberg), dating to approximately 275 ka (Lehmann 1949).

During the Middle Pleistocene some sites with large numbers of aurochs remains have been uncovered. These sites often have larger numbers of remains than sites from the Holocene, but the overall number of sites from this time period is lower. These sites include Castel di Guido in Central Italy, dated to around 317-260 ka – Marine Isotope Stage (MIS) 9 (Sala and Barbi 1996; Saccá 2009); Ilford, in southern England, dated to MIS 7 (Andy Currant *pers. comm.*); La Borde in the south of France, (Jaubert *et al.* 1990) and Solana del Zamborino, in Southern Spain (Penela 1988) both dated to MIS 5 (at the very end of the Middle Pleistocene around 130 ka). These sites are all dated prior to the Last Glacial Maximum, and are all from interglacial periods. The distribution of the aurochs fluctuated with the changing climate during the Pleistocene, and during Ice Ages, when the European northern boundary ran a much more southerly course, possibly through Southern France, Northern Italy and the Balkans, with the Iberian and Italian peninsulas being used as refugial areas (von Koenigswald 1999; Mona *et al.* 2010), this provides a good explanation for the rarity of the aurochs during colder periods in many areas of Europe.

Remains of aurochs from the Middle or Late Pleistocene have been uncovered in Britain, France, Spain, Portugal, Italy, and Germany. The aurochs first appeared in southern Scandinavia (Denmark and southern Sweden) during the Pleistocene/Holocene transition (The Younger Dryas) (Ekström 1993; Aaris-Sørensen 1999; Noe-Nygaard *et al.* 2005).

1.2.2.2 The Holocene

Most European aurochs finds are from the Holocene. Remains have been found in most areas of Europe. The increased warmer and wetter weather during the beginning of the Holocene seems to have promoted the expansion of the aurochs to its largest range.

The Mesolithic

The large geographic range of the aurochs during the Mesolithic is represented by the occurrence of a diversity of assemblages from a number of countries. Prominent sites from this period with aurochs assemblages include Star Carr in Britain (Fraser and King 1954; Legge and Rowley-Conwy 1988), a number of Danish sites, such as Sværdborg and Mullerup (Degerbøl and Fredskild 1970), Bedburg-Konigshöven in Germany (Street 1991; Street 1999), Ageröd in Sweden (Ekström 1993), the Muge middens in Portugal (Detry 2007), La Montagne in France (Helmer and Monchot 2006) and Grotta della Mura in Italy (Bon and Boscato 1993). The northernmost limit of the aurochs (in Sweden) seems to have been reached during the early Mesolithic, this is represented by fossil specimens at Östergötland, Västergötland and a Mesolithic site at Hornborgasjön (Ekström 1993: 16-22).

Despite being found across a wide geographical area, aurochs remains are generally found in relatively small numbers on an individual site basis during the Mesolithic period. A few sites stand out as having relatively large assemblages, such as Star Carr (UK), and the Muge middens (Portugal), but the majority of individual sites do not have particularly large concentrations of bone from this animal. Even in Denmark, where the aurochs has been found at a number of Mesolithic sites, each of these sites has relatively small numbers of bones, which only form a large sample when combined together. Work on this project has highlighted the fact that the aurochs is found in particularly small numbers in southern Europe, in comparison to northern Europe. In some areas, especially in central-eastern Europe, such as Hungary and Poland, the aurochs is present during the Mesolithic, but assemblages are even smaller than in western Europe. Overall the situation during the Mesolithic is quite different to the situation at the Middle Pleistocene sites discussed above, where the aurochs is often found in larger numbers, although at fewer sites.

The Neolithic

Aurochs remains are also commonly found on Neolithic sites, and it is at this time that central and more eastern European assemblages grow in size. With the coming of the Neolithic also comes the domestication of cattle, and often both wild and domesticated forms are present at the same site. Some of the largest assemblages during the Neolithic period have been found in Germany, such as at Bruschal Scheelkopf (Steppan 2003) and Hüde I (Hübner *et al.* 1988). Other important assemblages include Seeburg Burgäschisee-Süd in Switzerland (Stampfli 1963), and a number of Polish sites such as Gniechowice and Łojewo (Sobociński 1978; 1989). Proportions of aurochs in comparison to domestic cattle seem to be consistently small in Western Europe, in comparison to central and eastern areas. At British sites, for example, such as Hambledon Hill (Viner 2010) and Eton Rowing Lake (Jones *in press*) in the earlier Neolithic, and Durrington Walls (Albarella *et al. in prep.*) in the later

Neolithic, the aurochs is only represented by a small number of bones, which make up a minute proportion of each assemblage. In Spain and Italy the aurochs also seems to only be represented by small numbers of bones. One site, Rendina (Bökönyi 1982), in Italy seems to be an exception to this. It is only during the Chalcolithic period that more bones from wild cattle seem to appear in Spain (on some sites), although this pattern does not seem to be the case for Italy, where the aurochs seems to disappear almost completely during the later Neolithic period.

The Bronze and Iron Ages

After the Neolithic period, the number of aurochs remains across Europe decreases dramatically. The reasons cited for this have included overhunting as well as the destruction of habitats, such as the deforestation that occurred across most of western Europe in order to enable the expansion of agriculture (van Vuure 2005). It is likely that a combination of reasons contributed to the extinction of the aurochs, but the general scarcity of aurochs finds across much of Europe during the Neolithic period (perhaps with the exception of central and eastern areas), do not suggest that they were being hunted in very large numbers prior to extinction. For this reason the destruction of habitat may have been a more prominent factor. In addition, in some areas such as Scandinavia, extinction may also have been aided by rising sea levels which fragmented populations (Aaris-Sørenson 1999). By the Bronze Age the aurochs was rare in some areas, it disappeared from southern Scandinavia at around 500 cal BC (2500 B.P. cf Aaris-Sørensen 1999), and in Britain there are no finds later than c1500 cal BC (3245 +/ 40 BP cf Clutton-Brock 1986).

Whilst this thesis was being written a very large distal tibia was found in a British Late Iron Age context at Marston Park in Bedfordshire. This bone has a distal breadth measurement of 83mm, which is very large indeed (Mark Maltby *pers. comm.*). Hopefully future work, which should include radiocarbon dating will shed light on this.

The Historic Period

In addition to bone finds, historical sources also record the presence of aurochs in various European areas during the Roman and Medieval periods. Historical records show that wild animals including the aurochs were caught across the Roman Empire and sent back to Italy to be used in arena fights (Szalay 1917 cited by van Vuure 2005), but it seems likely that the aurochs had already become extinct in Italy itself prior to this, during the Bronze Age. In the Netherlands, aurochs archaeological finds are reported up until the 4th century AD (Lauwerier 1988), and historical sources report the presence of the aurochs in France until the 9th century AD (Szalay 1917 cited by van Vuure 2005).The most recent archaeological find from Hungary dates to the 12th century AD (Bökönyi 1974; Vörös, 1985). In Germany, aurochs remains are found throughout the Roman period (e.g. at sites such as Genshagen and Deutsch Wusterhausen (Muller 1996) and the latest aurochs finds are dated to between the 9th and 13th centuries AD, but the species is still mentioned as occurring in texts until the 14th century (Stella 1518, cited by van Vuure 2005; Maciej z Miechowa 1521, cited by van Vuure 2005).

It is advisable to be cautious about relying heavily on historical sources for a reconstruction of the timing of aurochs extinction in different areas. It could be that some writers are reporting ‘word of mouth’ and had not actually seen an aurochs themselves (this seems apparent in a description given by Julius Caesar, which is entirely unrealistic). Caution should also be used when dealing with real bone finds during the historical period, as whole animals or individual bones could easily have been moved across Europe due to the increased ease of long distance transport. A good example of this is the case of the few large cattle bones attributed to *Bos primigenius* found at the Welsh Roman site of Segontium (Caernarfon) in a 4th century AD context (Noddle, 1993). Because no other large ‘aurochs-sized’ bones have been found from this time period, these have been interpreted as ‘curiosities’ (Noddle, 1993) which could have been collected from a much earlier context, or transported from other areas of Europe.

By the 13th century the aurochs had disappeared from most of Europe, and only continued to live in a few areas in eastern Europe. The last herd lived in a marshy area with large amounts of deciduous woodland in the Jaktorów forest, south west of Warsaw in Poland. During the 16th century, the herd decreased rapidly in size from around 50 animals in 1557 to four by 1601. The aurochs finally became extinct in 1627 when the last individual died (Kędzierska 1959; 1965 in van Vuure 2005).

1.3 Factors affecting body size

There are many variables which correlate with body size (see Calder 1984; Schmidt-Nielsen 1984; Brown *et al.* 2000) such as biochemical activity and structures at the molecular and cellular level (e.g. mitochondrial density and enzyme and hormone activity), characteristics of organism structure and function (e.g. brain size and metabolic rate) and aspects of life history and population dynamics (e.g. litter size, life span, territory size). Body size is effectively determined by the forces of natural selection – selection for the right size depends on the niches available in any one environment (Bonner and Horn 2000).

Here these factors have been divided into two different types: ontogenetic factors and ecological factors. Ontogenetic factors are genetically coded within an organism, whereas ecological factors are external to that organism. Factors are discussed theoretically and in terms of their relevance to the aurochs.

1.3.1 Ontogenetic factors affecting body size

1.3.1.1 Age

In vertebrates, an individual becomes larger with age, and most of this size increase is achieved early on in life. Young bones have cartilaginous zones, which are able to grow until they become ossified. Once the bones have fused, growth in height is no longer possible and growth in width can only be limited; post fusion bone growth in width has been detected in a few bones, such as the scapula and the radius (Payne and Bull 1988: 30). Each bone fuses at a similar age across a species, so it is relatively simple to tell the rough age of a skeleton that has some unfused bones or bones that are still showing any signs of fusion.

Tooth size also increases with age, but only until the tooth is fully formed. After this the tooth may actually become smaller with age, due to wear. Despite this, it is still possible to determine the age of an animal through the presence and absence of deciduous and permanent teeth, and the amount of tooth wear.

Because there are no living aurochs, no direct data are available for the timing of bone fusion or tooth eruption, so we must rely on the data available from modern domesticated cattle for this information. Although we do not know if ageing information from modern domesticated cattle may provide a proxy for the absolute age of aurochs remains, the relative order of fusion and tooth eruption is likely to be similar between the two, as it is across a range of distantly related ungulates (e.g. cow, sheep, pig). In domesticated cattle the pelvis fuses within the first 6-9 months and all long bones are fused by the 4th year (Silver 1969). Once a bone is fully fused size differences can only be due to age to a limited extent. In cattle deciduous incisors and canines are usually present at birth, and deciduous premolars erupt through the gum during the first 3 weeks after birth. The permanent molars also erupt in a specific sequence (Silver 1969).

The effect of ageing on body size can, to some extent, be assessed by choosing to separate immature, unfused bones during analysis – see Methods: Chapter 2.2.

1.3.1.2 Sexual dimorphism

Among most mammals the degree of sexual dimorphism varies according to species and often between populations of the same species. Species within the subfamily Bovinae are highly dimorphic, with the males larger than females (Polák and Frynta 2010). Sexual selection through male-male competition is often cited as the reason for this kind of dimorphism, which itself is linked to group size, territoriality and resource availability (e.g. Geist 1974).

Zooarchaeological evidence shows that this is indeed the case for the aurochs. In fact, previous studies show a much greater degree of sexual dimorphism than seen in domestic cattle. This dimorphism is so great that initially some researchers described the two size groups as two different forms of *Bos primigenius* (e.g. Rütimeyer 1867; Pigott 1954). However, it is now clear that the size differences represent the male and female groups of one form (Jewell 1962; Grigson 1969; Degerbøl and Fredskild 1970- see Figure 1.2).

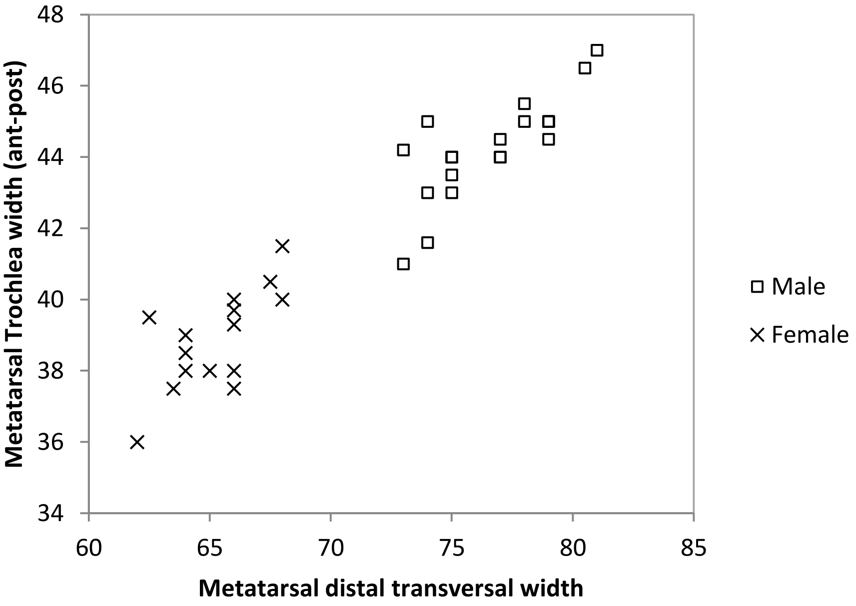


Figure 1.2: Measurements of the distal end of Danish aurochs metatarsals, clearly showing two different clusters, interpreted as belonging to males and females – reproduced from Degerbøl & Fredskild (1970).

Due to the fact that *Bos primigenius* is an extinct species, we lack modern work studying the factors driving its sexual dimorphism, but it has been demonstrated that body size, strength and fighting and/or mate guarding success contribute to reproductive success of bulls in other large wild bovids such as the American Bison (*Bison bison)* (Roden *et al.* 2003) and the African Buffalo (*Syncerus caffer)* (Estes 1992).

Figure 1.2 demonstrates how male and female groups maybe separated biometrically (as done by Degerbøl and Fredskild 1970). Distal metapodials are particularly suited for this approach as these bones are highly sexually dimorphic. The separation can also be attempted on other bones, such as the humerus, which is also quite sexually dimorphic.

1.3.2 Ecological factors affecting body size

1.3.2.1 Temperature

Temperature is often considered an important factor influencing size variation in both living and fossil mammals (e.g. Davis 1981; Klein 1986; Weinstock 2000; Albarella *et al.* 2006; 2009). Bergmann's Rule (Bergmann 1847) originally proposed that, in mammals, populations of a species living in colder climatic areas tended to be larger than those populations of the same species occupying warmer climates. This is linked to the theory that animals with a large body mass are more able to retain heat in a cold environment if their surface area is smaller as a result of a large body size (Schmidt-Nielsen 1984).

Various researchers have criticised Bergmann's rule on the basis that efficient ways of conserving body heat could be achieved through other physiological means, such as fur thickness or fat insulation (e.g. Scholander 1955; Geist 1987). Others have highlighted exceptions to the rule (Dayan *et al.* 1991; McNab 1971; Weinstock 2000). Dayan *et al.'*s study looked at data taken from 52 species of carnivores, 35 of which showed a size gradient that differed, as least partially, from that which would be expected according to Bergmann's rule. Weinstock's study found that the body size variation of reindeer (*Rangifer tarandus*) during the Upper Pleistocene contradicted the rule, because on average larger animals lived in cool, humid climates and smaller animals lived in very cold and very dry conditions. In addition to this there are also several competing explanations for the underlying cause of the Bergmann pattern in addition to mechanisms of thermoregulation, such as responses to seasonality, responses to food availability and starvation resistance in different habitats (e.g. Ashton *et al.* 2000).

Previous studies dealing with *Bos primigenius* material show a general size decrease between the Pleistocene and Holocene (correlating with a global warming trend – see Section 1.4) in various areas of Europe such as Denmark (Degerbøl and Fredskild 1970) Sweden (Ekström 1993), the Iberian peninsula (Estévez and Saña 1999), and in Central and Eastern Europe (Bökönyi 1974). This trend has also been seen in Israel (Davis 1981). A study by Cerilli and Petronio (1991) looked more in depth at the pattern during the Pleistocene. They examined the length and thickness of aurochs metapodials in order to determine whether size change had taken place, and concluded that the aurochs initially increased in size until it reached its maximum dimensions in the Riss Ice Age (c130,000 ya) and then subsequently became smaller. Some studies have also noticed a size gradient from south to north (Zeuner 1963; Grigson 1969; Jarman 1969). Therefore, general results so far indicate an agreement with Bergmann's rule according to temperature, although these studies have previously been limited by geographical area, or body part.

For this project, a more recent climatic change during the later Holocene, resulting, amongst other things, in a reduction of temperature, is of particular interest. This 'climatic deterioration' began around 3000 cal BC, and continued until the early historic period (Bell and Walker 2005). The reason why this is a focus of this project is because an increase in the size of other animals including wild boar (Albarella *et al.* 2006; 2009) and red deer (Davis 2006) has been seen to correlate with this change. An increase in size which correlates with a decrease in temperature might indicate that Bergmann's Rule is relevant to this situation, although of course it is difficult to unpick the effects of other environmental changes which took place alongside temperature change during this period.

The debate surrounding the validity of Bergmann's Rule confirms that many different adaptations can be implemented to deal with different environmental conditions, and also that body size could be affected by environmental factors other than temperature.

1.3.2.2 Food availability

Seasonal changes, caused by climatic factors including temperature and precipitation, can result in fluctuations in food abundance and possible food shortages. Boyce's (1978) work on American muskrats led him to state that the length of time that an individual can survive without food correlates positively with body weight, therefore increasing body size would be an adaptive strategy in seasonal environments. Taking this a step further Geist (1987) argues that body size should be directly correlated with the productivity of an environment and that food availability per animal is the most important factor governing variability in the body size within one species.

In a more general sense, a study looking at the European badger, states that food availability is the main factor affecting body size clines in this species (Virgós *et al.* 2011), and body size has been shown to correlate with food availability in white tailed deer (Wolverton *et al.* 2009). In fact in this case food availability also correlates positively with latitude, resulting in a pattern which could easily be interpreted in relation to temperature. This highlights the complexity in the interpretation of body size variation according to various ecological factors, and the need to consider all possible mechanisms.

Work looking at the American Bison has detected a link between abundant food and large body size (Lyman 2004), but no work seems to have mentioned this factor with regards to the aurochs. It will be interesting to see if related patterns can be detected in our results.

1.3.2.3 Population density

A large amount of work has looked at the relationship between population density and body size in animals (e.g. Damuth 1981; Calder 1984; Peters and Raelson 1984; Purdue 1989; Damuth 1991; Blackburn *et al.* 1993; Cotgreave 1993; Gaston and Blackburn 1995; Lyman 2004; Meiri *et al.* 2004; White *et al.* 2004; Woodward *et al.* 2005; White *et al.* 2007; Greve *et al.* 2008). Although there appears to be a relationship between body size and population density, the relationship is neither simple (e.g. Gaston & Blackburn 1995) nor fully understood (Blackburn and Gaston 1997; Greve *et al.* 2008; White *et al.* 2007). For white tailed deer population density is considered to have been an important factor affecting body size, however, it is difficult to distinguish from the effects of climate, latitude, and food availability (Wolverton *et al.* 2009).

It is difficult to know how aurochs population density may have fluctuated spatially or temporally during the time when it was living in Europe. As mentioned above, aurochs remains tend to either appear commonly, but in relatively small numbers, such as in the Holocene, or in large numbers but on few sites, such as in the Pleistocene. Their presence on archaeological sites may not be a good reflection of their actual population density, as an archaeological assemblage reflects a selection of available resources by humans and pre-human hominins, who may have chosen smaller more manageable animals to hunt over one of this size. It may be possible to detect changes in population density caused by human impact, such as a rise or fall in hunting pressure, by looking at body size fluctuations, but in order to do this we would also need correlating evidence of large or smaller proportions of aurochs being hunted.

1.3.2.4 Predation

It is possible that *Homo sapiens* would have been one of the largest predatory threats to the European aurochs. Various studies have looked to a change in hunting pressure to explain body size changes. This explanation is suggested as a possibility for a post-Mesolithic size increase in Portuguese red deer (Davis 2006) Italian wild boar (Albarella *et al.* 2006) and potentially the aurochs itself (Davis and Mataloto 2012; Davis and Detry 2013). A reduction in the size of wild boar inhabiting the Bialowieza forest in Poland has also been associated with a high culling of adult animals (Milkowski and Wojcik 1984). It is possible that similar patterns may be detectable for the aurochs, although we must be careful in distinguishing any potential size decrease in the wild populations without taking into account the effects of early domestication events.

1.3.2.5 Geographical isolation

Research has shown that geographical isolation of a population is likely to result in a decrease in the stature of large mammals (Foster 1964; van Valen 1973; Lomolino 1985). This is generally spoken about in terms of island populations, but there are also other geographical obstacles, besides the sea, such as mountain ranges, that might cut off animal populations, reducing or halting gene flow (Hewitt 1996; 2000; Knowles 2000). This process can happen if areas such as the Iberian or Italian peninsulas are used as refugia in order to escape mechanisms such as climatic change (Hewitt 2004).

A recent study has highlighted distinct genetic differences between the Italian aurochs and northern/central European aurochsen, caused by some kind of separation between the two groups, and a lack of gene flow across the Alps (Mona *et al.* 2010). It is thought that this could be due to a migration southwards, away from the extreme conditions in more northern regions during the Last Glacial Maximum. Currently no study has been undertaken to explore whether these genetic differences are also reflected in the biometry of the two groups, and hopefully this project will shed some light on the issue.

1.3.2.6 Domestic isolation (Domestication)

Domestication is normally recognised when animals are bred under artificial conditions, creating an isolated group from the wild form, and often causing a reduction in body size. This reduction in body size has been seen in cattle (Grigson 1969), pigs (Hongo and Meadow 1998; Albarella *et al.* 2006), sheep and goats (Uerpmann 1978; Meadow 1989), and dogs (Moray 1994).

Body size reduction in the context of domestication has been attributed to a variety of causes. Some believe that a reduction in body size is linked to a selection by humans for less aggressive animals (Hemmer 1990; Moray 1994). Others have attributed it to large body size no longer being a selective advantage for breeding success (Zohary *et al.* 1988). The body size reduction has also been argued to be a response to worsened diets which created a selective advantage for smaller body size (Meadow 1989).

Some more recent work has called into question the notion that body size reduction is an initial marker of domestication in goats, and possibly in other animals as well (Zeder 2001; 2003; 2006; Vigne *et al.* 2005). The impact of domestication in modern goats was found to be limited to a reduction in the length of long bones and a slight decrease in the robusticity of male postcranial bones. No apparent difference in body size was seen in females. Instead, sex and geographic variation seem to be more important factors affecting body size (Zeder 2006). Associated work on archaeological material from Iran and Iraq noticed that previous work undertaken on goats in the Fertile Crescent had mistakenly interpreted a body size decrease as related to early domestication, when in fact the pattern was related to a demographic shift in a managed herd (an increase in females), along with taphonomic bias against recovery of young males, and the effect of excluding unfused and fusing bones from osteometric analysis (Zeder 2006).

Much of the past work involving aurochs biometry has dealt with size differences between aurochs and domestic cattle in various European countries such as Britain (Jewell 1963; Grigson 1969; 1978) and Denmark (Degerbøl 1963; Degerbøl and Fredskild 1970). It is clear from this research that domestic cattle (*Bos taurus*) are almost all smaller than the aurochs. Following on from this, some studies have attributed size decrease of cattle during the Holocene to domestication. In one study, the size of the aurochs in Israel was seen to undergo two separate reductions in size, one at the end of the Pleistocene and another after the Pre-Pottery Neolithic, and this second reduction is interpreted as being related to domestication (Davis 1981). Despite patterns seen in earlier work on cattle, Zeder's work on goats highlights the fact that there is a danger of confusing a diminution in size related to climatic or demographic changes, or the other factors mentioned above, with that associated with domestication.

It is clear from the above discussion that mechanisms affecting body size can be complex, and there are a number of factors to take into account. The impact of these factors may vary depending on the biology of different species, and the nature of their interaction with humans, and we cannot necessarily expect that exactly the same mechanisms will occur in cattle as in other domesticated animals such as pig, or goat. The impact of some of these factors, such as age and sex, can be reduced by using specific methodology, whereas others can be tackled at the interpretation stage. From the current evidence it seems likely that climatic change will have a part to play, whether it be directly through temperature or through its effects on vegetation, or population distribution or density. Human impact may also be an important factor, through hunting pressure, or through the process of domestication.

1.4 Climate and environment in Europe during the Upper Pleistocene and Holocene

Unlike other European large wild mammals, such as wild boar or several species of deer, the aurochs has no living representatives. We therefore have to rely on historical, archaeological and palaeo-climatic and palaeo-environmental evidence for an understanding of the habitat in which it lived. In the course of the Pleistocene and Holocene the environment across Europe has been subjected to huge variation, both in time and space due to climatic as well as human-induced factors. Due to its wide distribution area, it seems likely that the aurochs would have been a relatively versatile animal, in order to adapt to these different environments (see Section 1.4.3 for a more detailed discussion of the preferred habitat of the aurochs).

The variation shown in the skeleton of the aurochs is likely to reflect adaptation to variable environmental and climatic circumstances and will have a bearing on the nature of the interaction of this species with humans, including the domestication context. Some work has demonstrated a general diminution of size in the aurochs between the Pleistocene and Holocene (e.g. Degerbøl and Fredskild 1970), which may be linked to climatic factors. However, this previous work tends to only look at small geographical areas (in the case of Degerbøl and Fredskild, Denmark). Because of the wider range of this project it is necessary to review the climatic and environmental information available for the Middle Pleistocene and Holocene across the whole of Europe.

The present geological period, known as the Quaternary Period, approximately has spanned the last 2.5 million years, and is characterised by extensive long term climatic fluctuations (Adams *et al.* 1999). It is currently considered as comprising of two epochs, the Pleistocene and the Holocene. The Pleistocene followed the Pliocene, approximately 2.5 million years ago (mya), and was followed by the Holocene approximately 11.5 thousand years ago (ka). In Europe the beginning of the Holocene corresponds to the end of the last Glaciation and, in cultural terms, to the transition from the Palaeolithic into the Mesolithic.

1.4.1 Proxy data used for reconstructing past climate and environment

There are various different types of evidence that we can use in order to reconstruct past climatic and environmental conditions. In the relatively short term we can look at weather records and other historical texts, but over longer periods of time we must look to the palaeoenvironmental record. Deep sea sediments (e.g. Bond *et al.* 1993; Bond *et al.* 1997) and ice cores (e.g. Johnsen *et al.* 1992; Dansgaard *et al.* 1993; Grootes *et al.* 1993; Petit *et al.* 1999; Johnsen *et al.* 2001; Watanabe *et al.* 2003; NorthGRIP-community-members 2004; EPICA-community-members 2004; Jouzel *et al.* 2007a; 2007b; Barbante *et al.* 2010) contain our most continuous record of changing isotopic composition over time, and often give very high resolution results. The isotopic composition of δD and $\delta^{18}O$ found in these cores has classically been used as an indicator of temperature change. Figure 1.3 shows a reconstruction of the temperature changes over the time period dealt with in this thesis, according to ice core data.

Other lines of evidence include isotopic evidence from lake basin cores (e.g. Mackay *et al* 2011; Jimenez-Espejo *et al.* 2007), pollen sequences (e.g. Reille and Andrieu 1995; Caspers and Freund 2001; Davis *et al.* 2003) coleoptera (e.g. Coope *et al.* 1998) and speleotherms (e.g. Onac and Lauritzen 1996). Various projects have aimed to integrate the information from different environmental proxies and to correlate them with each other (e.g. INTIMATE - Walker *et al.* 2001; The EuroCLIMATE project DecLakes - Lauterbach *et al.* 2011), and the work done by members of these groups has been used extensively in this review of the climate over the last c340kya.

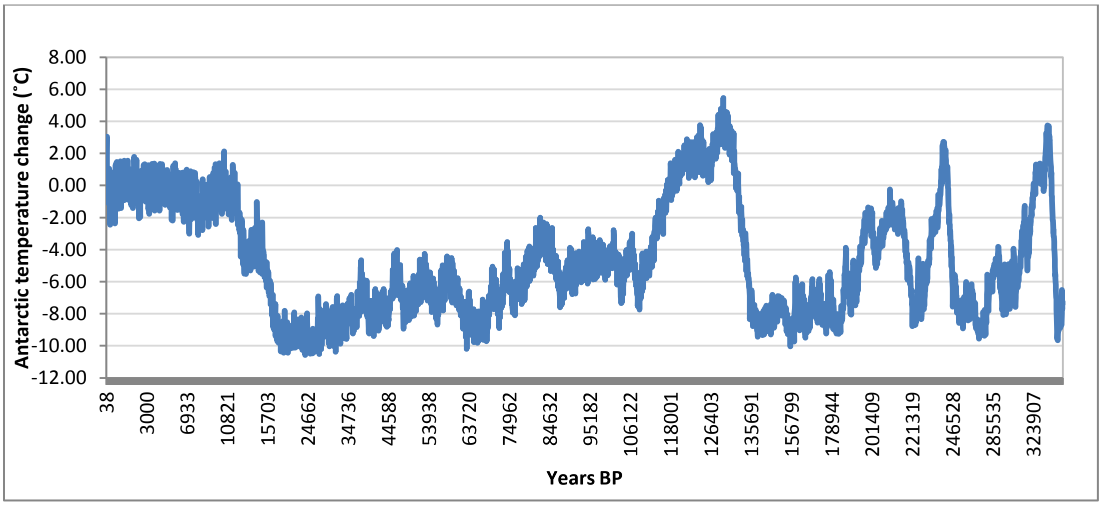


Figure 1.3: Temperature reconstruction for the past c350,000 years based on data from the EPICA Ice core (data source Jouzel *et al* 2007a; 2007b).

1.4.2 Climatic change over the last c340000 years

There is a popular conception of the Quaternary Period as the ‘Ice Age’, and a range of proxy data sources provide evidence showing that throughout this period the earth’s climate has gradually cooled (Andrews 1979). However, studies have shown that this is too simplistic a view. The pattern of climatic change over the last 2-3 million years shows major climatic oscillations (Adams *et al.* 1999). These oscillations are between cold ‘glacials’ and warmer ‘interglacials’, superimposed upon which are minor climatic fluctuations involving cold ‘stadial’ and warm ‘interstadial’ episodes. Over the past 800 ka the global climate has been fluctuating in a rhythmical manner in a series of cycles, ranging in length from 80-120ka, and some of the most recent studies have found a large amount of complexity and inconsistency within these cycles (e.g. Wanner *et al.* 2011).

Although the first evidence of the aurochs in Europe is from 700 ka, (Estévez and Saña 1999) the scope of this project will be much shorter; focusing primarily on the climate fluctuations around the Pleistocene/Holocene transition and beyond. This is partly due to problems with the availability and condition of older material, but mostly because by focusing on the climatic fluctuations at the end of the Pleistocene and beginning of the

Holocene we are dealing with the environment that is most relevant to human interaction approaching and including the period of domestication.

This section aims to give an overview of climatic change across Europe during the Upper Pleistocene and Holocene over the last c340000 years. It must be remembered that there would have been regional differences within Europe, sometimes even between very close areas. These will be dealt with later when discussing geographical variability of aurochs body size and shape.

1.4.2.1 The Pleistocene

The Pleistocene has traditionally been split into three stages; the Lower Pleistocene (c2.5mya-781ka) the Middle Pleistocene (c781-126 ka) and the Late (or Upper) Pleistocene (c126 ka-10 ka). The material included in this project will be from c340 ka (approx MIS 9), and so spans from the Middle Pleistocene onwards, and so this overview only deals with this time period. Ages for Marine Isotope Stages are after Bassinot *et al.* (1994).

c340-300 ka (Marine Isotope Stage 9) and c300-245 ka (Marine Isotope stage 8)

Evidence from ice cores (e.g. Jouzel *et al.* 2007a; 2007b), fluvial deposits (e.g. Green *et al.* 2006) and mammalian remains (Schreve 2001) suggest that MIS 9 was a warm interglacial stage, not quite as warm as MIS 5, but warmer than MIS 7. It is marked by forest expansion in a number of areas of Europe (Roucoux *et al.* 2007). MIS 8 was an overall cooler period compared to MIS 9, and is marked by a contraction of forests and increasing ice volumes and sea-surface temperatures (Petit *et al* 1999; EPICA community members 2004; Jouzel *et al.* 2007a; Roucoux *et al.* 2007).

c244-186 ka (Marine Isotope Stage 7) and c186-127 ka (Marine Isotope Stage 6)

Evidence from ice cores (e.g. Jouzel *et al.* 2007a;2007b), deep sea cores (e.g. Desprat *et al.* 2006), mammalian remains (Schreve 2001) and pollen sequences (Reille *et al.* 2000) indicate that MIS 7 was a warm interglacial period, not quite as warm as MIS 9, but potentially as warm as the last climatic optimum during the early Holocene. Within this interglacial there were warm intervals interrupted by slightly colder stadials (Reille *et al.* 2000). This period of warmth was followed by MIS 6, which saw the advance of ice sheets, and which was a much colder, glacial period (Petit *et al.* 1999; EPICA community members 2004; Jouzel *et al.* 2007a) characterised by the expansion of steppe vegetation, as recorded at a number of sites (Roucoux *et al.* 2007).

c127-71 ka (Marine Isotope Stage 5)

The beginning of MIS 5e (c126 ka) is characterised by a rapid change to much warmer conditions compared with the preceding period. This is the warmest interglacial period included in the timescale of this project, and reached up to 5˚C above present day temperatures in central Antarctica, according to information from ice cores (Jouzel *et al.* 2007b). This stage corresponds to the Eemian in Northern Europe (the Ipswichian in the

British Isles). The chronology of the deep ocean record suggests that this interglacial ended around 115-120 ka and was followed by a general cooling trend with warmer Interstadial episodes (Walker *et al.* 1999). The period between 110 and 75 ka is characterised by a series of rapid climatic oscillations (these are represented by MIS stages 5d-a). During the stadials represented by 5d and 5b the polar front extended southwards. The vegetation of northern Europe during this time was dominated by grasses, sedges and other species characteristic of a tundra environment (Caspers and Freund 2001). During the interstadials represented by MIS 5c and 5a, ice masses were reduced and there is evidence of pine and birch growth (Caspers and Freund 2001).

c71-57 ka (Marine Isotope Stage 4)

Around 71,000 years ago there was a shift to harsher conditions. A rapid decrease in $^{18}O/^{16}O$ ratios is observed in deep sea sediments, indicating a major expansion of the continental ice sheets (Sejrup *et al.* 2000). The polar front reached almost as far as during the glacial maximum (18 ka). Vegetation in the Netherlands, Denmark and Germany was characterised by open tundra with no tree pollen (Caspers and Freund 2001). Pollen sequences from more southern regions such as France suggest more steppe-like conditions (e.g. de Beaulieu and Reille 1984). Overall, conditions were only slightly less severe than those during the last glacial maximum.

c57-24 ka (Marine Isotope Stage 3)

This stage is characterised by a number of rapid climatic fluctuations. Isotope traces in ice cores from Greenland show 16 interstadials during this time (Dansgaard *et al.* 1993), although these were not as warm as MIS 5a and 5c.

Between 58-54 and 50-48 ka peaks of $\delta^{18}O$ represent the Oerel and Glinde interstadials which are reflected in pollen and coleoptera evidence (Behre and van der Plicht 1992; Caspers and Freund 2001; Behre *et al.* 2005). In the Oerel Interstadial temperatures were such that tree growth was inhibited, and vegetation was dominated by an open treeless scrub tundra (Caspers and Freund 2001).

Three more interstadials (or warm 'intervals') have also been identified in the northern European pollen records; the Moershoofd (c46-44 ka), the Hengelo (c39-36 ka) and the Denekamp (c38-28 ka) (Behre 1989; Caspers and Freund 2001). In Britain the coleopteran fauna indicates a single Interstadial – the Upton Warren Interstadial (c43-42 ka) (Coope and Angus 1975).

c24-11 ka (Marine Isotope Stage 2)

During MIS 2 a trend towards glacial conditions took place, reaching its climax (the Last Glacial Maximum) at around 23-18 ka. This is the coldest period included in the timescale of this project. The northern ice sheet reached its maximum size (Sejrup *et al.* 2000). Conditions during the glacial maximum were cold and dry. It has been estimated that global average temperatures were at least 5°C below their current values (Burroughs 2005). Low precipitation prevented tree-growth and produced an open vegetation (Reille and Andrieu 1995). Some pollen records indicate very little vegetation at all over this period (e.g. Reille *et al.* 2000). Conditions were so harsh that little or no human occupation has been recorded in Belgium, North West France, Northern Germany and Great Britain at around this time.

Shortly after 15 ka the climate began to improve leading into the Bølling Interstadial (c15-14 ka). The warming is reflected in pollen sequences, through an expansion of *Artemisia* and other steppic plants (de Beaulieu and Reille 1984; Reille and Lowe 1993) followed by an expansion of pine in some regions (e.g. Lauterbach *et al.* 2011). Some studies have shown that this warming transition was very rapid (Alley *et al.* 1993; Steffensen *et al.* 2008). Evidence of human occupation is found again during this period in the areas that were formerly uninhabitable during the Glacial maximum.

After the Bølling there was a brief period of cold and dry conditions, sometimes known as the 'Older Dryas' (c14 ka). At this time some areas show a vegetation dominated by shrub species (Reille and Andrieu 1995), however this stage only lasted for around 200 years and it is usually combined with the surrounding warm stages.

The Allerød Interstadial (c14-12.8 ka) followed, in which the Scandinavian ice sheets were reduced further. Most of Europe was warm enough for tree growth, although in the far north it was still too cold for this, as is the case today (Birks and Ammann 2000).

The Younger Dryas

Between c12.8 and 11.5 ka a period of climatic cooling took place, this is known as the Younger Dryas. Evidence for the Younger Dryas is found in a number of different environmental proxies across Europe from the far north in Finland (Bondestam *et al.* 1994) to the Iberian peninsula in the south (Allen *et al.* 1996), Ireland in the west (O'Connell *et al.* 1998) and to Eastern Europe (Onac and Lauritzen 1996). Measurements are recorded from as far away as Venezuela (Haug *et al.* 2001) and Ontario (Yu and Eicher 1998), and in the ice core and deep sea sediment records (eg. Bond *et al.* 1993; Dansgaard *et al.* 1993; Bjorck *et al.* 1998; Alley 2000) also indicate this sudden drop in temperature that remained in place for nearly 1000 years. During this period there was a reduction in tree growth, and herbaceous and dwarf-shrub communities dominated many areas (Reille and Andrieu 1995; Allen *et al* 1996; O'Connell *et al.* 1998; Valiranta *et al.* 2006).

1.4.2.2 The Holocene (where possible, Holocene dates are presented as cal BC)

11.5ka (c10000 cal BC)- Present (Marine Isotope Stage 1)

The Holocene has hosted major human innovations such as the onset of agriculture, the domestication of animals (with the exception of the dog, which was most probably domesticated during the Upper Pleistocene e.g. Germonpré *et al.* 2009), as well as the formation of complex societies.

The transition into the Holocene after the Younger Dryas marks the break from the turbulent climate which marked the 'ice age' to something more settled. A wide range of marine and terrestrial evidence records the onset of a sudden global warming beginning at c11.5 ka (c10000 cal BC). This includes snow-accumulation rates and isotope traces recorded in ice cores (e.g. Taylor *et al.* 1997; Severinghaus *et al.* 1998; Alley 2000); pollen and coleopteran evidence (e.g. Lemdahl 1991; Birks and Ammann 2000). This warming marks the beginning of the present interglacial. Evidence from Greenland ice cores suggests that this warming episode was abrupt, with the transition occurring over a number of decades (Taylor *et al.* 1997). An increase in methane indicates an expansion of global wetlands (Severinghaus *et al.* 1998, Alley 2000), and pollen data show the widespread replacement of scrub tundra by woodland by 9500 cal BC, and then by mixed woodland (Berglund *et al.* 1994). The Holocene Climatic Optimum was reached between c.7000-2000 cal BC (Huntley and Prentice 1993; Johnsen *et al.* 2001). Despite the relative stability of the climate during the Holocene, a number of short term variations did occur. At least 4 global periods of rapid climate change have been identified during this period.

The main cooling episode during the Holocene took place around 6300 cal BC. This has been recorded in ice core data (Thomas *et al.* 2007; Rasmussen *et al.* 2007), deep sea sediment core data (Ellison *et al.* 2006; Kleiven *et al.* 2008), and in pollen sequences (e.g.Tinner and Lotter 2001). However, it is a relatively short and sharp oscillation and there is thought to be only weak evidence for a significant climate change during this event outside of the North Atlantic region (Thomas *et al.* 2007).

Late Holocene climatic deterioration

More important for this study, is a longer term period of climatic deterioration that took place during the later Holocene. Greenland ice core records indicate a decline in temperatures beginning around 3000 cal BC (c4500 BP cf. Johnsen *et al.* 2001), and in some parts of Europe, such as Sweden, a decline in the upper limit of the treeline is recorded during the late Holocene (e.g. Barnekow *et al.* 1994). There is also evidence for renewed glacier activity in Europe during this time (Nesje and Dahl 2000). Previous work has seen changes in body size and shape which correlate with this period of deterioration in both wild boar (Albarella *et al.* 2006; 2009) and red deer (Davis 2006), and this period is therefore discussed frequently throughout this thesis with regards to possible evidence for this in the aurochs.

1.4.3 The aurochs and climate – previous work and implications

The distribution of *Bos primigenius* has shown that this species preferred a mild and humid climate with only limited snow cover (Guintard 1999; Estévez and Saña 1999) and many remains have been found in interglacial faunas. There is a suggestion that the aurochs may have retreated to refugial areas, such as the Italian Peninsula, during times when more northerly areas were experiencing harsh climatic conditions, such as during the Last Glacial Maximum (Mona *et al.* 2010).

The wide distribution and numerous remains of the aurochs during the Mesolithic, including its northernmost presence in Scandinavia (Ekström 1993) suggest that it was most comfortable in the open forests present during the Holocene Climatic Optimum (Degerbøl and Fredskild 1970). Work looking at carbon and nitrogen isotopes from Danish aurochs, suggests that during the very early Holocene their diet consisted of grasses supplemented by browsing in a light an open preboreal environment, and later moved towards a more mixed diet obtained from a more densely wooded setting (Noe-Nygaard *et al.* 2005). After the onset of agriculture, its continued presence in remaining similar environments in Eastern and Central Europe, such as in the Jaktorówka forest in Poland, also reflects its preference for forested environments.

As well as having an effect on the distribution of *Bos primigenius*, the changing climate may also have had an effect on its size and morphology. As it has been mentioned in Section 1.3, in accordance with Bergmann's Rule, we would expect body size to have reduced since the end of the last glacial, and in fact this diminution in size has been noted for a variety of European species. The pattern has been observed in both red and roe deer from archaeological and palaeontological contexts (Fraser and King 1954; Walvius 1961; Jarman 1971; Jensen 1991; Davis 2006), and also for wild boar (Albarella *et al.* 2009).

Previous studies dealing with *Bos primigenius* material also show this general size decrease between the Pleistocene and Holocene in various areas of Europe such as Denmark (Degerbøl and Fredskild 1970) Sweden (Ekström 1993), the Iberian peninsula (Estévez and Saña 1999) and Central and Eastern Europe (Bökönyi 1974), therefore correlating with the data for other species, and with the general warming trend in the climate. However, no extensive studies on this topic have been conducted, with this change only being mentioned in passing by these authors. Higher resolution projects have not been tackled, taking into account the more detailed climatic oscillations.

In addition to a body size reduction between the Pleistocene and Holocene, a size reduction was also detected during the early Holocene itself by Degerbøl (1963; 1970). Evidence for this is provided by a reduction in the size of third molars between earlier and Late Mesolithic (Ertebølle) sites in Denmark. A similar pattern is hinted at by the small size of aurochs remains in late Mesolithic Portugal, although aurochs remains from earlier in the Mesolithic are not available for comparison (Simon Davis *pers. comm.*). There is no record of this kind of size decrease in other animals.

Climate can also lead to spatial variability of body size and shape. Previous studies have shown that there was a size difference between reindeer in northern and southern latitudes in Europe during the late Glacial with northern animals being larger than southern ones (e.g. Weinstock 2000), and a size gradient from west to east has previously been identified in *Sus scrofa* with an increase in size the further east the material is from (Genov 1999; Magnell 2004; Albarella *et al.* 2009). Again temperature may play a role in this phenomenon as a large part of western Europe is affected by the warming effect of the Gulf Stream, and therefore these general patterns are in accordance with Bergmann's Rule.

A few studies have touched on this issue for *Bos primigenius*. The aurochs of Central Europe is considered to be larger than that from south-west Europe (Zeuner 1963) and aurochs from south-west Europe are larger than aurochs from Italy and Greece (Jarman 1969). Grigson (1978) mentions the possibility of crania from northern Europe being larger than those from

Hungary. As with size change over time, no extensive project has been undertaken on this subject and most of the studies cover limited geographical areas. In addition, most of these studies were undertaken more than 20 or even 30 and 40 years ago.

Overall there is a lack of rigorous work looking at body size change in *Bos primigenius* related to climate either over time or space in Europe, and it seems likely that the situation was more complex than a general decrease in size over time. In addition to the works mentioned above which seem to ‘prove’ Bergmann’s Rule both for *Bos primigenius*, and some other species, there are some situations where this has not been the case. For example in the study by Weinstock (2000) despite reindeer from northern Europe generally being larger than those from southern areas, at around the time of the last glacial maximum the species was actually smaller than in the following warm period, which contradicts the rule.

As discussed in Section 1.4 climatic changes can cause temperature fluctuations, but also can cause many other environmental changes, which can affect an animal’s habitat in many different ways. Additionally, it is likely that the picture may be complicated by the effect of ontogenetic factors, and the influence of domestication. Therefore we cannot expect a simple interpretation of body size change. Climatic change may be a major factor, but it is unlikely to be the *only* factor at play.

1.5 Domestication

Questions surrounding where and how cattle were eventually domesticated have been hotly debated in archaeology for many years. The identification of wild and domestic cattle bones is integral to this debate, because these remains can indicate the presence of the two different forms in different areas.

The biometric distinction of wild and domestic cattle can at times be problematic, due to a potential overlap in size between the two forms. This problem has been mentioned widely in the literature, although it has not been tackled in detail, and much of the work was completed over 40 years ago. The overlap has been interpreted in different ways. Some argue that it simply represents the small size of some female aurochsen and the large size of some early domestic male (e.g. Stampfli 1963; Jewell 1963; Degerbøl and Fredskild 1970; Rowley-Conwy 1995; Viner 2010). Others have argued instead that it indicates crosses between wild and domestic animals, and could be evidence of local cattle domestication (e.g. Grigson 1969; Bökönyi 1974; Nobis 1975). Most current researchers agree with the argument that states that the overlap is due to sexual dimorphism. It is difficult for the local domestication argument to be based entirely on the size overlap between the two populations because, even if one does not accept the sexual dimorphism explanation, the pattern could just as easily indicate unintentional cross-breeding between domestic and wild animals.

The question of where cattle domestication took place, and whether there was a single or multiple domestication events in Europe has been tackled most recently by genetic studies. Currently the most supported view according to this work is that cattle were domesticated in the Near East, and then introduced rapidly across Europe (Troy *et al.* 2001; Bollongino *et al.* 2006; Edwards *et al.* 2007; Bollongino *et al.* 2008), although there is also some work which suggests the possibility of local domestication (Beja-Pereira *et al.* 2006; Mona *et al.* 2010). But genetic studies themselves can be problematic. Firstly, on a purely practical level, they are very expensive to undertake, and it is often not possible to extract DNA from enough ancient material in order to have a representative sample. Secondly, the interpretation of genetic studies is often dependent on a correct understanding of the morphometric characteristics of the aurochs and its distinction from domestic cattle. This work is currently very patchy, and this is an important reason why this project is being undertaken.

This section will provide an overview of the previous biometrical and genetic work undertaken regarding cattle domestication.

1.5.1 Biometrical studies

Much of the past work involving aurochs biometry has dealt with size differences between aurochs and domestic cattle in various European countries such as Britain (Jewell 1963; Grigson 1969; 1978) and Denmark (Degerbøl 1963; Degerbøl and Fredskild 1970). It is clear from this research that domestic cattle (*Bos taurus*) are in most cases smaller than the aurochs. The reasons for this size reduction have been discussed previously in Section

1.3.2.6. However, there is also an overlap in the measurements of larger domestic cattle and smaller aurochs.

Work by Jewell (1963) showed a considerable overlap between *Bos primigenius* from Star Carr and domestic cattle from later periods in Britain, including Roman and Medieval material, based on measurements of the distal width of the metacarpal and the distal width of the humerus. Astragalus and metacarpal length measurements did not suffer from the same issue, and in fact highlighted possible wild specimens from Neolithic and Bronze Age sites, which were compatible in size with the Mesolithic specimens. Jewell discusses the possibility of the overlapping groups representing a cross between wild and domestic, but is aware that larger sample sizes are required to test this hypothesis. One of the main issues with this study was the relatively small sample of *Bos primigenius* material included.

Grigson (1969) compared measurements of both cranial and postcranial bones of *Bos primigenius* and early *Bos taurus* from a number of European countries. She highlights the presence of an ‘intermediate’ group at the Swiss site of Burgäschisee-Süd according to phalanx width measurements, metatarsal distal widths and astragalus lengths. Stampfli (1963) had previously interpreted this group as representing wild females, but Grigson argues that they could be wild/domestic crosses or an indication of possible local domestication of cattle.

In a later study (1978) Grigson compared skull measurements from *Bos primigenius* with those from modern *Bos taurus.* The results showed that *Bos primigenius* was larger than *Bos taurus,* but showed overlaps in all measurements. The confinement of this study to the use of cranial remains, however, is problematic, as sufficiently complete crania are uncommon in archaeological sites, and results deriving from crania may not be applied to postcranial bones.

Work by Degerbøl (1963; Degerbøl and Fredskild 1970) shows clear division between metacarpal and metatarsal lengths of *Bos primigenius* and Neolithic *Bos taurus* samples. However, metatarsal distal width measurements show quite an overlap between female *Bos primigenius* and Neolithic *Bos taurus* samples. In addition it is shown that M_3 lengths from the late Mesolithic Ertebølle kitchen middens (identified as *Bos primigenius,* due to associations with very large cranial remains) show a distribution which lies in an intermediate position, overlapping both the smaller end of the earlier *Bos primigenius* distribution and the larger end of the Neolithic *Bos taurus* distribution.

Rowley-Conwy (1995) looked at some small *Bos* postcranial bones from the Late Mesolithic site of Rosenhof in northern Germany which had previously been identified as domestic (Nobis 1975). On the basis of a comparison with the Ertebølle material from Denmark dealt with by Degerbøl and Fredskild (1970) he believes that these bones represent wild females. In the same study he also looks at some early Neolithic material from Sarsa, in Spain, and compares this to Mesolithic aurochs from the Muge middens in Portugal. Although the Neolithic material differs in size from the Mesolithic Portuguese sample, he highlights the fact that very little is currently known about the variation of the Iberian aurochs, and a larger sample including material from other areas is needed in order to make a more confident conclusion that the bones from Sarsa are domestic.

The above works highlight a number of issues with biometrical attempts to distinguish wild from domestic cattle bones. One is the issue of the overlapping measurements of the two species, another is the lack of comparative data from certain areas of Europe, the third is the lack of an in depth study on *Bos* postcranial material from anywhere other than Denmark. It is clear that the situation needs to be reviewed more thoroughly.

1.5.2 Genetic studies

Over the past 20 years, a number of genetic studies dealing with issues relating to cattle domestication have been undertaken. Most of the work has dealt with mitochondrial DNA (mtDNA), due to the fact that this is much more abundant in the cell and therefore more easily preserved than nuclear DNA. Work on mtDNA has suggested that there were two independent domestications of cattle worldwide, one resulting in a lineage including both European and African cattle, and the other containing Indian cattle (Loftus *et al.* 1994). This leads to the assumption of a single origin for European domesticated cattle, which is suggested to have taken place in the Near East (Troy *et al.* 2001; Edwards *et al.* 2007; Bollongino *et al.* 2012).

The basis for this work is on the identification of one domestic *Bos taurus* haplotype group ‘T’, which can be further divided into the sub groups T, T1, T2, T3 and T4, and one wild *Bos primigenius* haplotype ‘P’ (Loftus *et al.* 1994; Bradley *et al.* 1996; Troy *et al.* 2001). In addition, a different haplotype indicated as ‘I’ has been found in *Bos indicus*, which is not relevant to Europe (Baig *et al.* 2005; Lei *et al.* 2006; Magee *et al.* 2007). T, T1, T2 and T3 are all found in the Middle East, while T3 predominates in Europe and T4 is only found in Japan (Mannen *et al.* 1998; 2004).

However, a number of studies have indicated potential issues with assuming that all European cattle fit into either the T or P haplotype groups. Edwards *et al.* (2007) found a divergent *Bos primigenius* haplotype ‘E’ in one individual from Germany, and Achilli *et al.* (2008) found another divergent *Bos primigenius* haplotype ‘Q’ in European aurochsen. Others have also found the supposedly wild P haplotype in modern Asian cattle (Shin and Kim, unpublished data, reported by Stock *et al.* 2008). The situation in Italy, however, is most intriguing. Two separate studies, with multiple samples, have now found evidence of the T haplotype in wild, Palaeolithic cattle (Beja-Pereira *et al.* 2005; Mona *et al.* 2010; Lari *et al.* 2011). This suggests that the T haplotype was already present in Europe before 10000 years ago, and throws into question the original basis on which much work on cattle genetics has been founded.

Interestingly, much of the work that has been published since has not recognised the broad implication of the Italian studies (e.g. Bollongino *et al.* 2012), suggesting that Italy may represent just an exception, rather than a reminder of the possibility that other haplotypes are out there, but have just not been sampled. Even if the T haplotype were only confined to Italian aurochsen, the possibility remains of a local domestication in Italy, which then spread elsewhere in Europe. Some studies have used the P and T groups in order to identify biometrically problematic wild and domestic animals (e.g. Scheu *et al.* 2008), but this is potentially misleading if these haplotypes do not actually distinguish between wild and domestic.

MtDNA restricts the scope of exploration to the female line, and so a number of studies have attempted to address the same questions using nuclear DNA (Gotherstom *et al.* 2005; Bollongino *et al.* 2008). Nuclear DNA has always been more difficult to use than mtDNA, because it preserves less well – it is only found in the nucleus of the cell whereas mtDNA is found in the numerous mitochondria in the cell. So far these studies have mainly looked for evidence of hybridisation between male aurochs and female domestic cattle. Gotherstrom *et al.* (2005) believed that they had found evidence of this, but further work quashed this on the basis that their conclusions were based on the modern haplotype distribution, which may have been affected by recent breeding (Bollongino *et al.* 2008). There are considered to be two nuclear DNA haplotypes Y1 and Y2, but they are not considered to discriminate between wild and domestic animals (Bollongino *et al.* 2012). Not much else has been published based on nuclear DNA, although techniques have improved and so there are likely to be more studies in the coming years (Catarina Ginja *pers. comm*).

Further criticism of the work that has been done to date is related to the methodology used by certain teams, especially in relation to specimens from warmer climates, where ancient DNA does not preserve as well as those preserved under cold climatic conditions (Geigl 2008). Because of this, the majority of genetic work that has been done is from northern areas of Europe, and there are some large gaps in our knowledge. There is currently nothing published, for example, on ancient Iberian cattle – the earliest samples that have been published are from the Bronze Age (Anderung *et al.*. 2005) - and this means that we have no dataset from another potential refugial area of Europe, which may be similar to Italy.

The role of zooarchaeologists in these studies is very important, as we provide the samples and information about species identification, as well as contextual archaeological advice. Geneticists and archaeologists approach similar research questions using different tools, and with different understandings, and it is therefore vital that we work together to have a full understanding of what the evidence is being presented. In terms of domestication, zooarchaeologists are able to provide information about the presence of wild progenitors, the dispersal of domesticates, the pattern of domestication events, and the temporal sequence of domestication (Zeder *et al.*. 2006). However, giving detailed information on these subjects is difficult when the morphology of the wild progenitor has not been sufficiently investigated. For cattle, one of the reasons for this is that there has not been a resource which has looked at the morphology of the wild animal across a large geographical area, and many people have a limited comparative dataset of biometrical measurements to use in their work. This is especially important when dealing with specimens dating to the Neolithic period onwards, because the distinction between wild and domestic is so unclear. This project by no means aims to ‘solve’ the issue of distinguishing wild from domestic cattle, but instead aims to provide a far more rigorous study of the data that are there, and bring them all together in one place. Until this work has been done, we cannot be sure that the samples that we are providing, and the information that we are giving, is the most appropriate for answering the research questions of a multidisciplinary project.

1.6 *Bos* versus *Bison*

This final introductory section has been included in order to give some background to the issues surrounding *Bos* and *Bison* identification, and indicate how they are of relevance to this project. Whilst *Bos* and *Bison* have distinctive cranial morphologies, the osteological determination of fragmented postcranial bones can often be very difficult, or even in some cases impossible. This is due to the fact that these species are closely related (see Section 1.2.1).

Morphological differences between the postcranial bones of *Bos* and *Bison* are usually small and rarely clear-cut. The great morphological variation and sexual dimorphism in both genera increases the difficulty of identification. Nevertheless, a number of studies have attempted to tackle this issue (Reynolds 1939; Degerbøl and Iversen 1945; Lehmann 1949; Bibikova 1958; Olsen 1960; Stampfli 1963; Sala 1986; Martin 1987; 1990; Gee 1993).

During the time period covered by this study, two different species of *Bison* inhabited Europe. The long horned *Bison priscus,* or 'steppe bison', is the earlier form, thought to have become extinct at the end of the Pleistocene (Pfeiffer 1999). The shorter horned *Bison bonasus* is the Holocene species, often referred to as the 'European bison'. This species has representatives living today in parts of Eastern Europe such as Poland, Belarus, Lithuania and Russia, though it is a rare and endangered species.

Bison priscus had a wide distribution across Europe, from Spain, through central and eastern Europe and into Siberia. This species also crossed the Bering strait into North America (Kahlke 1994). *Bison priscus* was able to adapt to a wide range of environments, both glacial and temperate (von Koenigswald 1999), which presumably contributes to the explanation of its great morphological variability.

Of the two species, *Bison priscus* is thought to be particularly problematic in terms of its morphological distinction from *Bos primigenius* (Ekström 1993). The problem is enhanced by the fact that *Bison priscus* was relatively abundant in the Pleistocene, and seems to appear alongside *Bos primigenius* on several sites. Although in a very general sense *Bison priscus* bones are shorter and more slender than those of *Bos primigenius* (Gee 1993), this is a relative distinction, and can be complicated by sexual dimorphism. Overall *Bison priscus* was very similar in size to *Bos primigenius*, and this is the main issue with making confident identifications.

Various attempts have been made to find reliable morphological characteristics to enable a distinction of the two genera (e.g. Reynolds 1939; Degerbol & Iversen 1945; Lehmann 1949; Bibikova 1958; Olsen 1960; Stampfli 1963; Sala 1986; Martin 1987; 1990; Gee 1993). A number of these papers discuss the same morphological features, but it is also clear that variation of many of these morphologies is great. For example a common trait that is discussed is the apparently distinctive shape of the diaphyses of the metapodials. These are described as like a 'claret bottle' in *Bison* and a 'burgundy bottle' in *Bos* (Bibikova 1958; Olsen 1960), however, in other studies this feature was found to be much less reliable than previously assumed (e.g. Gee 1993). Most studies just look at the visual morphological differences between the two species, but Gee (1993) performed a reliability evaluation on all morphological differences noticed by eye, which was able to highlight some of the more reliable indicators. This work shows that there are a number of features that can be looked at, but that few of them have very high levels of reliability. Due to these issues confident identification of *Bison priscus* is difficult, and many faunal reports dealing with Pleistocene material refer to '*Bos/Bison*' as one group. The fragmentary nature of much Pleistocene material also adds to the problem, as it is dangerous to assign bones to a species based on the very few characteristics that may be present on small fragments.

Although the shorter horns of *Bison bonasus* are distinctive, their postcranial remains are morphologically similar to *Bos primigenius*. The postcranial bones of *Bison bonasus* are generally shorter and more slender than those of *Bos primigenius* (and *Bison priscus*). However, as with *Bison priscus* this distinction is relative, and a large amount of variation is present amongst both species, as well as sexual dimorphism. However, the Holocene European Bison is thought to be overall smaller in size than the aurochs. Lehmann (1949) and Stampfli (1963) have discussed the osteological characteristics useful for the determination of the two species, but in many cases, especially with highly fragmented bones, identification may still not be possible.

Despite this issue *Bison bonasus* is generally identified more confidently than *Bison priscus*, as has been the case at sites from France across central Europe to as far east as Belarus and the Ukraine and as far north as southern Scandinavia. *Bison bonasus* has never been firmly identified in Britain, or the Iberian peninsula, whereas *Bison priscus* was present in both of these areas. In most parts of Europe *Bison bonasus* is rare compared to *Bos primigenius*. Only in eastern Europe does it seem to be relatively more abundant. Consequently, the assumption is often made that *Bison bonasus* is absent from most European faunal assemblages, but in fact the possibility that some postcranial remains of *Bison bonasus* are hidden among Holocene aurochs assemblages cannot be excluded. The number of potentially misidentified *Bison bonasus* remains is, however, unlikely to be large, because the occurrence of the more easily identifiable cranial remains should, at least in some cases, be able to alert researchers to proceed with caution.

Overall, *Bison priscus* is more problematic than *Bison bonasus*, due to the smaller range and relative rarity of *Bison bonasus* across Europe. We can therefore be fairly confident that our Holocene samples are unlikely to contain so many bison bones that our results will be biased. For the Pleistocene material, we must be careful about what we include. We can be confident that large assemblages, such as that from Ilford (Essex, UK), where almost all bones have been identified as *Bos primigenius*, due to their general uniformity in size and presence of large numbers of crania, are unlikely to contain many rogue bison bones. Other assemblages must be treated on a case by case basis, and may only be included if there is clear evidence of cranial remains, or the postcranial remains show clear differences from other local *Bison priscus*. In most cases where *Bos primigenius* has been identified, this work will already have been undertaken.

The methods undertaken whilst recording the material, in order to take into account the identification problem will be outlined in Materials and Methods (Chapter 2).

1.7 Summary

The aim of this thesis is to investigate, using zooarchaeological methods, the morphological variability of the European aurochs, providing a broader picture of its size and shape changes across time and space, than has been presented before. It is hoped that this information will be an important tool for researchers, in order to make aurochs identifications relevant to geographical area or time period.

This chapter has provided some information on the aurochs in its European context (Section 1.2) and outlined the different factors that can affect body size, and the work that has been done regarding the aurochs for each of these to date (Section 1.3). An overview of the general climatic changes that have taken place over the last c340,000 years, has been laid out, in order to put body size change into a climatic context (Section 1.4), some background to studies looking at cattle domestication, has been given (Section 1.5), and finally, issues of determining *Bos* from *Bison* have been described, along with their relevance for this project (Section 1.6).

The following chapter will introduce the dataset and methodology used for this project (Chapter 2). This is followed by two chapters of results; Chapter 3 will contain results presented by geographical area, and Chapter 4 will present results by time period. A discussion is then provided of the results in relation to the research questions outlined at the start of this introductory chapter, followed by some conclusions and reflections on the project (Chapter 5).

Chapter 2: Materials and Methods

2.1 Material

In order to tackle the research aims outlined in the opening chapter to this thesis, *Bos primigenius* material from across Europe was selected for re-analysis. Assemblages were chosen in an attempt to try and collect data from as many different geographic and climatic zones across Europe as possible, but also depending on ease of access, and the amount of material in each place. In some countries (such as Denmark), much of the material is kept in one place, and it is relatively easy to analyse it all at once, while in other countries material is kept at local museums, and is therefore more difficult to access. Material that has been recorded personally by the author is shown in Table 2.1.

Inevitably, due to the impracticalities of visiting a very large number of localities, and the gaps created by this a fair amount of data needed to be extracted from databases of unpublished material recorded by other people, and from the literature. These data are shown in Table 2.2. (N.b Only data that have been analysed in this thesis have been included in Table 2.2. The database also contains more data that were not analysed due to issues such as unclear dating. Full references for these data can be found in the bibliography).

The material included in this project, including that personally recorded by the author as well as that extracted from databases or the literature, is mostly made up of remains accumulated as a consequence of human activity on archaeological sites. However, there are also some *Bos primigenius* remains included that are from lone skeletons, usually found articulated *in situ* in bog locations. The data from these skeletons were considered to be valuable in order to bolster the generally small sample sizes of *Bos primigenius* remains from archaeological sites. Although these remains cannot be used for site by site analyses, they provide extra biometrical data for certain time periods.

Overall, an attempt has been made to collect data from as many different geographic and climatic zones across Europe as possible, and also from a wide range of chronological periods covering the presence of the aurochs in Europe up until its extinction (i.e. from the Palaeolithic to the Middle Ages). Despite this, availability and accessibility of material and raw data was such that both geographical and chronological distribution is inevitably uneven and patchy. Although this may create a bias in the results, it does not make them invalid, as this will be taken into account at the interpretation stage. This is inevitable and in the nature of archaeological evidence generally.

Primarily bones previously identified as *Bos primigenius* have been recorded, but in some cases specimens identified as *Bos taurus* or identified as *Bos primigenius/taurus* have also been included. These data are from sites from the early Neolithic onwards and generally from sites where *Bos primigenius* has also been identified. A deliberate choice was made not to attempt identification at the time of recording, due to the current issues with distinguishing domestic from wild specimens. Considering all of the bones as '*Bos* sp' means that there are no preconceptions about individual specimens which may affect the interpretation of the data.

The fragmentary nature of much of the material makes it difficult to deal with the issues surrounding the identification of *Bos* and *Bison*. In an attempt to overcome this problem bones have been checked for any obvious *Bison* traits, as outlined in the literature (for a review see Section 1.6), and assemblages where *Bison* identifications outnumber those of *Bos* have been excluded.

A note on dates: A number of sites from the Pleistocene were only dated according to Marine Isotope Stage, or to cultural layer. Wherever possible dates have been presented in calibrated calendar years BP, or if C14 dates were available these were converted to cal BC. Holocene dates are presented as cal BC where possible. Calibrations were performed using Calib 6.0 (after Stuiver *et al.* 1993).

Table 2.1: Material personally recorded by the author. Calibrated dates have been provided where possible for ease of comparison. Conversions were performed using Calib 6.0.

Country	Material	Time period	Date	Institution
Britain	Ilford, Essex	Middle Pleistocene	MIS 7 (Schreve 2001)	Natural History Museum (NHM), London
	Grays Thurrock	Middle Pleistocene	MIS 9 (Schreve 2001)	NHM London
	Coygan Cave	Upper Pleistocene	64-38 ka BP (Aldhouse-Green *et al.* 1995)	National Museum of Wales, Cardiff
	Star Carr & Seamer Carr	Mesolithic	9870-8720 cal BC (Schlada-Hall 1990)	NHM London
	Goldcliff East	Mesolithic	5400-4000 cal BC (Bell *et al.* 2000)	National Museum of Wales, Cardiff
Denmark	Stokholthuse	Mesolithic	Pollen Zone IV (Degerbøl and Fredskild 1970) 8975 cal BC (Noe-Nygaard *et al.* 2005)	Zoological museum, Copenhagen
	Grænge 1942	Mesolithic	Pollen Zone IV (Degerbøl and Fredskild 1970)	Zoological museum, Copenhagen
	Gøderupgaard	Mesolithic	Pollen Zone IV (Degerbøl and Fredskild 1970) 8150 cal BC (Noe-Nygaard *et al.* 2005)	Zoological museum, Copenhagen
	Store Damme	Mesolithic	Pollen Zone VI (Degerbøl and Fredskild 1970) 8825 cal BC (Noe-Nygaard *et al.* 2005)	Zoological museum, Copenhagen
	Ullerslev	Mesolithic	Pollen Zone V (Degerbøl and Fredskild 1970)	Zoological museum, Copenhagen
	Grænge 1944	Mesolithic	Pollen Zone V (Degerbøl and Fredskild 1970)	Zoological museum, Copenhagen
	Svaerdborg	Mesolithic	Pollen Zone VI (Degerbøl and Fredskild 1970)	Zoological museum, Copenhagen
	Lundby I and II	Mesolithic	Dates to be published in	Zoological

			(Magnell *in Press*)	museum, Copenhagen
Denmark (cont.)	Holmegaard I	Mesolithic	7064-6681 cal BC (Fischer *et al.* 2007)	Zoological museum, Copenhagen
	Mullerup	Mesolithic	7350-7285 cal BC (Leduc 2010)	Zoological museum, Copenhagen
	Ulkestrup lyng	Mesolithic	7512-6595 cal BC (Richter 1982)	University of Copenhagen, Department of Geology
	Øgaarde	Mesolithic	Pollen Zone VI (Degerbøl and Fredskild 1970)	Zoological museum, Copenhagen
	Braband Sø	Ertebølle – late Mesolithic/early Neolithic	4357-4076 cal BC (Gravlund et al. 2012)	Zoological museum, Copenhagen
	Dyrholmen	Ertebølle – Late Mesolithic/early Neolithic	5322-4559 cal BC (Gravlund *et al.* 2012)	Zoological museum, Copenhagen
	Hjerk Nor	Ertebølle – Late Mesolithic/early Neolithic	'Ertebølle' no specific dates (Hatting *et al.* 1973)	Zoological museum, Copenhagen
	Norslund	Ertebølle – Late Mesolithic/early Neolithic	5621-4271 cal BC (Andersen and Malmros 1965)	Zoological museum, Copenhagen
	Krabbesholm	Ertebølle	4322-3810 cal BC (Gravlund *et al.* 2012)	Zoological museum, Copenhagen
	Mejlgaard	Ertebølle	4046-3713 cal BC (Gravlund *et al.* 2012)	Zoological museum, Copenhagen
	Bønnelykke	early Neolithic	Pollen Zone VII	Zoological museum, Copenhagen
	Ugilt	early Neolithic	Pollen Zone VIII	Zoological museum, Copenhagen
	Bønnerup 1	early Neolithic	2345 cal BC (Noe Nygaard *et al.* 2005)	Zoological museum, Copenhagen
	Tinglev Sø	Bronze Age	1930 cal BC (Noe Nygaard *et al.* 2005)	Zoological museum, Copenhagen
France	Noyen-sur-Seine	Mesolithic	7234-6090 cal BC (Vigne & Marinal-Vigne 1988)	Natural History Museum, Paris
Portugal	Cabeço da Arruda (Muge)	Mesolithic	c6300-5500 cal BC (Bicho et al. 2012)	Geological Museum, Lisbon; Natural History Museum, Porto
	Moita do Sebastião (Muge)	Mesolithic		Geological Museum, Lisbon; Natural History Museum, Porto
	Cabeço da Amoreira (Muge)	Mesolithic		Geological Museum, Lisbon; Natural History

				Museum, Porto
Italy	Castel di Guido	Middle Pleistocene	327-260 ka BP (Michel *et al.* 2008)	Department of Archaeological Science, University of Pisa
	Canale Mussolini	Upper Pleistocene	MIS 5a-MIS 3 (Farina 2011)	Natural history Museum, Calci (Pisa)
	Grotta del Fossellone	Upper Pleistocene	Late Mousterian to Aurignacian (Alhaique *et al.* 1996)	Pigorini National Museum of Prehistory and Ethnography, Rome
	Santa Croce	Upper Pleistocene	MIS 4 (Boscato *et al.* 2010)	Department of Archaeological Science, University of Siena
	Grotta Paglicci	Upper Pleistocene	C33 ka BP (Boscato 1994; 2004)	Department of Archaeological Science, University of Siena
	Grotta Romanelli	Upper Pleistocene	Epigravettian: 12812-10794 ka BP (Tagliacozzo 2003)	Pigorini National Museum of Prehistory and Ethnography, Rome

Table 2.2: Data taken from unpublished databases and the literature. Precise dates and archaeological cultures have been provided where possible. References for dates have been provided in the 'Date' column, and references for biometrical data have been provided in the 'Data source' column.

Country	Material	Time Period	Date/culture	Biometrical Data Source
Britain	Alice skeleton	Early Neolithic	3354-3397 cal BC (unpublished date, from original RC lab form labelled 'Nash Aurochs' there does seem to be some confusion about the date for this skeleton though.)	Sarah Viner database, recorded at Newport Museum as part of her PhD research
	Eton Rowing Lake	Early Neolithic-Bronze Age	3940-830 cal BC (Early Neolithic and Bronze Age phases) (Tim Allen, Oxford Archaeology)	Data recorded by Gill Jones and Sarah Crump unpublished data. Forthcoming publication: Jones G.G (In press)
	Durrington Walls	Late Neolithic	2525-2440 cal BC (Parker Pearson *et al.* 2011)	Feeding Stonehenge unpublished database (University of Sheffield),

Britain (cont.)				recorded by Sarah Viner-Daniels and Umberto Albarella
	Mount Pleasant	Late Neolithic		Harcourt (1979)
	North Marden	Late Neolithic	2760 cal BC	Browne (1986)
	Snail Down	Bronze Age	2140-1440 cal BC (Thomas 2005)	Clutton-Brock & Jewell (2005)
Denmark	Kolind	Ertebølle - TRB		Degerbøl and Fredskild (1970)
	Havnø	Ertebølle - TRB		Kurt Gron unpublished data
	Vikso		Pollen zone VIII	Degerbøl and Fredskild (1970)
	Holmene		3575 cal BC (Gravlund *et al.* 2012)	Degerbøl and Fredskild (1970)
	Borremose		Pollen zone VIII	Degerbøl and Fredskild (1970)
	Gammellung moor		Pollen Zone VIII	Degerbøl and Fredskild (1970)
	Vedbaek II		Pollen Zone VIII	Degerbøl and Fredskild (1970)
	Pindstrup		Pollen Zone VIII	Degerbøl and Fredskild (1970)
	Lidsø	Middle Neolithic	c3000 cal BC	Hatting (1978)
	Bundsø	Middle Neolithic	c3000 cal BC	Degerbøl (1939)
Sweden	Önnarp	Early Mesolithic	8080 cal BC	Ekström (1993)
	Steglarps Mosse	Early Mesolithic	7880-7720 cal BC	Ekström (1993)
	Almeö	Mesolithic	8278-7951 cal BC	Ekström (1993)
	Ageröd	Mesolithic	6206-6017 cal BC	Ekström (1993)
	Esperöd	Mesolithic	7590 cal BC	Ekström (1993)
	Frörums Mosse	Mesolithic	7480-7450 cal BC	Ekström (1993)
	Nevishög	Mesolithic	7470-7440 cal BC	Ekström (1993)
	Stora Slågarp	Mesolithic	7420 cal BC	Ekström (1993)
	Östra Värlinge	Late Mesolithic – Early Neolithic	6590-6570 cal BC	Ekström (1993)
	Alvastra	Middle Neolithic	c3000 BC	During (1986)
	Lindängelund	Middle Neolithic		Boëthius (2009)
	Stora Förö	Bronze Age	2460 cal BC	Ekström (1993)
Germany	Bedburg-Konigshoven	Mesolithic	10465-8797 cal BC (Street 1993)	Martin Street unpublished data
	Hohen Viecheln	Mesolithic	c7200 cal BC (Schuldt 1961).	Gehl (1961)
	Rosenhof	Mesolithic/Neolithic	5200-3980 cal BC (Breuning 1987)	Nobis (1975)

Germany (cont.)	Neustadt LA 156	Mesolithic/Neolithic	4678-3955 cal BC (Hartz 2005; 2011)	Aikaterini Glykou unpublished data
	Straubing-Lerchenhaid	Neolithic	Linearbandkeramik (LBK)-Stichbandkeramik (SBK)	Ziegler (1985/86)
	Meindling	Neolithic	LBK	Clason(1992)
	Künzing-Unternberg	Neolithic	4900-4500 cal BC	Ott-Luy (1988)
	Hüde I	Neolithic	c4600-2800 cal BC	Hübner *et al.* (1988)
	Schernau	Neolithic	Rössen culture	Nobis (1981)
	Ehrenstein	Neolithic	4245-3371 cal BC	Scheck (1977)
	Bruchsal Scheelkopf	Neolithic	c3800 cal BC	Karlheinz Steppan unpublished data
	Riekofen	Neolithic	2200 cal BC	Busch (1985)
	Griesstetten	Neolithic	2660-2900 cal BC	König (1993)
	Dresden-Coschütz	Late Bronze – Early Iron Age	Halstatt	Ambros (1986)
	Rottweil	Roman		Kokabi (1988)
	Genshagen & Deutsch Wusterhausen	Roman		Müller (1996)
	Eggolsheim	Roman	2nd-5th century AD	Breu (1986)
	Hildesheim-Bavenstedt	Roman		Missel (1987)
	Hanfwerder	Medieval	11th-13th century AD	Prilloff (1994)
	Weinberg	Medieval	8th-15th century AD	Walcher (1978)
Poland	Bocień	Early Neolithic	LBK (c5500-4500 cal BC)	Makowiecki (In prep)
	Grabie	Early Neolithic	LBK (c5500-4500 cal BC)	Sobociński (1985b)
	Bożejewice 22/23	Early Neolithic	LBK (c5500-4500 cal BC)	Daniel Makowiecki (unpublished) database
	Łojewo	Early Neolithic	LBK (c5500-4500 cal BC)	Sobociński (1989; 1985b)
	Żuławka Mała	Early Neolithic	5180-4020 cal BC	Makowiecki (2009)
	Gniechowice	Neolithic & Bronze Age	LBK-TRB (c5500-3000 cal BC)	Sobociński (1978)
	Łęki Majątek	Bronze Age – Medieval		Makowiecki & Makowiecka Unpublished report
	Bruszczewo	Bronze Age		Daniel Makowiecki database
	Smuszewo	Bronze/Iron Age		Godynicki & Sobociński (1979)

Poland (cont.)	Gniezno 17a	Roman		Makowiecki Unpublished report
	Ujście	Early Medieval		Sobociński (1975a)
	Chmielno	Early Medieval		Sobociński (1979)
	Bytom Odrzański	Medieval		Makowieki Unpublished data
	Bialogard	Medieval		Makowiecki database
France	La Borde	Mid/Late Pleistocene	MIS 5	Brugal unpublished data
	La Montagne	Mesolithic	8298-7944 cal BC (Helmer and Monchot 2006)	Helmer and Monchot (2006)
Spain	Solana del Zamborino	Middle Pleistocene (MIS 5)		Penela (1988)
	Cueva de Mazaculos II	Mesolithic	10013-7503 cal BC (Arroyo & Morlaes 2009)	Arroyo and Morales (2009)
	La Sierra de Gibijo	Mesolithic	6505-5927 cal BC	Altuna (1974)
	Mendandia	Mesolithic – Neolithic	6550-4490 BC	Castaños (2005)
	Arenaza	Mesolithic - Chalcolithic	9500-2600 cal BC	Altuna (1980) Guy Straus (2008)
	La Draga	Early Neolithic		Maria Saña unpublished data
	Cueva de Chaves	Neolithic	4820-4170 cal BC	Castaños (2004)
	La Renke	Neolithic - Chalcolithic		Altuna (2001)
	Cueva de La Vaquera	Neolithic		Morales and Martin Garcia (1998)
	Fuente Flores	Neolithic - Chalcolithic		Cabanilles & Valle (1988)
	Los Castillejos	Chalcolithic	c2000 cal BC	Castaños (1997)
	Las Pozas	Chalcolithic		Morales (1992)
	Cerro de la Virgen	Chalcolithic – Bronze Age		von den Driesch (1972)
Portugal	Castro do Zambujal	Chalcolithic	c2400-1600 cal BC	von den Driesch and Boessneck (1976)
Italy	Puntali	Pleistocene	MIS 5	Brugal (1987)
	Vado all'Arancio	Late Pleistocene	13184-13725 ka BP	Boscato (1996)
	Grotta delle Mura	Mesolithic	7489-6847 cal BC (Calattini 1996)	Bon and Boscato (1993)
	Grotta dell'Uzzo	Mesolithic	6380-6620 cal BC (Tagliacozzo 1993)	Tagliacozzo (1993)

Italy (cont.)	Favella	Early Neolithic	5971-5674 cal BC	Tagliacozzo and Pino Uria (2009)
	Arene Candide	Early Neolithic – Bronze Age		Rowley-Conwy (1997)
	Cornuda	Neolithic	c3000 cal BC	Riedel (1988)
	Santa Maria in Selva	Neolithic		Wilkens (Unpublished report)
Switzerland	Seeburg Burgäschisee-Süd	Neolithic		Stampfli (1963)

2.2 Methods

The general aim of this project is to investigate the morphological variability of the European aurochs, and the methods that have been employed here have been chosen in order to try and tackle this effectively, whilst also completing data collection within the time that was available. The collection of biometrical data is obviously of the utmost importance, as this provides the most direct surviving evidence of aurochs morphology, but in combination with this, the recording of age and sex is vital. This information is especially important as both age and sex can have a large impact on body size (as discussed in Section 1.3.1). The importance and contribution of ageing, sexing and biometrical information will be discussed in more detail below.

2.2.1 Ageing

In a biometrical study, it is vital to consider the age of each specimen that is recorded. As discussed in Section 1.3.1, bones from young animals continue to grow until they are fused, and so are not biometrically comparable with those from adult animals. All juvenile bones must be isolated before analysis takes place or else there is a risk that results might indicate a population where animals look misleadingly small, or show a pattern that looks like two separate populations of animals.

The identification of juvenile bones in an assemblage can also tell us about preservation levels at a site. Juvenile bones tend to be more susceptible to damage than adult bones. The presence of a high proportion of juvenile bones may indicate favourable conditions for preservation, and therefore may indicate that taphonomic factors did not have a large impact on the assemblage.

It is worth bearing in mind that some bones, such as the scapula and the radius, do experience some growth in width after fusion (Payne and Bull 1988: 30). This can be of some use when trying to determine the age of animals within an assemblage, but can complicate biometrical studies hoping to detect the effects of external ‘ecological’ factors (cf chapter 1) as opposed to ontogenetic factors such as age.

Age also affects tooth size, although instead of getting larger as an animal gets older, teeth get smaller over time through wear. Wear mainly affects tooth height, but in very old animals it can also affect tooth width. It is important to bear this in mind whilst analysing tooth size.

2.2.1.1 Methods for ageing employed in this project

The method of estimating age in this project is based on the state of epiphysial fusion in conjunction with the eruption and wear of mandibular teeth. Most of the bones included in the recording protocol were chosen specifically to maximise the amount of information that could be collected per specimen, including ageing information. Consequently, most of the selected skeletal elements have a recordable area of fusion.

2.2.1.1.1 Fusion

Ageing zooarchaeological assemblages by epiphyseal fusion needs to be done with caution. There is general agreement between researchers that epiphyseal fusion within the skeleton takes place in the same order for animals within the same species, but it is also accepted that there can be variation in the exact timing of this fusion. The rate of fusion can vary due to the influence of a number of factors including nutrition, health, environment, sex, domestication and castration (Davis 1987: 39; O'Connor 2000: 95-96; Reitz and Wing 2008: 72). In addition, fusion sequences are based upon the study of modern animals, and there is no way to be sure that they are comparable with the age of fusion in prehistoric animals. As a result this study has assigned bones to broad categories based on their placement within the fusion sequence. Age categories were established using O'Connor (2003) and Silver (1969), and are shown in Table 2.3.

The state of fusion has been recorded for both distal and proximal ends of the bone. Metapodials and the scapula have been recorded as having only a distal end, as have the pelvis and atlas, despite their fusion areas not actually being distally placed – this is in order to keep the number of database columns to a minimum. Phalanges and calcanea have been recorded as having only a proximal end. Since the astragalus has no epiphysis, its records include characterisations as 'normal', 'light' or 'porus', which are likely to be age-related. An astragalus was recorded as 'light' when the bone surface had the normal (adult) appearance but the bone was lighter than would be expected for a fully ossified specimen. 'Porous' specimens are those which feel light but also look porous, this indicates that the bone surface is underdeveloped. Judging the level of lightness or porosity in this way is inevitably subjective, but these characterisations provide a rough guide for ageing an animal and enable us to exclude young astragali from analysis.

Fusion has been recorded as 'fused', 'fusing', 'fused or fusing', 'unfused diaphysis', 'unfused epiphysis', or 'unfused, with both diaphysis and epiphysis present'. Epiphyses were considered as 'fused' when the fusion line was no longer visible and 'fusing' when any part of the line was still open. This information was used to assign bones to age categories according to how early they fuse (Table 2.3).

Table 2.3: The attribution of cattle elements to age categories, based on Silver (1969) and O'Connor (2003)

Earliest	Early	Intermediate	Late
Pelvis	Distal humerus	Distal metacarpal	Proximal humerus
Scapula	Proximal radius	Distal metatarsal	Proximal femur
		Distal tibia	Proximal tibia
			Distal radius
			Distal femur
			Calcaneum

Biometry can also be used to investigate animal age in a population. This can be done by taking measurements from bones that are especially age-dependent, such as the smallest width of the scapula neck (SLC) (Albarella and Payne 2005). This information will be used in combination with other ageing data in order to identify age groups, and look at size change according to age over time.

2.2.1.1.2 Tooth eruption and wear

The eruption and wear of teeth (both deciduous and permanent) can provide more extensive information about the age of an animal than the fusion of postcranial bones. Epiphysial fusion provides information about the development of an animal until it reaches maturity (when its bones are fully fused). This means that once adulthood is reached no further information about advancing age can be gathered from the state of epiphysial fusion. In contrast, tooth wear can continue to provide information throughout an animal’s life.

As with epiphyseal fusion, there are a number of issues that one must be aware of when attributing animals to an age category using tooth wear. The age of tooth eruption could vary due to a number of factors, including nutrition (Grant 1978: 103), as well as sex and castration (Moran and O’Connor 1994). In addition it must be remembered that, as toothwear increases with the age of an animal, the variation of toothwear patterns in a population also increases, so that if you are dealing with especially old animals you have to be very careful about attributing them to a very narrow age range.

The rate of tooth wear may also vary depending on the abrasiveness of different foods (Davis 1987; Moran and O’Connor 1994; Reitz and Wing 2008), although this assumption has been challenged by Grant (1978: 105) who found no difference in the level of wear on the teeth of sheep from Scotland that consumed a diet with substantial sand inclusions, when compared with Roman animals from the south of England. Material included in the present study is from across a wide area and a large time span, with many different climatic and environmental conditions, therefore it is more likely that variation in both eruption and wear may be present, and this must be taken into account during data analysis.

For this investigation, eruption and wear stages from the lower molars, the 4th premolar and deciduous 4th premolar were recorded using the system established by Grant (1982), as wear from these teeth is thought to be the best indicator of age (Grant 1982). In order to analyse these data a method has been employed in which mandibles have been grouped following the system outlined by O’Connor (2003). O’Connor identified a number of age categories based on the wear stages of Grant (1982) (‘neonatal’, ‘juvenile’, ‘immature’, ‘subadult’, ‘adult’ and ‘elderly’) these are outlined below (Table 2.4). These age categories are broad enough to be able to take into account a fair amount of variation in tooth eruption and wear.

Although tooth samples recorded for this project were generally small, and so it was not possible to perform an in-depth analysis of ageing by toothwear, these data are still included in the database, and may be of further use in future.

Table 2.4: Age categories used in the analysis of tooth wear data, as outlined by O'Connor (2003)

Category	Description
Neonatal	dP4 unerupted or erupting.
Juvenile	dP4 in wear, M1 not in wear.
Immature	M1 in wear, M2 not in wear.
Subadult	M2 in wear, M3 not in wear.
Adult	M3 in wear.
Elderly	Dentine exposure on the M_3 up to or beyond stage 'j'.

2.2.2 Sexing

The ratio of female to male animals in an assemblage can provide information about hunting and husbandry practices, but it is also extremely important in the context of biometrical work to investigate sex as one of a number of possible factors that can affect body size. As mentioned in the introductory chapter to this thesis, both *Bos primigenius* and *Bos taurus* show a certain degree of sexual dimorphism, with males larger than females. This is important in the context of a biometrical study, because an assemblage with a higher proportion of females to males may produce biased results, by making the population look like it has a smaller average body size than in reality. In addition to male and female animals another group that needs to be considered with relation to sex and body size is castrates. It has been argued that castration would have been common from the beginning of domestication (Clutton-Brock 1999: 37), but it may be difficult to identify in zooarchaeological assemblages. Castration delays epiphyseal fusion allowing bones to continue their longitudinal growth resulting in animals with long, slender bones (Davis 1987: 44). In some cases castrates may be relatively easy to spot, but in others they may be difficult to distinguish from both males and females, and blend into the two sex groups, or obscure patterns of sex variation. Most of the material studied for this project is from wild cattle and so will not be affected by this, but when we come to the more recent time periods and are dealing with both wild and domestic animals together it is important to remember the potential for this third group.

2.2.2.1 Methods for sexing employed in this project

Despite the presence of sexual dimorphism in both wild and domestic cattle there are no clear morphological differences that can be recorded in order to distinguish males from females. This study therefore relies on the identification of sex groups through biometry. One of the most common methods for separating male and female cattle remains is through the use of measurements from the distal metapodials, particularly the breadth of the distal end (coded as 'BFd' in the protocol for this project), as these measurements have been shown to be especially highly sexually dimorphic (Higham 1969; Thomas 1988; Davis *et al.* 2012). Metapodials tend to be short and slender in cows, short and wide in bulls, and longer and slenderer in castrates. There is also general agreement that metacarpals tend to be more sexually dimorphic than metatarsals due to the greater weight supported on the front than on the back legs (Bartosiewicz 1987: 48). Distinguishing male and female aurochs through the use of metapodial measurements has been demonstrated by Degerbøl and Fredskild (1970) as mentioned in Chapter 1, and the use of cattle metapodial biometry has been discussed in detail by Albarella (1997).

The use of metapodial measurements can be extremely useful for distinguishing males from females, however it is important to consider the other variables that could be causing a similar pattern. Morphological differences between breeds, for example, can obscure the differences between the different sexes (Albarella 1997). In addition, previous studies have shown that there can be some degree of overlap between the size of the two sexes when length measurements are included (e.g. Degerbøl and Fredskild 1970), and that different populations can vary considerably (Fock 1966). These things will need to be taken into account during data analysis.

2.2.3 Biometry

It has been argued for many decades and by many researchers that the measurement of animal bones from archaeological sites is important to zooarchaeological investigation (e.g. von den Driesch 1976; Boessneck and von den Driesch 1978; Albarella 2002). Most faunal reports now include some biometrical information, even if it appears in a summarised form, but measurements are often included without much consideration of their relevance to the specific research question. This can result in a limited biometrical analysis, constituting not much more than a description of the assemblage, and with no real contribution to the archaeological interpretation of a site. With this in mind, it is vital that measurements must be taken consistently, and with close regard to the questions that one is attempting to answer. In order to efficiently exploit the potential of taking measurements from the assemblages under investigation, the aims of the research must be central to recording protocol decisions. This section will present the main aims of the use of biometry in this project.

The general aim of this project is to explore the morphometric variability of the aurochs in relation to the effect of a number of factors. These include climatic and environmental factors, as well as cultural factors such as hunting pressure and domestication. In order to effectively look for body size differences related to these factors it is important to remember the effect that age and sex can have on body size. These factors can also be explored through the use of biometry, as has been mentioned above. This section will concentrate on biometry in relation to climate and environment, and domestication.

Differences in the size and shape of animals in relation to climatic differences in different areas or climate change over time have previously been investigated by a number of biometrical studies. Generally these studies have correlated smaller body size with areas or time periods with a warmer climate (in accordance with Bergmann's Rule – see Chapter 1 for a more in depth discussion of this). Davis (1981) conducted a study in which he found that a number of animals in Israel underwent a size decrease at around the time of the Pleistocene-Holocene transition, which he attributes to the increase in temperature during this period. Albarella *et al.* (2009) have observed a north/south and east/west cline in the body size of wild boar, with the largest wild boar being found in north-eastern areas, and the smallest in the south west. This is thought to have been related to temperature differences. Albarella *et al.* (2006) highlight an increase in the size of post-Mesolithic wild boar in Italy, that could be related in part to a climatic deterioration in the 4th Millennium BC. There have also been some exceptions to the rule, with studies such as that by Weinstock (2000) finding that during the Late Pleistocene in Western Europe larger reindeer were found in cool and humid climates, whilst smaller Reindeer were found in cold and dry conditions. Weinstock's work indicated that factors other than temperature – such as continentality – can affect body size. The affect of climatic differences across space and climatic changes across time are an integral part of this project and therefore it will be important to try and spot correlated changes during biometrical analysis.

Likewise, a number of biometrical studies have investigated the impact of domestication on the body size and shape of different animals. One of the most commonly used criteria for spotting domestication is a reduction in body size. This reduction in body size has been seen in cattle (Grigson 1969) pigs (Hongo and Meadow 1998; Albarella *et al.* 2006); sheep and goats (Uerpmann 1978; Meadow 1989), and dogs (Moray 1994) (see Chapter 1 for a more in depth discussion on this). Through looking for this reduction in body size, biometrical analysis can be used to look for the presence of wild and domestic animals in an archaeological assemblage. In this project both wild and domestic *Bos* will be analysed together in the hope that both groups can be identified biometrically, the range and overlap of the two groups can be seen clearly, and therefore that the morphological variation of *Bos* within and between the two groups can be analysed more effectively. Through this it is hoped that biometrical analysis will assist in creating a more reliable morphometric identification of wild and domestic cattle from the Neolithic onwards.

Although biometry is an extremely useful tool for identifying cattle domestication, it can be problematic. Although it is clear from previous work that domestic cattle are smaller than aurochsen (Jewell 1963; Grigson 1969; 1978; Degerbøl 1963; Degerbøl & Fredskild 1970), there is actually an overlap in the measurements of larger domestic cattle and smaller aurochs. This means that distinguishing between wild and domestic cattle biometrically has proven difficult. It is important that care is taken not to over interpret the dataset and identify domestication too readily.

2.2.3.1 Methods for the analysis of biometrical information used in this project

Small sample size is a prevalent issue in zooarchaeology, and can be problematic when undertaking biometrical studies. This is something that is of particular relevance to this project. Aurochs remains generally appear on archaeological sites in relatively small numbers, and if measurements are being compared between assemblages (or even areas) using scatterplots, then there may not really be enough evidence in order to make reliable interpretations. In this project this problem is combated by using an index scaling technique for analysis (see Meadow 1999). Index scaling techniques essentially allow different measurements to be placed on the same scale and therefore combined in order to create larger units. In order to use this technique a standard value for each measurement is required, to which the archaeological material can be compared.

The standard measurements can be based on one animal, or can be means taken from a modern or archaeological population. The problem with using only one animal is that decisions must then be made regarding whether a male or a female should be used, or if the age of the animal is going to affect results. For this study, therefore, the mean measurements from a palaeontological aurochs assemblage will be used. This standard population is from Ilford in Essex (UK) and has one of the largest sample sizes of all of the aurochs assemblages in this project, and certainly the largest in Britain. It has also previously been used as a standard population for a biometrical study looking at cattle size and shape change related to domestication (Viner 2010). This assemblage has been dated to Marine Isotope Stage 7 (186-242kya) (Schreve 2001; Andy Currant *pers. comm.*), and the standard measurements which were used are listed in Tables II-1 – II-8 of appendix II.

For this project we employed a log ratio scaling technique in order to compare the relative size of each dataset to the Ilford standard (Meadow 1999). In order to do this we calculated the logarithm of the ratio between each measurement and its standard (Simpson *et al*. 1960) This was repeated for each measurement. This process is described using this basic formula:

$$=\log_{10}(x/y)$$

Where x is the value of the archaeological specimen, and y is the standard of that same measurement (mean) calculated from the standard population. Each resulting log ratio value was then plotted with the “standard” being 0.

In order to use this technique effectively, a judgement was made about which specific measurements would be included in the analysis. This was based on what kind of information different measurements would give, and the sample size of specimens that made up the standard measurement from the Ilford population. Measurements included in the log ratio analysis are listed in Table 2.5.

Table 2.5: Measurements chosen for use in the log ratios (see Tables 2.7 and 2.8 for measurement code definitions).

Bone/Tooth	Measurements
astragalus	GLl, GLm, Bd
calcaneum	GL, GD
femur	DC
humerus	BT, HTC
metacarpal	GL, SD, BFd, BatF, 1, 6
metatarsal	GL, SD, BFd, BatF, 1, 6
tibia	GL, Bd, Dd
3^{rd} Molar	L, W

Summary statistics are presented throughout the results sections, and include means, ranges, standard deviations and coefficients of variation for samples of over 5 specimens. All raw biometrical data are included on the database included on the CD accompanying this thesis.

Finally, where possible, the changes seen across time and space were tested statistically using Mann-Whitney tests. These tests were performed on log ratios and therefore the results should be treated with caution, as it has previously been suggested that the application of statistical tests to ratios may be biased (Atchley *et al.* 1976). Statistical testing was only performed on samples of over 20, and only one measurement from each bone was included in order to reduce the duplication of data from the same animal. Because of the nature of zooarchaeological material we cannot guarantee, however, that we do not have any duplicated data from the same animal. The measurements chosen from each bone are laid out in Table 2.6.

Table 2.6: Measurements chosen for use in the Mann Whitney test (see Table 2.7 for measurement code definitions).

Bone/Tooth	Measurement
astragalus	GLl
calcanuem	GL
Femur	DC
humerus	BT
metacarpal	BFd
metatarsal	BFd
tibia	Bd

Overall, the biggest challenge when analysing and interpreting biometrical change is teasing apart the effects of different factors on body size and shape change. Care must be taken not to confuse the effects of climatic change with those of domestication, for example, and one must always take into account the effects of ontological factors such as age and sex. Potential confusion can be reduced by selecting the most appropriate measurements for spotting the affects of particular factors. This is explained in more detail below.

2.2.4 The selection of skeletal elements and measurements: the recording protocol

2.2.4.1 Skeletal elements

The recording protocol employed to record information from *Bos* postcranial bones and teeth for this project allowed the recording of as much useful information as possible related to age, sex, size and shape in a relatively short space of time. The protocol follows a system based on that outlined by Davis (1992) and Albarella and Davis (1996), with some modifications relevant to this project. This system is based on the identification and recording of only specific zones of a number of skeletal elements. The zones recorded are generally those that include information about ageing (such as the epiphysial ends of long bones), and those that yield the most useful biometrical measurements.

The full recording protocol is included in Appendix I.

2.2.4.2 Measurements

Measurements follow those defined by von den Driesch (1976), Davis (1992) and Albarella and Payne (2005). Most measurements were taken using a pair of digital callipers to the nearest tenth of a millimetre. Due to the difficulty of carrying a measuring board, greatest length (GL) measurements exceeding the length of the callipers (200mm) were taken by placing the bone against two vertical surfaces (e.g. the wall and a box) and then measuring the distance between the two. Because of the likelihood of higher error using this method, measurements were only recorded to the nearest millimetre. Measurements on postcranial material have been taken when possible on fused, fusing and unfused bones. Measurements of unfused bones are unsuitable to assess the size of fully grown animals, and therefore they are not commonly taken by zooarchaeologists. However, they have been measured here because of their potential in highlighting differences in size groups (e.g. males and females; wild and domestic) culled at different age stages (e.g. Zeder and Hesse 2000; Zeder 2001)

Measurements were chosen on the basis of 4 main criteria:

1. Availability in faunal assemblages. The elements selected to be measured are generally relatively robust, and have proven to be most resistant to breakage and loss by both pre- and post- depositional processes.
2. Ease with which the measurements can be taken and defined.
3. Ease with which the measurements can be compared to those in the literature. Because of the necessity to use previously published data, the measurements need to be broadly comparable to those which other researchers have taken.
4. Relevance to the specific questions of this project. Questions relevant here include the environmental impact on size and shape change, as well as issues of sexual dimorphism, and wild versus domestic animals.

The reason for the selection of different bones and teeth for the taking of measurements, is outlined below. Sources for the definitions of each of the different measurements taken on postcranial bones, teeth and crania are given in Tables 2.7, 2.8 and 2.9 respectively. The choice of measurements is based on previous work looking at the effect of both ontological and ecological factors on certain measurements. The most comprehensive study of this kind is by Payne and Bull (1988) who looked at this issue in the context of distinguishing wild and domestic pig remains, and further work was done by Albarella and Payne (2005) on this issue also with regards to pigs. Obviously this is a different species, and it is possible that not all of their conclusions may be relevant to cattle. However, the few comments that have been made in other papers with regards to cattle do seem to agree with the findings of the work on pigs (e.g. Degerbøl 1963; Grigson 1969; Degerbøl and Fredskild 1970; Grigson 1982), and there is no real reason to believe that there should be a great difference between the two species.

Different parts of the body are affected to a greater or lesser degree by different factors, and so certain measurements are useful for investigating different things. Some measurements are highly affected by the age of an animal, and others are more affected by sexual dimorphism. This has been taken into account when considering what kind of information the different measurements can provide. In order to separate larger wild from smaller domestic animals, or to investigate size change between different periods, the most useful measurements will ideally have low sexual dimorphism and low age related change (Payne and Bull 1988). Postcranial measurements tend to show higher sexual dimorphism than teeth, and forelimbs may be more affected by sexual dimorphism than hindlimbs (Degerbøl 1963; Bartosiewicz 1987; Payne and Bull 1988). These issues have also been taken into account whilst selecting the measurements to use for this project. The basis on which measurements have been chosen for each bone, tooth or cranial element is outlined below.

2.2.4.2.1 Postcranial bones

Postcranial measurements chosen for use in this project are laid out in Table 2.7.

Atlas

The atlas is easily identifiable in terms of element and taxon. It exhibits a high level of sexual dimorphism (Grigson 1982: 9) and so the measurements chosen (H and BFcr) may be most useful in distinguishing between the sexes.

Scapula

The scapula is also highly taxonomically diagnostic. This bone survives well in the archaeological record due to its relatively early fusion (around 7-10 months, Silver 1969). The neck of the scapula is the most robust part of this bone, and is often found in archaeological assemblages. The width of the neck (SLC) is highly dependent on the age of an animal, and some parts of the bone will continue to increase in size even once the bone is fully fused (Albarella and Payne 2005: 596-598; Payne and Bull 1988: 30). Therefore the main benefit of taking this measurement is for its use in investigating the age of animals.

Humerus

The distal humerus has an early fusing epyphisis (Silver 1969) and therefore survives better in archaeological assemblages than the proximal end. Two measurements on the distal humerus have been taken for this project. The first, the HTC (height of the trochlea) is not affected a great deal by sexual dimorphism or age-related change, and therefore is most useful for distinguishing ‘ecological’ body size change, such as the affect of domestication (Payne and Bull 1988: 31-32) and climatic or environmental change. The second measurement, BT (breadth of the trochlea), is more affected by sexual dimorphism (Payne and Bull 1988: 31-32) which means that it may be possible to compare wild/domestic status with sex variation within the same bone.

Radius

The proximal radius fuses early while the distal epiphysis remains unfused almost until an animal reaches adulthood (Silver 1969: 285). The development of the proximal end is highly dependent on age, and as with the scapula may continue to increase in size even after fusion

(Payne and Bull 1988: 30). Two measurements were taken on the proximal radius, Bp (the width of the proximal end, and BFp (width of the humeral articular surface). With these measurements it is possible to investigate animal age and will boost the information provided by the scapula. The greatest length (GL) of the radius was also recorded where possible. The radius is the most likely long bone to be found complete. Length measurements are also much less affected by age after fusion, than width and depths.

Metapodials

As discussed above metapodial measurements are extremely useful for sexing cattle bones. Distal metapodials survive well in the archaeological record, despite the fact that they do not fuse particularly early (between 16 months and 2 ½ years (Silver 1969: 285-6). In contrast the proximal ends of the metacarpal and metatarsal of cattle do not have an epiphysis and are therefore of little biometrical use, due to their large related increase, which cannot be monitored through fusion. A combination of length and distal width measurements of these bones have been used to distinguish different sex groups. As well as identifying sexual dimorphism metapodial measurements can be used to distinguish between wild and domestic cattle (Degerbøl and Fredskild 1970) and different breeds of cattle (Albarella 1997 – although this may not be a variable that needs to be considered in depth for this project), and will also be of use in looking for the affects of climate. A combination of different metapodial measurements were taken in order to enable a number of different variables to be investigated. The measurements taken were the greatest length (GL), the smallest diameter of the diaphysis (SD), the breadth of the distal end (BFd), the breadth at the distal fusion line (BatF), the depth of the distal end (Dd), and a number of measurements on the distal condyles (a, b, 3 and 6).

Pelvis

The length of the acetabulum (LA after von den Driesch 1976: 82-83) was taken on the archaeological material. This measurement is relatively unaffected by sexual dimorphism or age-related factors, and therefore it can most usefully be used to distinguish body size change due to ‘ecological’ factors, such as climatic and environmental change, or domestication (Payne and Bull 1988: 32).

Femur

Both the proximal and distal ends of the femur fuse late in the sequence of skeletal development (Silver 1969: 286) making them susceptible to destruction and a less common occurrence in the archaeological record than other elements. As a result, only one measurement was taken on the femur, DC (depth of the caput). This measurement varies little with age once fully fused and is not highly sexually dimorphic (Albarella and Payne 2005: 597), therefore it is probably of most use in distinguishing ecological factors.

Tibia

The tibia tends to survive well in the archaeological record as it is relatively robust. The breadth and depth of the distal end (Bd and Dd) were taken, along with the greatest length (GL). The breadth of the distal end is not greatly influenced by sexual dimorphism or age and is therefore most useful for distinguishing ecological factors such as domestication, (Payne and Bull 1986: 32; Albarella and Payne 2005: 595), and climatic change.

Calcaneum

The calcaneum is commonly found in zooarchaeological assemblages, and measurements are easily taken. Measurements taken for this project are the greatest length (GL) and the greatest depth (GD). Measurement of the calcaneum are useful for distinguishing between wild and domestic pigs (Lasota-Moskalewska *et al*. 1987: 67) so we may assume that this will be the same for cattle.

Astragalus

The astragalus tends to survive quite well in archaeological assemblages, and is often found with little damage due to its compact shape. As a result it is often possible to take measurements and has probably provided the most useable measurements in this project. The astragalus shows the lowest sexual dimorphism of all of the limb bones (Grigson 1969) and so is an especially useful bone for distinguishing between wild and domestic animals (Albarella and Payne 2005; Payne and Bull 1988), but will also be useful when looking for the effects of other ecological factors. Although the astragalus does not have an epiphysis, once porus and light specimens are excluded, there is not going to be much variability due to age-related increase, probably because the bone is constrained within an articulation.

Measurements taken on the astragalus for this project are the GLl (greatest length of the lateral side) GLm (greatest length of the medial side) and the Bd (breadth of the distal end). The two length measurements are likely to provide the same kind of information, but will increase the number of measurements available for analysis, and are useful in the construction of scatterplots.

Phalanges

The first and second phalanges were recorded. The relatively early fusion of the first and second phalanges makes them useful in when assessing animal ages in faunal assemblages, and particularly helps to identify particularly young animals. No measurements were taken from the phalanges, this is due to the problems with attributing each bone to a fore or hind limb. There is no distinctive morphological detail allowing the attribution of phalanges to the fore or hind limb so this is usually done by looking at size. Obviously, though, this can cause confusion when a project is looking specifically at body size because different size groups of phalange bones could be mistakenly identified as indicating different sized animals, when actually they represent forelimb and hindlimb groups.

Table 2.7: Measurements taken on postcranial bones, and the source of their definitions

Element	Code	Description	Reference
Atlas	H	Height	Albarella & Payne (2005)
	BFcr	Breadth of cranial articular surface	von den Driesch (1976)
Scapula	SLC	Smallest width of the collum	von den Driesch (1976)
Humerus	BT	Width of the trochlea	Payne & Bull (1988)
	HTC	Minimum height of the trochlea	
Radius	GL	Greatest length	von den Driesch (1976)
	Bd	Breadth of distal end	
	BFp	Breadth of the humeral articular surface	
	Bp	Breadth of proximal end	
Metacarpus III & IV	GL	Greatest length	von den Driesch (1976)
	SD	Smallest diameter of the diaphysis	von den Driesch (1976)
	BFd	Breadth of the distal end	von den Driesch (1976)
	Dd	Depth of the distal end	von den Driesch (1976)
	BatF	Breadth at the distal fusion line	Davis (1992)
	a	Breadth of medial condyle	Davis (1992)
	b	Breadth of lateral condyle	Davis (1992)
	3	Diameter of the lateral part of the medial condyle	Davis (1992)
	6	Diameter of the medial part of the lateral condyle	Davis (1992)
Pelvis	LA	Length of the acetabulum including the lip	Von den Driesch (1976)
Femur	DC	Diameter of the caput	von den Driesch (1976)
Tibia	GL	Greatest length	von den Driesch (1976)
	Bd	Breadth of the distal end	
	Dd	Depth of the distal end	
Astragalus	GLl	Greatest length of the lateral side	von den Driesch (1976)
	GLm	Greatest length of the medial side	
	Bd	Breadth of the distal end	
Calcaneum	GL	Greatest length	von den Driesch (1976)
	GD	Greatest depth	Albarella & Payne (2005)
Metatarsus III & IV	GL	Greatest length	von den Driesch (1976)
	SD	Smallest diameter of the diaphysis	von den Driesch (1976)
	BFd	Breadth of the distal end	von den Driesch (1976)
	Dd	Depth of the distal end	von den Driesch (1976)
	BatF	Breadth at the distal fusion line	Davis (1992)
	a	Breadth of medial condyle	Davis (1992)
	b	Breadth of lateral condyle	Davis (1992)
	3	Diameter of the lateral part of the medial condyle	Davis (1992)
	6	Diameter of the medial part of the lateral condyle	Davis (1992)

2.2.4.2.2 Teeth

Teeth are commonly found in faunal assemblages and tend to survive better than bones. The size and shape of teeth are relatively unaffected by the age of an animal beyond the effect of wear in older animals (see Ageing section 2.2.1 for a discussion of this), because once teeth have formed they do not continue to grow over time. Teeth are also relatively unaffected by sexual dimorphism (Grigson 1982: 7-8; Payne and Bull 1988: 30). As a result teeth can be especially useful when distinguishing wild and domestic groups (Degerbol 1963: 71; Payne and Bull 1988: 31). Measurements from the mandibular third molar (M_3) are especially useful for this in cattle, Degerbøl (1963) and Payne and Bull (1988) have highlighted that M_3 widths are particularly useful in pigs due to the fact that they are less affected by wear and inter-dental attrition, and it therefore seems likely that this is also the case for cattle.

In this study, M_3 length measurements are taken according to von den Driesch (1976), but tooth width measurements are taken according to our own definition. This is due to the fact that von den Driesch (1976) suggests taking this measurement at the occlusal surface, which would be an extremely variable measurement, as it depends on how the tooth wears. Measurements chosen to take on teeth during this project are listed in Table 2.8

Table 2.8: Measurements taken on teeth, and the source of their definitions

Element	Code	Description	Reference
dP^4	W	Width, taken at the widest part of the tooth	My own definition, see Figure 2.1
M^1	W		
M^2	W		
M^3	W		
dP$_4$	W		
M$_1$	W		
M$_2$	W		
M$_3$	W		von den Driesch (1976) - as for Pig M3, see Figure 2.1
	L	Length, take at the widest part of the tooth	
Mandible	Mand H	Mandible Height in front of the M1 on the buccal side	von den Driesch (1976)

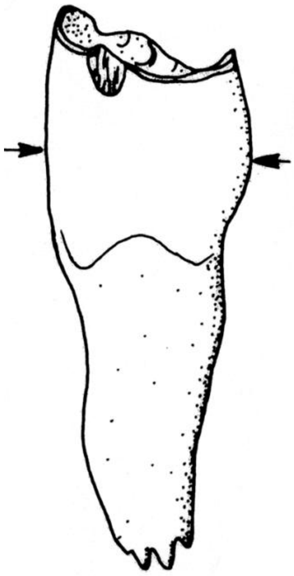
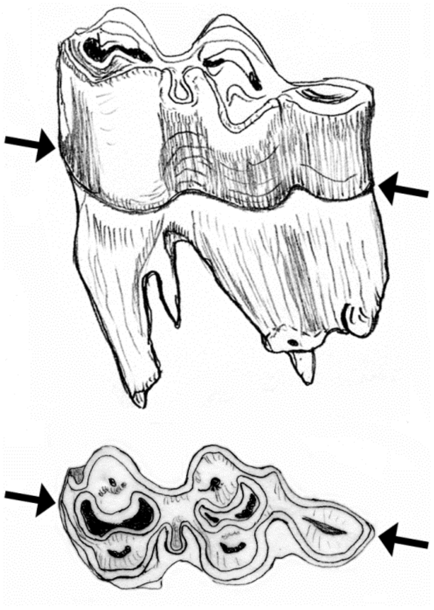
Premolar/Molar width (widest part of the tooth)	**Third Molar length (widest part of the tooth).**
	

Figure 2.1: Diagrams showing the way in which measurements were taken on cattle mandibular molars and deciduous fourth premolars. The exact place of the tooth that the measurements should be taken may vary depending on the tooth, but it will always be the widest part. Diagrams by Simon Davis, with permission.

2.2.4.2.3 Crania

Intact cranial remains are not common in archaeological assemblages meaning that measurements are difficult to take and not often included in zooarchaeological reports. However, a surprising number of *Bos primigenius* crania do seem to be kept by museums. This is due to the large number of isolated 'non-archaeological' *Bos primigenius* skeletons found in ancient bog deposits. The most likely reason for the larger number of isolated finds than for some other animals is probably simply that they are more distinctive and easy to spot due to the sheer size of the bones, and the size and shape of the horns. Whilst many people will not alert their local museum to an exposed pig or sheep skeleton, they might alert them to the remains of an extinct wild cattle skeleton. Considering the number of skulls available it seemed valuable to include some measurements in the protocol. These will be included in the data resource available from this project, but have not been used in the overall analysis and interpretation, because sample sizes were still relatively small, and very few of the crania included have been precisely dated. The included measurements are listed in Table 2.9.

Von den Driesch (1976: 27-28) provides a long list of measurements to take on whole cattle crania, but it would have been unfeasible, and not very useful, to take so many in a limited time period. Therefore a few measurements were selected, according to those most strongly associated with size or shape by Bartosiewicz (1999). Most cranial measurements are affected by sexual dimorphism (Grigson 1982: 8), and so most of the measurements taken may be most useful for identifying sex groups. There are a few exceptions to this though: a few particular measurements have been identified as being unaffected by sexual dimorphism (Bartosiewicz 1999). Of these the greatest breadth of the foramen magnum (von den Driesch no. 28) was selected for the protocol on the basis that it is better defined and less susceptible to damage compared to the other measurements. This measurement may be of most use for looking for evidence of the effects of climatic change or domestication. Horncores are more commonly found than many other cranial parts in archaeological assemblages and are less susceptible to damage than other cranial parts therefore measurements in this area are easily taken. However horn size is affected by sexual dimorphism (Grigson 1982: 9; Bartosiewicz 1999) so these measurements may be most useful for investigating sex groups.

Table 2.9: Measurements taken on crania, and the source of their definitions

Element	Code or Number (von den Driesch 1976)	Description	Reference
Horncores	Min (46)	Minimum diameter of the base	von den Driesch (1976)
	Max (45)	Maximum diameter of the base	
	GL (47)	Greatest Length	
Cranium	3	Basal length	
	25	Greatest mastoid depth	
	28	Greatest breadth of the foramen magnum	
	29	Height of the foramen magnum	
	30	Smallest occipital breadth	
	32	Smallest frontal width	
	33	Greatest width across the orbits	
	35	Facial breadth	

2.3 Summary

This chapter has outlined the materials and methods chosen for this project on the basis that they will be most suited for answering the research questions set out in the previous chapter. Material for re-analysis was chosen bearing in mind the time and cost constraints of the project, whilst trying to record material from as many different areas and time periods as possible. The data that were taken from unpublished databases and the literature were chosen in order to fill in the gaps in time and space left by the physical data collection. Even so, it is impossible in a project of this nature to collect all of the potential data from the assemblages that were studied. The methodology employed for the collection of data has therefore been specifically selective in order to address the research questions as best as possible without wasting time.

This chapter has also outlined the potential limitations of the methodology employed during data collection. The effects of a number of different factors, such as age, sex, climatic change and domestication have been taken into account, as well as taphonomic issues, when choosing the methodology, and therefore they can be more easily taken into account during the analysis phase.

Chapter 3

Biometrical Variation Across Time by Geographical Area

This chapter will present results, looking at a number of geographical areas across time. The countries/areas included in this analysis are Denmark and Sweden (Section 3.1), Britain (3.2), Germany and Poland (3.3), Iberia (3.4) and Italy (3.5). These results will provide information about the changing size and shape of *Bos* over time. The measurements were chosen in such a way that, wherever possible, the effects of age and sexual dimorphism would be minimised. The astragalus was usually the most common element yielding a sufficient number of measurement pairs appropriate for plotting on a scatterplot, so this element has been commonly used in the biometrical analysis here. Because astragali are quite compact in shape and survive well, it is often possible to take more than one measurement from the same bone. The astragalus is also less affected by sexual dimorphism than many other limb bones (Grigson 1969). The use of measurements from this bone will allow us to look for changes related to domestication and/or ecological, geographic and climatic factors. Within the distribution of its measurements it will also be necessary to consider the effect of sexual dimorphism, however minor it could be.

In combination with scatterplots, log ratio comparison of *Bos* remains will be employed. Log ratios have the advantage of being able to combine a number of different measurements on the same scale, therefore producing larger samples. Measurements can also be grouped by length and breadth, or according to skeletal element or even specific measurement in order to pinpoint where, in the body, change is taking place. The standard population used for creating the log ratio diagrams was established from measurements of aurochs bones from a British Pleistocene site (Ilford, in Essex) (discussed in Chapter 2). On the log ratio diagrams the standard has been marked with a line, and the mean has been marked with a star, means have only been calculated for samples of more than 5. The aim of the biometrical analysis here is to look for changes or stability over time in different areas of Europe. We can then start to tease out the causes of these phenomena, whether they are related to environmental or climatic change, domestication or other kinds of human interaction such as fluctuating hunting pressure.

Some ageing information has also been presented, but because the samples recorded by the author were generally quite small, and raw fusion data is generally not resented in the literature there not enough fusion data to do a thorough ageing analysis across all sites in each geographical area.

Where possible, similar data from *Sus* have also been presented, in order to provide a comparison for *Bos*. In some cases the raw data were available, and so a more direct comparison was possible, whereas in other cases it was only possible to present graphs created by others. Either way this is still a valuable comparison and an aid in the interpretation of the patterns indicated by the *Bos* data.

3.1 Denmark and Sweden

This section deals with data from Denmark and Sweden. Potential aurochs biometrical data were available from the Mesolithic (c10000 cal BC) to the Late Neolithic (c1700 cal BC). Domestic cattle data from the Neolithic period have also been included here for comparison, these were identified by Degerbøl (1970).

Most of the Danish data included here were recorded by the author at the Zoological Museum, Copenhagen, but some were also taken from the literature, including a number of measurements from the classic work by Degerbøl and Fredskild (1970). All of the Swedish data were taken from the literature. The majority of Swedish aurochs measurements were taken from Ekström (1993). Details of the locations of all of the data discussed in this chapter can be found in Chapter 2. Very few tooth measurements were available for analysis, and so these have only been included from some periods in Denmark.

A relatively large proportion of the aurochs bone finds in Denmark and Sweden come from complete or near complete skeletons found in bogs. Only the left side of these animals has been considered here, so as not to duplicate information. Where the left side was not available then the right has been used instead. Individual skeletons and archaeological finds are combined on the scatterplots (where possible), but separated on the log ratio diagrams in order to highlight the potential biases caused by having measurements from the whole of one side of a skeleton on the same graph.

In the same way as for the analysis of most material in this project, all *Bos* specimens, whether they had previously been identified as ‘wild’ or ‘domestic’, are included on every graph and appear as one ‘*Bos*’ group. This means that there are no preconceptions about individual specimens which may affect the interpretation of the data. It does, however, mean that domestication must be taken into account as a potential factor affecting size and shape change. After initial analysis the original identifications may then be referred to in discussions of the interpretation of the graphs.

The data have been split according to archaeological period. In grouping sites by period we are potentially combining sites of different chronological age. This is unavoidable to some extent, when not all sites have been well dated. The groups are laid out in Table 3.1.1.

Table 3.1.1: The broad chronological groups used for the analysis of the Danish and Swedish data.

Group	Broad dating
Mesolithic	c10000-5600 cal BC (broadly corresponds with the Preboreal and Boreal)
Late Mesolithic Ertebølle	c5300-3950 cal BC – dates for these sites continue to extend further into the Neolithic period, and so there may be some overlap with material in the early Neolithic group.
Early Neolithic	c3900-3300 cal BC
Middle Neolithic	c3300-2800 cal BC
Late Neolithic	c2800-1700 cal BC

Sites included in the 'Mesolithic' group include individual skeletons from Graenge (1942) Stockholthuse, Ullerslev and Store Damme, and archaeological material from Holmegaard I, Lundy I and II, Mullerup Syd and Nor, Sværdborg (1918 and 1923) Øgaarde and Ulkestrup Lyng. Swedish material is included from Ageröd I, Ageröd III and Almeö**.** The majority of sites included in the Mesolithic group are relatively early in date (between approx 9000 and 6400 cal BC) and therefore originate from a time when sea level was very low. After this period the sea level rose, splitting the area between modern Denmark and Sweden into islands (Christensen 1995; Christensen *et al.* 1997). This led to the fragmentation of animal populations, and eventually the local extinction of the aurochs on Zealand at around 5000 cal BC (Aaris-Sørenson 1999). It is important to bear in mind the effects this may have also had on body size throughout this period.

Sites attributed to the Late Mesolithic Ertebølle culture post-date this geographical event. Sites included in this project which have been attributed to this culture were located in both Denmark and also the very northern part of Germany (in the state of Schleswig-Holstein). It therefore seems appropriate to include the German sites with the Danish material for the purposes of this analysis. Unfortunately, no Swedish Ertebølle data were available, but specimens from the northern German sites of Rosenhof and Neustadt LA 156, both of which are thought to have some component of Ertebølle material, are included here with the Danish material. Although all of the sites included in this group have some component of Ertebølle material, there is a possibility that some material from the Early Neolithic Funnelbeaker (TRB) culture is also included. Sites where this may be a problem are Havnø, Mejlgaard, and Krabbesholm in Denmark and Neustadt LA 156 in northern Germany. Of all of these sites Havnø has especially young dates, currently published as 5000-3700 cal BC (Andersen 2008), but recent work has yielded dates that are even younger than this, and the cattle remains included here are most likely to be more recent in date (Kurt Grøn *pers. comm.*). For a summary of all of the dates available from these sites see Table 3.1.2. The stratigraphic situation for much of the material from a number of these sites is not entirely clear, so in theory the cattle specimens could come from either the Ertebølle or TRB cultures. No radiocarbon dates are available for the sites of Kolind, Hjerk Nor and Norslund, although Norslund and Hjerk Nor are considered to have only Ertebølle material, and Kolind a mixture of Ertebølle and TRB material. All of the dates available for sites with and Ertebølle component are included in Table 3.1.2.

Middle Neolithic material is from the Danish sites of Bundsø (Degerbøl 1939) and Lidsø (Hatting 1978) and from the Swedish mainland sites of Lindängelund (Boëthius 2009) and Alvastra (During 1986). The Late Neolithic period is represented by individual skeletons only from Denmark and mainland Sweden.

Table 3.1.2: Dates for the sites included in the 'Ertebølle' group for this analysis.

Site name	C14 date BP	Calibrated date through Calib 6.0 unless otherwise stated (at 95% probability)	Reference
Dyrholmen	6185 ± 85	5322-4559 cal BC	Gravlund *et al.* (2012)
Norslund	6420±130 - 5680±120	5621-4271 cal BC	Andersen and Malmros (1965)
Braband Sø	5425 ± 45	4357-4076 cal BC	Gravlund *et al.* (2012)
Rosenhof	6010±70 – 5370 ±95	5200-3980 cal BC	Breunig (1987)
Neustadt LA 156	5682±40 – 5182±31	4678-3955 cal BC	Hartz (2005; 2011)
Krabbesholm	5240 ± 85	4322-3810 cal BC	Gravlund *et al.* (2012)
Mejlgaard	5115 ±70	4046-3713 cal BC	Gravlund *et al.* (2012)
Havnø		5000-3700 cal BC (direct from reference)	Andersen (2008)
Hjerk Nor	No dates	Ertebølle	Hatting *et al.* (1973)
Kolind	No dates	Ertebølle and TRB	Mathiassen *et al.* (1942)

3.1.1 Ageing

As opposed to most other areas where raw data was collected, the recording of the Danish material prioritised the collection of biometrical information over ageing information such as fusion. This was due to the limited amount of time that there was available to collect data from the Zoological Museum in Copenhagen. Bones were only recorded if they had useful biometrical information, and this imposes a bias on the fusion information that was recorded with it. Danish fusion data is not therefore useable in this work. Very few teeth and jaws were available, so age could not be explored using these data either. The majority of specimens that were physically recorded by the author were from the Mesolithic period, and the pattern of fusion obtained was not unlike that from Mesolithic assemblages from elsewhere (i.e. Britain and Portugal), in that late fusing bones were most commonly unfused, whilst earlier fusing bones were fused. The main impact of this is that biometrical information from the proximal femur and calcaneum were often not available for inclusion in the analysis here.

3.1.2 Biometry

3.1.2.1 Postcranial remains

An initial look at the summary statistics (Table 3.1.3) shows that there is a general reduction in mean values in all measurements displayed between the early Mesolithic and the Middle Neolithic periods, the Middle Neolithic measurements also generally plot within a narrower range than during the earlier periods, even though the Middle Neolithic group tends to have larger samples than the previous Ertebølle period. In order to explore these patterns further, and investigate the spread of animals within a population, individual measurements will be plotted on scatterplots and log ratio histograms.

Scatterplots mainly contain Danish measurements (with a few from Germany), as the combination of suitable measurements was generally not available from the Swedish material for any time period except the Mesolithic. Nevertheless, a comparison of astragalus measurements from this time period, between the two areas (Figure 3.1.1) suggests that there is little size or shape difference between the two datasets, despite the occurrence of two quite small specimens in the Swedish dataset. It is possible that these two specimens may actually be elk. Although the two specimens from Sweden were not recorded by the author, the other small Danish astragalus that plots near to them was. The morphology of this particular specimen did look more like elk, although it was kept with the *Bos* material in the museum. The fact that this specimen, and the smaller two from Sweden plot away from the rest of the Danish Mesolithic *Bos*, and within the range of positive elk identifications, suggests that these three specimens may be elk. These specimens have been excluded from further parts of the analysis for this reason. All of the Swedish aurochs material is from the Southern part of the country, so the datasets from the two countries come from an area which would have experienced a similar climate. It may therefore be relatively unproblematic to group data from both countries together for some parts of these analyses.

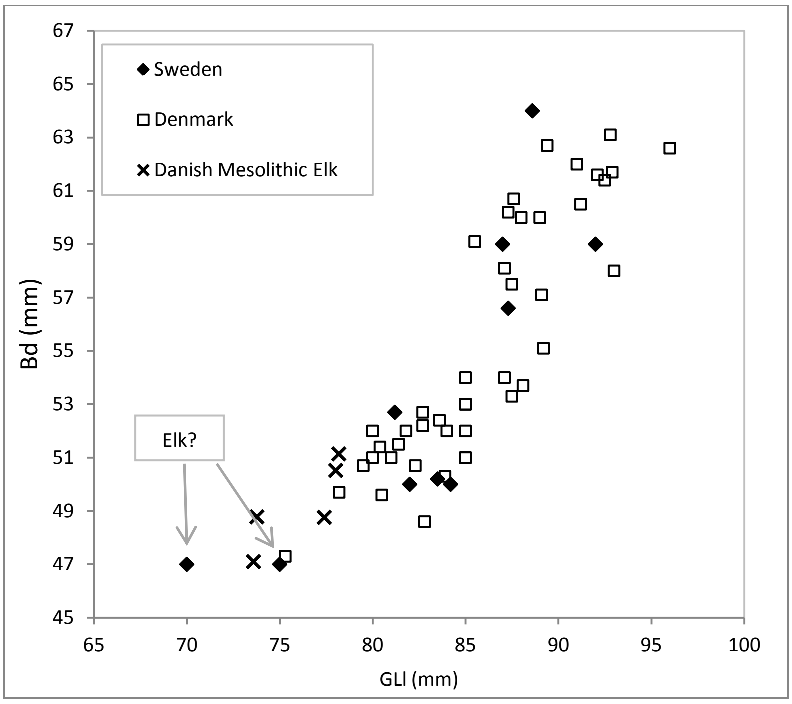


Figure 3.1.1: Mesolithic astragalus measurements from Denmark and Sweden. GLl= greatest length of the lateral side, Bd=breadth of the distal end.

Figure 3.1.2 shows cattle astragalus measurements over time. Data included on the graph are from animals identified as both wild and domestic. All of the Mesolithic specimens plot to the top end of the range, as would be expected. Most specimens from Ertebølle sites overlap with this group, although to the smaller end of the range. There is some evidence of particularly small specimens in the Ertebølle group, which plot in the same area as the Middle Neolithic material. None of the few Early/Middle Neolithic individual skeletons plot within the ‘domestic’ range. All of the Middle Neolithic specimens plot to the smaller end of the range indicating that most, if not all of these specimens, are from domestic animals. One of the two specimens from the Late Neolithic plots well within the ‘wild’ range, whereas the other plots beyond the bottom of this range. This specimen, which is from a bog skeleton at Bønnerup, and another from Middle Neolithic Lidsø plot in-between the larger and smaller groups which could be attributed to wild and domestic animals respectively. It does not seem possible to attribute either of these specimens to the wild or domestic form, and the possibility that they could be elk should also be considered.

The distinction between males and females is not easy, which is unsurprising considering the limited sexual dimorphism of the astragalus. The Mesolithic sample does, however, have a vaguely bimodal distribution, and potential sex groups have been marked on the diagram.

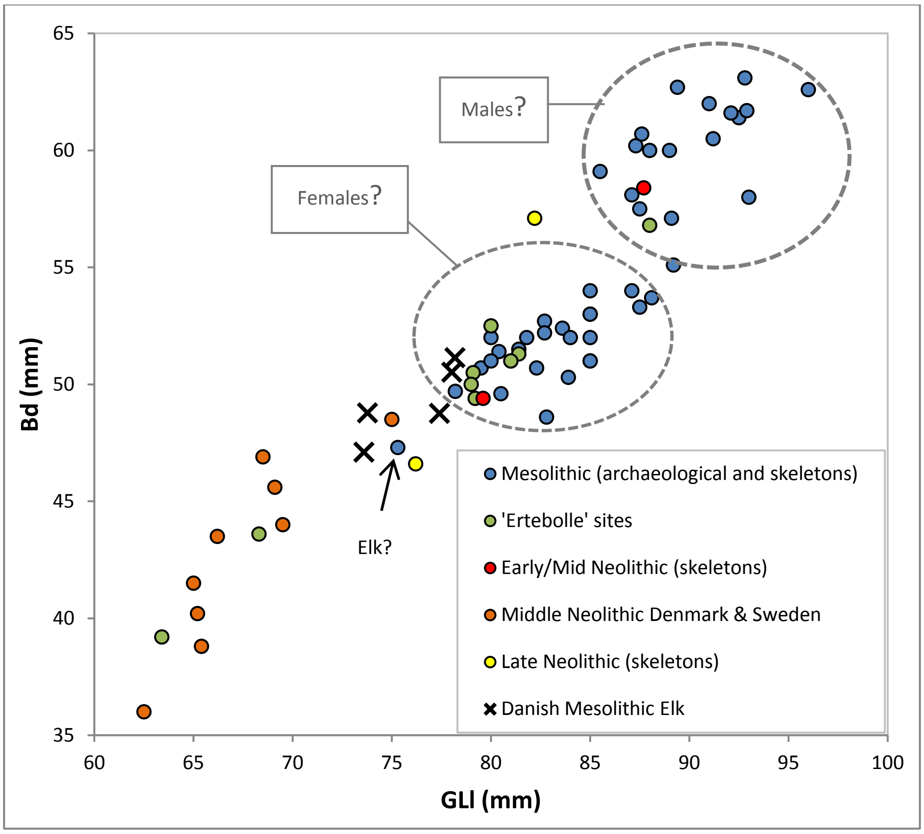


Figure 3.1.2: Astragalus measurements over time from Danish sites. GLl=greatest length of the lateral side, Bd=breadth of the distal end.

There are far fewer tibia measurements available (Figure 3.1.3), but a similar pattern is seen with the measurements that are available. Mesolithic specimens plot to the larger end of the range. Early/Middle Neolithic individual skeletons show a larger variation in size compared to the astragalus, with one particularly small specimen. Middle Neolithic specimens plot to the bottom end of the range and again the Late Neolithic Bønnerup Strand specimen plots somewhere in-between, although this time it is more clearly larger than any from Middle Neolithic Lidsø. The only Ertebølle specimen appears to be large enough to be confidently identified as a wild animal.

There is no clear indication of sex groups on the tibia scatterplot, but the sample size is small and the tibia is not a particularly sexually dimorphic bone.

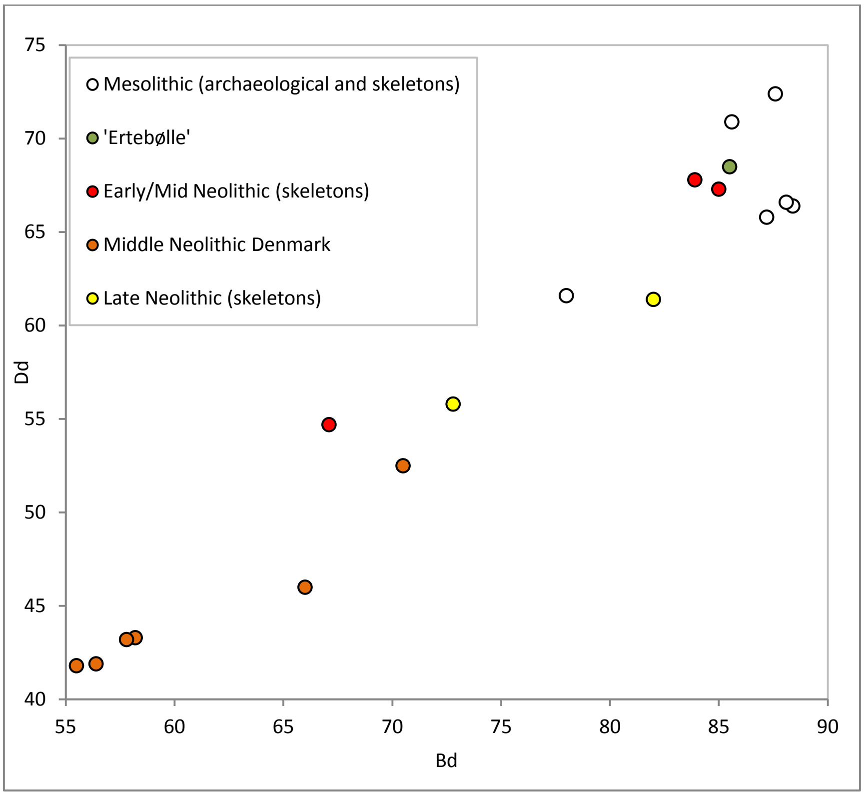


Figure 3.1.3: Tibia measurements over time from Danish sites. Bd=breadth of the distal end, Dd=depth of the distal end.

Humerus measurements, separate into two clear groups, regardless of chronology (Figure 3.1.4), potentially attributable to female and male animals. The lack of availability of the small Middle Neolithic settlement specimens means that domestic animals are unlikely to figure in this diagram. The two size groups are likely to correspond to those already tentatively identified for the astragalus, though the greater sexual dimorphism of the humerus makes them even more distinct.

Two Late Neolithic specimens with measurements were available, the larger of these was from a bog skeleton at Tinglev Sø. Astragalus and tibia specimens from this animal (see above) are associated with wild specimens, but sex attribution is unclear. Degerbøl (1970) identifies this animal as a male, and the humerus' slightly closer proximity to the male Mesolithic specimens, and its closer proximity to the larger astragalus group in Figure 3.1.2 suggests that he is correct. If this is the case, the specimen is rather small in comparison to other male aurochsen from previous periods. If the animals in the Late Neolithic were on the smaller size of the potential range, this would support the suggestion that the other Late Neolithic specimen (Bonnerup 2) could be a wild female, rather than a domestic cattle. The male/female specimens highlighted on this diagram fit with Degerbøl's identifications of the same specimens in his 1970 publication, although he seems to predominantly use metapodial measurements for sexing and does not produce any diagrams containing humerus measurements.

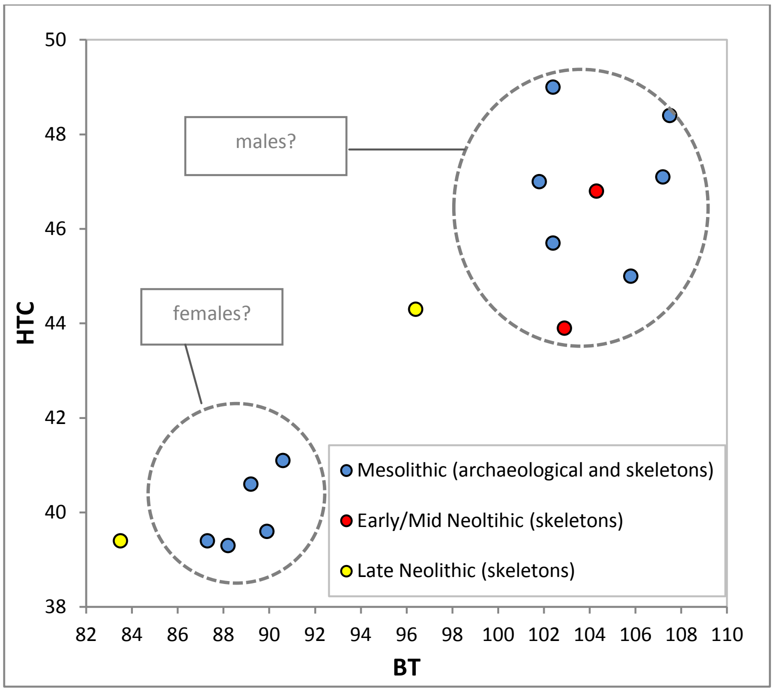


Figure 3.1.4: Humerus measurements over time from Danish sites. BT=breadth of the trochlea, HTC=height of the trochlea.

Comparison of postcranial log ratios from Denmark and Sweden (Figures 3.1.5 & 3.1.6) shows little difference between the two areas in all of the time periods for which there is comparative data (Mesolithic, Middle Neolithic and Late Neolithic), with very similar means in both countries during each time period. This is what would be expected considering their close geographical proximity. The largest difference is between the Late Neolithic specimens, but as the Swedish dataset only includes measurements from one skeleton, this is unlikely to be significant.

Among the individual bog finds in all periods, those that have previously been identified as female, such as Ullerslev from Mesolithic Denmark and Stora Slågarp from Mesolithic Sweden, do seem to plot to the smaller end of the range, and in fact occupy an almost identical position.

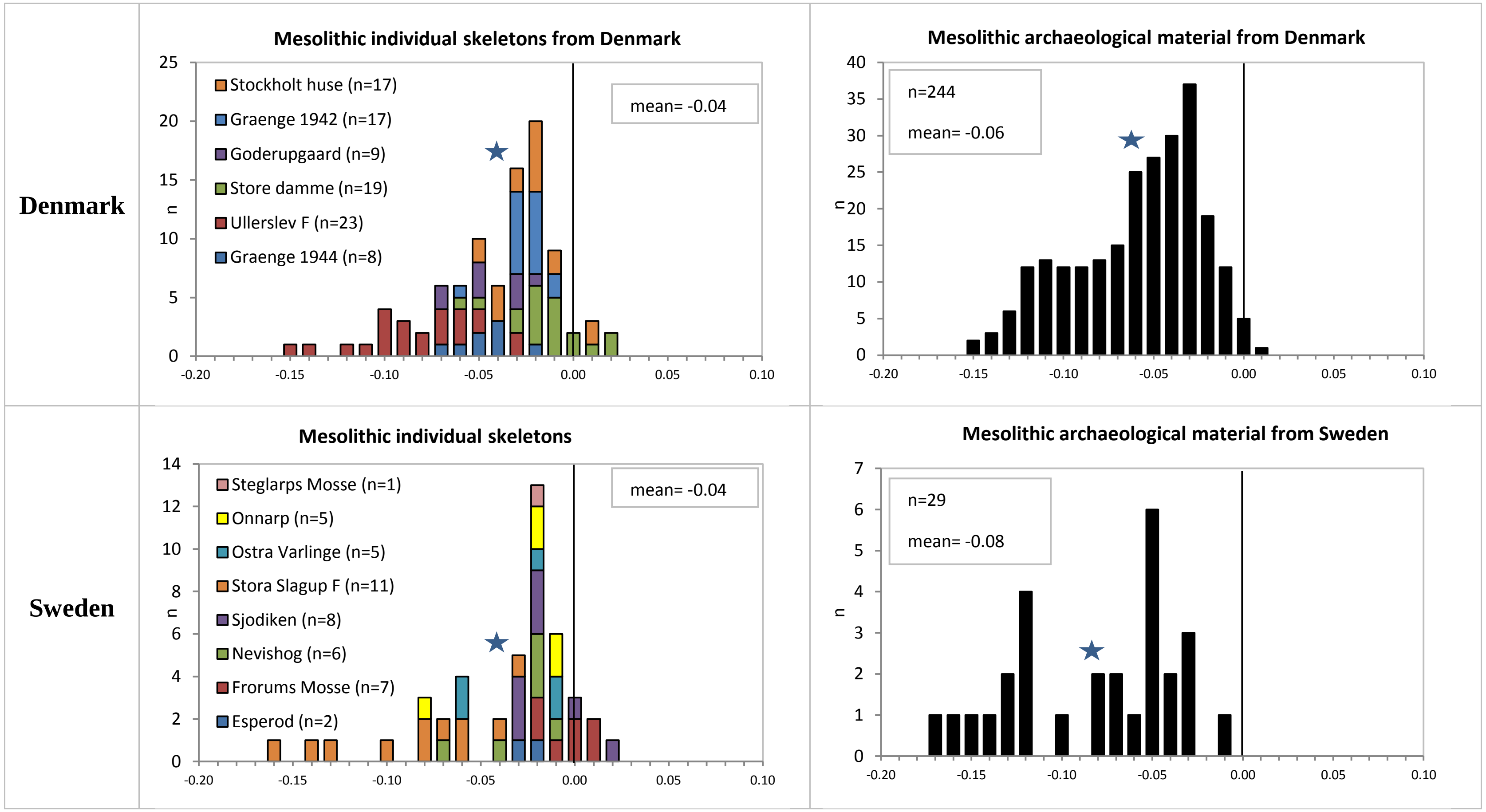


Figure 3.1.5: Log ratio diagrams showing a comparison between Danish and Swedish postcranial Mesolithic material. Skeletons previously identified as female are marked with an 'F'. Means are marked with a star, and the standard has been marked with a line. Means have only been calculated for samples of more than 5.

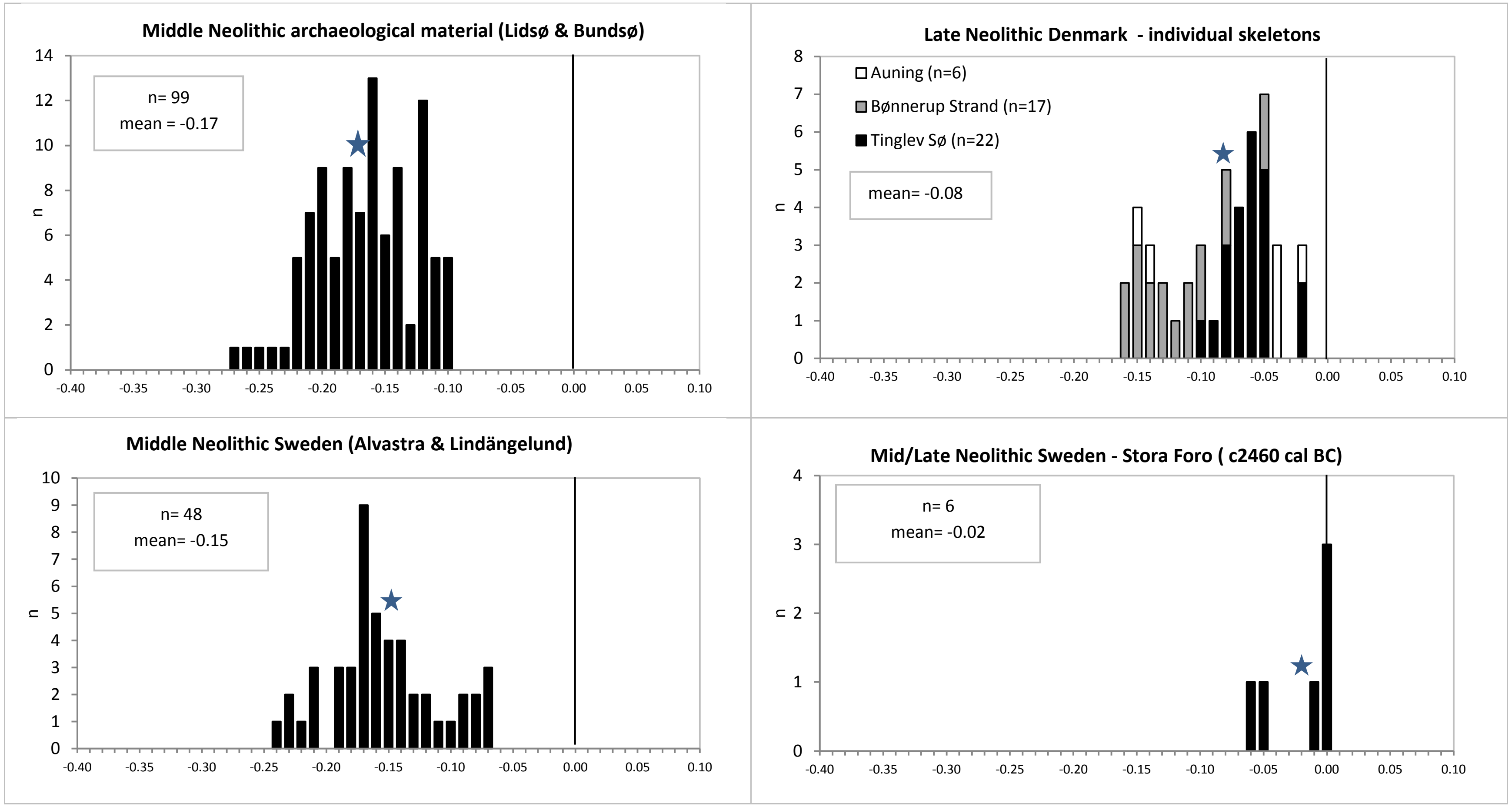


Figure 3.1.6: Log ratio diagrams showing a comparison between Danish and Swedish postcranial Neolithic material.

A comparison of log ratios containing postcranial measurements from Denmark and Sweden over time shows that an almost identical pattern of size change occurs in the two countries (Figure 3.1.7). Northern German material has been included with the Danish material, but is only present in the Ertebølle group.

The Danish dataset may show the clearest transition over time to smaller animals and potentially from wild to domestic, through the data from Ertebølle sites (with material that dates from the Late Mesolithic to the Early Neolithic) and the individual bog skeleton data dated to the Early/mid Neolithic. These two datasets occupy a very similar space on their log ratio diagrams and show a shift to a smaller size from the Mesolithic dataset. All of the individual bog skeletons were identified as wild or domestic by Degerbøl (1970), with all of the domestic cattle (with the exception of Borremose) being identified on the basis of cranial remains. Whilst in some cases it is relatively straight-forward to distinguish between wild and domestic on this basis (i.e. if a cranium has either very large or very small horn cores), these identifications should be treated with caution. Work by Grigson (1978) has shown that there is overlap in cranial dimensions between the two groups, and therefore distinguishing crania on this basis may not be reliable. Nevertheless, this group contains some very small animals which most certainly are domestic cattle – it is those at the larger end of this range that we must be wary of. All of the bones from these potential domesticates are shown in the duller colours on the Early/mid Neolithic diagram (light and dark grey, brown, black and white). In contrast the animals identified as wild are in brighter colours (purple, green, yellow and red). The similarity of the Early/mid Neolithic and Ertebølle patterns suggests that the shift to smaller size in the Ertebølle material could be due to the presence of a number of bones from domestic cattle at these sites, although these could potentially be from Early Neolithic layers. It is also worth bearing in mind the geographical changes that took place in the region between the earlier and later Mesolithic periods. The splitting of the landscape by rising sea levels could also have contributed to the shift in body size.

The Ertebølle group displays a large coefficient of variation compared with other time periods according to a number of measurements, despite its small sample size (Table 3.1.3). This confirms its character as a more ‘mixed group’ potentially containing both wild and domestic material.

The Pindstrup and Bønnerup 1 skeletons were both previously identified as female aurochsen, and this fits well with the pattern shown here, with the skeletons identified as male (Bønnelyke and Ugilt) forming their own smaller peak at the top end of the range. There is clearly an overlap between the larger domestic and the smaller female aurochs skeletons, which is what creates the peak in the middle of the Early/Middle Neolithic range. A very similar pattern is seen in the Ertebølle material, with a smaller peak at the very top end of the range which lines up almost exactly with the same peak created by the Early/middle Neolithic male aurochsen. On both diagrams the smaller end of the cattle range on the left hand side displays a larger variation of log ratio scores than the larger end on the right hand side. This means that no smaller ‘domestic female’ peak can be seen and indicates that domestic female variation was relatively high. We can also see that wild female variation is larger than wild male variation, with both Bønnerup 1 and particularly the skeleton from Pindstrup occupying large areas of the diagram. This fits with the pattern for Mesolithic individual skeletons that has already been mentioned. The Ertebølle group will be discussed in more detail in Section 3.1.2.1.

A very similar change takes place between the Mesolithic and Middle Neolithic datasets in both countries. The Swedish dataset does not contain what could be described as a ‘transitional’ period, as represented by the Ertebølle dataset in Denmark, but the similarity of the changes that take place around it suggests that a similar transition from wild to domestic animals may have taken place across the whole of this area. The Middle Neolithic datasets from both Denmark and Sweden fit well with the range of the Danish Early/Middle Neolithic domestic bog skeletons, except that there is a lack of measurements at the top end of the range, which would coincide with those from the skeletons from Ugilt and Bønnelyke. Therefore there is no evidence for the presence of wild cattle at any of the Middle Neolithic sites included.

All of the Late Neolithic skeletons included here are from isolated bog specimens identified as aurochs by Degerbøl (1970). The Bønnerup skeleton was identified by Degerbøl as a female, but this diagram suggests that, based on size, it could just as easily be a domestic male. All others have previously been identified as males. The male skeleton from Tinglev Sø is slightly smaller than the males identified in the Early Neolithic in Denmark. This animal also stood out on the scatterplots as smaller than other Neolithic male aurochs specimens but larger than the females, or the domestic cattle. This could serve as evidence of a reduction in size of the aurochsen, but a single specimen is not enough to support this argument. In addition the relatively large male from Stora Förö (near Gothenburg) in Sweden suggests no change.

Statistical comparison of the archaeological groups displayed here, using a Mann-Whitney test (Table 3.1.4) shows that there is a significant difference between all archaeological groups. The largest significance is shown between the Mesolithic and Middle Neolithic groups, whilst it is smaller between Mesolithic and Ertebølle material. This very much confirms the pattern shown by the log ratio diagrams, and is further evidence that the Ertebølle group is likely to be more mixed and the Middle Neolithic contains a majority of domestic animals.

<table>
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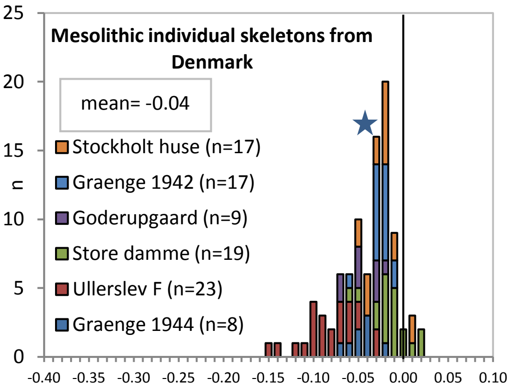
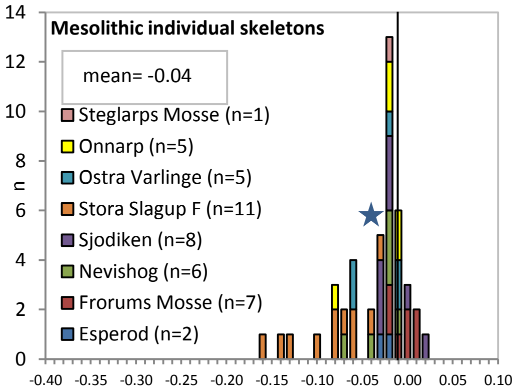
<tr><td>
</td><td>
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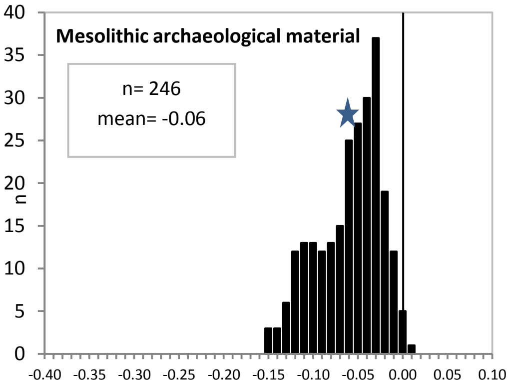
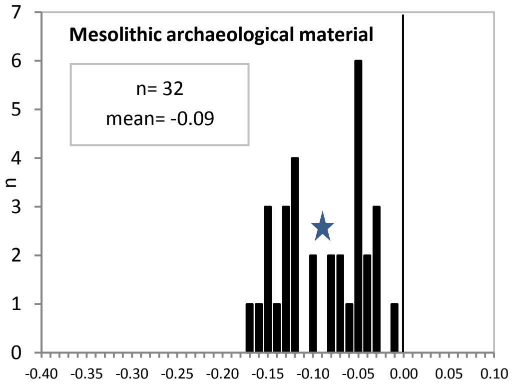
<tr><td>
</td><td>
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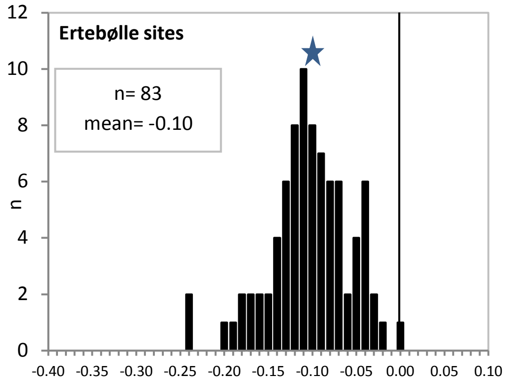
<tr><td>
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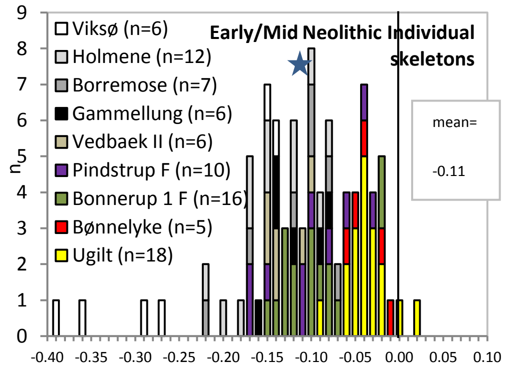
<tr><td>
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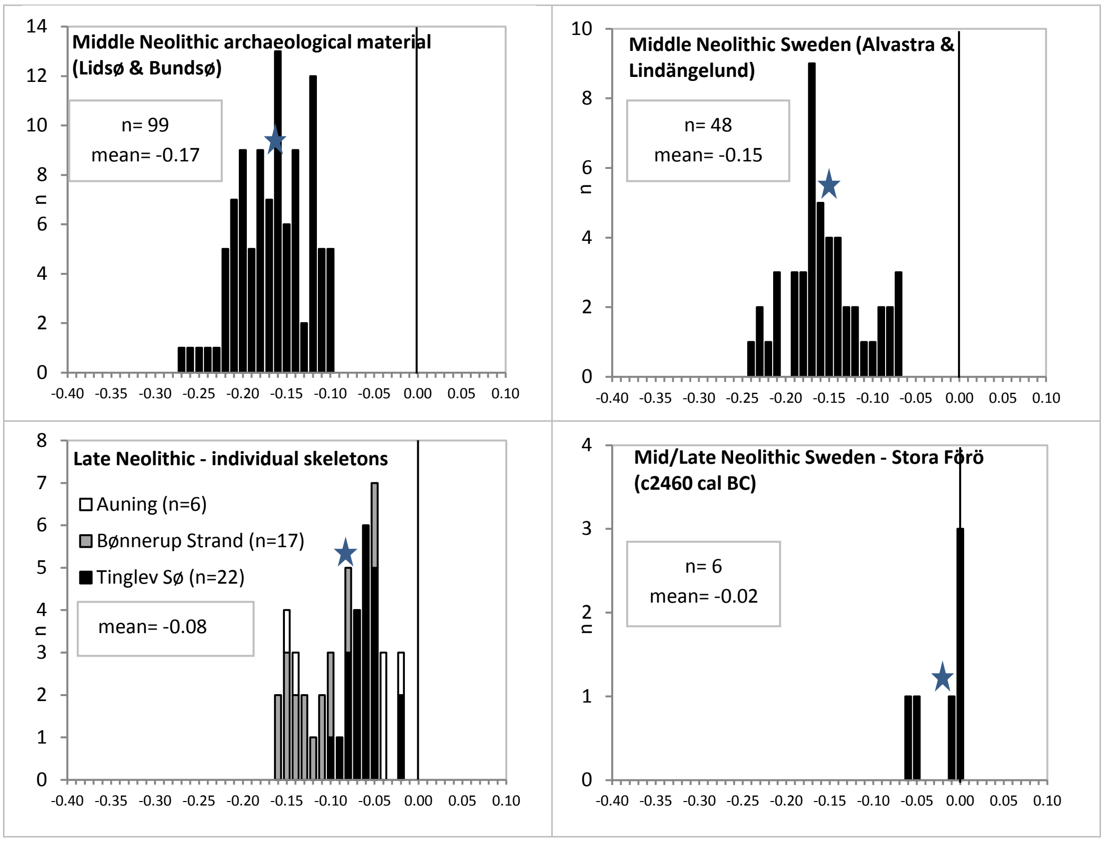
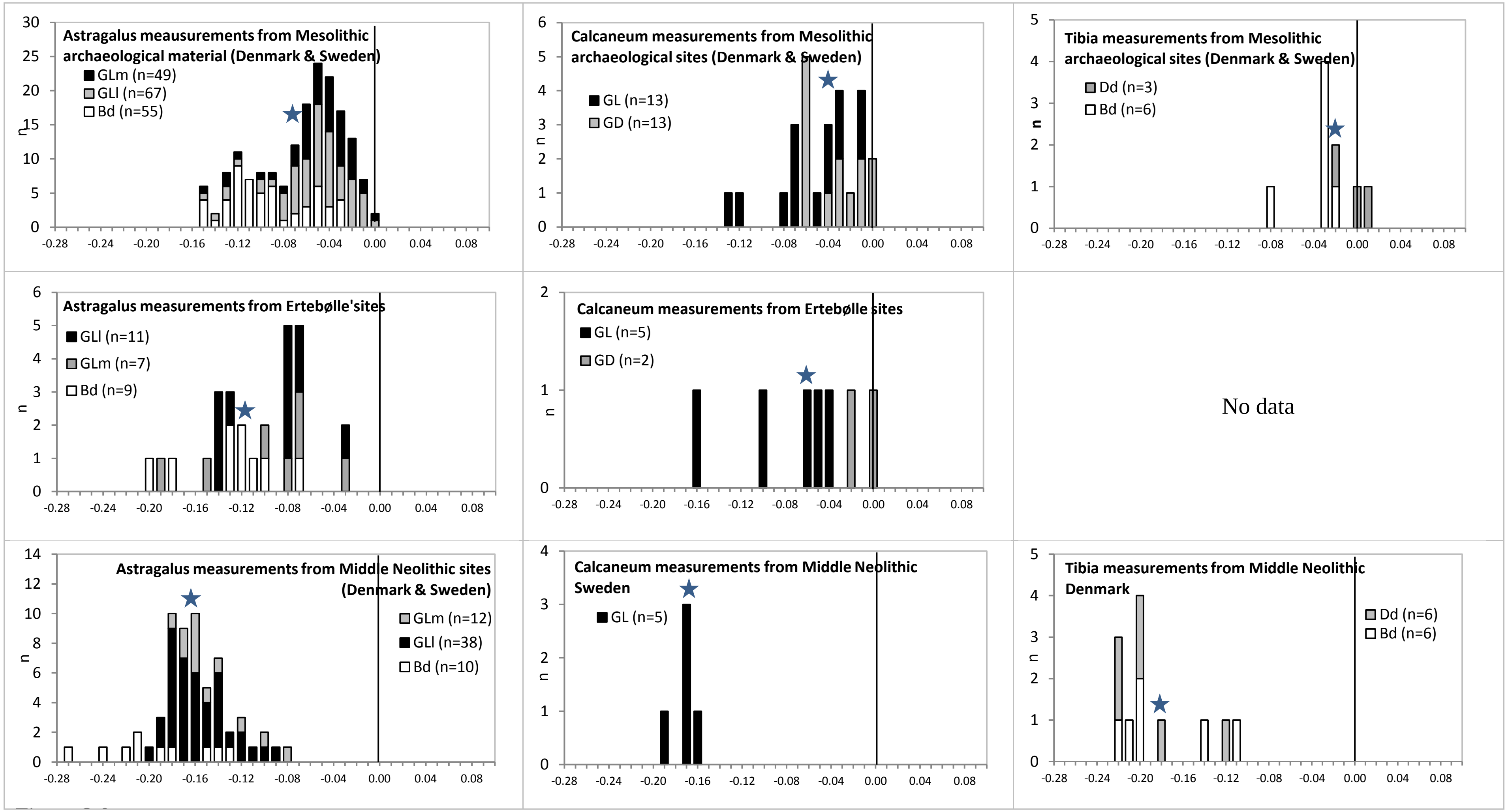


Figure 3.1.7: Danish (left column) and Swedish (right column) cattle measurements over time.

Considering the similarities between the datasets from Denmark and Sweden they have been combined for further analysis. Log ratios have been presented by bone, in order to investigate the changes in individual measurements and bones (Figures 3.1.8 & 3.1.9).



Astragalus meausurements from Mesolithic archaeological material (Denmark & Sweden)

Calcaneum measurements from Mesolithic archaeological sites (Denmark & Sweden)

Tibia measurements from Mesolithic archaeological sites (Denmark & Sweden)

Astragalus measurements from Ertebølle'sites

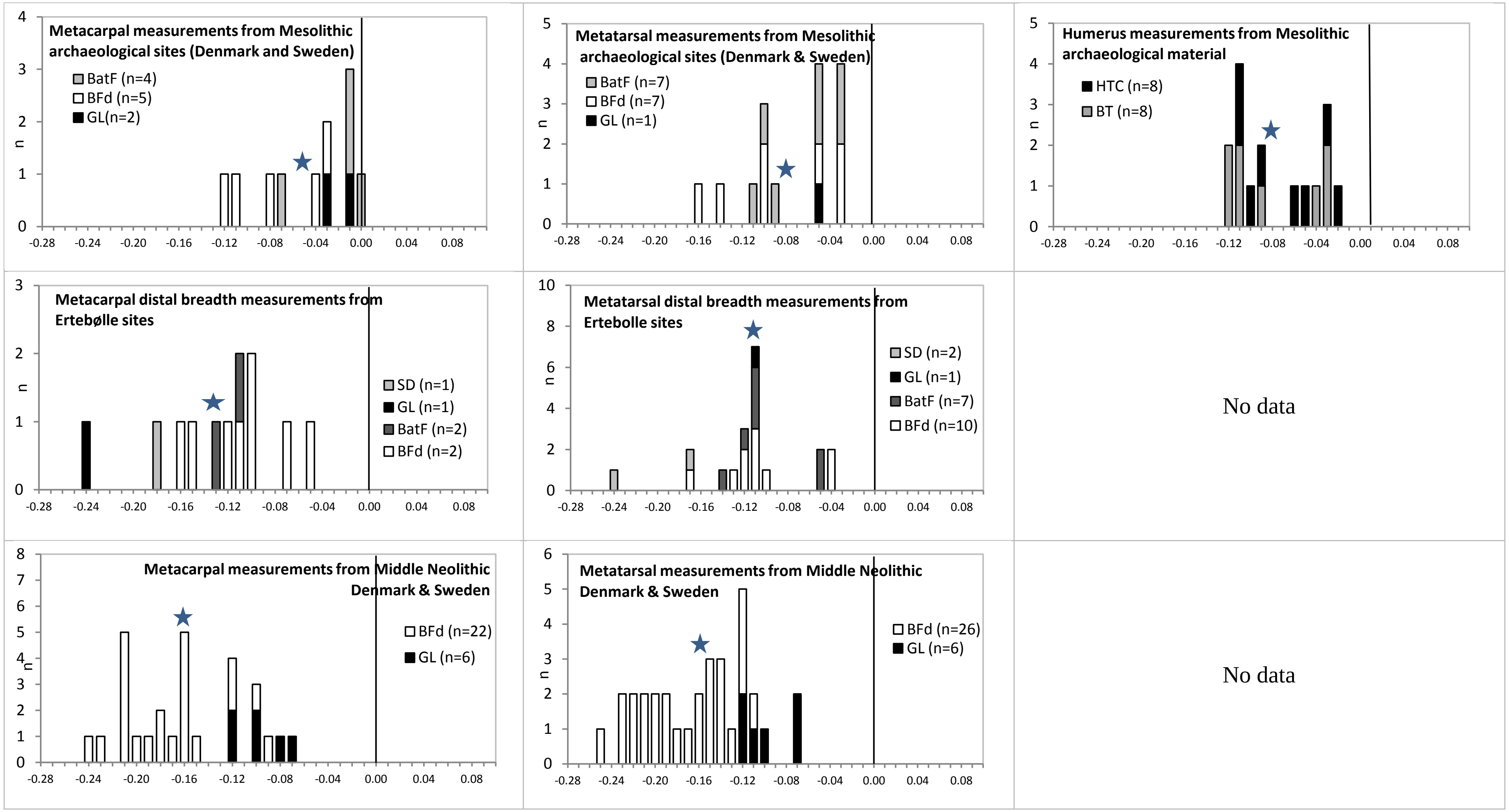
Calcaneum measurements from Ertebølle sites

Astragalus measurements from Middle Neolithic sites (Denmark & Sweden)

Calcaneum measurements from Middle Neolithic Sweden

Tibia measurements from Middle Neolithic Denmark

Figure 3.1.8: Log ratio diagrams displaying individual measurements from the astragalus, calcaneum and tibia from archaeological sites over time.


Metacarpal measurements from Mesolithic archaeological sites (Denmark and Sweden)

Metatarsal measurements from Mesolithic archaeological sites (Denmark & Sweden)

Humerus measurements from Mesolithic archaeological material

Metacarpal distal breadth measurements from Ertebølle sites

Metatarsal distal breadth measurements from Ertebolle sites

Metacarpal measurements from Middle Neolithic Denmark & Sweden

Metatarsal measurements from Middle Neolithic Denmark & Sweden

Figure 3.1.9: Log ratios displaying individual measurements from the metapodials and humerus from archaeological sites over time.

Astragalus measurements from Mesolithic sites (Figure 3.1.8) show an interesting pattern, with breadth measurements forming a more bimodal pattern and length measurements showing a more unimodal pattern. One explanation for this pattern is that astragalus distal breadth measurements are more affected by sexual dimorphism than length measurements. If the two peaks do correspond to sex groups then the distal breadth measurements suggest a slight predominance of females. This is consistent with the pattern shown by humerus distal breadth measurements (Figure 3.1.9). Metapodial distal breadth measurements (Figure 3.1.9), also considered to be more sexually dimorphic, show an unclear pattern, mainly due to their small sample size.

Compared to the astragalus, other bones have relatively few measurements from all time periods, but within the Mesolithic period itself it is possible to make some inferences. Calcaneum and tibia measurements, which are relatively unaffected by sexual dimorphism, tend to plot at the larger end of the range (Figures 3.1.8). The combination of many measurements from different bones plotting in a similar part of the diagram (in this case to the larger end of the range), suggests that the shape of the overall Mesolithic pattern (Figure 3.1.7) is not caused by a predominance of males in the sample, and instead relates more to the abundance of specific measurements chosen to include in the log ratio analysis.

Turning now to the patterns of change seen over time, it is possible to observe a decrease in the size of all astragalus measurements between Mesolithic and Ertebølle sites, and then between the Ertebølle and the Middle Neolithic, and a very slight indication that breadth measurements were more affected by size change than length measurements, especially during the Middle Neolithic where there is a cluster of particularly small breadth measurements. For the calcanei there is a very slight indication that length measurements reduced more readily than depth measurements, as greatest depth (GD) measurements from the Ertebølle period fall directly in the range of these measurements from the Mesolithic period. Unfortunately we cannot see what happens to the greatest depth measurement in the Middle Neolithic because these data are not available. Both breadth and depth measurements from the tibia reduce in size in a similar way, although there is perhaps a slight suggestion that depth measurements reduce more severely than breadth measurements.

In the metapodials there is a suggestion that breadth measurements might reduce more readily than length measurements. This suggests the occurrence of relatively slender metapodials in the Middle Neolithic compared to the Mesolithic, and an overall reduction in robustness.

Overall there is an indication that breadth measurements were more affected by size change than length measurements through time, resulting in more slender bones in domestic than wild cattle, as would be expected. Depth measurements seem to be more unpredictable. Breadth measurements also seem to be more variable than length measurements generally. This can be seen on the log ratio diagrams, but is also demonstrated by coefficients of variation, where astragalus breadth measurements show a larger degree of variation than astragalus length measurements in both the Early Mesolithic and Middle Neolithic.

3.1.2.1 .1 The Ertebølle group in focus

Although the general pattern in the Ertebølle material suggests the presence of domestic cattle, or at least some very small wild cattle, it is not clear from which sites these specimens are from when they are grouped together. Considering that some of the specimens included here have been heavily discussed in previous work (e.g. specimens from Rosenhof – Rowley-Conwy 1995), it is useful to see in more detail where the measurements from each site fall. Figure 3.1.10 shows each site in a different colour on the log ratio diagram. With those sites which continue into the 4th from the 5th millennium BC in the duller colours: black, dark blue, grey, brown and white and others in colour. Kolind and Hjerk Nor have been included even though their dates are less clear.

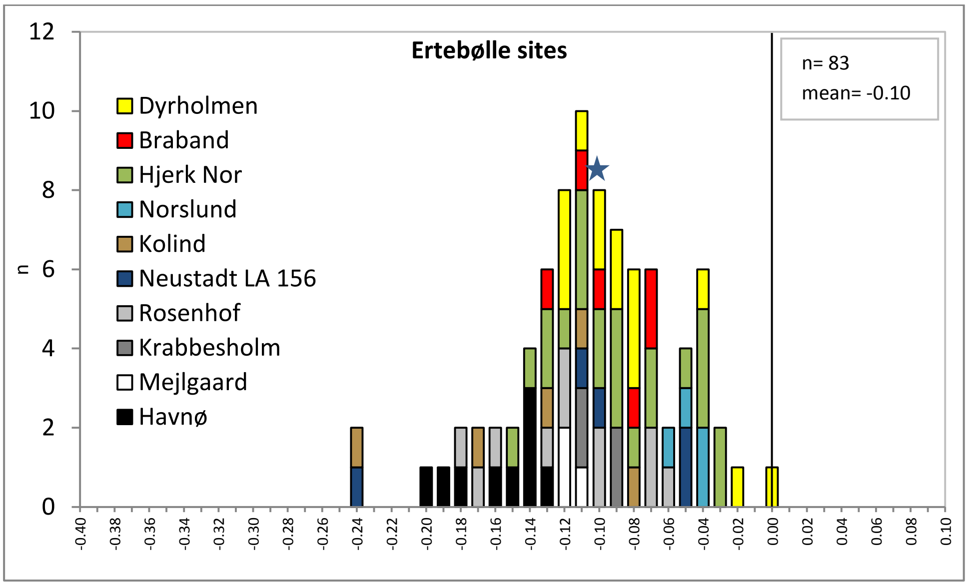


Figure 3.1.10: Log ratio diagram displaying Ertebølle postcranial measurements by site.

Sites with potential TRB material plot at the smaller end of the diagram in comparison to those confirmed to only contain Ertebølle material. Included at the smaller end of the range are some measurements from Rosenhof specimens, which were initially identified as domestic, but have since been reassessed biometrically and confirmed to be small wild females (Rowley-Conwy 1995). These specimens were also analysed genetically, and seen to have the presumed wild haploype ‘P’ (Scheu *et al.* 2008). There is overlap between these measurements from Rosenhof, and measurements from Havnø, where all of these specimens have been identified as domestic (Kurt Grøn *pers. comm.*). Two of the Havnø measurements are smaller than any from Rosenhof, and some measurements from Neustadt and Kolind are particularly small and could be the safest evidence we have in this group for the presence of domestic cattle.

To explore these issues further, log ratios have been created showing individual measurements from each site (Figures 3.1.11 - 3.1.14). These data could just as easily have been displayed using simple histograms, but it is useful to also include the standard, and also allow them to be compared directly to each other by placing them on the same axis. This method also allows the combination of similar measurements (such as BFd and BatF on the metapodials) in order to increase samples and also reduce the number of graphs.

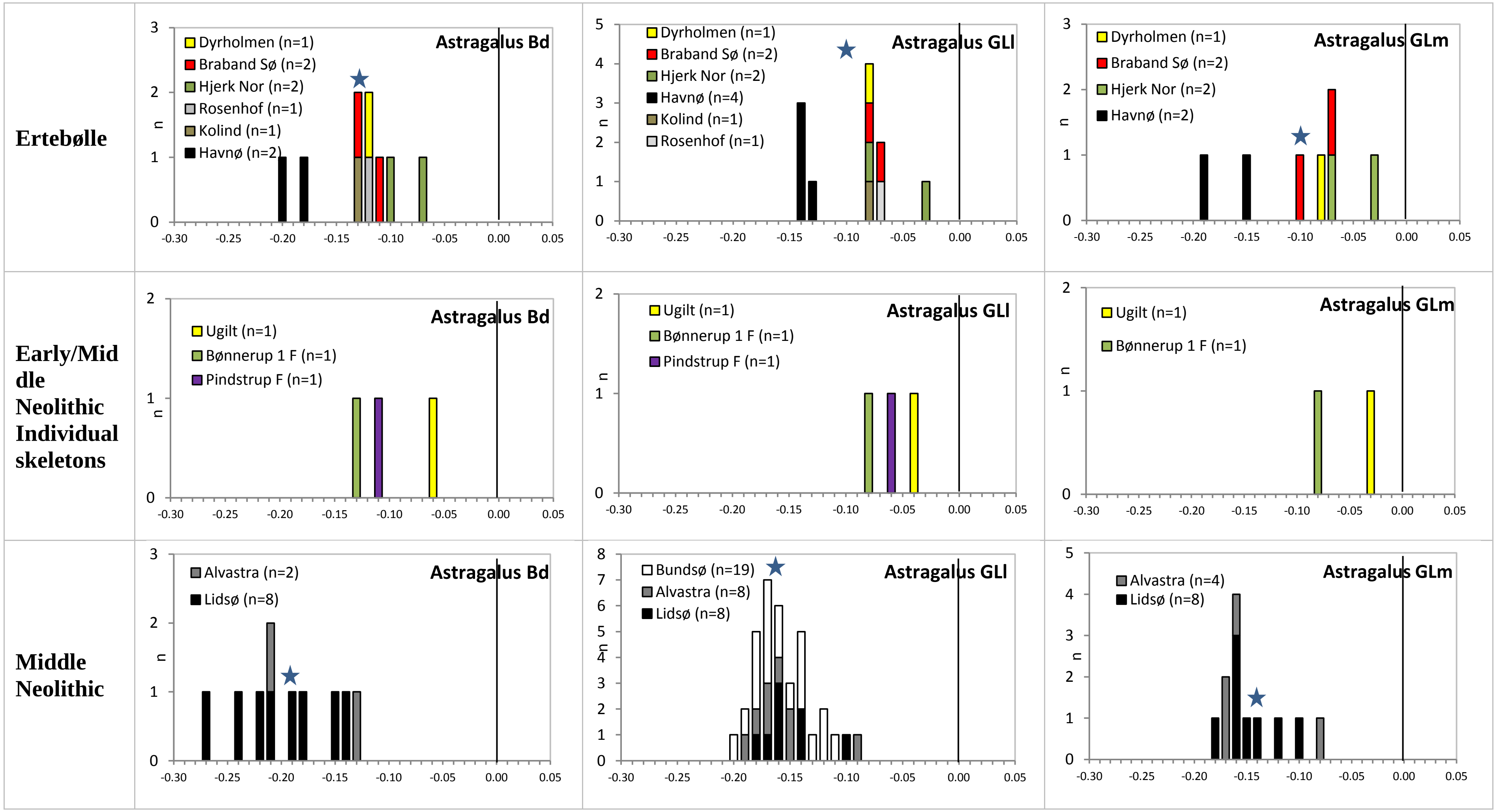


Figure 3.1.11: Log ratio diagrams displaying astragalus measurements over time from Ertebølle – Middle Neolithic material.

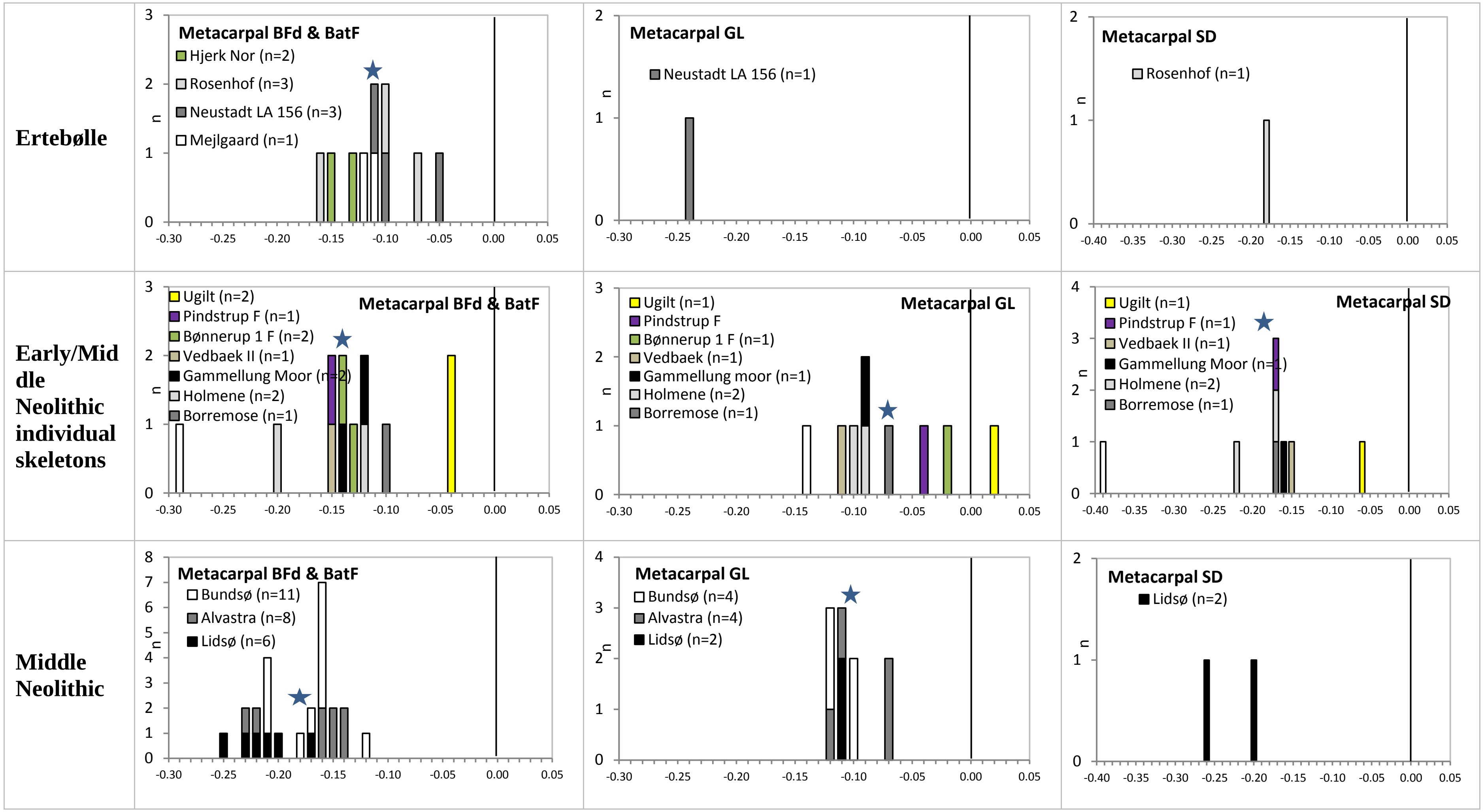


Figure 3.1.12: Log ratio diagrams displaying metacarpal measurements over time from Ertebølle - Middle Neolithic material

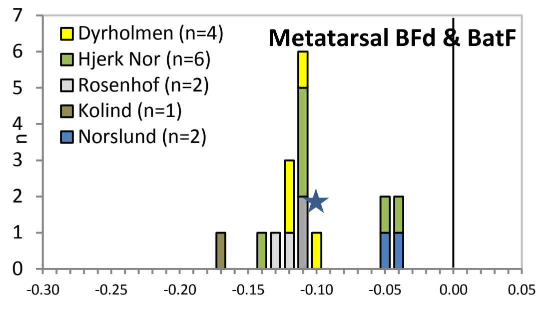
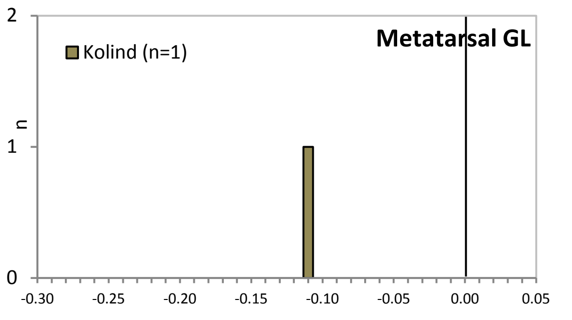
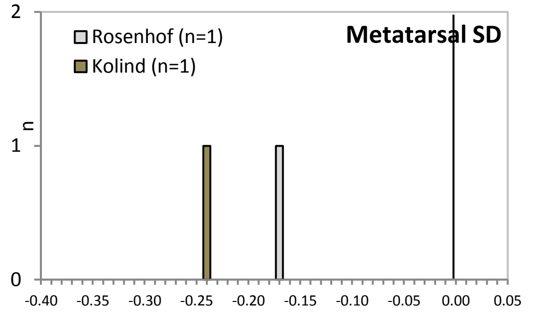
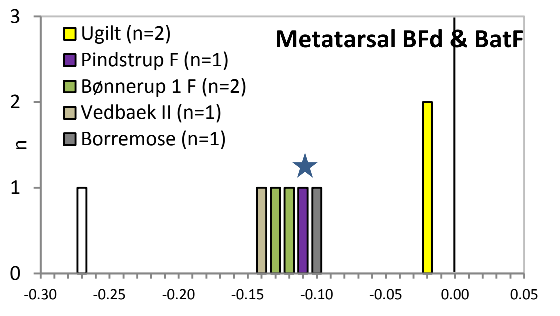
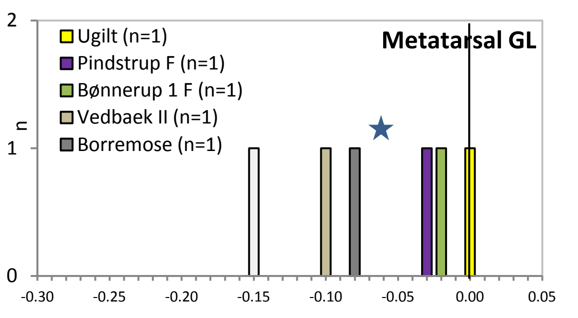
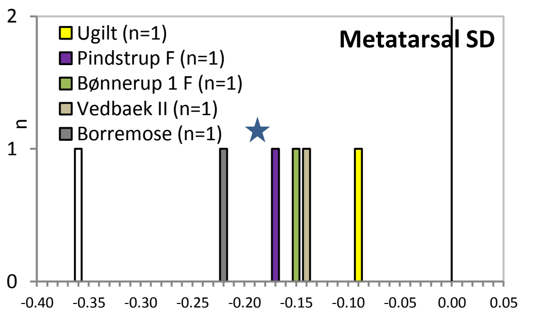
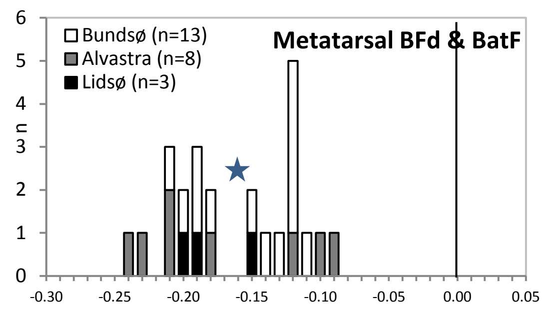
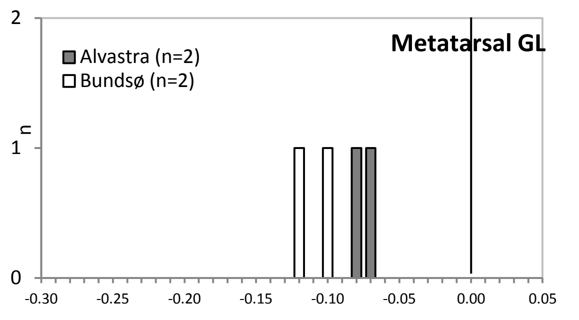
Ertebølle			
Early/Middle Neolithic individual skeletons			
Middle Neolithic			No data

Figure 3.1.13: Log ratio diagrams displaying metatarsal measurements over time from Ertebølle - Middle Neolithic material

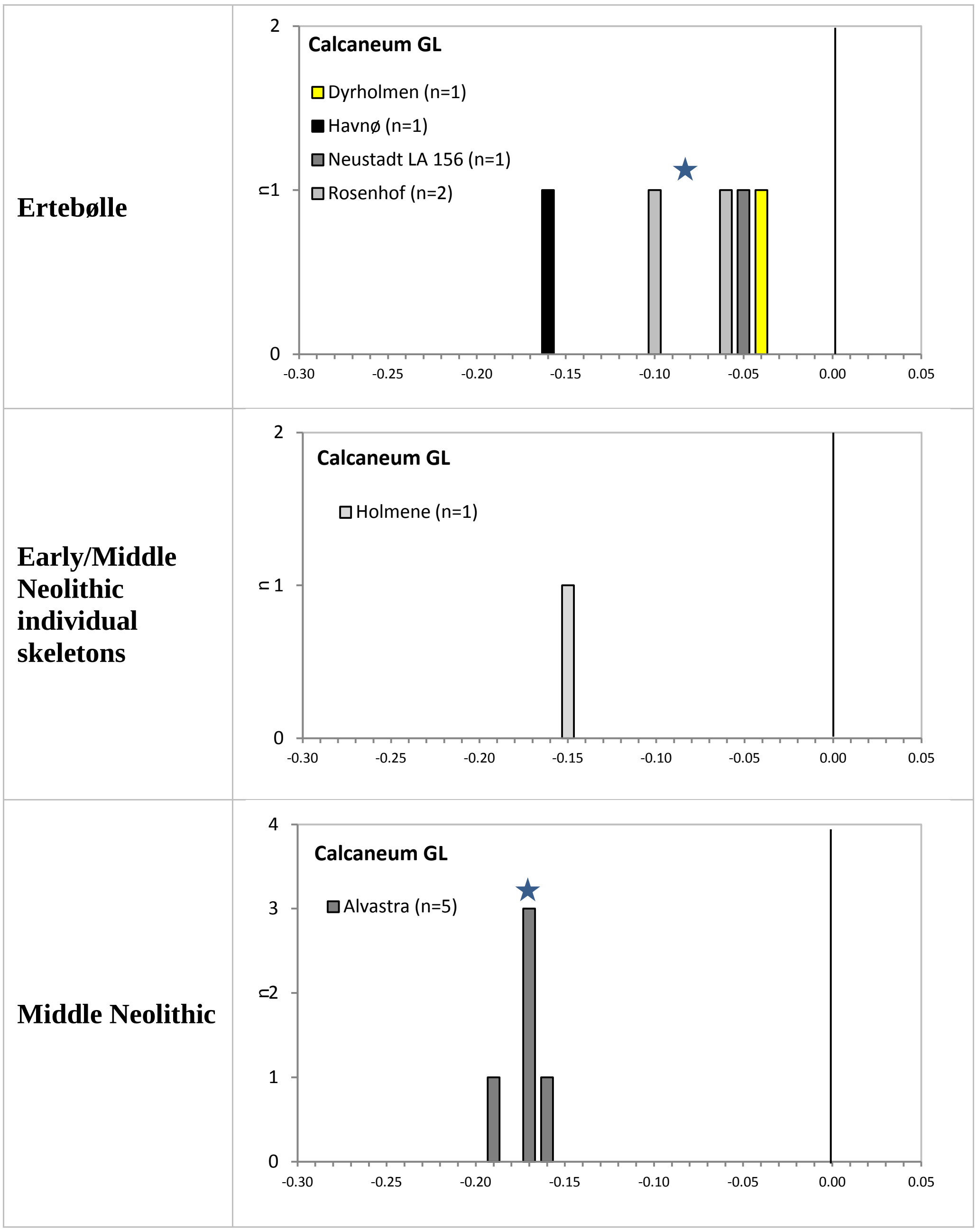


Figure 3.1.14: Log ratio diagrams displaying calcaneum measurements over time from Ertebølle – Middle Neolithic material

All astragalus measurements show a clear shift between wild and domestic by the Middle Neolithic (Figure 3.1.11). Measurements from Havnø consistently stand out as being smaller than any others from the 'Ertebølle' group, and always fall within the Middle Neolithic domestic range. None of the measurements from Havnø overlap with the measurements from wild individual skeletons (Early Neolithic), but unfortunately astragalus data were not available from domestic individual skeletons. In contrast, Rosenhof and Kolind both group with the specimens from Dyrholmen and Braband Sø (which both have definite Ertebølle dates) and with the wild Neolithic individual skeletons. The only specimens, therefore, that can confidently be considered to be domestic, from the Ertebølle group are those from Havnø.

Measurements from domestic Early/Middle Neolithic individual skeletons are available for metapodials, which is advantageous for this analysis (Figures 3.1.12 and 3.1.12). Metacarpal distal breadth measurements show a complicated pattern, potentially due to the amount of sexual dimorphism they display (Figure 3.1.12). The smallest measurement from Rosenhof is not much smaller than the measurements from Hjerk Nor, and the wild female specimens below. Therefore there is not enough evidence to suggest that this measurement is from a domestic animal despite the fact that it does overlap with domestic measurements from both individual skeletons and archaeological material. The metacarpal greatest length measurement from Neustadt LA 156 is so small, that this must be from a domestic animal, when all others from later periods are likely to be wild.

It is worth noting that metacarpal lengths from the wild individual skeletons are really quite large, with all of these measurements from both male and female animals grouping close to the standard line. As the standard also represents a Pleistocene northern European population, this could suggest that metacarpal length measurements did not change as readily as breadth and depth measurements with the climatic change at the start of the Holocene. Metatarsal measurements also show this same pattern and, although it is less clear, there is also a hint of it in the astragalus pattern.

Metacarpal shaft diaphysis (SD) measurements show an overlap between the wild and domestic Neolithic individual animals, as with the distal breadth measurements. The Rosenhof measurement plots within this overlap and therefore it is not possible to claim that this is from a domestic animal. This measurement is from the same bone as the small breadth measurement which plots near to the wild females, so the combination of these two measurements suggests this bone is also from a wild female. This conclusion is in agreement with the studies of both Degerbøl (1970) and Rowley-Conwy (1995) that have also looked at this specimen in detail.

Metatarsal measurements show very similar patterns to those from metacarpals, as one might expect (Figure 3.1.13). Again wild and domestic are best separated according to length measurements. The small breadth measurement from Kolind is the only one which plots outside of the wild range of the individual skeletons. This measurement is from the same bone as the length measurement, which is also relatively small compared to most other length measurements. This bone is not discussed by Degerbøl (1970) even though he provides the measurements for it in his work.

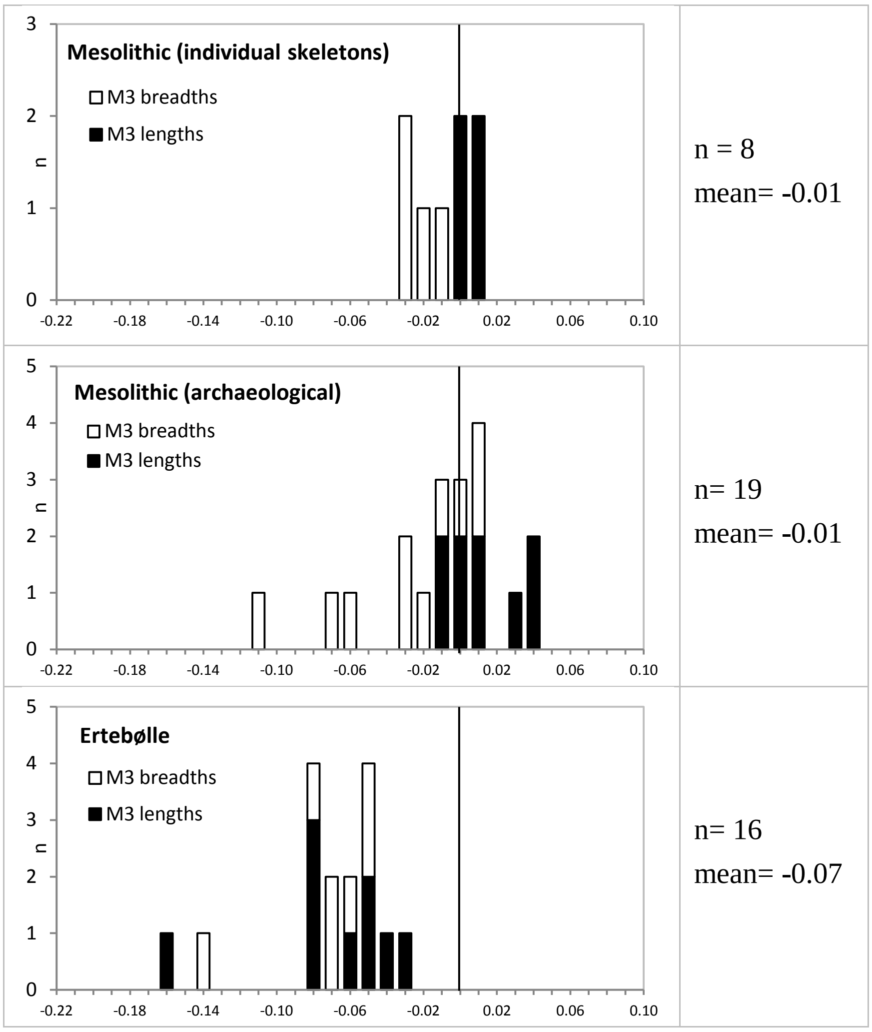
Fewer calcaneum measurements were available but enough to show the potential for the greatest length (GL) measurement from this bone to be useful in the distinction of wild and domestic (Figure 3.1.14). There is the suggestion that wild and domestic will plot quite separately although it is difficult to say confidently when this measurement is not available from any of the wild individual skeletons. Again the measurement from Havnø is particularly small, and the only real potential candidate to be domestic of all of the measurements from the Ertebølle group.

Here the use of log ratios has shown that the issues previously discussed in the literature can be explored in a slightly different way, but come up with similar results. Degerbøl (1970) does include some diagrams in his work: both scatterplots and histograms, but much of his analysis is conducted in the discussion of individual measurements in the text.

Overall, Swedish and Danish material show very similar patterns of change over time, and there is very little synchronic difference between the two areas. Patterns show a gradual change from wild to domestic, which causes a situation where it can be very difficult to tell the difference between the two in Early Neolithic contexts. There is evidence of domestic cattle on sites with an Ertebølle component, but it is likely that the domestic cattle come from the Early Neolithic TRB levels of these sites as there is no evidence of domestic cattle at sites with only Late Mesolithic Ertebølle dates. A general lack of sites with solely Early Neolithic dates means that there is not enough evidence to say much more about the origins of cattle domestication in this area.

3.2.2.2 Teeth

Samples of teeth recorded for this project were generally quite small, especially for the Holocene, but Mesolithic and Ertebølle Danish sites have yielded enough to display and compare using log ratio diagrams. Most teeth that were recovered were loose first and second molars, which could not be distinguished, so this analysis concentrates on third molar measurements.



n = 8
mean= -0.01

n= 19
mean= -0.01

n= 16
mean= -0.07

Figure 3.1.15: Log ratio diagrams displaying Danish third molar measurements over time.

It was only possible to analyse tooth measurements taken by the author of this thesis, because tooth measurements from other sources tend to be taken at the occlusal surface, rather than the widest point of the tooth, and they are therefore not compatible for use in comparison. This is why there are no data from the Middle Neolithic sites of Bundsø and Lidsø.

Although the samples are still very small, there does seem to be a change in size between the Mesolithic and Ertebølle samples (Figure 3.1.15), which is demonstrated by the change in the mean value. This is, unfortunately, not possible to test statistically, because the samples are too small, but seems to affect both length and breadth measurements. The change is similar to that seen in postcranial remains (Figure 3.1.7), but perhaps slightly clearer. Interpreted alongside the postcranial data, taken from the same sites, it seems more likely to be related to a change in the size of the aurochs, than to the presence of domesticated animals. This is the way in which Degerbøl (1970) interpreted the change. The only two specimens which could be from domestic animals are the two smallest specimens, which are both from Krabbesholm, a site with dates that extend into the Neolithic period. These particular specimens do not seem to be included or discussed by Degerbøl, but were clearly associated with other material from this site in the museum and had been identified as domesticates.

Interestingly breadth measurements always seem to plot further to the left than length measurements on the log ratio diagrams, indicating that these teeth are all of a slightly different shape to those of the standard population from Ilford (Middle Pleistocene MIS7).

Overall the third molar measurements support the pattern displayed by the postcranial remains, and there does seem to be an indication of a change in the size of the aurochs between the Early and Late Mesolithic in Denmark.

3.1.3 Danish *Bos* and *Sus* in comparison

Wild and domestic pig data are available for comparison with the cattle. These data were kindly made available by Peter Rowley-Conwy via Umberto Albarella, and an analysis of these data has already been published in Rowley-Conwy and Dobney (2007). Reference to the Mesolithic wild boar dataset for Denmark is also made in Albarella *et al.* (2009). The availability of the raw data has made it possible to do a very similar parallel analysis of the pig, to go alongside the cattle. Some of the sites are included in both the cattle and pig studies, although, due to a number of reasons such as preservation and availability of data, a number of sites are different. In any case, this analysis is presented to get an idea of the overall pattern in Denmark, rather than to do a comparison of individual sites. The Ertebølle sites included here are all dated more firmly to this period than those included in the cattle analysis. This makes the analysis easier, but does not constitute a direct comparison to the cattle pattern. *Sus* measurements from Havnø, for example, have not been included, as the the poor preservation of pig material at the site meant that very little biometrical information was available (Kurt Grøn *pers. comm.*). As with the cattle remains, there is a lack of Early Neolithic pig material, so we must remember that there is a gap in time which is unaccounted for here.

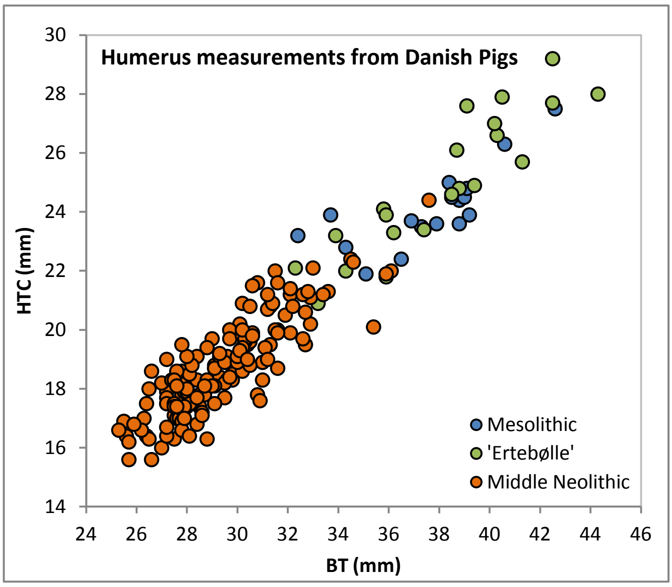


Figure 3.1.16 Scatterplot showing Danish pig humerus measurements over time.

HTC=height of the trochlea, BT=breadth of the trochlea

Sites included:

Mesolithic: Bloksbjerg (Kongemosen culture – Late Middle Meso)

Ertebølle: Nivaa, Norslund, Agernaes, Flynderhage, Ølby Lyng

Middle Neolithic: Troldebjerg

Pig humerus measurements (Figure 3.1.16) show a clear reduction in size over time from the Mesolithic to the Middle Neolithic period, which is evident in the cattle results too. Within each time period, there is less of a clear separation between male and female animals, in comparison to the cattle results, and in fact it would be quite difficult to separate the two sexes here. Mesolithic and Ertebølle specimens occupy a very similar space on the scatterplot, indicating that perhaps there are no domestic pigs present in the Ertebølle group. In fact Ertebølle specimens show a large range, with the largest being larger than any from the Mesolithic group and the smallest also being smaller. Although there were no cattle humeri that could be plotted from Ertebølle sites, other bones did show some very small measurements which stood well below the Mesolithic range, unlike pigs. There are some particularly large Middle Neolithic humeri here, at least one of which plots well into the Mesolithic size range. This could be an indication of the presence of wild boar in this Middle Neolithic population. In contrast, there were no particularly large cattle specimens in the Middle Neolithic assemblages included in this study.

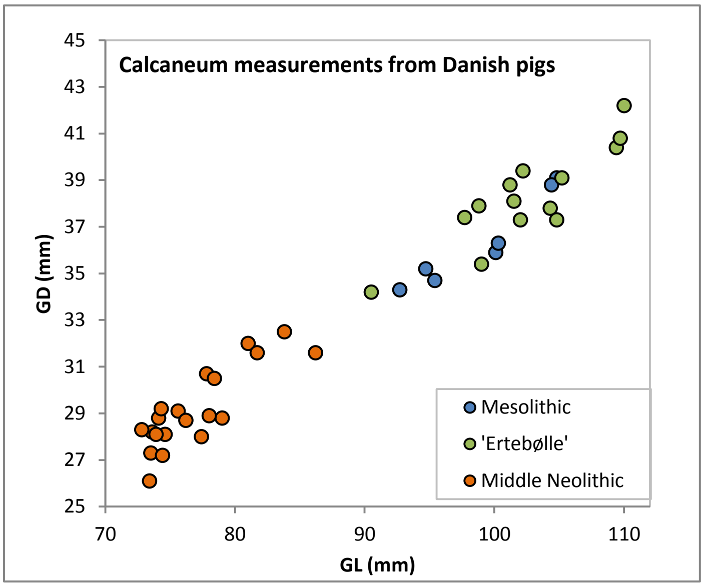


Figure 3.1.17: Scatterplot showing calcaneum measurements from Danish pigs over time. GL=greatest length, GD=greatest depth.

Material included:

Mesolithic: Bloksbjerg (Kongemosen culture – Late Middle Meso)

'Ertebølle': Nivaa, Flynderhage, Norslund.

Middle Neolithic: Troldebjerg.

Calcaneum measurements (Figure 3.1.17) show a similar pattern to humerus measurements, with a clear reduction in size over time. In fact the separation between the Middle Neolithic and earlier specimens is far clearer here as there is no overlap at all, which is probably a consequence of the smaller calcaneum sample size. Again there are no particularly small Ertebølle specimens, indicating that none of the calcaneum specimens from these sites are from domestic animals. As for the humerus, there are some Ertebølle specimens that are larger than any from the Mesolithic group and the smallest is also smaller. Unlike the humerus, there are no indications here that there are any Middle Neolithic wild boar specimens, as they all fall far below the smallest Mesolithic calcaneum.

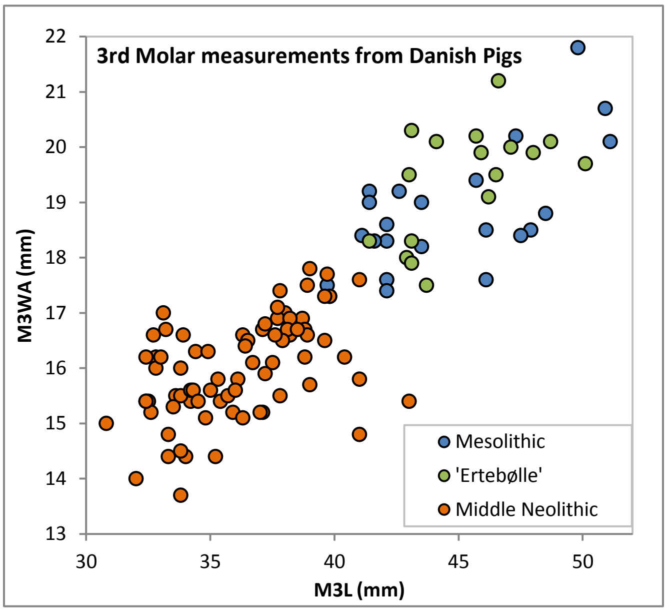


Figure 3.1.18: Scatterplot showing 3rd molar measurements from Danish pigs over time. M3L=length of 3rd molar, M3WA=anterior width of the 3rd molar.

Material included:

Mesolithic: Lundby II, Holmegaard IV, Mullerup, Svaerdborg I & Bloksbjerg (Kongemosen culture – Late Middle Meso)

Ertebølle: Nivaa, Norslund, Agernaes, Flynderhage, Ølby Lyng

Middle Neolithic: Troldebjerg

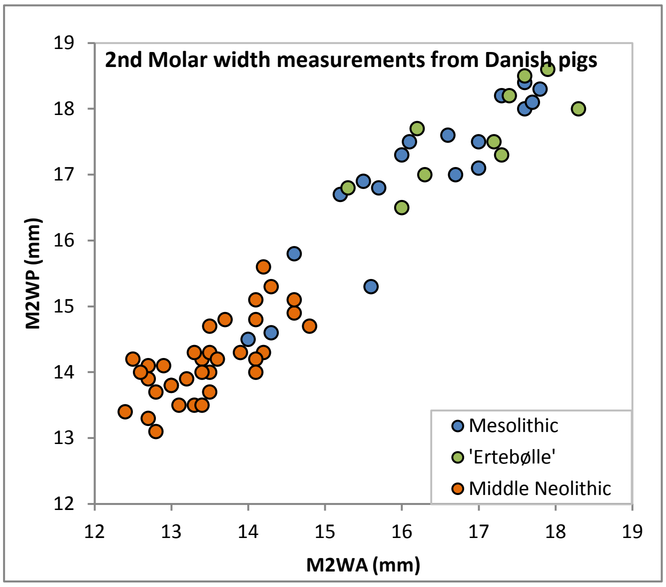
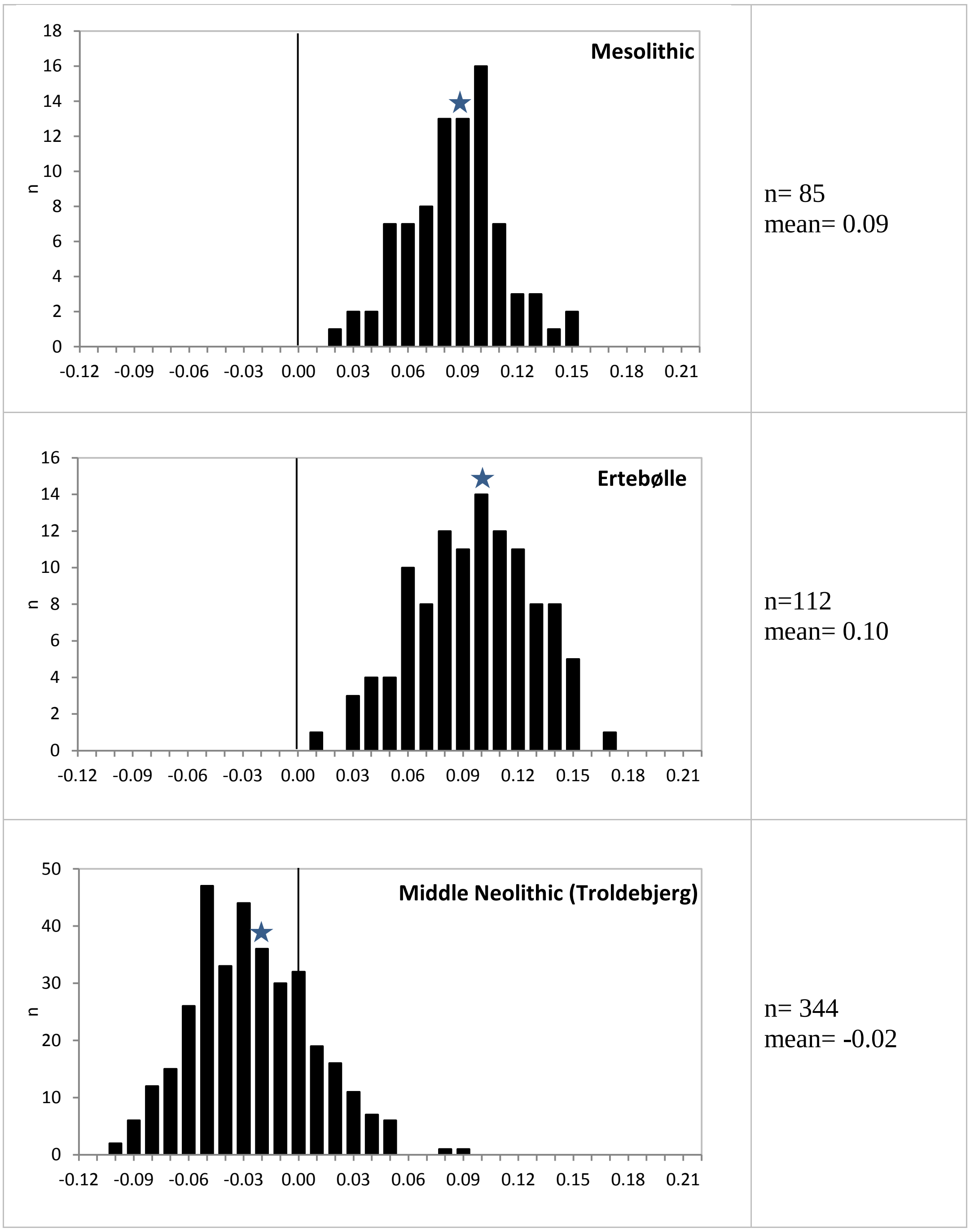


Figure 3.1.19: Scatterplot showing 2nd molar measurements from Danish pigs over time. M2WA=anterior width of the 2nd molar, M2WP=posterior width of the 2nd molar.

Material included: see above, fig 3.17

Tooth measurements (Figures 3.1.18 and 3.1.19) show a similar pattern to postcranial bones, with a reduction in size by the Middle Neolithic. A particularly interesting pattern is shown by the few particularly small Mesolithic specimens which fall within the Middle Neolithic group. It would be unlikely for these to be domesticated, due to their early date. This scatterplot then suggests that the extent of overlap between wild and domestic may be greater than one might initially think.



n= 85
mean= 0.09

n=112
mean= 0.10

n= 344
mean= -0.02

Figure 3.1.20: Log ratios showing *Sus* postcranial measurements over time in Denmark. The standard population is late Neolithic Durrington Walls, UK (Albarella and Payne 2005).

Log ratio diagrams (Figure 3.1.20) combining *Sus* postcranial measurements show that, despite the number of relatively large bones from Ertebølle sites, the overall range and average is very similar to the Mesolithic group (statistically the difference is not significant; see Table 3.1.5). This diagram confirms the lack of small outliers in the Ertebølle group and therefore the likely lack of domestic pigs at these sites. It could be that these sites have less influence from the TRB culture than the than some of the samples included in the *Bos* analysis (such as Havnø and Neustadt), - in fact most of the sites contributing *Sus* samples do not have evidence of Funnelbeaker pottery. The Middle Neolithic pig population overlaps very little with the earlier groups in comparison to the cattle results, although there are a couple of relatively large measurements which may represent the presence of wild boar in this assemblage.

Overall the pattern seen here is indicative of a mature domestication of pigs in the Middle Neolithic, as is concluded by Rowley-Conwy and Dobney (2007), although the lack of comparative material securely dated to the Early Neolithic means that we have a period of time which is unaccounted for, which does not allow us to say whether the process was gradual or sudden.

There are some differences between the patterns for pigs and cattle. Both patterns are indicative of a change to a majority of domestic animals, probably sometime during the Early Neolithic, but the change in cattle seems to be more gradual than in pigs. For cattle the Ertebølle-TRB sample likely contains both wild and domestic animals, but in pigs the Ertebølle sample is probably entirely made up of wild animals, as it overlaps with the Mesolithic sample more. This is reflected in the results of the Mann-Whitney test performed for pigs, which results in a non significant result for pigs but a highly significant result for cattle. However, as the only potential domestic cattle bones are from sites with TRB components, it would seem likely that these reflect the introduction of domestic cattle in the earliest Neolithic rather than a local domestication of cattle during the Late Mesolithic. Unfortunately the lack of definite Early Neolithic specimens from either animal does not allow us to track the change from wild to domestic animals in any more detail. There is also no indication of a reduction in size of the wild boar between the earlier Mesolithic and Ertebølle samples, which is in contrast to the aurochs, which does display a reduction in size between these two periods, even when the few domestic inclusions in the Ertebølle sample have been discounted.

Table 3.1.3: Summary statistics for archaeological *Bos* (Denmark and Sweden combined). Only archaeological material has been included. Samples of less than 5 were excluded.

Measurement	No.	Min	Max	Mean	Standard deviation	Coefficient of variation
Astragalus GLl						
Early Mesolithic	67	67.8	96	84.53	6.00	7.10
Ertebølle	11	68.2	88	76.59	6.74	8.80
Middle Neolithic	35	60	76.5	66.56	3.92	5.89
Astragalus GLm						
Early Mesolithic	49	62.3	88	77.79	5.56	7.15
Ertebølle	7	57	81.5	70.23	8.23	11.72
Middle Neolithic	12	58.3	73	62.75	4.37	6.96
Astragalus Bd						
Early Mesolithic	55	47	62.6	54.04	4.43	8.19
Ertebølle	9	41.7	56.8	49.64	4.53	9.13
Middle Neolithic	10	36	49.5	43.02	4.33	10.06
Calcaneum GL						
Early Mesolithic	13	143.5	191	171.19	14.75	8.61
Ertebølle	5	135	176	162	16.97	10.48
Middle Neolithic	5	126.5	134.7	131.44	3.07	2.33
Metacarpal BFd						
Early Mesolithic	5	71	86	78.56	6.85	8.71
Ertebølle	8	63.5	82.4	72.76	6.30	8.66
Middle Neolithic	25	54.2	71	62.15	4.32	6.95
Metatarsal BFd						
Early Mesolithic	5	65.9	77.2	72.02	5.68	7.89
Ertebølle	10	56	74.8	65.03	5.74	8.82
Middle Neolithic	24	47.8	67	57.03	5.80	10.17
Third Molar L						
Early Mesolithic	9	47.2	53.4	50.03	2.34	4.67
Ertebølle	9	33.8	45.3	41.68	3.38	8.10
Third Molar W						
Early Mesolithic	10	16.1	21.5	19.48	1.70	8.74
Ertebølle	7	15	18.7	17.61	1.24	7.04

Table 3.1.4: Results of Mann-Whitney tests on *Bos* postcranial log ratios from Denmark and Sweden. Significant results (<0.05) are marked with an * and highly significant results (<0.01) are marked with **. Samples smaller than 20 have been excluded. Only one measurement from each bone was included, and samples of under 20 were excluded.

Group	n.	Group	n.	U	z	Sig.
Mesolithic	105	Ertebølle	34	682.0	-5.405	0.000**
Mesolithic	105	Middle Neolithic	101	247.0	-11.82	0.000**
Ertebølle	34	Middle Neolithic	101	393.0	-6.712	0.000**

Table 3.1.5: Results of Mann-Whitney tests on *Sus* postcranial log ratios from Denmark and Sweden. Significant results (<0.05) are marked with an * and highly significant results (<0.01) are marked with **. Only one measurement from each bone was included, and samples of under 20 were excluded.

Group	n.	Group	n.	U	z	Sig.
Mesolithic	56	Ertebølle	69	1587.5	-1.720	0.085
Mesolithic	56	Middle Neolithic	174	59.0	-11.142	0.000**
Ertebølle	69	Middle Neolithic	174	72.0	-12.031	0.000**

3.2 Britain

The British dataset includes a larger proportion of material from the Pleistocene in comparison to most of the other areas included in this project. The only other country with a comparable amount of Pleistocene data is Italy. British data are available from Marine Isotope Stage 9 to the Bronze Age, when the aurochs is thought to have gone extinct in Britain.

Pleistocene data provide a valuable comparison with the Holocene data, but must be treated with caution due to the numerous climatic fluctuations that took place during the Middle and Late Pleistocene. To try and deal with this issue the sites from this period have been presented separately rather than in one 'Pleistocene' group.

Pleistocene data included in this analysis are from the sites of Grays Thurrock (MIS 9), Ilford (MIS 7), both in Essex, and the Middle Palaeoltihic site of Coygan Cave (64-38 ka BP – Aldhouse-Green *et al.* 1995) in Wales. The material from Grays Thurrock and Ilford is kept in the Palaeontology department at the Natural History Museum in London, and the material from Coygan Cave is kept at the National Museum of Wales, in Cardiff. All of this material was recorded by the author.

The majority of Mesolithic material is from Star Carr, with a few specimens from Goldcliff East and the sites at Thatcham. These were all recorded by the author at the Zoology department at the Natural History Museum in London. In addition, material from the site of Cherhill was also included; this site has both Mesolithic and Neolithic material and was recorded by Sarah Viner-Daniels (University of Sheffield) at the Natural History Museum store in Wandsworth, London.

Neolithic material is from Eton Rowing Lake (recorded by Gill Jones and Sarah Crump – material held by Oxford Archaeology), Durrington Walls (recorded by Sarah Viner and Umberto Albarella), Mount Pleasant (measurements taken from Harcourt 1979); North Marden (measurements taken from Browne 1986) and an individual articulated skeleton found at Uskmouth, near Newport, known as 'Alice' (this skeleton is held at the Newport Museum in Wales, and was recorded by Sarah Viner-Daniels). For analysis the Neolithic material has been split into two groups: 'Early Neolithic' (c4000-3000 cal BC) – represented by the earlier levels from Eton Rowing Lake and the 'Alice' skeleton, and 'Late Neolithic' (c3000-2500 cal BC) comprising of the material from Durrington Walls, Mount Pleasant, and North Marden. The initial aim was to also include material from the Early Neolithic site of Hambledon Hill, but these data were eventually not available.

Bronze Age material is from Eton Rowing Lake (details as above), Snail Down (measurements taken from Clutton-Brock and Jewell 2005) and an individual skeleton from Lowe's Farm in Cambridgeshire (measurements take from Shawcross and Higgs 1961).

Where individual skeletons have been used ('Alice' and the skeleton from Lowe's Farm) only the left side of the animal has been included. Where a measurement from the left side was not available then the right has been used instead. As there are only two of these skeletons they have been combined with the archaeological material on both scatterplots and log ratios – and this must be taken into account throughout the process.

The data analysis included in this section has been conducted in the same way as most of the analysis in this project, with almost all data being combined into one *Bos* group. Presenting the data in this way means that there are no preconceptions about domestic and wild groups when undertaking the analysis. As for most of the areas included in this study very few tooth measurements were available for analysis, so these have not been included here. The lack of teeth in all assemblages except for that from Durrington Walls has also meant that age at death patterns cannot be compared.

3.2.1 Ageing

Only a few of the British assemblages contained enough bones to look at ageing through epiphysial fusion. Both Ilford and Grays Thurrock had 100% fused bones. This could be a reflection of the storage of these assemblages post excavation rather than anything else. The bones from these sites were collected by enthusiasts during the 19th century and donated to the Natural History Museum at a later date. It was common that the more complete and well preserved bones were given preferential treatment by collectors, and that fragmentary and unfused bones may have been discarded. It is also worth bearing in mind that the bones from these two sites are all fossilized, which may mean that astragali that are 'light' in weight may not be so obvious. This may result in the astragali from younger animals being included in the biometrical analysis when usually they would be excluded.

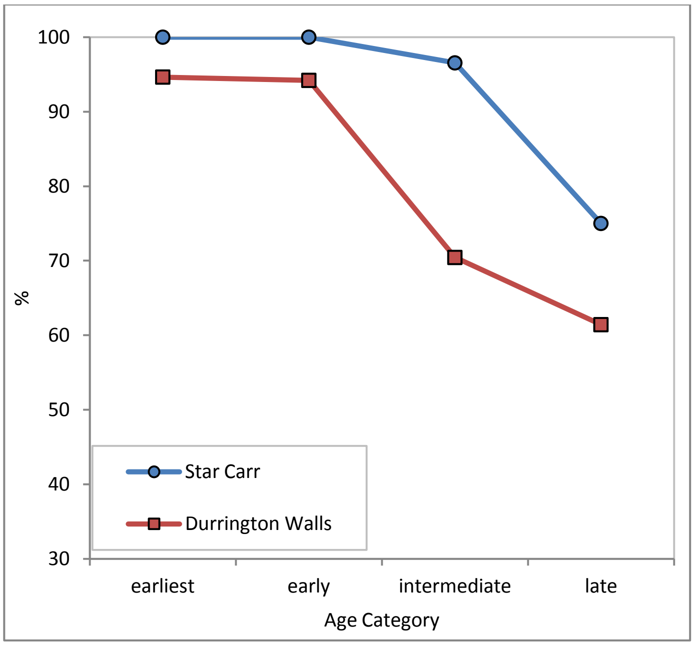


Figure 3.2.1: Fusion of *Bos* bones from Star Carr and Durrington Walls.

Fusion data could be analysed for the material from Star Carr and Durrington Walls. The results from Star Carr indicate that very few young animals at the site, but that not all animals were fully adult (Figure 3.2.1). The results from Durrington Walls show a larger proportion of younger animals in comparison to Star Carr. The shortage, at Durrington Walls, of measurements available from late fusing bones such as the proximal femur and calcaneum are a consequence of this.

These differences in age between a population that is entirely made up of wild cattle and one that is thought to be dominated by domestic cattle support the idea put forward by Legge (1996) that a higher number of juvenile bones can indicate that domestication has taken place. In fact this pattern seen between British Mesolithic and Neolithic populations has previously been highlighted by Viner (2010).

3.2.2 Biometry

Summary statistics (Table 3.2.1) show a general reduction in the mean over time in most measurements. The Late Neolithic and Bronze Age samples tend to show the widest ranges, indicating that these samples may contain a mixture of wild and domestic animals, although Bronze Age samples for some measurements are very small and this often results in a very small coefficient of variation score. In order to explore how each of these populations is made up, it is necessary to present the data using scatterplots and log ratio histograms.

Astragalus measurements (Figure 3.2.2 – top diagram) show a clear decrease in size over time. There are just two Pleistocene specimens that overlap with those from the Holocene. These two specimens from Grays Thurrock plot away from the majority of specimens from this site, and it is worth bearing in mind the issues presented by fossilisation mentioned above – perhaps when unfossilised these bones would have been ‘light’ in weight. Within the Pleistocene sample there is little size difference, and this makes sense considering these sites are all from warm periods. Mesolithic specimens group in a clear cluster, separated from the bulk of the rest of the Holocene specimens. There are a few specimens from both the Early and Late Neolithic that plot with the Mesolithic group as opposed to the rest of the Neolithic material, and it seems likely that these are aurochs, whereas the rest are domestic cattle. There is quite a clear separation between the wild and domestic groups here. There is no clearly detectable separation between potential male and female specimens here as there was in the Danish material.

Tibia measurements present a slightly more confusing pattern (Figure 3.2.2 – bottom diagram). There is still a reduction in size over time, but the separation between wild and domestic is much less clear. There is more variation within the Mesolithic sample than for the astragalus. Still, there are two specimens, one from the Early the other from the Late Neolithic, which plot away from the bulk of this group and probably represent wild animals. The three Neolithic specimens that plot close to the bottom of the Mesolithic range may represent male domesticates, or female aurochsen.

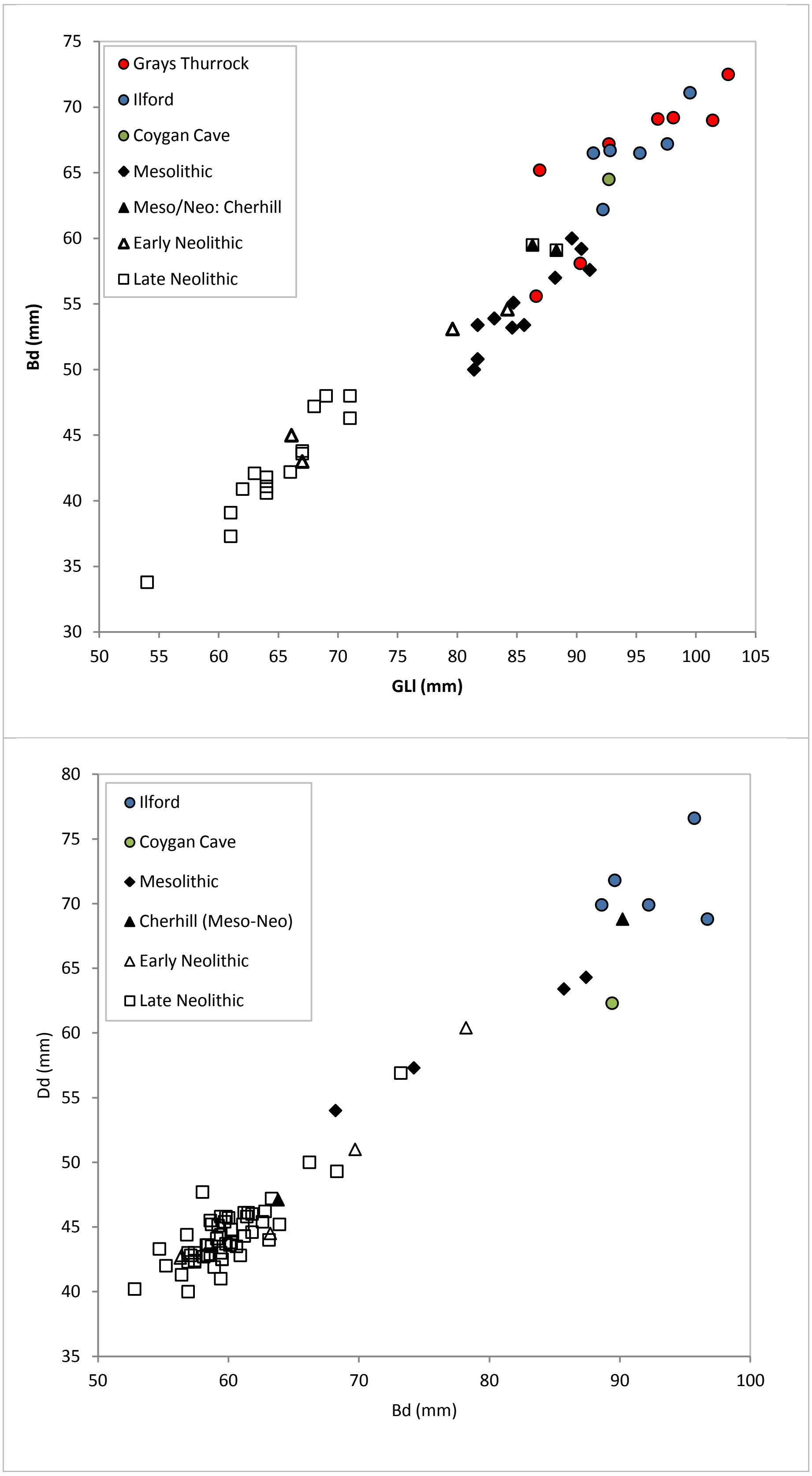


Figure 3.2.2: Scatterplots showing British astragalus (top diagram) and tibia (bottom diagram) measurements over time. GLl=greatest length of the lateral side, Bd= distal breadth, Dd=distal depth

Metacarpals split into two clear groups, which could reflect domestic and wild animals (Figure 3.2.3 - top diagram). The larger group includes some large Bronze Age specimens which plot close to the Pleistocene specimens. Unfortunately there are no Mesolithic specimens with the required measurements, so it is not possible to compare them to other Holocene aurochsen. There is one Neolithic specimen that plots quite clearly in the ‘wild’ group.

Humerus measurements also show an overall pattern of reduction in size over time (Figure 3.2.3 – bottom diagram), with the Ilford and most of the Late Neolithic specimens plotting in two distinct groups, and Mesolithic and two Neolithic specimens plotting in between. Especially strange is the placement of one of the Mesolithic specimens in a position that does not seem to correlate with the rest of the *Bos* group. This is a specimen from East Ham, which seems to have a particularly large trochlea height (HTC) measurement for its trochlea breath (BT) measurements (indicating a shorter and fatter trochlea than you would expect for *Bos*). This specimen correlates slightly better with the *Alces* group, but it is still larger than any of these specimens. It is not possible to say for sure with the measurements available this is either *Bos* or *Alces* and so therefore the measurements from this bone have been excluded from the rest of these analyses. It would be useful in the future to go back to look at the specimen again in order to take more measurements and reassess the morphology. Humerus measurements do not show any indication of plotting into separate sex groups, but this could be a result of small sample size.

Overall scatterplots show a reduction in the size of *Bos* over time. There is a clear change in size between Pleistocene and Mesolithic wild cattle, which could be related to the effects of climate on body size and shape. After this there is a further reduction which is likely to be related to domestication. Those animals which can be identified as wild from the later periods do not seem to be a great deal smaller than those from the Mesolithic. Both the Neolithic and Bronze Age samples have some specimens that plot to the top of the Mesolithic range. There is no real evidence of an increase in size after the onset of the climatic deterioration at around 3000 cal BC, although the sample sizes from after this may be too small to spot this kind of pattern.

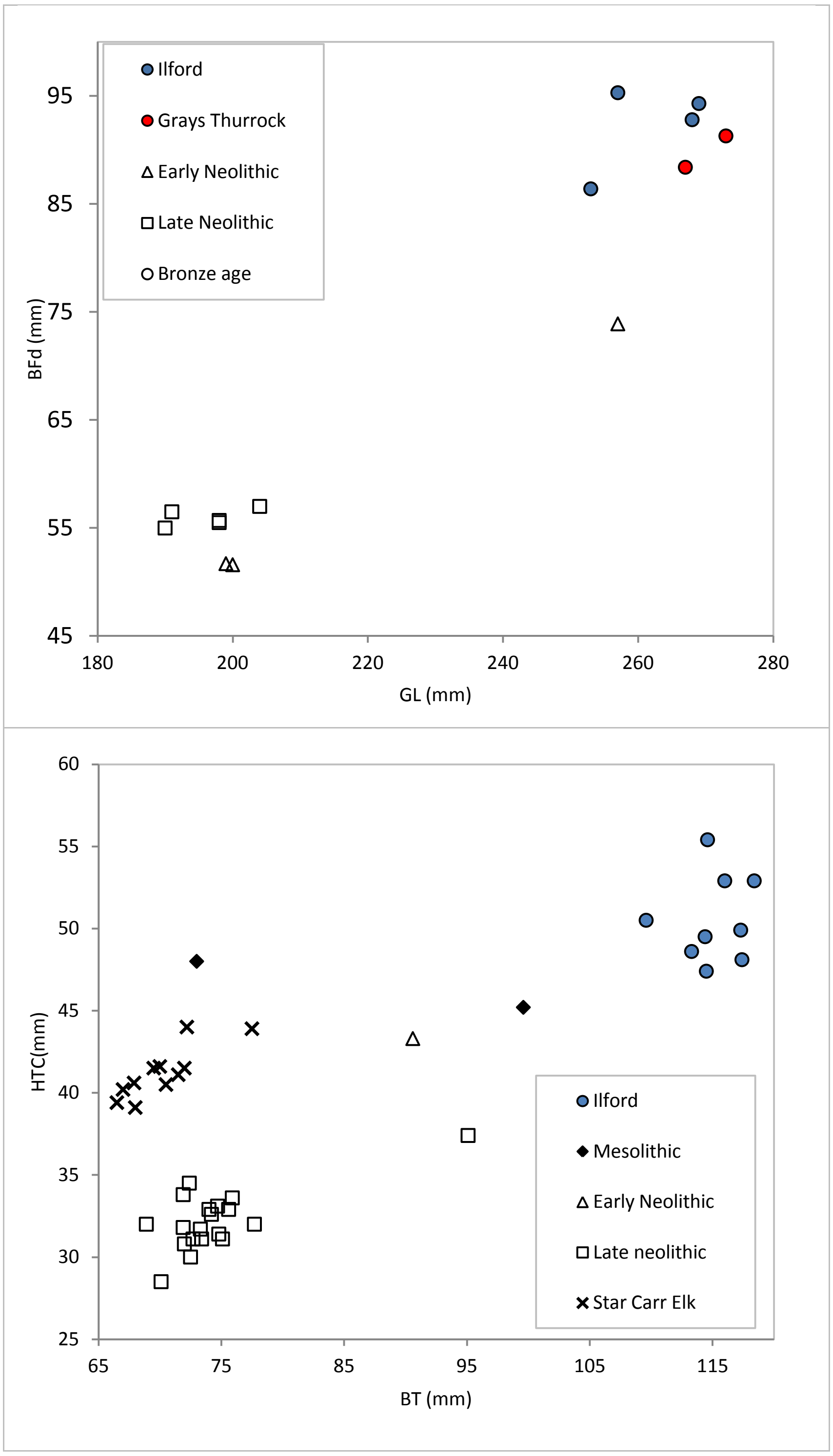


Figure 3.2.3: Scatterplots showing British metacarpal (top diagram) and humerus (bottom diagram) measurements over time. GL=greatest length, BFd=breadth of the distal end, BT=breadth of the trochlea, HTC=height of the trochlea.

Elk (*alces alces*) measurements from Star Carr have been included on the humerus plot in order to try to explain the placement of the Mesolithic *Bos* outlier (taken from Legge and Rowley-Conwy 1988). It is worth noting that the BT measurement taken by Legge and Rowley-Conwy is slightly different than the one taken on material for this study. Their measurement is that defined by von den Driesch (1976), whereas for this study the measurement is that defined by Bull and Payne (1988). This would probably result in my measurements being very slightly smaller than they would have been if the measurement was taken according to von den Driesch (1976).

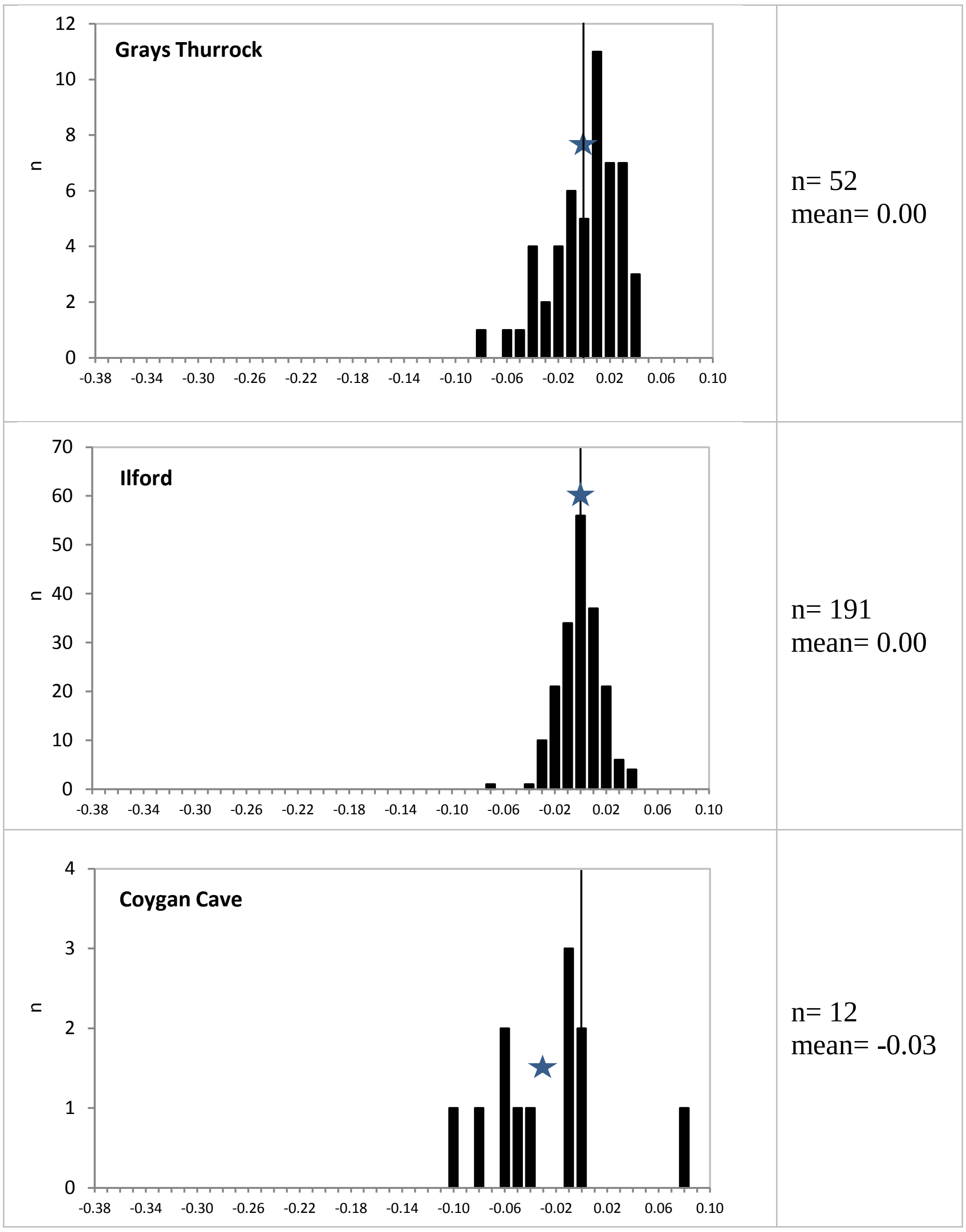


Figure 3.2.4: Log ratios containing postcranial measurements from British Pleistocene sites.

Log ratios from Pleistocene sites (Figure 3.2.4) indicate no size change between the material from Grays Thurrock and Ilford, as they have identical means – this is further supported by the statistical analysis, which demonstrates that there is no significant difference between these two datasets (Table 3.2.2). This pattern is not surprising considering that they are both from similar warm phases.

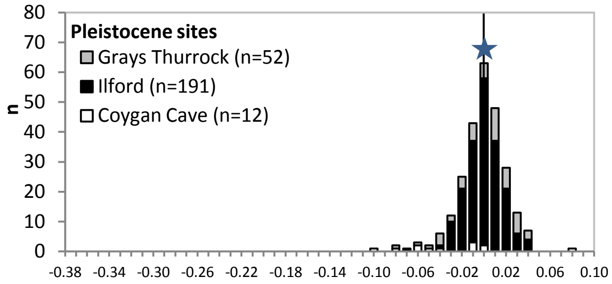
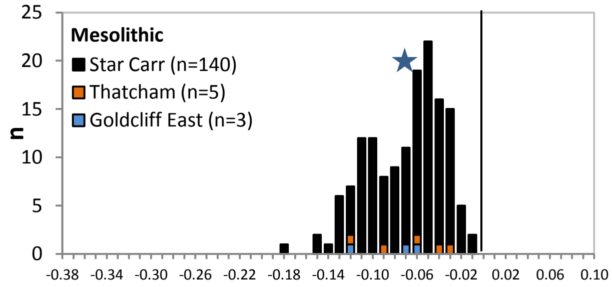
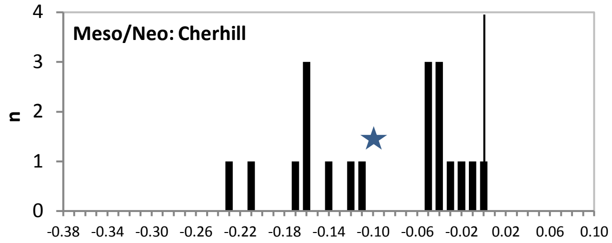
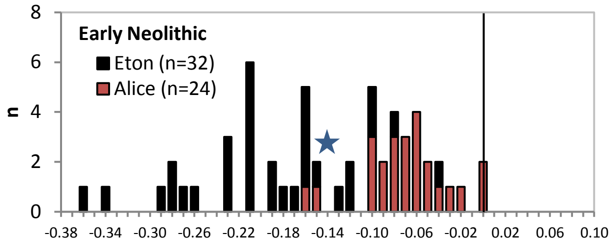
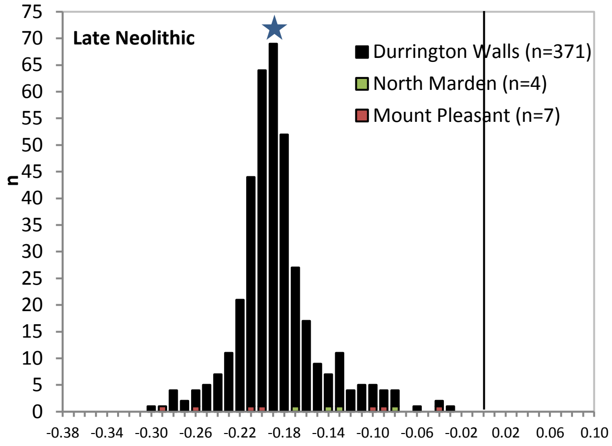
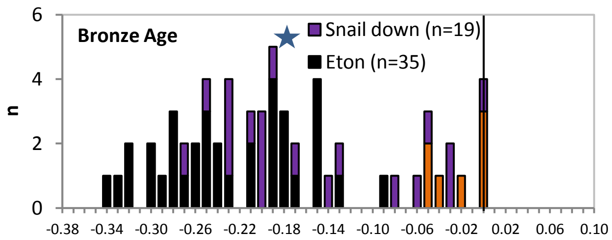
The material from Coygan Cave shows indications of a slight shift to a smaller size, although the sample size was too small to test this statistically. This is interesting because, although this material is dated to a period of climatic fluctuations, the overall temperature is lower than during MIS 9 and 7 so you would expect that there might be a slight increase in size. The only indication of this is the one very large measurement in the assemblage. The size range indicated by this very small sample size, especially when you compare it to the narrower ranges indicated by the larger sample sizes at Grays Thurrock and Ilford, fits with this assemblage being from an expanded time of fluctuating climate in comparison to these earlier sites, where the climate as evidently more stable. However, it is also worth bearing in mind that this site dates to after the last interglacial. The small amount of data that we do have from the last interglacial up until the end of the Pleistocene, from areas across Europe, suggests that the main decrease in size of the aurochs may have taken place during the last interglacial rather than at the very end of the Pleistocene (see Sections 3.5 and 3,6).

When Pleistocene and Holocene remains are compared (Figure 3.2.5) log ratio means show a steady reduction in size over time until the Late Neolithic and Bronze Age samples. The means of these two latter samples are very similar, and the statistical analysis demonstrates that they have the least significant difference between them of all of the samples compared (Table 3.2.2).

The Mesolithic pattern indicates a slight bimodality, which could indicate a predominance of male specimens within this sample. However, the analysis of Danish Mesolithic measurements in the previous section highlighted that this could in fact be a bias caused by the measurements selected for the log ratio analysis. Further analysis discussed below may assist in the interpretation of this pattern.

The material from Cherhill shows the first signs of a splitting of the measurements into two groups, which could be attributed to wild and domestic animals. This is a likely consequence of the fact that Mesolithic and Neolithic material from this site is mixed. Only a small number of specimens from Early Neolithic Eton appear to be larger enough to be consistent with the aurochs. These large outliers are similar in size to those from the ‘Alice’ skeleton, which is thought to be a female. In the Late Neolithic the pattern of domestic predominance is further exaggerated, with only a few large, aurochs-like, outliers having been recorded.

Despite the similarity in the means of the Late Neolithic and Bronze Age samples, the Bronze Age contains a number of relatively large specimens, larger than any in the Late Neolithic and even larger than any from the Mesolithic. These measurements are from the skeleton at Lowe’s Farm, which is evidently a very large animal, but also from bones at Snail Down. Conversely, the group of small Bronze Age animals suggests that size reduction of these domestic forms must have occurred after the Neolithic.

	n= 255 mean= 0.00
	n= 148 mean= -0.07
	n= 19 mean= -0.10
	n= 56 mean= -0.14
	n= 382 mean= -0.19
	n= 61 mean= -0.18 **Figure 3.2.5: Log ratios for postcranial remains from British sites over time. Note that 'Alice' and Lowe's Farm material is from individual skeletons. All other material is archaeological.**

There are some particularly small measurements from Eton in both the Early Neolithic and Bronze Age samples. This contributes to these samples having very large ranges considering their sample sizes, indicating a large amount of variation during these time periods. Alternatively, as these measurements were not taken by the author there could be some kind of methodological issue here affecting the pattern. This may become more apparent below when we see which measurements they are.

More in depth analysis of the Pleistocene measurements (Figures 3.2.6 and 3.2.7) shows that the measurements which show the largest shift between Ilford and Grays Thurrock, and Coygan Cave are depth measurements from the tibia, and breadth measurements from the metacarpal. Interestingly the metacarpal breadth and length measurements at Coygan Cave plot quite far away from each other on the log ratio, even though all of these measurements are from the same bone. This indicates a particularly long and slender metacarpal in comparison to those from earlier time periods, which may just represent an unusually tall animal.

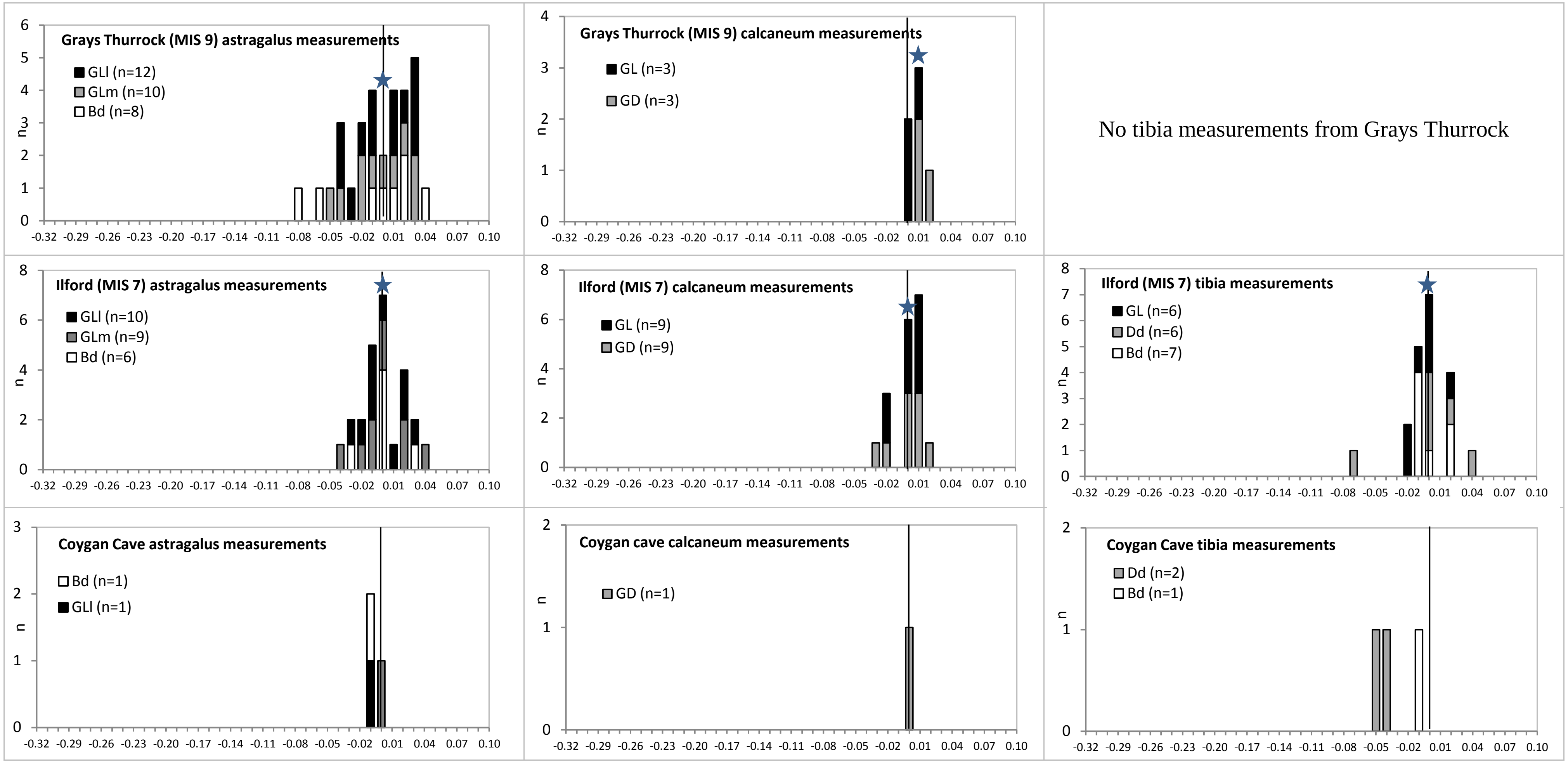


Figure 3.2.6: Log ratios showing individual measurements from the astragalus, calcaneum and tibia at British Pleistocene sites.

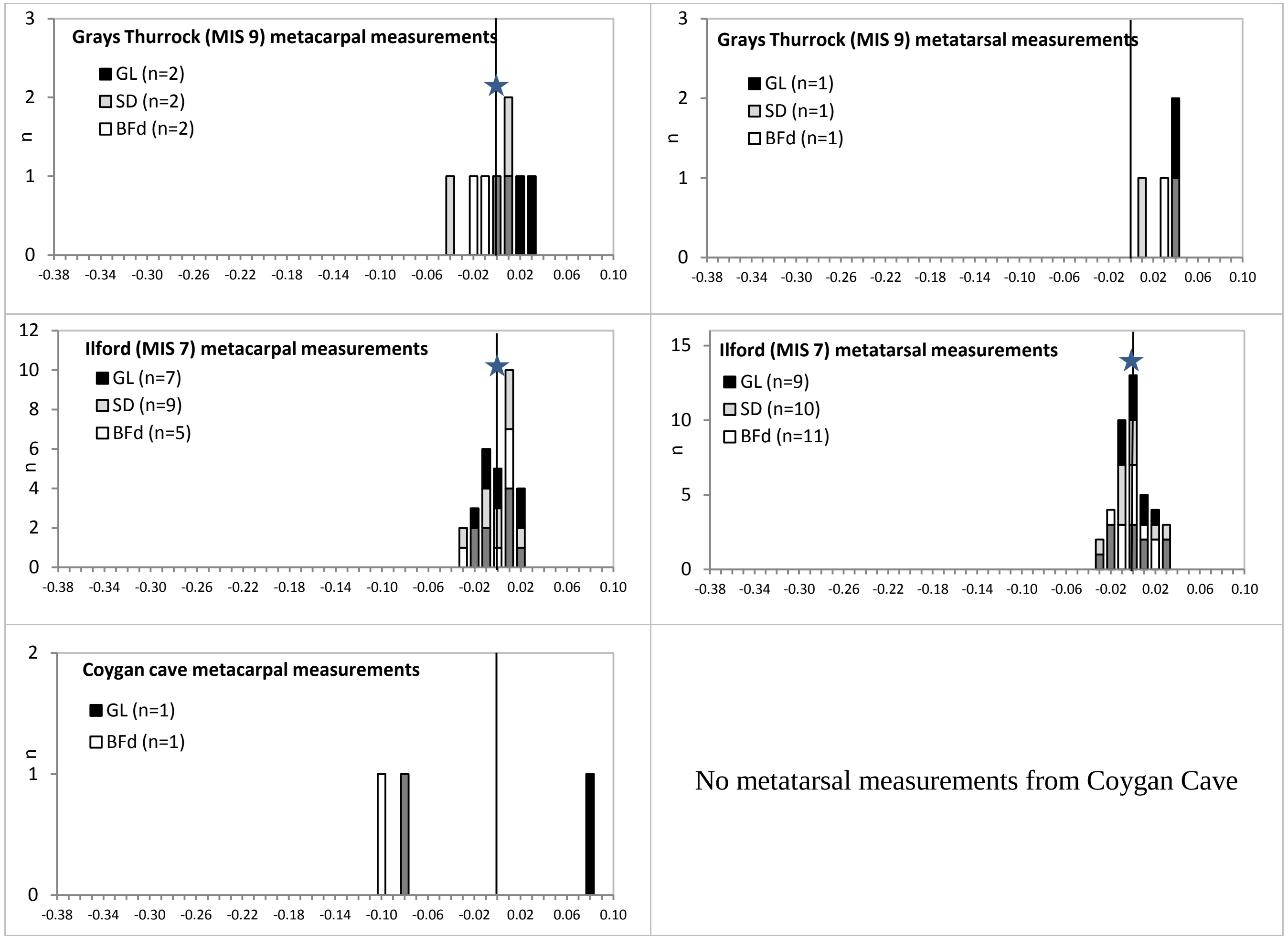


Figure 3.2.7: Log ratios showing individual measurements from metapodials at British Pleistocene sites.

Individual measurements are also compared across the Holocene (Figures 3.2.8-3.2.11) Similarly to the Danish case, astragalus breadth measurements tend to have more variation than length measurements and they also seem to change in size more readily than length measurements (Figure 3.2.8). Holocene breadth measurements plot further away from the standard than length measurements, implying a relatively slender astragalus during the Holocene in comparison to the Pleistocene. This pattern was also hinted at in Denmark, where astragalus breadth measurements consistently plotted further from the standard than length measurements. The implication is that climatic change brought about shape as well as size change. It is possible to identify the presence of both wild and domestic animals in both Neolithic groups, and potentially also at Cherhill, as the distributions form two groups. There are no large measurements in the Bronze Age astragalus sample, implying that this represents only domestic cattle according to astragalus measurements. This group contains specimens from both Eton and Snail's Down, but not from the wild animal from Lowe's Farm.

Data available for the calcaneum are far fewer (Figure 3.2.8). There is clearly a reduction in both length and depth measurements between the Pleistocene and the Holocene and there are some large specimens in both the Early Neolithic and Bronze Age samples which are likely to be from wild cattle. These include length measurements that are larger than the one available for the Mesolithic, but it is difficult to interpret this due to the small sample size. The largest Holocene sample is from Durrington Walls where both length and depth measurements occupy a very similar range. This implies that in domestic cattle both measurements have been reduced at a similar rate.

Tibia measurements show a similar reduction in size to those from the astragalus (Figure 3.2.9). There are some particularly large measurements at Cherhill, but apart from these all Holocene measurements are smaller than the standard. There is a hint that breadth and depth measurements reduce in size at a faster rate than length measurements, as for the astragalus, as these are always the smallest measurements, however there are too few length measurements to make a clear interpretation.

There are fewer femur measurements than for any other bone (Figure 3.2.9). This is likely to be related to the femur being a later fusing bone resulting in fewer measurements in the Holocene samples where younger animals are increasingly frequent. Despite this it is still possible to see the reduction in size between the Pleistocene and Late Neolithic samples. There does not seem to be evidence for the presence of wild cattle in the Late Neolithic sample because there are no outliers from the unimodal group.

Metapodials show a number of interesting patterns (Figure 3.2.10). After the usual average reduction in size through the Holocene, Bronze Age metacarpals show an increase in size on average in comparison to Late Neolithic metacarpals, due to a number of particularly large length measurements in the sample. This suggests that the Late Neolithic sample does not contain any, or very few wild metapodials, whereas the Bronze Age sample has a larger proportion of wild specimens – from Lowe's Farm and Snail Down. The Bronze Age and Early Neolithic samples both contain some very small shaft diameter (SD) measurements, which are clearly the cause of the the odd pattern. Both of these time periods therefore display a very large range for their sample sizes and indicate a large amount of variability in the sample from Eton Rowing Lake. Breadth and depth measurements are reducing at a faster rate than length measurements over time. The larger length measurements in the Durrington Walls sample belong to some of the same bones as the breadth and depth measurements in the smaller group, so this is not a case of wild versus domestic animals. Overall it seems that both climatic change and domestication led to more slender metapodials, as exemplified by the relatively smaller breadth measurements.

Metapodial shaft diameter (SD) measurements have been seen to be more variable throughout this study, but not to the extent seen at Eton Rowing Lake. One other explanation for this pattern could be that the shaft diameter (SD) measurement was being taken slightly differently by different researchers. However the material from Eton was measured by two separate people (Gill Jones recorded the Early Neolithic and Sarah Crump recorded the Bronze Age) on separate occasions using the same protocol (according to von den Driesch, 1976). It is unlikely that they would both take this measurement differently from the author of this project and all of the other studies from which measurements have been used in this work. In addition, the shaft diameter (SD) is not a particularly problematic or ill-defined measurement. A more likely explanation could be that these smaller measurements are a reflection of this particular cattle population, and indicates cattle with particularly slender metapodials.

There are relatively small sample sizes of humerus measurements from most time periods within the Holocene, but it does look like both the trochlea breadth (BT) and trochlea height (HTC) reduce in size over time, and that they reduce at the same rate. The Cherhill sample seems to only contain domestic specimens, and the Early Neolithic sample only wild specimens, whereas there are two larger outlying measurements in the Late Neolithic sample which are likely to be wild. There does not seem to be any clear distinction in the humerus measurements here between male and female animals.

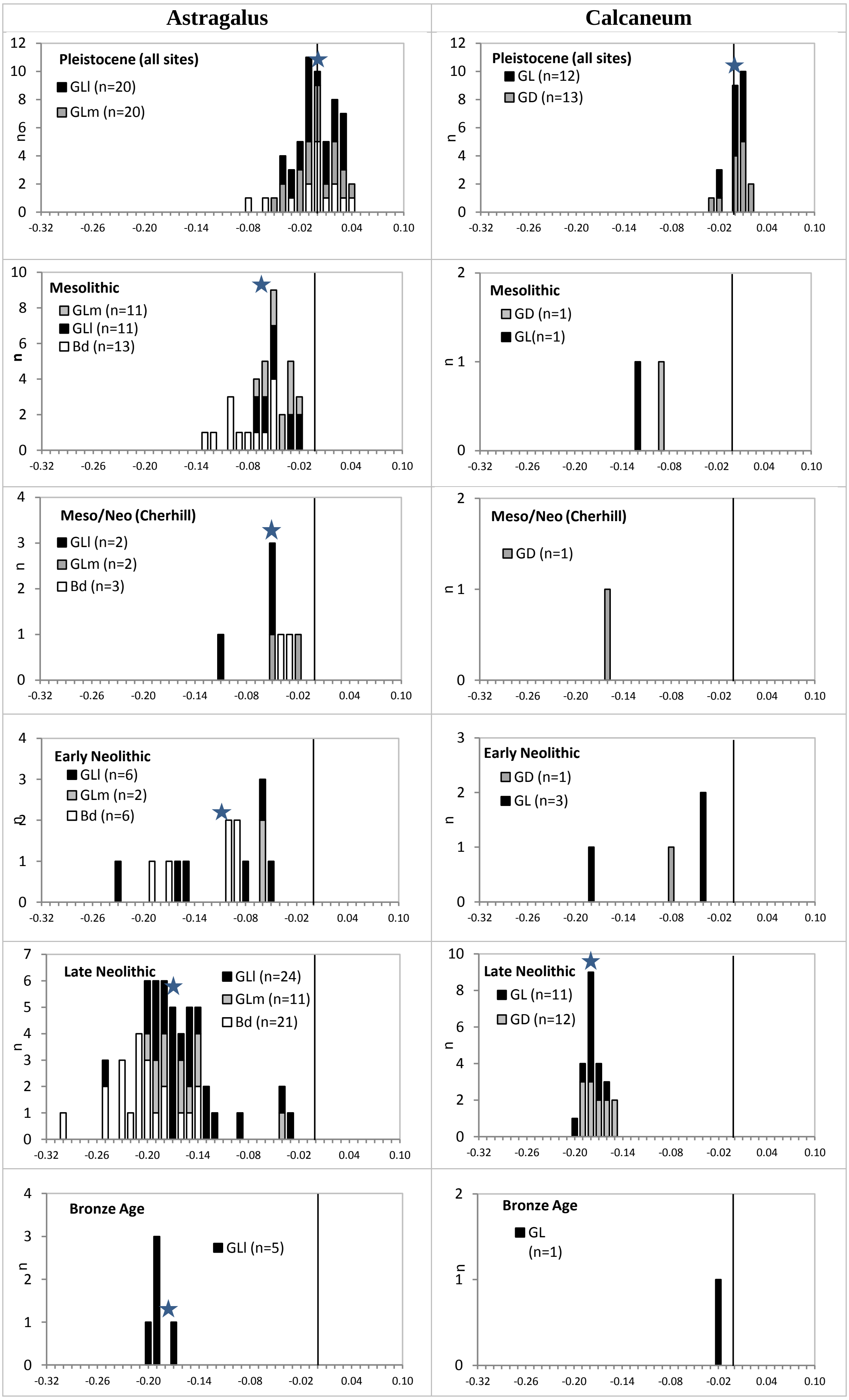


Figure 3.2.8: Log ratios showing individual measurements over time from the astragalus and calcaneum

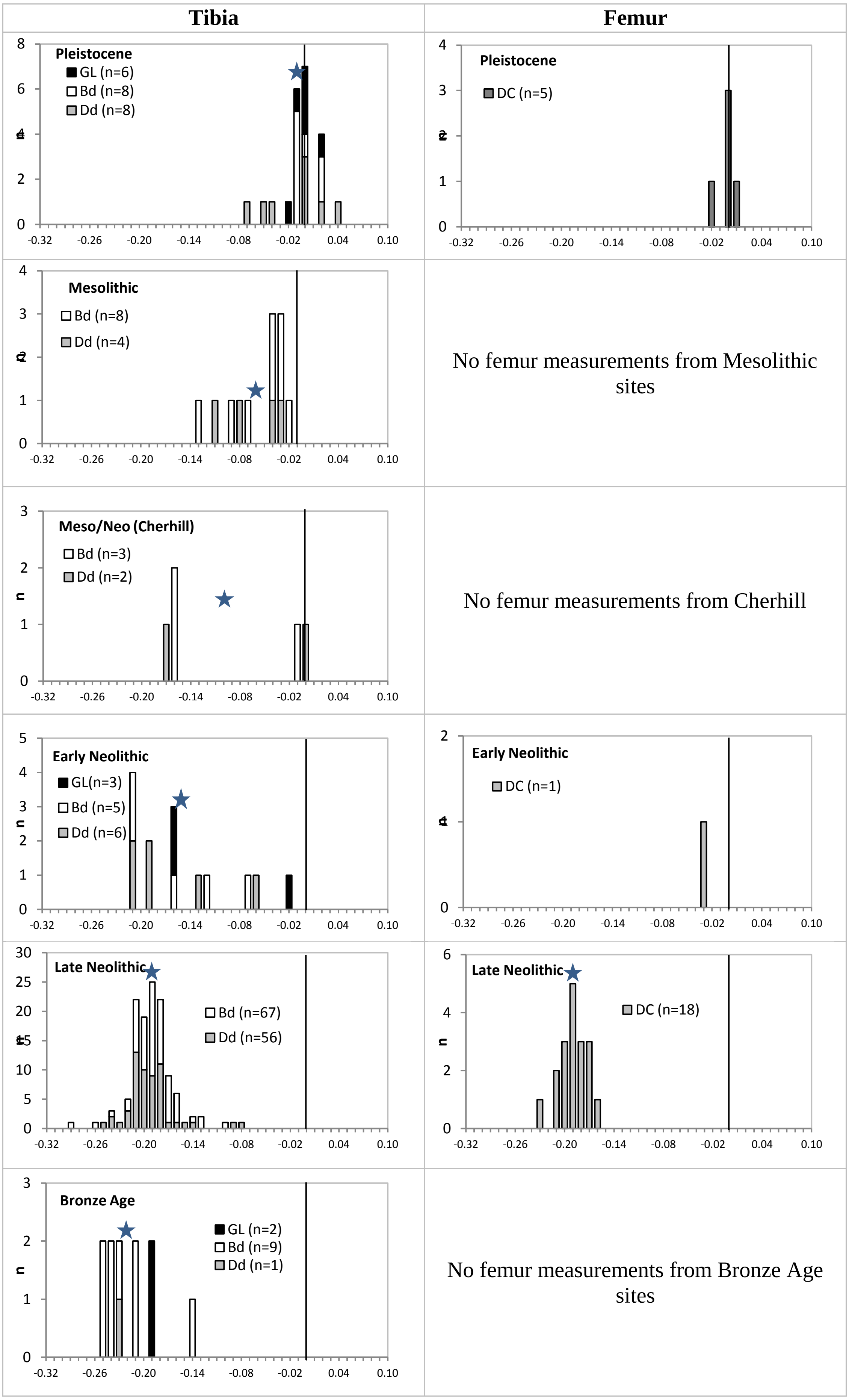


Figure 3.2.9: Log ratios showing individual measurements over time from the tibia and femur.

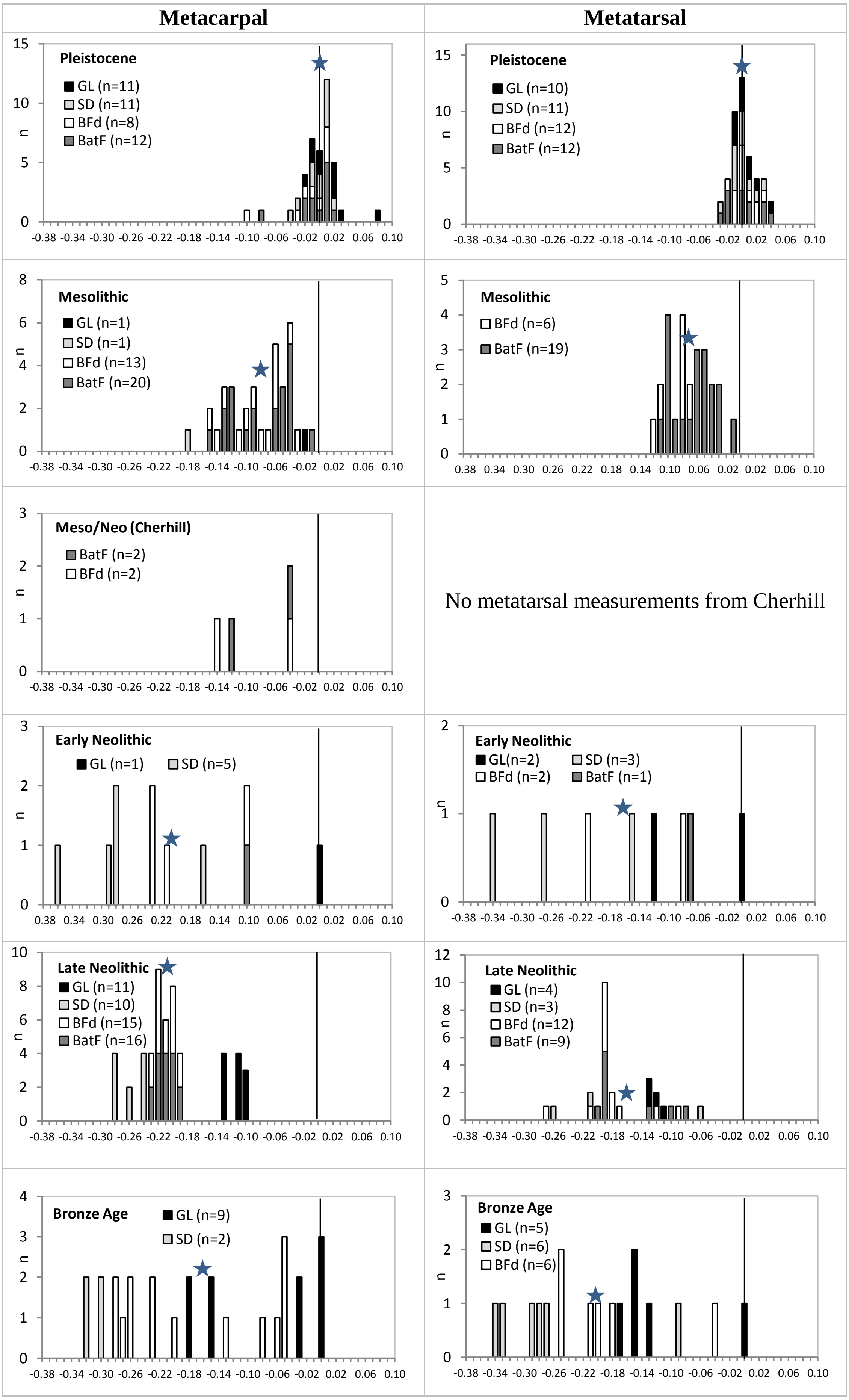


Figure 3.2.10: Log ratios showing individual measurements over time from the metapodials.

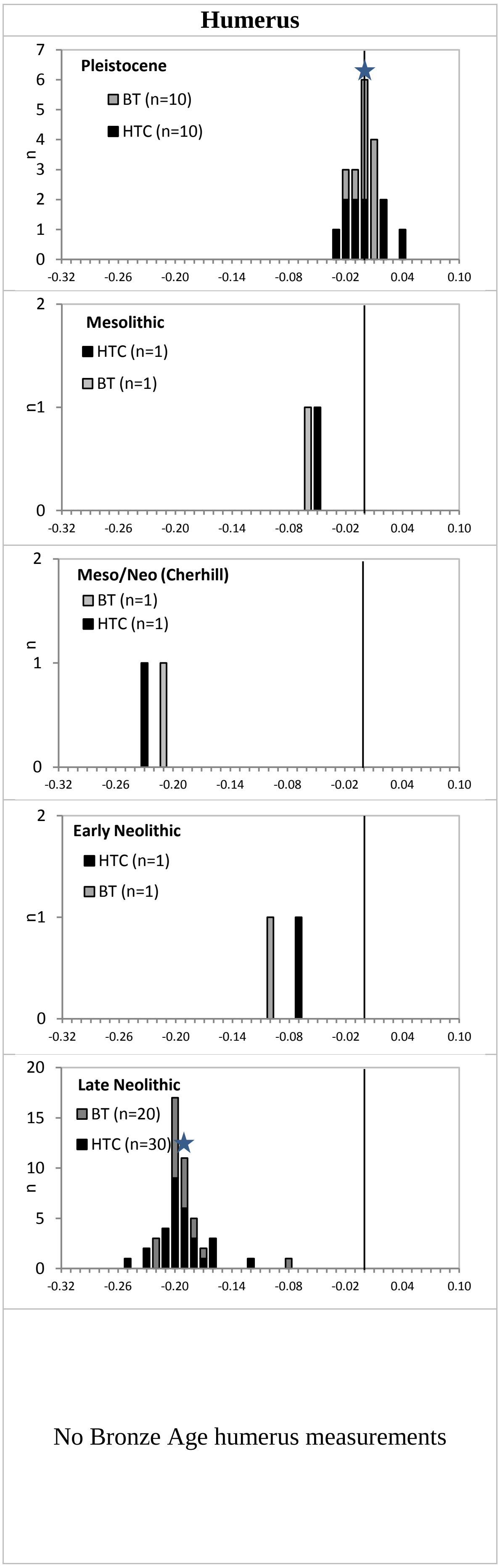


Figure 3.2.11: Log ratios showing individual measurements over time from the humerus.

Overall, both scatterplots and log ratios show a reduction in size of British *Bos* over time, from the Pleistocene to the Holocene, and then within the Holocene itself. A slight reduction is noticeable by the Middle Palaeolithic in metacarpal measurements (despite the average temperature actually dropping), although because of the gap in the dataset, we do not know what happened during the Upper Palaeolithic. The reduction in size within the Holocene seems most likely to be related to domestication. Where there are large cattle measurements in these samples, they do not tend to be smaller than those from the Mesolithic.

Some large metapodial measurements contribute to an increase in the metacarpal mean value in the Bronze Age compared with the Late Neolithic period. This size increase is exaggerated by an increase in the proportion of wild animals in the Bronze Age sample compared to the Late Neolithic sample, rather than an increase in the size of wild animals themselves. Bronze Age metapodial measurements clearly reflect both wild and domestic animals and perhaps it is better if these are dealt with separately. When the pattern is analysed in this way, it actually looks like there is a decrease in the size of Bronze Age domestic animals compared with the Late Neolithic, especially in terms of length measurements. There are clearly no wild animals represented by Late Neolithic metapodial measurements, but the largest Bronze Age measurements are lengths, of which there are few from the Mesolithic and Early Neolithic. There is nothing here to suggest that Mesolithic length measurements would have been smaller than they were on the Bronze Age.

There is no evidence here of any substantial change in the size of the aurochs during the Holocene in Britain. One reason why this can be claimed is that in post-Mesolithic sites it seems generally possible to distinguish the remains of wild and domestic specimens. This may indicate limited intermixing of the two populations, as has already been suggested by Viner (2010).

The very small shaft measurements from both the Early Neolithic and Bronze Age layers at Eton Rowing Lake seem to be best explained by a true pattern in the measurements, rather than a methodological or recording issue. This shows that it is possible to characterise cattle morphotypes through careful analysis of the measurements, but this applies in this case to populations that are likely to be domestic rather than wild. Even in aurochs though, it has been possible to highlight a general tendency towards greater slenderness after the Pleistocene.

3.2.3 British *Bos* and *Sus* results in comparison

Biometrical information from pigs was available from the Mesolithic to Late Neolithic periods. Pig remains become far rarer on Bronze Age sites and so this period has not been included here. All of the data included were recorded by Sarah Viner-Daniels and in the case of Durrington Walls by Umberto Albarella and Sarah Viner-Daniels. Where possible sites were chosen that had also been included in the cattle study; those for which this was possible were Star Carr and Seamer Carr, Goldcliff, Thatcham and Durrington Walls. Sites that were not included in the cattle study are Faraday Road (Mesolithic), Hambledon Hill (Early Neolithic) and Runnymede (Early Neolithic). Hambledon Hill and Runnymede are in fact contemporary in date, even though Runnymede has been published as a Middle Neolithic site (Serjeantson 1991; 2006).

Pig astragalus measurements (Figure 3.2.12) show a slightly different pattern to those of cattle (Figure 3.2.2). Mesolithic pig specimens seem much smaller than you might expect considering that these are from wild animals. The Mesolithic specimens group with the bulk of Neolithic specimens, although they are towards the larger end of this range. This makes it particularly difficult to distinguish the wild and domestic animals in the Neolithic samples. The two very large Late Neolithic specimens are presumably from wild boar, but the rest of the Late Neolithic sample plots towards the smaller end of the range. The large gap between these and the large outliers suggests that the majority of these animals are likely to be domestic. The two large Late Neolithic specimens are far larger than any from the Mesolithic and the Early Neolithic.

Sus tibia measurements also display relatively little change over time (Figure 3.2.13 – top diagram), but the Late Neolithic sample does not contain any large outstanding specimens as it does for the astragalus. All Late Neolithic tibiae plot towards the smaller end of the range, and display less variation than either the Mesolithic or earlier Neolithic samples. The Early Neolithic group has a few larger specimens, which could be indicative of the presence of wild boar.

Pig humeri (Figure 3.2.13 – bottom diagram) do not show much change over time either. Mesolithic specimens overlap completely with those from the Neolithic. Similarly to both the astragalus and tibia the Late Neolithic group plots towards the smaller end of the range. The largest specimens are from the Early Neolithic, and this groups displayed the greatest variation of all three samples. As for cattle, there is little indication of male and female groups.

Pig astragalus, tibia and humerus scatterplots show quite a different pattern to the equivalents for cattle, in that it is hard to distinguish much change over time in pigs, beyond the fact that the bulk of Late Neolithic specimens consistently plot to the smaller end of the range. Mesolithic cattle overlap to a lesser extent than Mesolithic pigs with the Neolithic samples, and there is evidence for the presence of large cattle which can be identified as wild with more certainty than the pig bones. This pattern is also very different to that seen in similar periods in Denmark (see the previous Section 3.1).

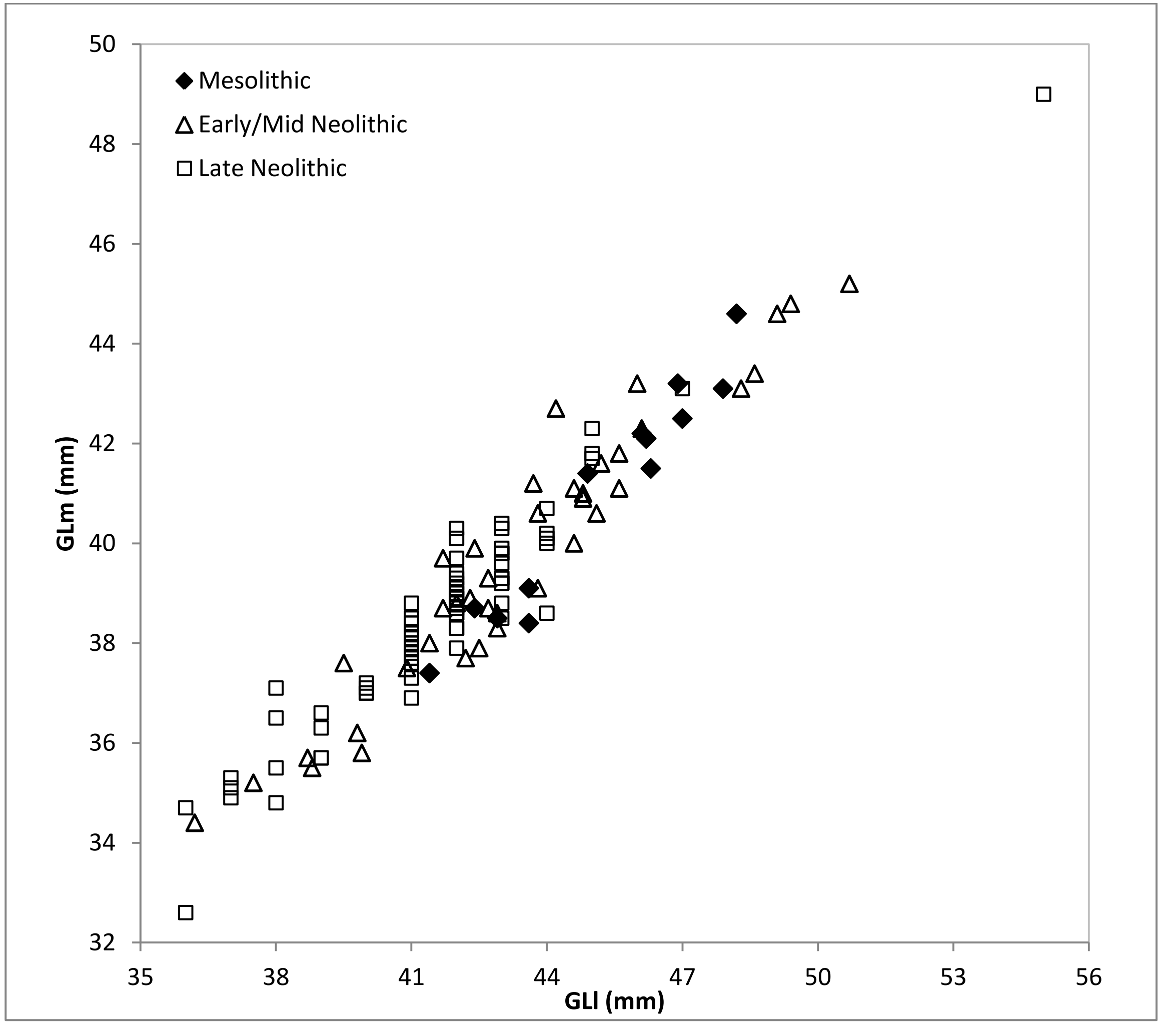


Figure 3.2.12: Scatterplot showing British *Sus* astragalus measurements over time. GLl=Greateast length of the lateral half; GLm= Greatest length of the medial half.

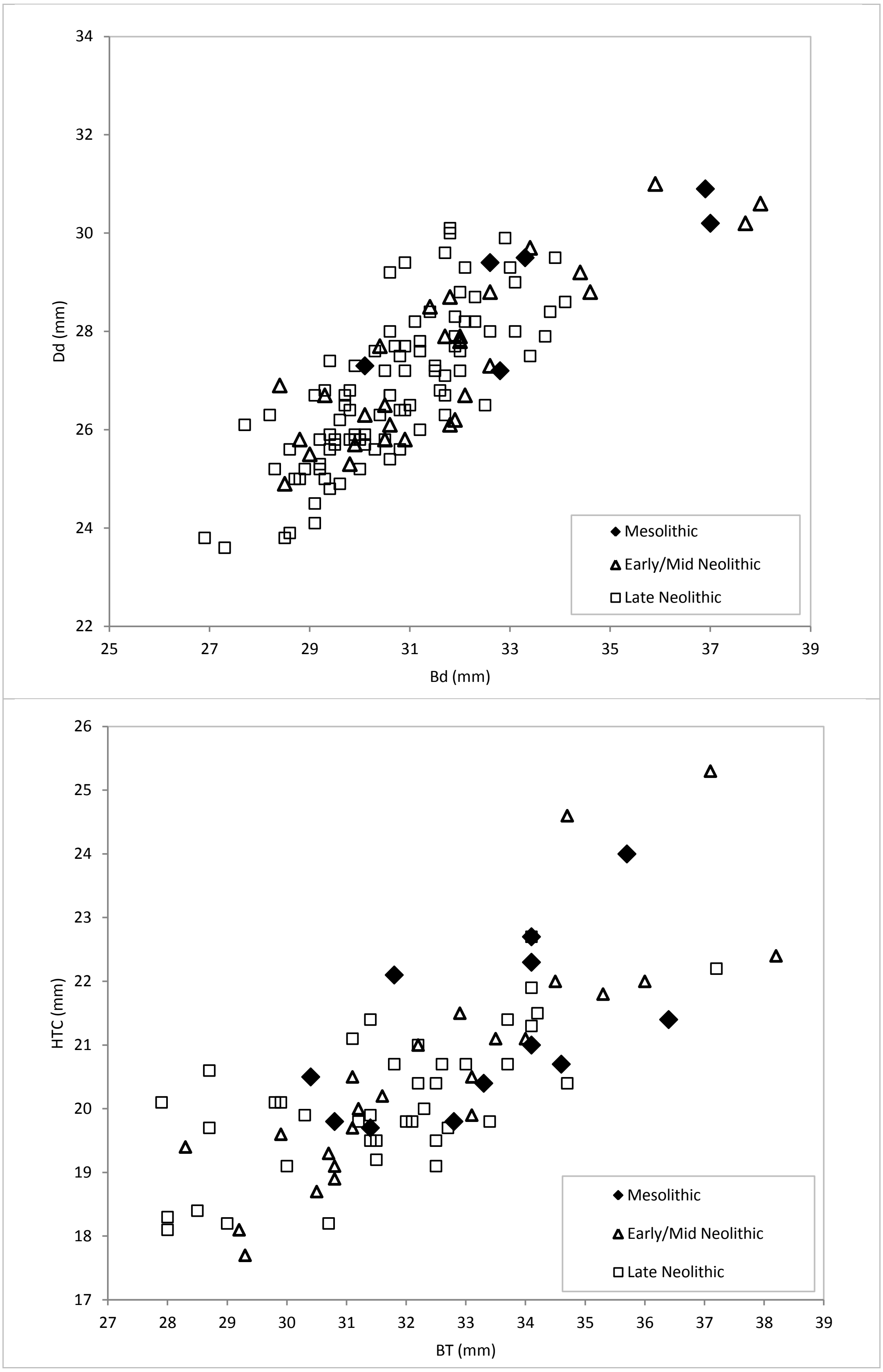


Figure 3.2.13: Scatterplot showing British *Sus* tibia (top diagram) and humerus (bottom diagram) measurements over time. Bd=Distal breadth; Dd=Distal depth. BT=breadth of the troclea; HTC=height of the trochlea.

Measurements from the third molar are often used to try and distinguish wild from domestic animals (e.g. Ervynck *et al.* 2001; Dobney *et al*. 2007; Rowley-Conwy and Dobney 2007) Large enough tooth sample sizes seem to be rare in the cattle assemblages included in this study, but they are available for British pigs.

The scatterplot of third molar measurements shows a slightly clearer pattern of change over time (Figure 3.2.14). Overall Mesolithic specimens provide the larger measurements, and they overlap far less with Neolithic specimens than they did in the postcranial samples. Early Neolithic specimens still show some overlap with the Mesolithic specimens, but mostly plot to the smaller part of the diagram. There is still some overlap of the Late Neolithic group with earlier groups, but most of these specimens plot to the bottom left of the range. Both the Early and Late Neolithic samples contain a few quite large specimens which could be from wild boar.

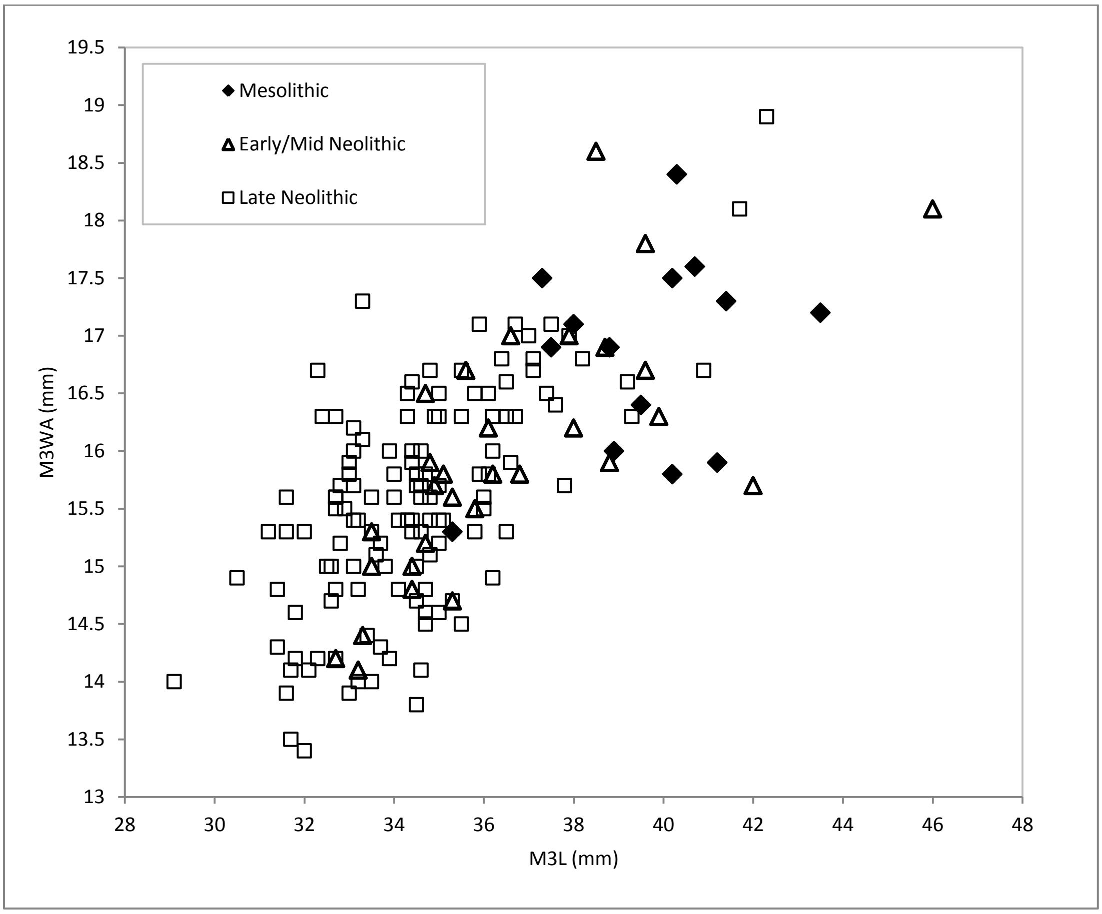


Figure 3.2.14: Scatterplot showing British *Sus* 3rd mandibular molar measurements over time. M3L=greastest length of the 3rd molar; M3WA= width of the anterior cusp of the 3rd molar.

Of all of the pig scatterplots, tooth measurements most resemble the pattern seen in the cattle scatterplots, although the cattle scatterplots are consistently more stretched out and clearer groups can be distinguished.

Log ratio diagrams for postcranial remains confirm the small size of the British Mesolithic pig postcranial remains, which have an identical mean to the Early Neolithic sample (Figure 3.2.15). A larger overall decrease in size is actually seen between the Early and Late Neolithic periods, rather than between the Mesolithic and Neolithic samples. These diagrams also highlight the presence of a few large outliers in both the Early and Late Neolithic periods, suggesting the presence of wild boar during these periods, though the species was probably quite rare, or at least rarely hunted. Some of these large Neolithic specimens are much larger than any of those from the Mesolithic group. Interestingly, despite the similarity between the Mesolithic and Early Neolithic samples, when tested statistically the difference is highly significant (Table 3.2.3).

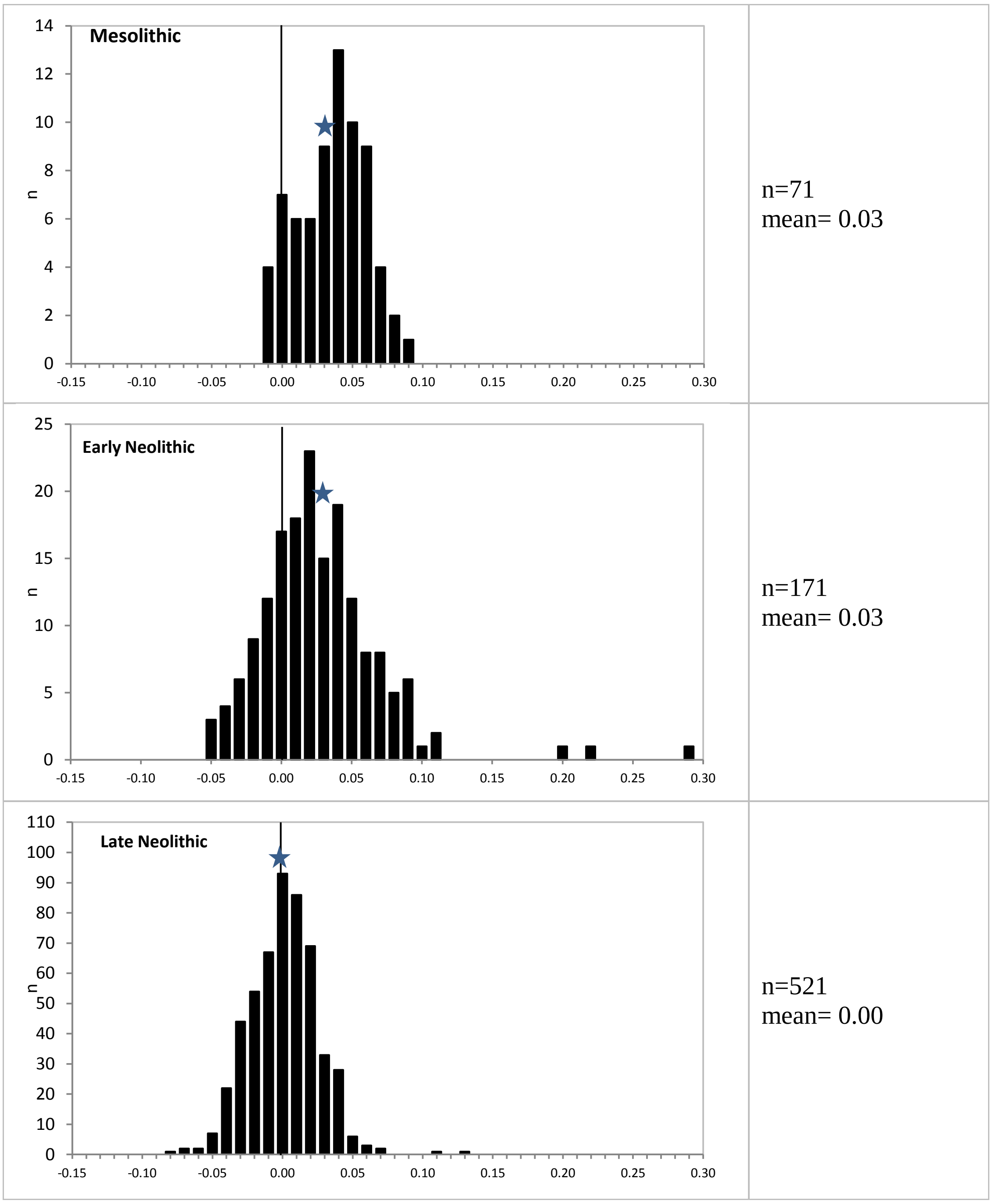


Figure 3.2.15: Log ratios showing British *Sus* postcranial remains over time (the standard population is from Durrington Walls – Albarella and Payne 2005)

Log ratios displaying mandibular third molar measurements (Figure 3.2.16) confirm the pattern seen on the scatterplot (Figure 3.2.14). The Mesolithic third molar sample has a larger mean than both the Early and Late Neolithic samples, and resembles the Mesolithic cattle postcranial sample (see Figure 3.2.5) more than the pig postcranial Mesolithic sample.

Late Neolithic third molar measurements show an overall similarity with the Early Neolithic sample, the mean reduces only very slightly in comparison with the change between Mesolithic and Early Neolithic, and when tested statistically the different is not significant (Table 3.2.4). Both Early and Late Neolithic samples have a few particularly large specimens, but they are not so well separated from the main sample as the postcranial measurements are. This makes it more difficult to distinguish exactly which measurements are from wild boar, but it does seem likely that there are some present in both of these samples. Most interesting is the few especially large Neolithic measurements which exceed any from the Mesolithic sample.

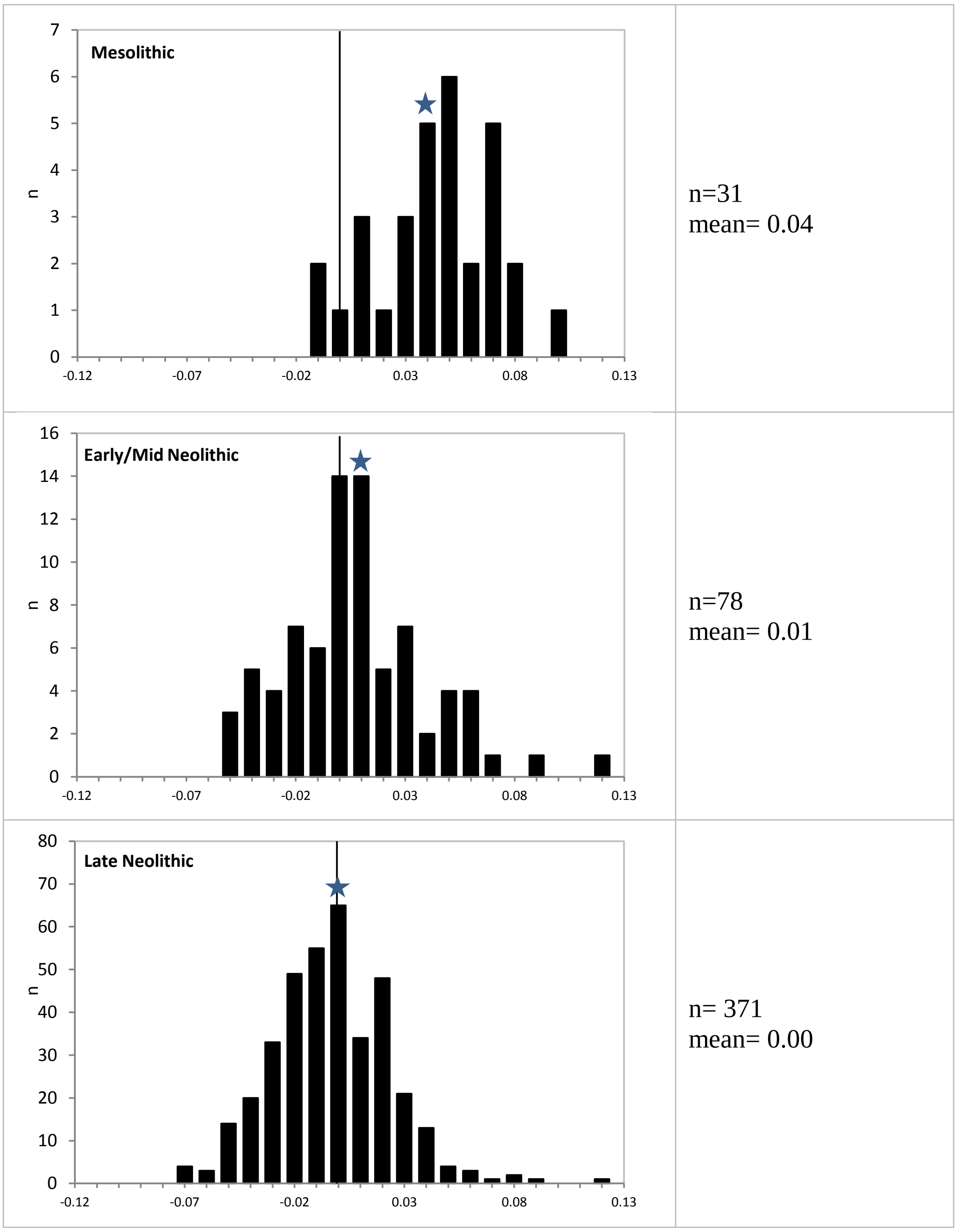


Figure 3.2.16: Log ratios showing British *Sus* mandibular M3 measurements over time. Measurements included are M3L= length of 3rd Molar and M3WA=width of 3rd molar anterior cusp.

This pattern in pig biometry is different to what we have seen in both the cattle and pigs so far in this study. These results contrast with the pig results from Denmark, where Mesolithic postcranial remains show large measurements compared to those from the Neolithic. Here it is only in the third molar measurements that a clear overall larger size can be found in the Mesolithic assemblage.

This greater change in the size of British pig teeth, in comparison to postcranial remains has previously been interpreted as evidence against the idea of local domestication in British pigs (Viner 2010). The domestication of local wild boar is more likely to bring about a more rapid reduction in postcranial bones, which are more plastic than teeth, and therefore this pattern is indicative that Neolithic domestic pigs were more likely to have been introduced from an external source.

British pigs and cattle show rather different biometrical patterns. Cattle postcranial remains display a much more noticeable change in size between the Mesolithic and Neolithic periods (Figure 3.2.5). Unfortunately there were not enough cattle teeth to be able to compare the postcranial and tooth patterns, and an interpretation therefore cannot be made on this basis. Cattle postcranial remains show a relatively abrupt reduction in size over time, with the immediate appearance of smaller animals during the Early Neolithic. This is the same pattern noticed by Viner (2010) and can be considered evidence for the introduction of domestic cattle rather than local domestication in Britain.

Neither the cattle nor pig results provide evidence of a clear increase in body size of the wild form after 3000 cal BC in Britain. The analysis of pig remains has highlighted a few particularly large wild boar specimens in both the postcranial and tooth remains during the Neolithic period, but these are present in both the Early and the Late Neolithic samples. Postcranial bones actually show a reduction in size of the largest animals between the Early and Late Neolithic. It is interesting that the largest specimens in both the postcranial and tooth samples are from the Early Neolithic as opposed to the Mesolithic. This could partly be a result of sample size, although the Mesolithic samples are not particularly small, especially compared to some of the samples we have for cattle. The size change is unlikely to be related to climatic change, because the climatic deterioration does not start until 3000 cal BC, and these specimens are dated to around 3500 cal BC. An alternative explanation is that it was caused by a relaxation in hunting pressure after the Mesolithic. This explanation has been used for a post-Mesolithic increase in size in Portuguese Red Deer (Davis 2006). The dominance of domestic pigs in the Early Neolithic samples supports the idea that there was a relatively abrupt switch from the use of predominantly wild animals to the use of predominantly domestic animals after the Mesolithic in Britain, and therefore there could have been a massive sudden release of pressure on the wild population.

The particularly large Early Neolithic postcranial remains plot quite distinctly from the rest of the *Sus* group, and there are no others that might confidently be identified as wild boar. This might suggest a system where wild and domestic animals were kept separately from each other, with very little interbreeding. Postcranial cattle remains do not show such a clear pattern as the *Sus* remains when all postcranial remains are combined on log ratios, but can be split relatively easily on the basis of certain bones displayed on scatterplots, and by length measurements on log ratio diagrams.

Both cattle and pig results suggest a relatively abrupt change from the use of wild to domestic animals during the British Neolithic period, through a swift change in size to smaller animals and the separation of wild and domestic groups. Although there is some overlap, the use of specific measurements allows for an easier separation of these groups within the cattle remains. Overall this evidence suggests incoming populations of both cattle and pigs during the British Neolithic, and no real evidence for local domestication. After domestication the size of domestic cattle decreases quite obviously, whereas pigs do not to the same degree. There is no evidence of larger wild cattle during the Neolithic than during the Mesolithic, and therefore no sign that climatic deterioration, or a release in hunting pressure, during the Holocene, had an impact on the size of wild cattle in Britain.

Table 3.2.1: Summary statistics for archaeological *Bos* from Britain. Only archaeological material was included Samples of less than 5 were excluded.

Measurement	No.	Min	Max	Mean	Standard deviation	Coefficient of variation
Astragalus GLl						
Grays Thurrock	12	86.6	102.7	94.86	5.85	6.17
Ilford	10	88.3	102.3	95.15	4.50	4.73
Mesolithic	11	81.4	91.1	85.79	3.49	4.07
Late Neolithic	24	54	88	67.08	7.96	11.86
Bronze Age	5	60	65	61.92	1.87	3.02
Astragalus GLm						
Grays Thurrock	10	78.3	94.3	86.58	5.61	6.48
Ilford	9	80.4	95.7	87.33	4.65	5.32
Mesolithic	11	74.6	83	79.34	2.79	3.52
Late Neolithic	21	55.7	79.2	61.15	6.57	10.75
Astragalus Bd						
Grays Thurrock	8	55.6	72.5	65.74	5.89	8.97
Ilford	6	62.2	71.1	66.70	2.83	4.24
Mesolithic	13	50	60.1	55.59	3.45	6.21
Late Neolithic	11	33.8	48	41.81	3.59	8.58
Tibia Bd						
Ilford	7	88.6	96.7	91.60	3.38	3.69
Mesolithic	8	68.2	87.4	80.9	6.84	8.45
Late Neolithic	67	47.0	73.2	59.6	3.78	6.33
Bronze Age	8	51.0	67.0	55.3	5.13	9.28
Tibia Dd						
Ilford	6	58.4	76.6	69.23	5.99	8.65
Late Neolithic	56	38.8	57.5	44.51	3.23	7.25
Calcaneum GL						
Ilford	9	184	201	194.67	5.79	2.97
Late Neolithic	11	124	134	129.36	2.66	2.05
Calcanuem GD						
Ilford	9	71.3	78.7	75.83	2.61	3.44
Late Neolithic	12	48.8	53.7	50.91	1.67	3.29
Femur DC						
Ilford	5	63.9	68.9	66.96	1.86	2.78
Late Neolithic	18	39.4	46.4	43.63	1.65	3.78
Metacarpal BFd						
Ilford	5	86.4	95.3	92.76	3.68	3.97
Mesolithic	13	66.1	86.2	76.74	6.53	8.50

Late Neolithic	15	55	59.4	57.13	1.70	2.98
Bronze Age	12	48.4	82	60.40	13.03	21.57
Metatarsal BFd						
Ilford	11	78.3	87.3	82.59	2.66	3.22
Mesolithic	6	62.7	70.5	67.12	3.23	4.81
Late Neolithic	13	44.3	68	55.78	6.53	11.70
Bronze Age	5	46.5	54.6	50.24	3.50	6.97
Humerus BT						
Ilford	10	109.6	118.4	115.26	2.59	2.24
Late Neolithic	20	68.9	95.1	74.20	5.41	7.29
Humerus HTC						
Ilford	10	47.4	55.4	50.42	2.54	5.04
Late Neolithic	30	28.5	37.9	32.36	1.76	5.45

Table 3.2.2: Results of the Mann-Whitney tests on *Bos* postcranial Log Ratios from Britain. Significant results (<0.05) are marked with an * and highly significant results (<0.01) are marked with **. Only archaeological material has been included in the statistical analyses. Samples of less than 20 were excluded.

Group	**n.**	**Group**	**n.**	**U**	**z**	**Sig.**
All Pleistocene	78	Mesolithic	63	137.0	-9.62	0.000**
All Pleistocene	78	Late Neolithic	168	12.0	-12.64	0.000**
All Pleistocene	78	Bronze Age	30	3.0	-8.01	0.000**
Mesolithic	63	Late Neolithic	168	201.0	-11.30	0.000**
Mesolithic	63	Bronze Age	30	91.0	-7.02	0.000**
Late Neolithic	168	Bronze Age	30	1543.0	-3.40	0.001**

Table 3.2.3: Results of the Mann-Whitney tests on *Sus* postcranial Log Ratios from Britain. Significant results (<0.05) are marked with an * and highly significant results (<0.01) are marked with **. Only archaeological material has been included in the statistical analyses. Samples of less than 20 were excluded.

Group	**n.**	**Group**	**n.**	**U**	**z**	**Sig.**
Mesolithic	39	Early Neolithic	123	1697.5	-2.768	0.006**
Mesolithic	39	Late Neolithic	362	2093.5	-7.233	0.000**
Early Neolithic	123	Late Neolithic	358	13719.0	-6.281	0.000**

Table 3.2.4: Results of the Mann-Whitney tests on *Sus* tooth (M3 – breadth measurements) Log Ratios from Britain. Significant results (<0.05) are marked with an * and highly significant results (<0.01) are marked with **. Only archaeological material has been included in the statistical analyses. Samples of less than 20 were excluded.

Group	n.	Group	n.	U	z	Sig.
Early Neolithic	47	Late Neolithic	229	5113.5	-0.542	0.588

3.3 Germany & Poland

This section deals with data from Germany (excluding the area covering modern day Schleswig-Holstein, which is included with Denmark and Sweden in Section 3.1) and Poland. For Germany data are available from the Mesolithic to the Medieval period, and for Poland from the Early Neolithic until the Medieval period. All of the data included from both of these areas were recorded by others. Most were taken from published reports, but some are unpublished data, which were kindly made available by those who recorded them. The sources for all of the data included can be found in Chapter 2. An analysis of the pig data has not been included here, as in-depth analyses of pig and wild boar in the same vein as those completed in Denmark, Spain, Britain and Italy have not previously been completed, and it would have been a project in itself to compile a suitable dataset for comparison with the cattle.

Data have been grouped broadly according to archaeological period, but also taking into account the time periods covered by the data that were available, and also the period of climatic deterioration after 3000 cal BC. These groups are displayed in Table 3.3.1.

Table 3.3.1: The broad chronological groups used for the analysis of the German and Polish data.

Group	Cultures included	Broad dating
Mesolithic		c10000-7000 cal BC
Early Neolithic (pre-3000 cal BC)	Linearbandkeramik (LBK/KCWR), Rössen culture, Stroked Pottery culture (SBK/KCWK), Funnelbeaker culture (TBK/KPC)	c5500-3000 cal BC
Late Neolithic (post-3000cal BC)	Corded Ware culture	c3000-2000 cal BC
Late Bronze/Early Iron Age	Halstatt	c1200-600 cal BC
Roman period		c0-500 AD
Medieval period		7th-16th centuries AD

German Mesolithic data are from the sites of Bedburg-Königshoven and Hohen Viecheln, which are relatively early in date, resulting in a substantial chronological gap between the material included in this group and that of the Early Neolithic group, which contains material from sites attributed to a number of different cultures, the earliest of these being the Linearbandkeramik. German Early Neolithic sites included are Künzig-Unternberg, Meindling, Straubing-Lerchenhaid, Schernau, Bruschal-Scheelkopf, Ehrenstein and Hüde I. Polish Early Neolithic data are from Żuławka Mała, Grabie, Bochien, Bozejewice, Łojewo and Gniechowice. German Late Neolithic data are from Griesstetten and Riekofen. There are no Polish data from the Late Neolithic period included here.

There are also gaps in the dataset for the Bronze and Iron Ages. Sites included in this group date to the Late Bronze and Early Iron Age - the material included here is from phases attributed to the Halstatt culture in both Germany (Dresden-Coschütz) and Poland (Bruszczewo) and the Lusatian culture in Poland (Leki Majatek).

The sample used here for Medieval Germany is biased by the fact that only measurements from animals previously identified as wild were available from the site of Hanfwerder. Domestic cattle measurements were not available from this site. The wild specimens were presented anyway, because the other site from this period – Weinburg – contained only domestic cattle, and this was a way of presenting at least some data from wild animals. Polish Medieval data are included from Łęki Majątek, Chmielno, Bytom Odrzański, Ujście and Bialogard.

In the same way as for the analysis of most material in this project, all *Bos* specimens, whether they had previously been identified as 'wild' or 'domestic', are included on every graph and appear as one '*Bos*' group. This means that there are no preconceptions about individual specimens which may affect the interpretation of the data, but it does mean that domestication must be taken into account as a possible factor affecting size and shape change. After initial analysis the original identifications may then be referred to in discussions of the interpretation of the graphs.

3.3.2 Ageing

All of the German and Polish data included in this project were recorded by others and raw ageing data are very rarely presented in zooarchaeological reports. In addition, the majority of German and Polish projects use a different methodology for the recording of toothwear, than was used in this project (usually after Müller 1973, and other variations on this system). As a result of all of these issues, no ageing analysis has been undertaken here. Nevertheless it is still worth bearing in mind the effects that the presence of animals of different ages can have on an assemblage, and on the biometrical data that can be gained from it. As for all of the datasets included in this project, and indeed in most biometrical projects, there were relatively few femur and calcaneum measurements available from the German and Polish datasets, these being the last bones to fuse.

3.3.3 Biometry

Summary statistics for Germany (Table 3.3.2) indicate wide ranges in all most time periods (except for the Mesolithic period), suggesting that both domestic and wild cattle are present in most post-Mesolithic samples. There is a general reduction in the mean over time in most measuremenst (with the exception of metapodial breadths) until the Medieval period, when the mean increases, suggesting that there are are larger proportion of larger specimens during this period. Polish summary statistics (Table 3.3.3) indicate a very similar pattern. In order to explore how each of these populations is made up, it is necessary to present the data using scatterplots and log ratio histograms.

Although there was a relatively large amount of data from this geographical area, in comparison to some of the other areas included in this project, the specific measurements published in the literature were often not the most suitable for producing the most useful scatterplots. Often one measurement from a bone might be given, but nothing to plot it against. As a result it was only possible to produce scatterplots of astragalus measurements.

The German results are split between two scatterplots in order to more clearly see all of the different time periods (Figures 3.3.1 and 3.3.2). The Mesolithic sample was, as has often been the case in this study, relatively small. Nevertheless these specimens plot towards the top end of the diagram. The Early Neolithic group shows a fair deal of variation, with some specimens as large as those from the Mesolithic, and some which are much smaller. The Early Neolithic group spreads across a large part of the diagram on both scatterplots, and there is no clear separation of this material into two groups which could be attributed to wild and domestic animals. This is in contrast to the Late Neolithic pattern, which hints at a clearer split into two groups. Just a few specimens in this group are (almost) as large as the Mesolithic specimens, and the majority plot away from these. It is most likely that these few particularly large specimens are from wild animals, but it may be too simplistic to identify all other Late Neolithic specimens as domestic. There is a group of intermediate sized astragali in this group (more obvious according to length measurements), which display some separation from the smallest specimens from this time period. It is possible that this group may also contain some wild (possibly female) aurochsen, but this cannot be confidently determined. Overall, it is especially difficult to split wild and domestic animals from the Neolithic period in Germany. There is also no evidence of an aurochs size increase coinciding with the time of the climatic deterioration at around 3000 cal BC during the Neolithic in Germany.

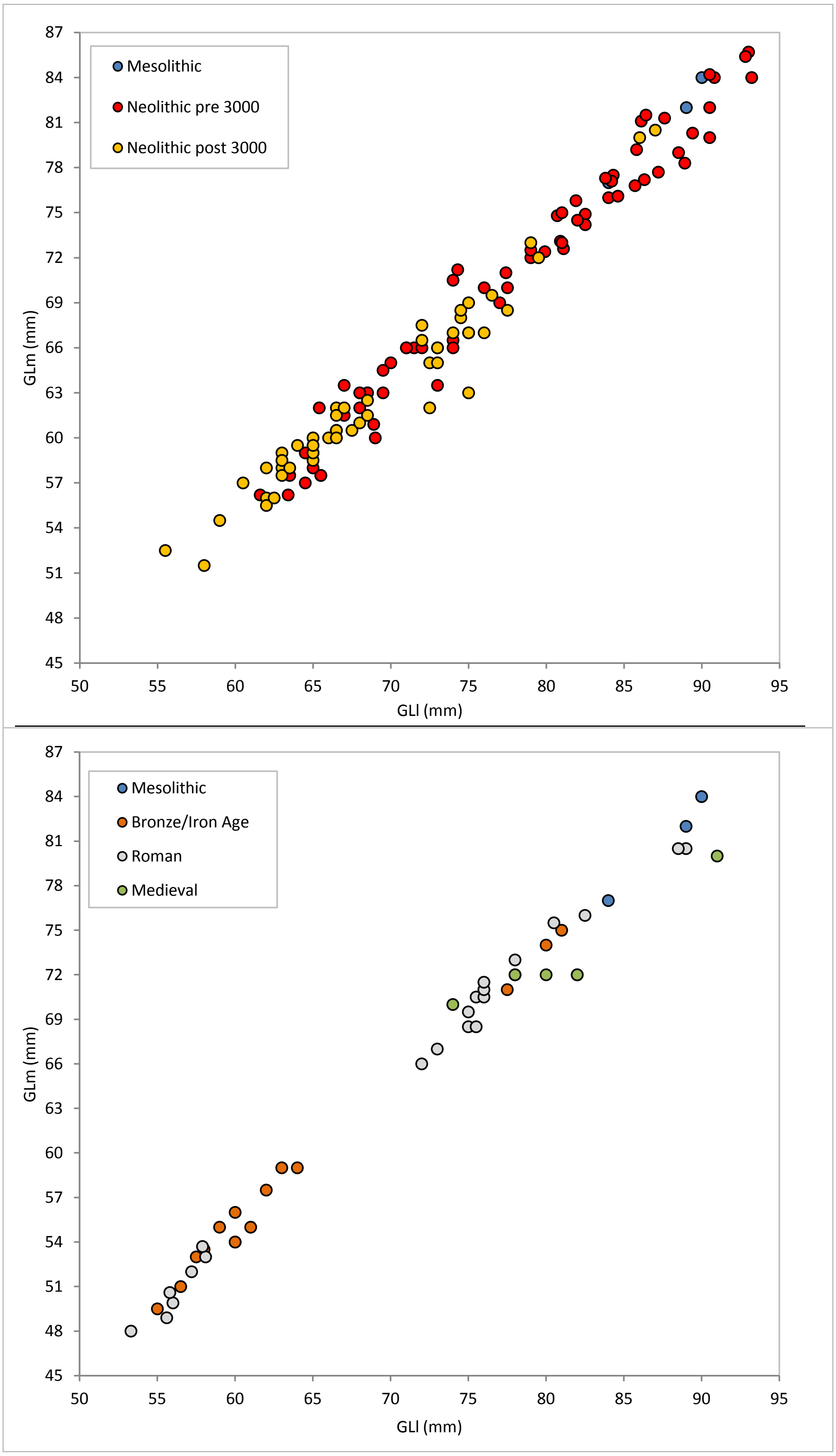


Figure 3.3.1: Scatterplots of astragalus length measurements from Germany over time. The top diagram shows Mesolithic and Neolithic specimens and the bottom diagram shows Mesolithic, Bronze/Iron, Roman and Medieval specimens. GLl=greatest length of the lateral half, GLm=greatest length of the medial half.

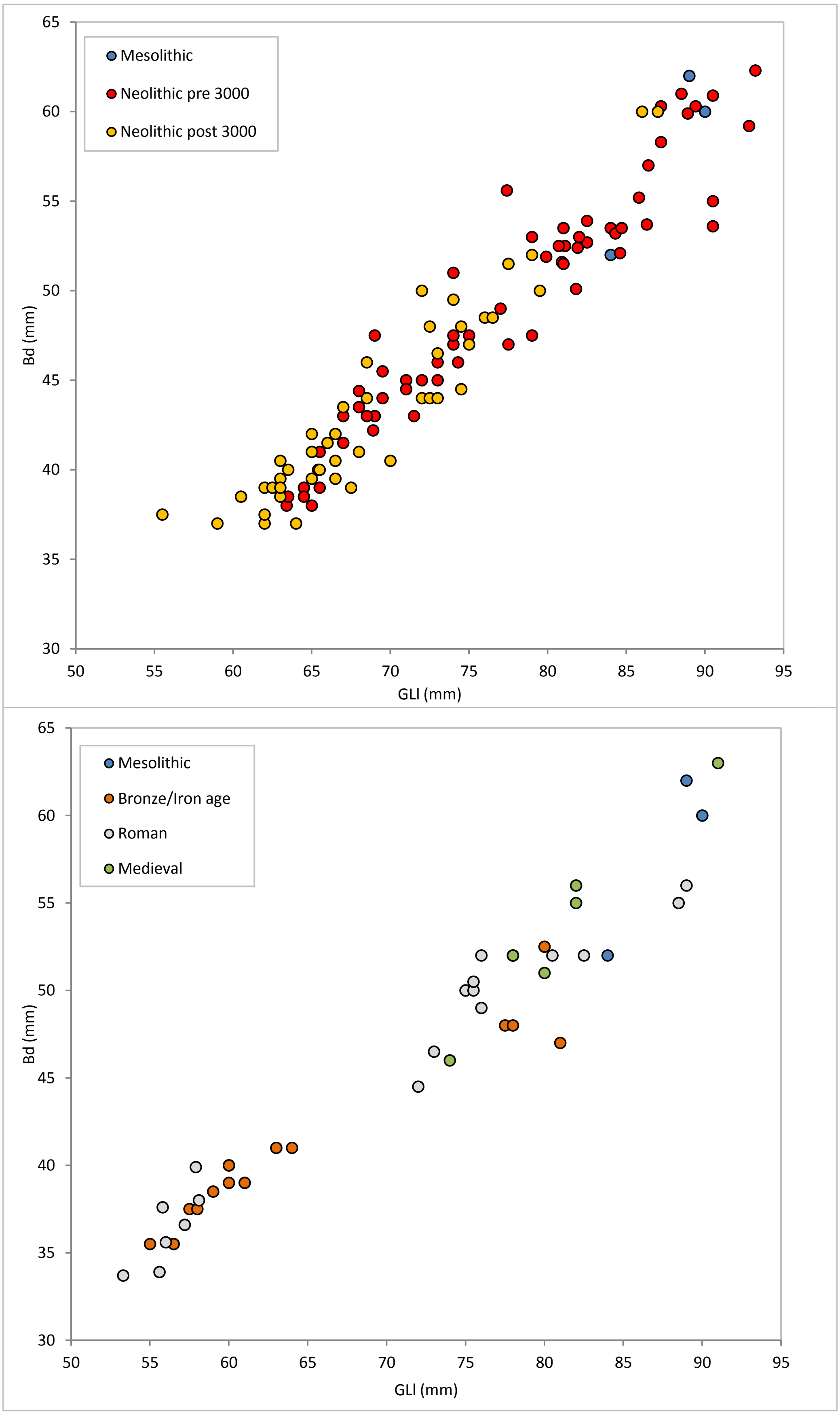


Figure 3.3.2: Scatterplots showing astragalus length and breadth measurements from Germany over time. The top diagram shows Mesolithic and Neolithic specimens and the bottom diagram shows Mesolithic, Bronze/Iron, Roman and Medieval specimens. GLl=greatest length of the lateral half, Bd=distal breadth.

From the Late Bronze Age onwards astragali split into clearer groups, which are likely to represent wild and domestic animals. The lower end of the potential wild group falls in an almost identical place to the lower end of the Late Neolithic intermediate sized group. This gives some support to the idea that the Late Neolithic intermediate sized group may be representing wild animals.

An alternative possibility is that the group representing larger animals from the later time periods could contain some larger domestic cattle from improved breeds that were introduced during the Roman period. The larger variation of the Roman and Medieval datasets in comparison to the Bronze Age group lends support to this idea. However, the location of the sites from which most of these specimens originate (Genshagen and Deutsch Wusterhausen are near Berlin, Egglosheim is in eastern Germany in a similar area to Neuremburg) is outside of the extent of the Roman Empire. Rottweil is the only site that was within the area included in the Empire. There are just two astragali from this site on the scatterplot, and these are the two largest, and most confidently wild specimens. Considering these factors, we can have more confidence in assigning the Bronze/Iron Age specimens here to wild and domestic groups than we can for the Roman and Medieval periods.

There were no specimens from the Mesolithic or Late Neolithic periods available from Poland, so there are further chronological gaps affecting patterns of change over time. The Early Neolithic group shows a spread of measurements that are not distinguishable into two groups. There is just one very small specimen in this group, which is likely to come from a domestic animal. The overall pattern is therefore similar to that seen in Germany for this period.

As for Germany, Bronze and Iron Age specimens plot into two clear groups, with some of those in the upper group being particularly large, though comparable with the German Mesolithic specimens. The Roman Age sample size is much smaller for Poland than for Germany and there is only one relatively large specimen, which could be wild. Unlike in the German dataset there are no intermediate sized Roman specimens in Poland. The area now covered by Poland was well outside the extent of the Roman Empire and perhaps was characterised be an indigenous, small and unimproved type of domestic cattle. Medieval specimens are also more easily separated into two groups than in Germany as the potential wild specimens from this period in Poland are particularly large.

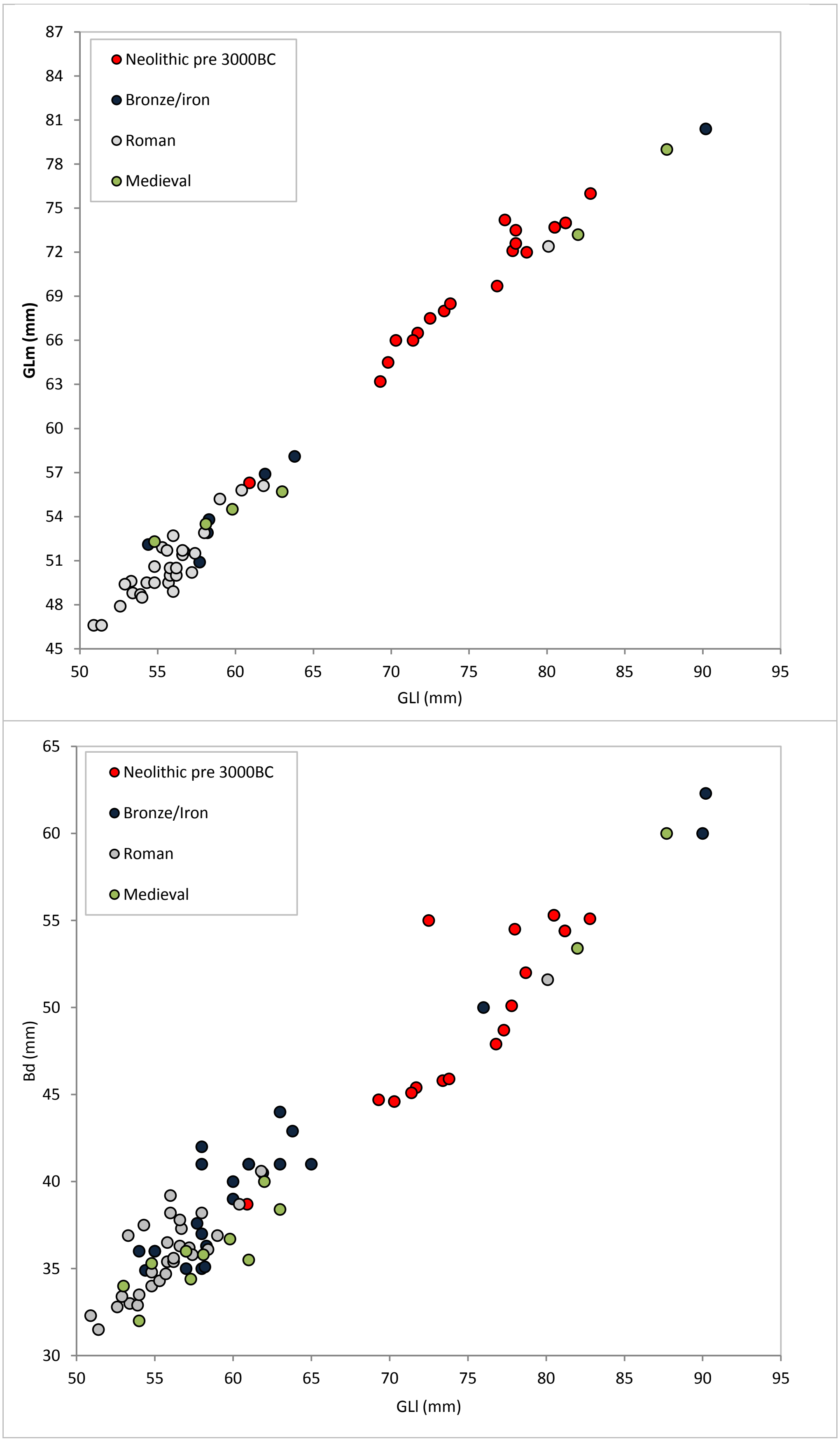


Figure 3.3.3: Scatterplots showing astragalus measurements from Poland over time. The top diagram shows length measurements, and the bottom diagram length vs depth measurements. GLl = greatest length of the lateral half, GLm = greatest length of the medial half, Bd= distal breadth.

The Early Neolithic groups were most suitable to compare between areas, as this group had the largest sample size (Figure 3.3.4). The German sample extends beyond the majority of Polish specimens in both directions, but the presence of one quite small Polish specimen shows the potential of the Polish dataset to extend as far as the German one, and therefore suggests that the difference between them is likely to be a result of sample size.

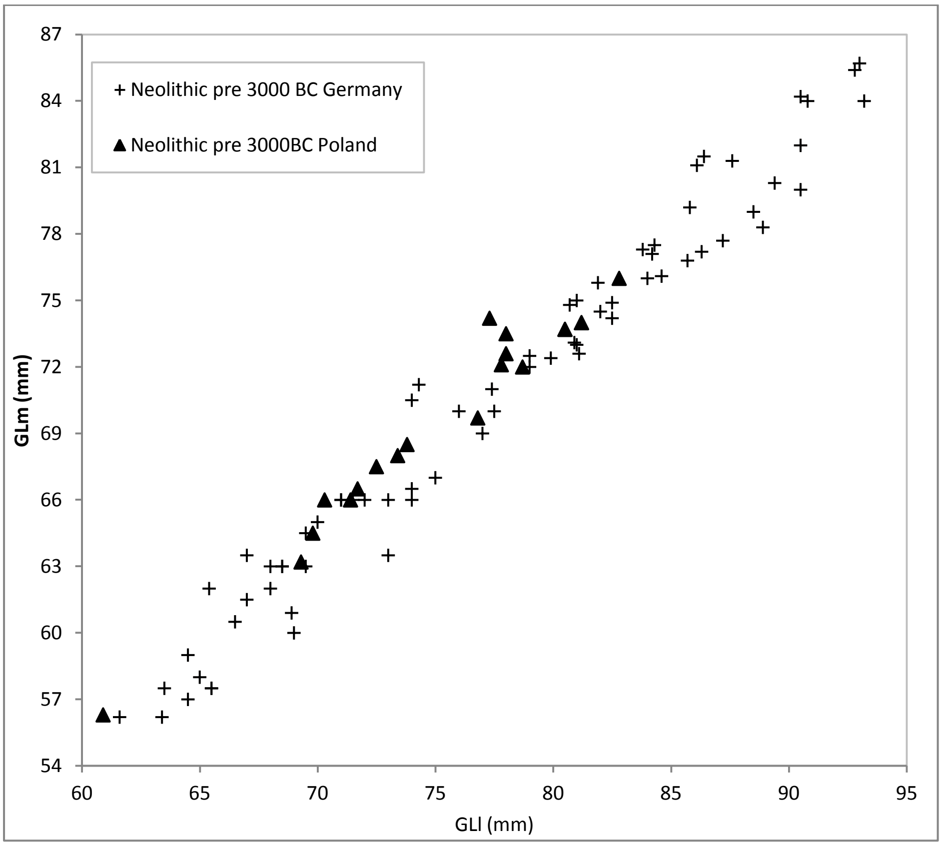


Figure 3.3.4: Scatterplot showing astragalus length measurements from Early Neolithic Germany and Poland. GLl= greatest length of lateral half, GLm= greatest length of medial half.

Animals included in the above plots from the Neolithic period have often been identified as wild or domestic based upon these measurements. There is some variation in the size at which astragali have been split, with some choosing to identify astragali as wild when they have a GLl of as small as c67mm (e.g. Nobis 1981), and others choosing to wait until a specimen reaches c80mm (e.g. Ziegler 1985/86). The variation in opinions is not surprising considering the difficulty in distinguishing the two groups based upon these scatterplots. The analysis above has shown that it is not possible to distinguish animals as wild or domestic if they are in this group. It is likely that many of these specimens have been identified without taking into account the spread of measurements from this period from sites likely to have been subject to relatively similar climatic and environmental conditions.

A comparison of log ratios containing postcranial measurements from Germany and Poland for each time period displays very similar means for the datasets from the two countries for the Early Neolithic and the Bronze/Iron Age distributions (Figure 3.3.5). The log ratio distribution from Early Neolithic Poland extends very close to the extent of the distribution for this period from Germany, although the German distribution peaks at a slightly larger size. The Bronze/Iron Age distributions for Germany shows a peak and tail pattern, whereas there is a clear gap between the main part of the distribution and the larger tail in the Polish material. Roman and Medieval distributions show more differences between regions and more variation in the individual distributions (Figure 3.3.6). Roman Poland has a similar pattern to the Bronze/Iron Age, with a likely majority of domestic cattle and a few wild cattle, whereas Roman Germany shows much greater diversity, including a higher proportion of larger sized cattle. This confirms the patterns seen in the astragalus scatterplots and continues to raise the question of whether these large cattle represent wild animals, or improved large cattle breeds.

A statistical comparsion of each country according to time period demonstrates that the only time period where the difference is not significant between the two regions is the Bronze/Iron Age (Table 3.3.4).

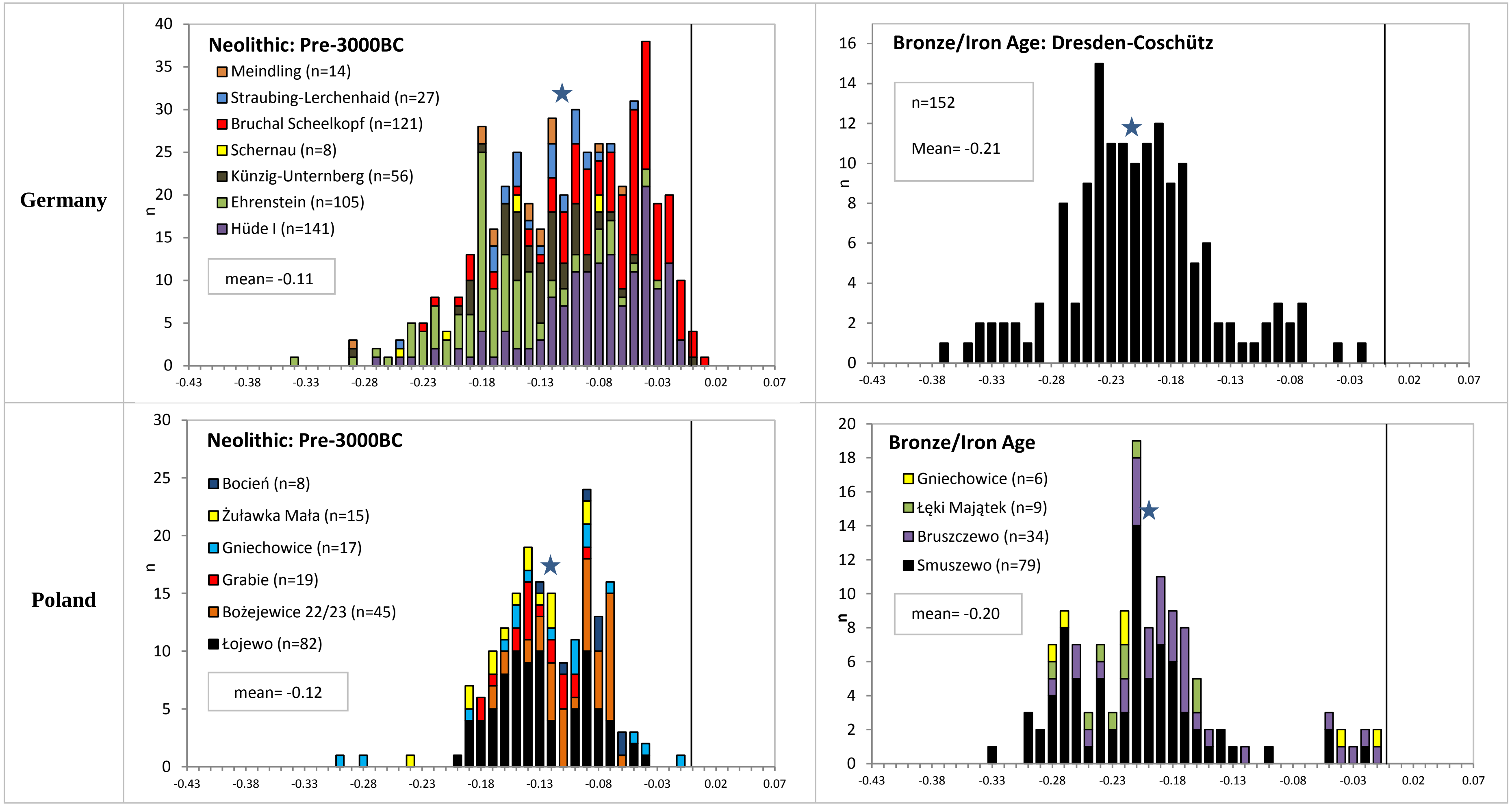


Figure 3.3.5: Log ratios showing all postcranial measurements from the Early Neolithic and Bronze/Iron age of Germany and Poland.

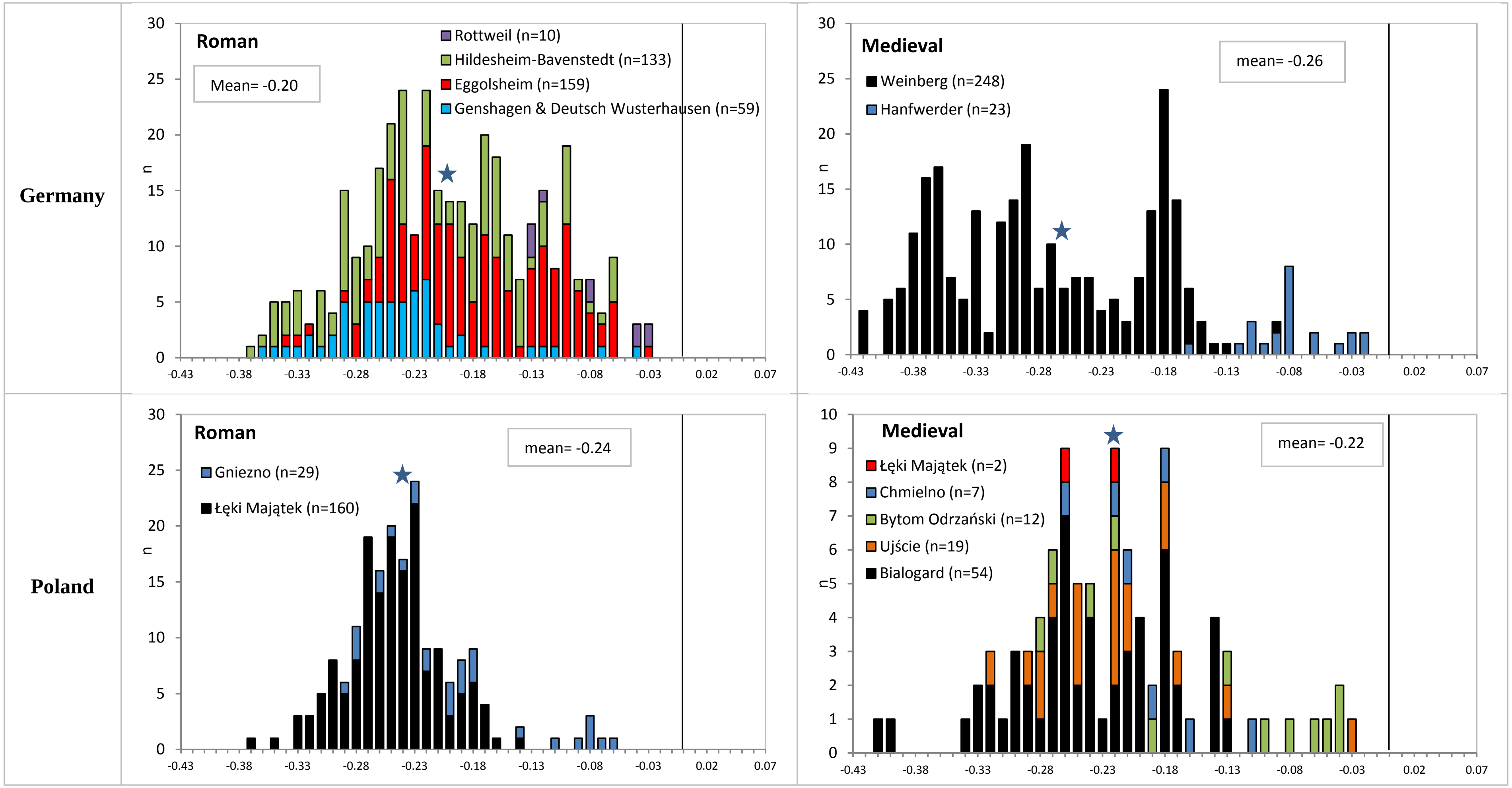


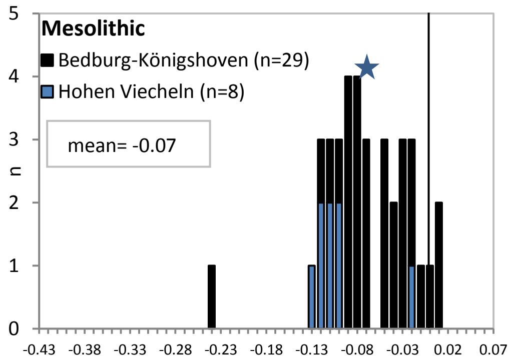
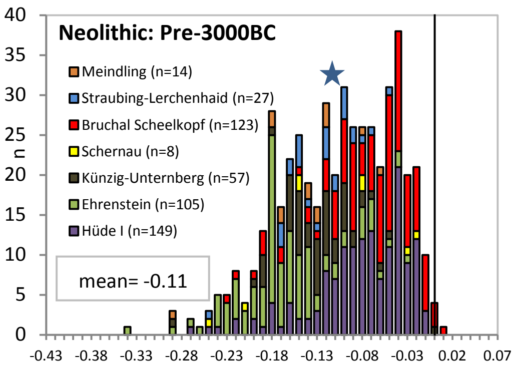
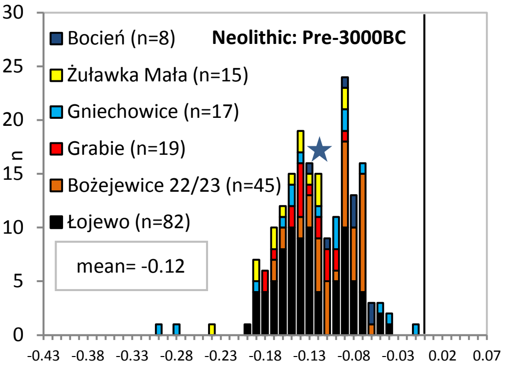
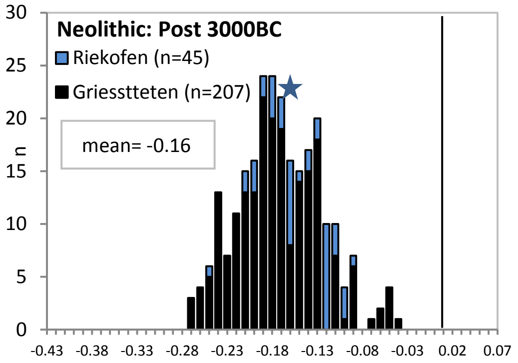
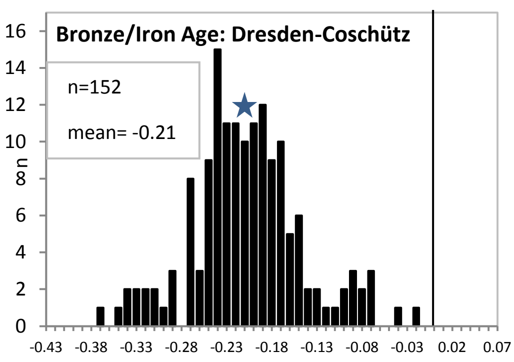
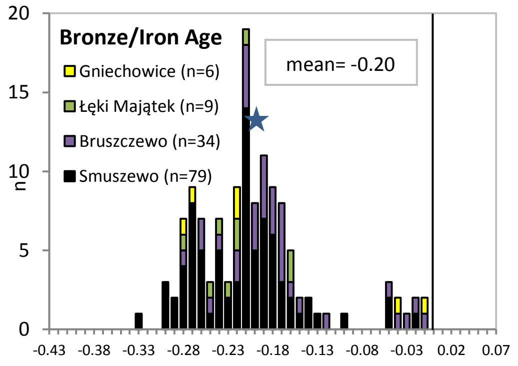
Figure 3.3.6: Log ratios showing all postcranial measurements from the Roman and Medieval periods in Germany and Poland.

A comparison of log ratios containing postcranial measurements from Germany and Poland over time shows that a very similar pattern of size change occurs in the two countries (Figure 3.3.7). In both areas the main shift to a smaller size take place after the Early Neolithic. German data indicates that it takes place during the Late Neolithic, but data for this period are not available from Poland. Both countries display a narrowing of *Bos* variability during the late Prehistoric period, and then an increase in variation during later periods. In Germany this is in the Roman period, whereas in Poland this does not take place until the Medieval period.

Mesolithic data from Germany group together at the top end of the diagram, and show relatively little variation compared to the other periods. The few particularly small measurements from the Mesolithic period are metapodial diaphysis measurements, and can probably be discounted on the basis of this measurement being relatively variable (particularly with age) in comparison to the other measurements included in the log ratio analysis.

The Early Neolithic period indicates an increase in variation in comparison to the Mesolithic period, likely to be related to the onset of cattle domestication, but overall there is a good amount of overlap with the preceding period. When tested statistically the difference between the two periods is not significant (Table 3.3.5). Early Neolithic sites have been separated in Figure 3.3.8, and a clear differentiation can be seen between different sites. Hüde I and Bruchal Scheelkopf are more dominated by larger cattle, whereas Ehrenstein has a larger number of smaller measurements. This may be an indication of differences in cattle management at sites in Germany during the Early Neolithic, with some concentrating more on the hunting of wild specimens, and others on husbandry. This pattern is not so evident in the Polish data, which show a more equal spread at all sites.

Data from the Neolithic period post-3000 cal BC in Germany display a shift to an overall smaller size and a smaller mean compared with the Early Neolithic period. This results in a peak and tail pattern, indicating the presence of some larger, potentially wild cattle, but very few in comparison to domestic cattle. Potential wild and domestic specimens now become easier to separate compared with the Early Neolithic. There is no evidence of size change in either aurochs or domestic cattle. The Late Neolithic large tail (presumably aurochsen) is consistent in size with the assemblage from Hüde I and Bruschal Scheelkopf, which for the Early Neolithic have been interpreted as being mainly characterised by wild animals. The Late Neolithic main distribution (i.e. domestic) is, conversely, consistent with the range recorded for Early Neolithic Ehrenstein, probably mainly made of domestic cattle. This means that, in Germany, the above-mentioned size shift between Early and Early Neolithic is due to a change in the relative proportion of wild and domestic cattle.

Germany	**Poland**
	No data from Poland
	
	No data from Poland
	

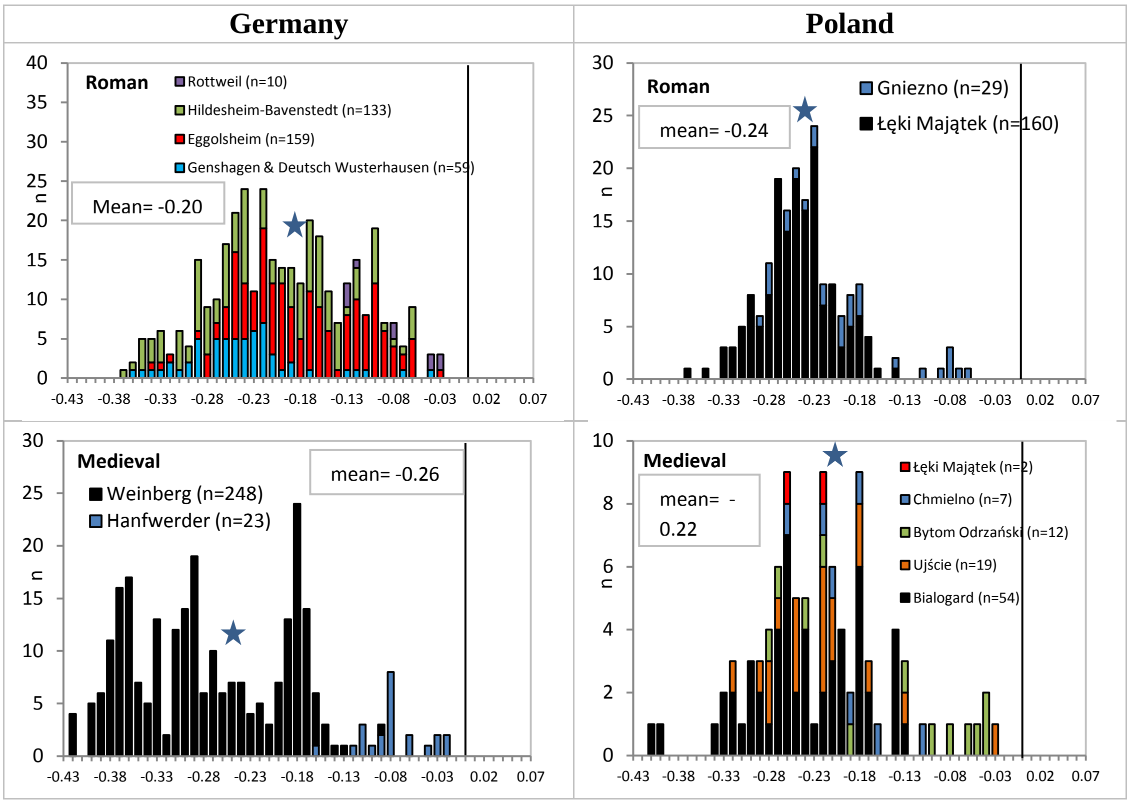


Figure 3.3.7: Log ratios showing German (left column) and Polish (right column) postcranial measurements over time.

The peak and tail pattern continues into the Bronze/Iron Age in Germany, although there is now an increase in variation, due to the number of particularly small measurements from this period. The overall pattern is also seen in the Polish dataset for this period, although the cluster containing larger cattle measurements is more separate from the bulk of the data than for Germany, meaning an easier determination of wild and domestic animals.

The Roman period sees the introduction of larger cattle specimens in the German dataset, which confuse the pattern and make determining wild from domestic animals more difficult. It seems likely that both domestic and wild animals are present, but the pattern could be further confused if there is also the inclusion of Roman larger breeds. This pattern seems to be present in the majority of sites included, except for Genshagen and Deutsch Wusterhausen which contain very few larger cattle. The difference of the means between the Bronze/Iron Age and Roman period in Germany is not significant when tested statistically (Table 3.3.5), which is not surprising as the difference is mainly in variability rather than overall size. Roman data from Poland do not show the same pattern as Germany, with the pattern continuing to look very similar to that of the Bronze and Iron Age, although the overall size in cattle is decreasing. This has resulted in a significant difference between the two periods when tested statistically (Table 3.3.6). This pattern indicates the presence of domestic and wild cattle groups, which are relatively straightforward to identify, and a lack of the larger cattle which are confusing the pattern in Germany.

The Medieval period shows a further increase in variation. The German pattern is especially variable, with multiple peaks which do not conform to the usual distribution shape. The specimens from Hanfwerder form a group that may represent wild cattle, whereas there is little evidence that any of the animals from Weinberg are wild. This distribution could potentially be related to different cattle breeds, but the splitting of the log ratios by bone and measurement may help to shed light on this matter (see below). The Polish dataset also shows increased variation, but not to the same as extent as in Germany. There is still a small group which could represent wild animals, made up of measurements from Bytom Ordański and Ujście, but the majority of the other measurements seem likely to be from domestic cattle.

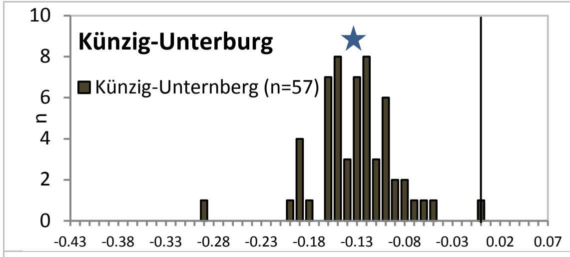
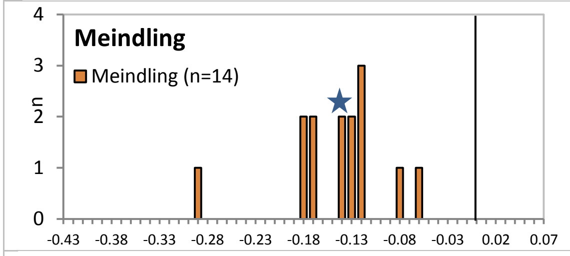
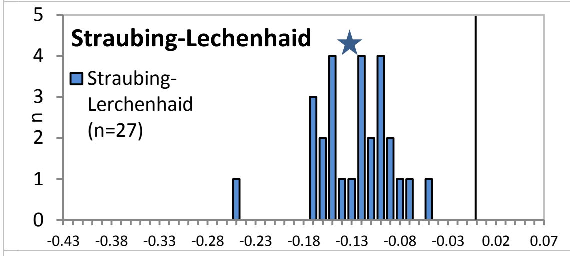
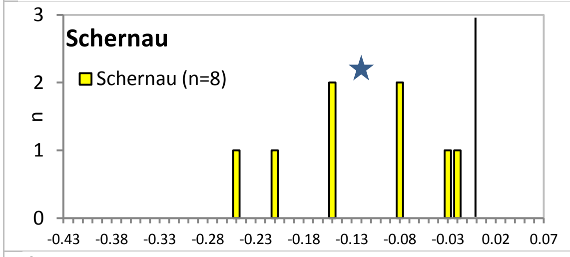
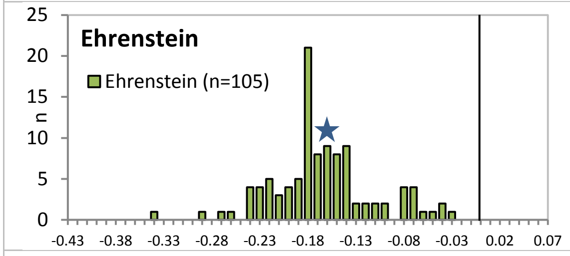
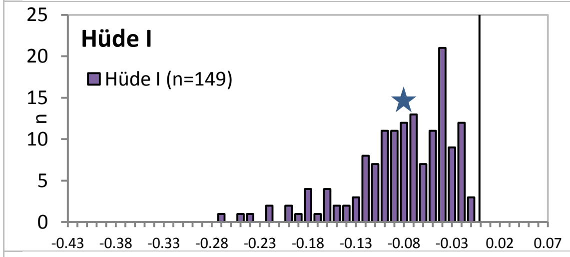
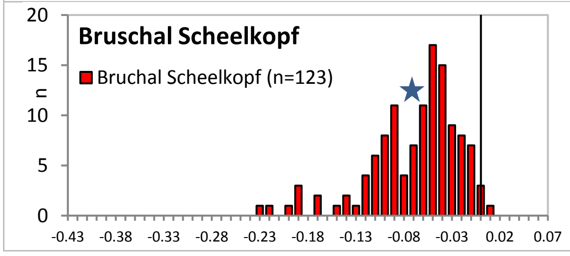
	n=57 mean= -0.13
	n=14 mean= -0.14
	n=27 mean= -0.13
	n=8 mean= -0.12
	n=105 mean= -0.16
	n=149 mean= -0.08
	n=123 mean= -0.07

Figure 3.3.8: Log ratios of postcranial remains from Early Neolithic Germany in broad chronological order.

Log ratios have also been split according to bone and individual measurement in order to see the change over time in each bone, and also the effects of different measurements on the pattern (Figures 3.3.9 and 3.3.10 for Germany, 3.3.11 and 3.3.12 for Poland).

In Germany, a clear change over time can be seen in astragalus measurements. During the Mesolithic the measurements show a small amount of variation (albeit through a small sample size). In the Early Neolithic group there is a large increase in variation. This can be seen in both length and breadth measurements, despite the fact that the latter have, in this study, consistently shown more variation. The increase in variation is a pattern which can be seen throughout Early Neolithic astragalus plots from across Europe in this study, but is most clear here because of the larger sample size. The pattern seen in Mesolithic distributions has shown length measurements (in particular) with a relatively small amount of variation (here and in other areas of Europe) – this large change in the Early Neolithic almost certainly indicates a mixture of wild and domestic animals.

During the Late Neolithic there is further overall reduction in size, with just a few larger animals forming a separate group – the two groups formed could be attributed to wild and domestic animals. There is also a consistent reduction in variation of all three astragalus measurements, as indicated by the coefficients of variation (Table 3.3.2). The coefficient of variation values remain, however, high and consistent with the admixture of wild and domestic specimens (c.f. Payne and Bull 1988). In the Bronze and Iron Age, two size groups can still be identified, but these have become even more separated from each other, as a consequence of the size reduction in the domestic group.

Roman astragalus measurements continue to show a similar pattern, with two identifiable groups, although the gap between the groups has now narrowed again. There is a clear pattern in the group representing smaller animals – with length measurements always plotting to the right of the group. The group representing larger animals is outside of this distribution range. Here larger Roman breeds may potentially be confusing the pattern. The variation of length measurements within the larger group of cattle here, in comparison to earlier time periods may be evidence of this. The overall increase in variation in the Roman period is demonstrated by the coefficients of variation (Table 3.3.2).

Medieval astragalus measurements are relatively large, but the distribution is skewed by the fact that only measurements deriving from specimens that were identified as wild (Prilloff 1994) were available for this period. Without seeing the whole distribution it is difficult to make much of a judgement here about these animals. Their similarity with the larger group from the Roman period, though, indicates that these measurements are from animals of a similar size – they could all be wild, or a mixture of wild and large domestic breeds.

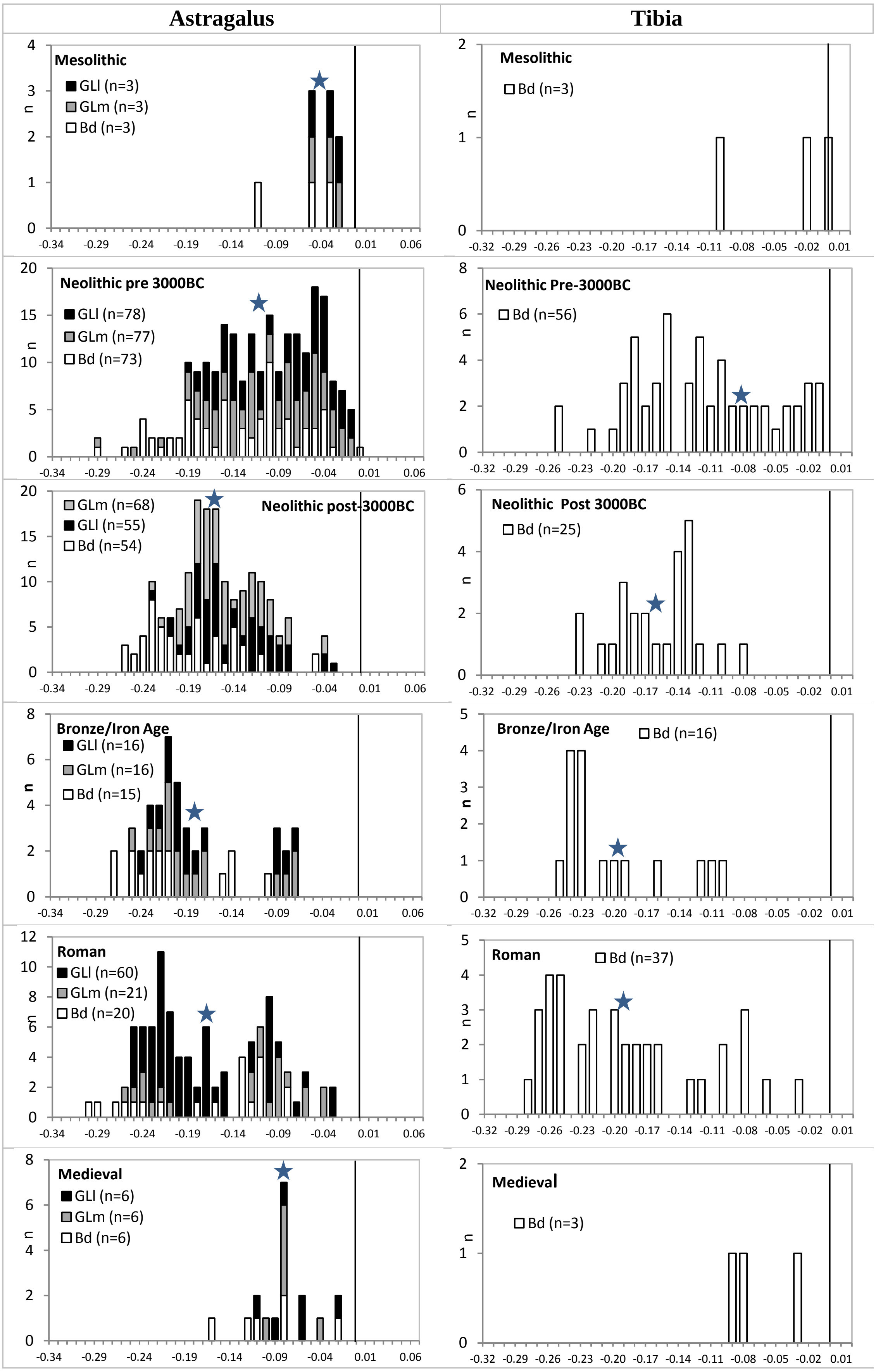


Figure 3.3.9: Log ratio diagrams showing German astragalus and tibia measurements.

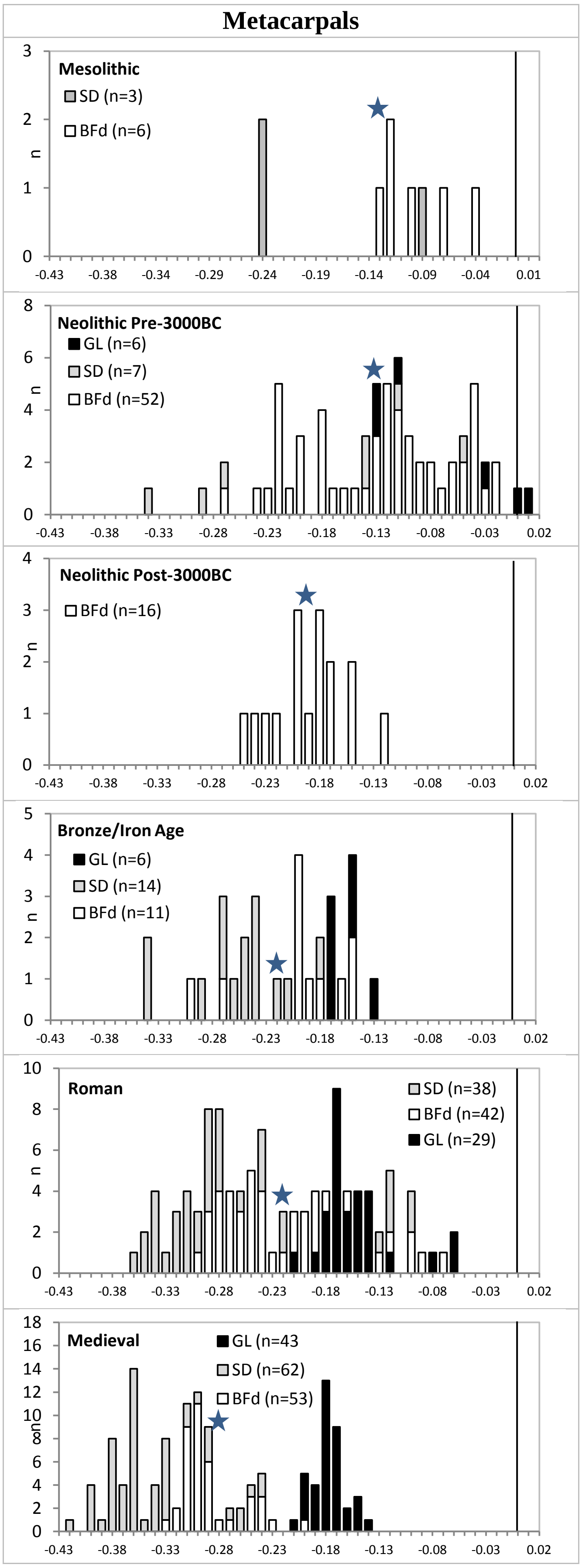


Figure 3.3.10: Log ratio diagrams showing German metacarpal measurements over time.

Tibia measurements show a very similar pattern to the astragalus. Distal breadth measurements still form groups during the Bronze/Iron and Roman periods, but they are not quite as distinct as those formed by the astragalus. It is more difficult to see the separation of the two groups during the Late Neolithic according to tibia distal breadth measurements.

Metacarpal measurements have been included due to the relatively large sample size available here, and the potential for seeing sexual dimorphism in the patterns available. In fact the data do not seem to group according to potential sex groups, and instead often group according to measurement. Distal breadth (BFd) and shaft breadth (SD) measurements tend to display greater variation than length measurements, which is something that has commonly been seen in other geographic areas too.

The overall variation seen in the Early Neolithic metacarpal measurements mirrors that seen in the astragalus and tibia measurements, and this variation indicates a mixture of wild and domestic animals in this period. The most clearly defined groups within this can be observed in metacarpal length measurements. The samples are small, but the groups are clear and could potentially indicate wild and domestic animals. The separation is more likely to be caused by the contemporary occurrence of wild and domestic animals, rather than sexual dimorphism, because otherwise we would expect to see four groups in a population containing both wild and domestic animals. That this is a mixed group, with a presence of both wild and domestic animals is further evidenced by the large jump in the coefficients of variation between the Mesolithic and Early Neolithic period here (Table 3.3.2).

It is not possible to separate the Late Neolithic data into two groups, but the Bronze/Iron Age distribution does not indicate that there is a wild component at all – there is only one group of length measurements. All of these measurements were identified as deriving from domestic animals in the original report (Nitra 1986).

In the Roman and Medieval distributions a very clear pattern according to measurement emerges, presumably in the domestic group. The measurements at the far right of the distribution could potentially be from wild specimens, but the majority of measurements sit within the multiple peaked distribution to the left of the diagram.

There is a clear difference in the way that different metacarpal measurements change over time during the domestication process. As we have seen throughout this study, length measurements are less prone to change, and continue to plot nearer to the standard population. Distal breadth (BFd) measurements change more readily, and shaft breadth (SD) measurements are the most plastic of all. This results in a German domestic cattle metapodial that is far more slender than that of the wild aurochs from the Pleistocene of Britain – as represented by the standard population from Ilford. Bearing this in mind, there is no reason why we should assume the occurrence of wild animals in the Medieval group, as the various peaks in the distribution are due to the relative differences in the metapodial measurements. This argument could also be used to exclude the idea that larger ‘Roman’ domestic animals are present.

The distribution of Polish measurements from the astragalus, tibia and metapodials broadly mirrors that seen in Germany (Figures 3.3.11 and 3.3.12). The Early Neolithic astragalus pattern is not quite as varied as that in Germany, but that could be a result of smaller sample sizes in Poland. Bronze/Iron, Roman and Medieval patterns all have one group closer to the bottom end of the distribution, containing more specimens and it seems likely that these are domestic animals. All of these groups follow a similar pattern to the astragalus measurements from Germany, with breadth measurements reducing in size more than length measurements.

The Bronze/Iron, Roman and Medieval distributions all have a number of large outliers which plot away from the main group. These probably represent wild animals, but the samples are too small to investigate possible changes in size of the aurochs through time.

Breadth (Bd) and depth (Dd) measurements from the tibia indicate that in the Early Neolithic, as for the astragalus, there is a large amount of variation. Although there are some large outliers, there are no clear groups, indicating that once again it is difficult to separate domestic cattle and aurochs in the Early Neolithic. Plots for later periods show a clear reduction in the size of the domestic stock, which makes it more realistic to separate wild from domestic animals in the Bronze/Iron Age and Roman distributions. The Medieval pattern appears to only include domestic cattle.

The largest change in size is between the Early Neolithic and Bronze/Iron age distributions. It is likely that domestic cattle dominate the assemblages from the Bronze/Iron, Roman, and Medieval periods, which all show a pattern similar to that in Germany, with measurements clearly changing at different rates. Any large outliers which plot away from this distribution may be considered wild. The samples of wild cattle are too small to be able to make a judgement about change over time in the wild animal, but the large outlier in the Medieval plot demonstrates that some particularly large animals were still present in this area during this period. The patterns seen in the overall log ratio diagrams (Figures 3.3.6 and 3.3.7) are generally confirmed by patterns seen in the individual measurements, so in this case there seems to have been little confusion generated by pooling different measurements together,

The pattern seen in metacarpal measurements is particularly interesting, and indicates a clear difference in the size change of different measurements in relation to domestication. The distribution resulting from this is extremely useful when trying to distinguish wild specimens.

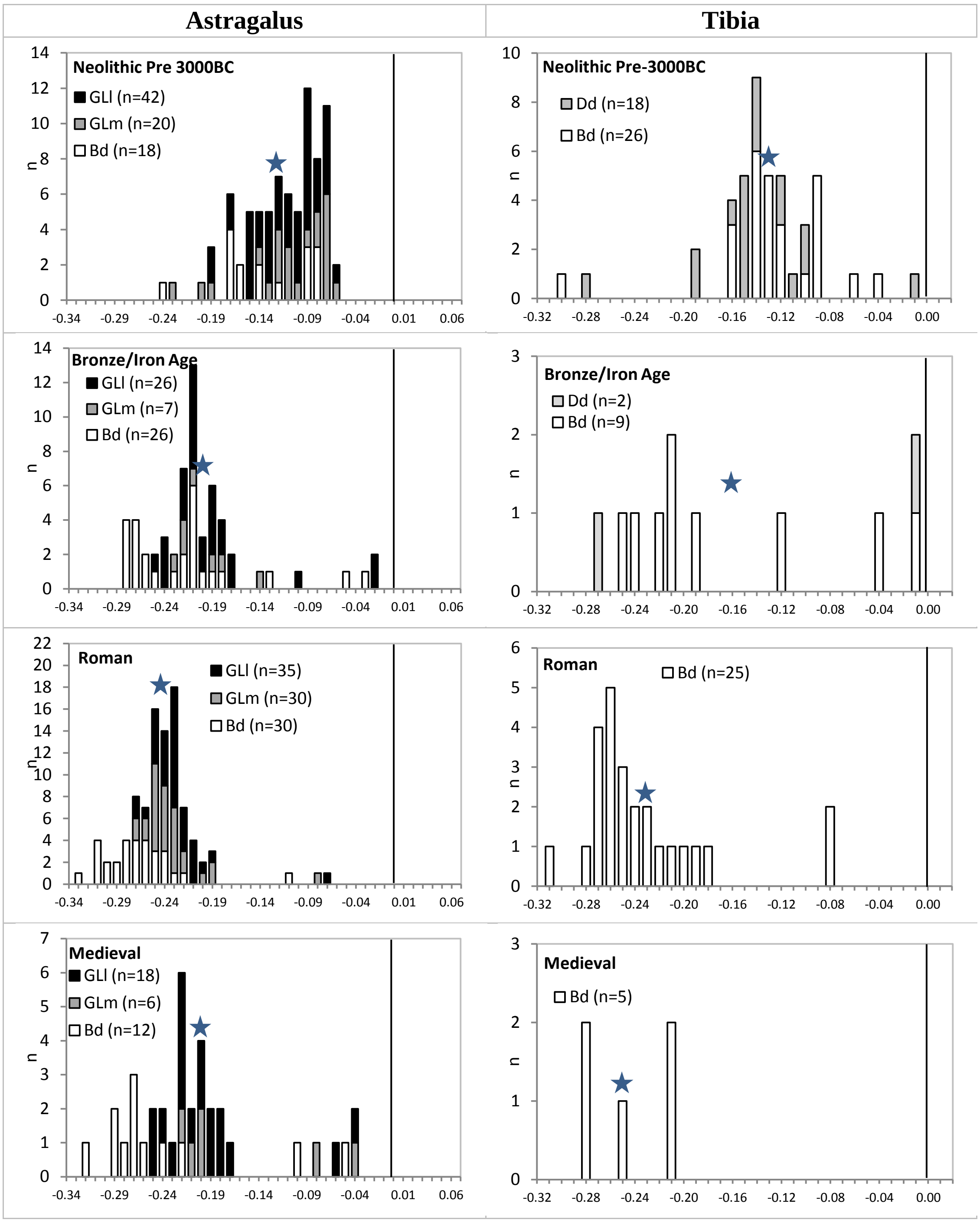


Figure 3.3.11: Log ratios showing Polish astragalus and tibia measurements.

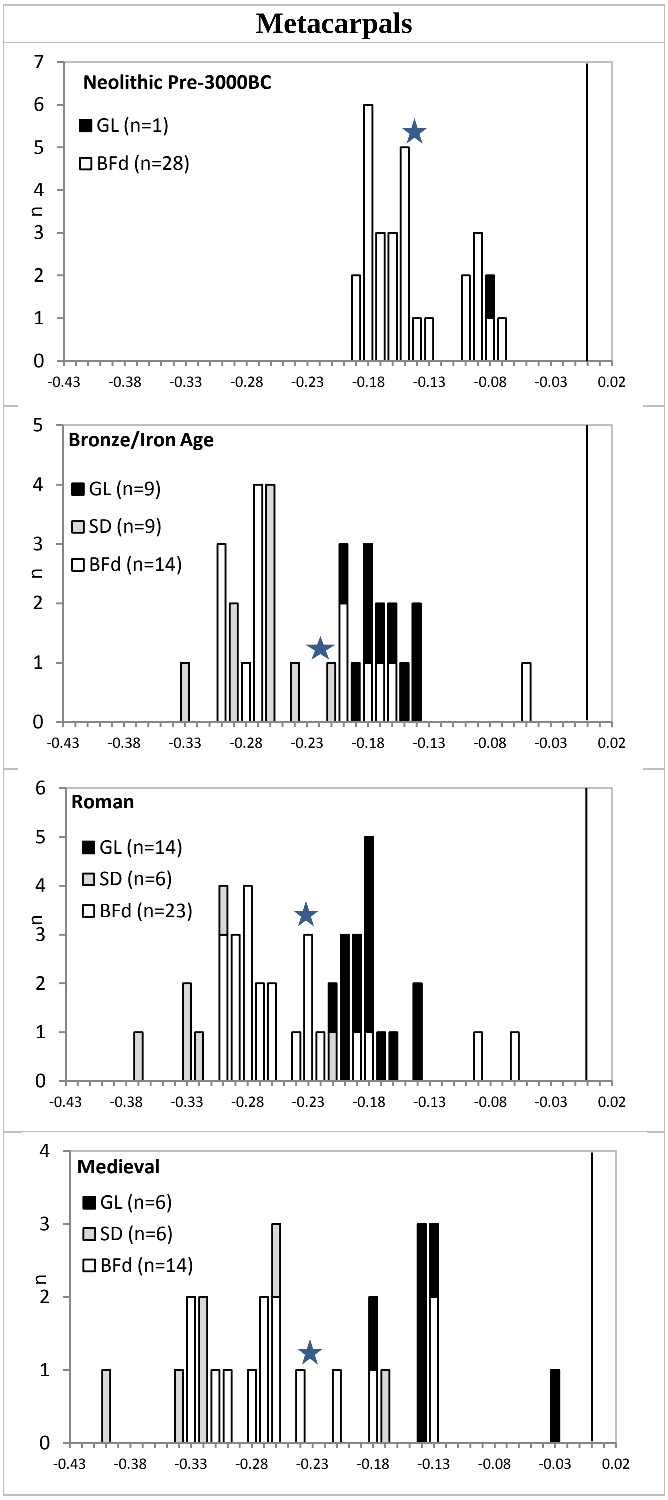


Figure 3.3.12: Log ratio diagrams displaying Polish metacarpal measurements.

Overall, the German and Polish distributions show a similar pattern of change over time, displaying a gradual reduction in size, most likely related to the onset of domestication, and a reduction in the proportion of wild animals contributing to the patterns. The largest size change takes place between the Early Neolithic and later phases rather than the Mesolithic and Neolithic. Sample sizes of the groups likely to be representing wild animals are quite small after the Early Neolithic, but there is no indication of a size increase in the aurochs after 3000 cal BC. There is no great deal of change in the size of the aurochs over time in Germany, and there is no real indication of a reduction in the size of the wild animal between the Mesolithic and Early Neolithic, although the Mesolithic sample size is small. In Poland there is the indication of a slight decrease in size of the wild animal after the Bronze/Iron age, but this could be a result of sample size.

Both areas have an Early Neolithic group which is difficult to unpick, and is likely to contain a mixture of wild and domestic animals. In Germany it is clear that such a mixture is not homogeneously represented across sites, as some have a clear predominance of wild animals and others of domestic cattle. Some Early Neolithic sites therefore seem to have still been fairly dependent on hunting aurochsen, which were consistent in size with their Mesolithic ancestors. The domestic animals from sites such as Ehrenstein are too small to be likely to be the product of the domestication of indigenous aurochsen and may well represent a consequence of the introduction of domestic stock from other geographic areas. Interestingly the earliest Neolithic sites (such as Künzig-Unternberg and Straubing-Lerchenhaid) do not seem to have such a large representation of wild cattle as the later Early Neolithic sites (such as Hüde I and Bruschal Scheelkopf). This suggests some kind of change of procurement strategy over time during this period.

During the Late Neolithic in Germany, the pattern becomes clearer, and we see the largest change in average size between time periods. This is the consequence of a reduction in the number of wild specimens in the sample. Wild and domestic groups are now more easily identifiable, both on the overall diagram, and according to individual measurement. By the Bronze/Iron Age in both areas the two groups are still fairly distinct. The Roman period in Germany sees an increase in variation, which may be due to a greater component of wild animals in this time period in comparison to late prehistory, or that larger cattle breeds were introduced or a mixture of both. In Poland this pattern is not seen. By the Medieval period more variation is seen in both areas, and the investigation of the individual measurements making up the distribution demonstrates that this is due to the culmination of a gradual change in metapodial shape over time – resulting in slenderer domestic cattle compared to its wild counterpart. This pattern is seen in both areas, and begins to emerge in the Bronze Age. This pattern may be instrumental in determining wild from domestic animals, as anything from this time period which plots outside of this range could be identified as wild. Clearly breadth measurements are those that are more likely to change, and show more plasticity, so might be most useful for determining wild from domestic animals, although the increased variation due to the sexual dimorphism expressed by these measurements can sometimes prevent clear groupings. The potential presence of large domestic cattle breeds in the Roman period, may be a complication in this process, and the likelihood of this needs to be explored.

All Roman sites in this study, with the exception of Rottweil (where the bones are especially large and most likely all from wild cattle), come from outside the furthest extent of the Roman Empire, and therefore you might expect all of the cattle at these sites to be of the smaller unimproved kind. However, the presence of larger cattle outside Roman territory has previously been attributed to Roman influence (e.g. Teichert 1984; Lauwerier *et al*. 1999), and we cannot exclude this possibility here.

Large cattle bones, identified as large improved domestic cattle, from the Dutch site of Heeten (4th century AD), which was also outside of Roman territory, include some tibiae distal breadths (Bd) with measurements as large as 82mm. In comparison, at Eggolsheim (2nd-5th centuries AD) – one of the German sites included in this study - tibiae with Bd measurements of between 72.5-85mm were previously identified as aurochs (Breu 1986), and these bones plot between -0.10 and -0.03 on the log ratio plots here. These all appear as outliers on the tibia Bd log ratio, but only one of these measurements (85mm /-0.03) plots away from the bulk of measurements on the overall German log ratio diagram where all postcranial measurements are combined. On this basis, perhaps this is the only specimen which should be considered to be wild. Likewise, at the German site of Mühlberg which was a Germanic settlement site outside of Roman territory, tibia measurements from bones identified to be domestic cattle reach up to 77mm (Teichert 1984).

A number of astragali have also been recorded from Germanic sites, and identified as large domestic cattle, which have greatest length (GLl) measurements of 80-85.5mm (Teichert 1984). Astragali from Eggolsheim have been identified as aurochs when they have a GLl of 75mm or above.

It does seem likely that large cattle of improved Roman breeds were present outside of the Roman Empire, on sites in the area covered by modern day Germany, and may have been present at some of the sites included in this study – notably Eggolsheim. The difficulty of distinguishing different groups compared to previous time periods, and the difference between the German and Polish pattern demonstrated here provides evidence for this. This could have been through trade, but also could be related to the passing on of the technological know-how of cattle breeding. However, there is evidently some confusion about how to distinguish between the large Roman cattle and the aurochs. Teichert (1984) mentions distinguishing between wild and domestic cattle on the basis of the thickness of the bone walls, and his measurements are based on identifications using this method. This is unlikely to be a reliable method for distinguishing between the two, and reflects the age of this work – this is not a method that is used today. Lauwerier (1999) does not mention this method of distinction. It is evident that more work needs to be done on this specific issue in order to better determine between larger Roman domestic cattle and the aurochs. This would be best done by looking again at the original specimens, which is unfortunately not within the scope of this project.

The German and Polish data have been able to provide a pattern much further into the Holocene than for any other geographical area included in this project. This has provided an insight into the complications brought about by the introduction of improved cattle breeds. The large sample sizes have also provided an opportunity to see the clear change in shape of domestic cattle bones in comparison to those from the wild animals.

Table 3.3.2: Summary statistics for Germany. Samples of less than 5 were excluded.

Measurement	No.	Min	Max	Mean	Standard deviation	Coefficient of variation
Astragalus GLl						
Neolithic pre-3000BC	78	61.6	93.2	77.5	8.98	11.60
Neolithic post-3000BC	56	55.5	88.5	69.3	7.24	10.45
Bronze/Iron	16	55.0	81.0	64.5	9.02	13.98
Roman	60	53.0	88.5	63.7	9.07	14.24
Medieval	6	74.0	91.0	81.2	5.67	6.99
Astragalus GLm						
Neolithic pre-3000BC	78	45.0	85.7	69.4	9.28	13.37
Neolithic post-3000BC	68	51.5	80.5	62.4	6.03	9.66
Bronze/Iron	16	49.5	75.0	59.3	8.59	14.49
Roman	21	48.0	80.5	65.0	10.93	16.82
Medieval	6	70.0	80.0	73.0	3.52	4.82
Astragalus Bd						
Neolithic pre-3000BC	72	34.0	66.0	49.5	7.43	14.99
Neolithic post-3000BC	55	37.0	60.0	43.4	5.27	12.13
Bronze/Iron	15	35.5	52.5	41.3	5.11	12.37
Roman	20	33.7	56.0	45.7	7.50	16.40
Medieval	6	46.0	63.0	53.8	5.71	10.60
Calcaneum GL						
Neolithic pre-3000BC	31	129.0	194.1	156.8	18.17	11.59
Neolithic post-3000BC	9	120.0	147.0	132.9	8.92	6.71
Bronze/Iron	10	111.5	132.0	120.8	6.49	5.38
Roman	10	110.6	167.0	133.4	19.57	14.67
Metacarpal BFd						
Mesolithic	6	68.8	85.0	74.6	6.28	8.43
Neolithic pre-3000BC	52	50.2	89.5	70.1	10.79	15.39
Neolithic post-3000BC	16	52.0	71.0	60.1	4.75	7.91
Bronze/Iron	11	46.5	65.0	58.8	5.93	10.08
Roman	42	46.7	79.0	56.2	8.46	15.04
Medieval	39	43.0	58.0	47.8	3.35	7.01
Metatarsal BFd						
Mesolithic	6	64.0	81.0	69.6	6.94	9.98
Neolithic pre-3000BC	66	49.0	81.0	66.7	8.32	12.47
Neolithic post-3000BC	22	46.5	72.0	57.8	6.30	10.90
Bronze/Iron	20	44.5	58.0	49.7	3.94	7.92
Roman	47	44.1	72.5	52.7	7.69	14.60
Medieval	38	41.0	77.0	46.2	6.81	14.74

Table 3.3.3: Summary statistics for Poland. Samples of less than 5 were excluded.

Measurement	No.	Min	Max	Mean	Standard deviation	Coefficient of variation
Astragalus GLl						
Neolithic pre-3000BC	42	60.9	82.8	73.71	5.75	7.80
Bronze/Iron	26	54	90.2	62.10	9.34	15.04
Roman	35	50.9	80.1	56.49	4.71	8.33
Medieval	18	53	87.7	61.57	9.07	14.73
Astragalus GLm						
Neolithic pre-3000BC	22	52	76.1	68.13	6.66	9.77
Bronze/Iron	7	50.9	80.4	57.87	10.26	17.73
Roman	30	46.6	72.4	51.34	4.60	8.96
Medieval	6	52.3	73.2	61.37	11.61	18.92
Astragalus Bd						
Neolithic pre-3000BC	16	38.7	55.3	49.11	5.15	10.49
Bronze/Iron	26	34.9	62.3	40.83	6.95	17.02
Roman	30	31.5	51.6	36.25	3.65	10.06
Medieval	12	32	60	39.29	8.50	21.63
Calcaneum GL						
Neolithic pre-3000BC	14	143	173	157.50	9.59	6.09
Bronze/Iron	13	111	131.5	122.83	7.31	5.95
Metacarpal BFd						
Neolithic pre-3000BC	28	60	79	66.47	5.72	8.60
Bronze/Iron	14	47	81.8	55.41	9.75	17.59
Roman	23	46.5	80.2	53.48	8.68	16.24
Medieval	14	43.2	69.3	52.81	8.53	16.16
Metatarsal BFd						
Neolithic pre-3000BC	66	49	81	66.73	8.32	12.47
Bronze/Iron	6	43	56.5	50.17	5.77	11.49
Roman	19	39.7	54.9	46.33	4.58	9.89
Medieval	14	41.1	55.4	47.13	4.51	9.58

Table 3.3.4: Results of the Mann-Whitney tests on *Bos* postcranial log ratios comparing each time period from Germany and Poland. Significant results (<0.05) are marked with an * and highly significant results (<0.01) are marked with **. Only archaeological material has been included in the statistical analyses. Samples of less than 20 were excluded.

Germany	n.	Poland	n.	U	z	Significance
Neolithic Pre-3000BC	308	Neolithic Pre-3000BC	129	13458.50	-5.33	0.000**
Bronze/Iron	76	Bronze/Iron	68	2566.50	-0.07	0.944
Roman	198	Roman	102	5928.00	-5.87	0.000**
Medieval	86	Medieval	53	1396.00	-3.84	0.000**

Table 3.3.5: Results of the Mann-Whitney tests on German *Bos* postcranial log ratios comparing time periods to each other. Significant results (<0.05) are marked with an * and highly significant results (<0.01) are marked with **. Only archaeological material has been included in the statistical analyses. Samples of less than 20 were excluded

Group	n.	Group	n.	U	z	Significance
Mesolithic	23	Neolithic Pre-3000BC	308	2732.50	-1.83	0.067
Mesolithic	23	Neolithic Post-3000BC	128	214.00	-6.53	0.000**
Mesolithic	23	Bronze/Iron	76	90.50	-6.50	0.000**
Mesolithic	23	Roman	198	319.00	-6.76	0.000**
Mesolithic	23	Medieval	86	133.00	-6.37	0.000**
Neolithic Pre-3000BC	308	Neolithic Post-3000BC	128	8199.00	-9.63	0.000**
Neolithic Pre-3000BC	308	Bronze/Iron	76	2657.00	-10.46	0.000**
Neolithic Pre-3000BC	308	Roman	198	8169.00	-13.92	0.000**
Neolithic Pre-3000BC	308	Medieval	86	2316.50	-11.72	0.000**
Neolithic Post-3000BC	128	Bronze/Iron	76	2322.50	-6.25	0.000**
Neolithic Post-3000BC	128	Roman	198	7261.50	-6.52	0.000**
Neolithic Post-3000BC	128	Medieval	86	1481.00	-9.07	0.000**
Bronze/Iron	76	Roman	198	7253.50	-0.46	0.644
Bronze/Iron	76	Medieval	86	1231.50	-6.85	0.000**
Roman	198	Medieval	86	3574.00	-7.78	0.000**

Table 3.3.6 Results of the Mann-Whitney tests on Polish *Bos* postcranial log ratios comparing time periods to each other. Significant results (<0.05) are marked with an * and highly significant results (<0.01) are marked with **. Only archaeological material has been included in the statistical analyses. Samples of less than 20 were excluded

Group	n.	Group	n.	U	z	Significance
Neolithic Pre-3000BC	129	Bronze/Iron	68	1045.50	-8.80	0.000**
Neolithic Pre-3000BC	129	Roman	102	691.50	-11.69	0.000**
Neolithic Pre-3000BC	129	Medieval	53	571.00	-8.83	0.000**
Bronze/Iron	68	Roman	102	1879.50	-5.01	0.000**
Bronze/Iron	68	Medieval	53	1306.00	-2.60	0.009**
Roman	102	Medieval	53	2314.00	-1.47	0.141

3.4 Iberia

This section looks at data from the Iberian Peninsula, namely Portugal and Spain. Portuguese data are restricted to the Mesolithic and Chalcolithic periods, but Spanish data are available from more time periods, from the Middle Palaeolithic to the Bronze Age.

Portuguese data come from the Mesolithic shell middens of Muge (Cabeço da Arruda, Cabeço da Amoreira and Moita do Sebastião) and the Chalcolithic site of Castro do Zambujal. The assemblages from the Muge middens were recorded by the author, whereas the biometrical information for Castro do Zambujal was taken from a publication on the fauna from the site (von den Driesch and Boessneck 1976). This publication provided a number of measurements for the *Bos* from the site, but not all. Most 'domestic' measurements were just given as ranges, although the complete set of astragalus measurements was made available by Simon Davis.

For Spain a more complete picture of change over time can be provided, with raw data available for the Mesolithic (Cueva de Arenaza, La Sierra de Gibijo and Cueva de Mazaculos II) - all of these sites are from the earlier Mesolithic and date to pre-6000 cal BC, Neolithic (c5000-3500 cal BC) (Arenaza; Cueva de Chaves; La Draga; La Renke), Chalcolithic (c3000-2000 cal BC) (Los Castillejos; Las Pozas; Gobaederra; Fuente Flores; Cerro de la Virgin) and Bronze Age (c2000-1000 cal BC) (Cerro de La Virgen). Some measurement ranges are also available for a Pleistocene site dated to the Middle Palaeolithic (Solano del Zamborino). A potentially important gap in the Spanish sequence is the Late Neolithic (c3500-3000 cal BC), which coincides with the onset of the climatic deterioration at around 3000 cal BC. All of the Neolithic data included here are early in date with the exception of those from the Neolithic level at La Renke. The dates for this site straddle the onset of the climatic deterioration and so this assemblage may not be ideal for trying to spot any effects it might have had on the fauna. Effects of the climatic deterioration may be easier to spot in the Chalcolithic sample, although we will not know how much earlier than this an impact was seen. All of the Spanish data were taken from the literature (references are provided in Chapter 2), and so issues of observer error must be taken into account.

As with the other areas in this study, *Bos* specimens, whether they had previously been identified as 'wild' or 'domestic', appear as one '*Bos*' group. This means that there are no preconceptions about individual specimens which may affect the interpretation of the data, but it does mean that domestication must be taken into account as a likely factor affecting size and shape change. This does complicate things slightly when analysing and interpreting the Portuguese Chalcolithic data from Castro do Zambujal, where calcaneum and tibia measurements identified as domestic were not included in the bone report. Although the overall log ratio contains both wild and domestic bones it must be remembered that the pattern is slightly biased by the fact that these data are missing (i.e. the wild component may be slightly exaggerated). Likewise when measurements from individual bones are compared, only those identified as wild were available for comparison for the calcaneum and tibia and this must be taken into account.

3.4.1 Ageing

The only assemblages that were recorded fully by the author were those from the Muge middens. Not enough teeth were available in order to do a detailed analysis of tooth eruption and wear, but the general pattern can be seen using fusion data (Figure 3.4.1). The results follow a similar pattern to other Mesolithic populations. Star Carr is included here for comparison, and both patterns indicate very few young animals on site, but that not all animals were fully adult. The comparison between Star Carr and Durrington Walls (see Section 3.2.1) demonstrates the increase in very young animals found on sites with the presence of domestic cattle. As always, this pattern can affect the availability of measurements from some of the later fusing bones, such as the proximal femur and the calcaneum.

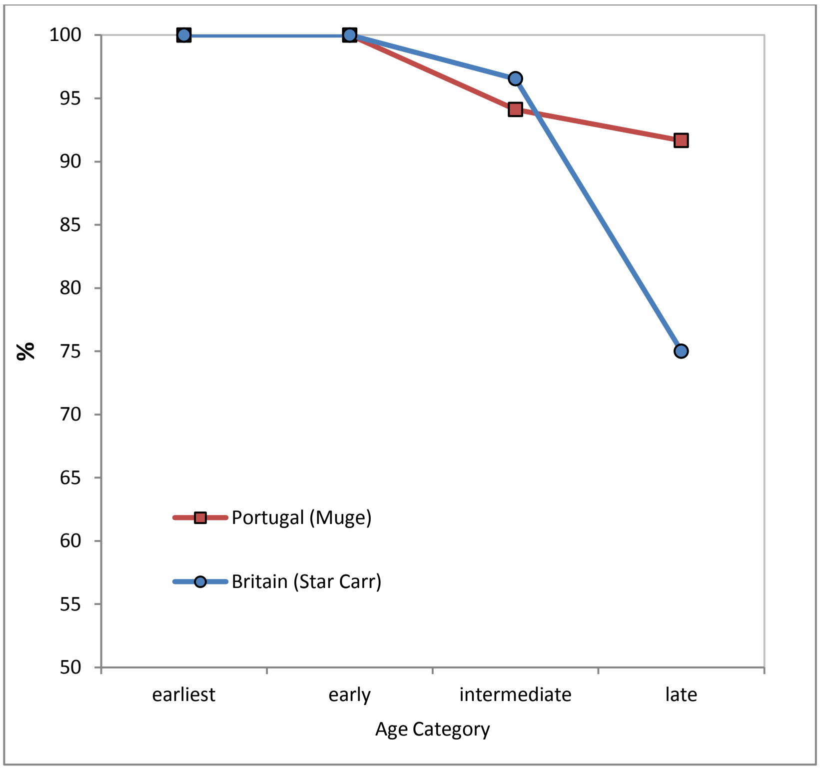


Figure 3.4.1: Fusion of *Bos* bones from the Portuguese Mesolithic Muge middens, compared with British Mesolithic Star Carr.

3.4.2 Biometry

3.4.2.1 Portugal

Summary statistics indicate a reduction of the means values for most bones between the Mesolithic and Chalcolithic periods. Calcaneum length (GL) however, shows an increase in its mean, suggesting that there are some very large animals in this sample. The Chalcolithic samples have wider ranges compared to the Mesolithic samples (high coefficient of variation values) which suggests that there is a mixeture of both wild and domestic animals in the samples, but the exact nature of the populations need to be explored further using scatterplots and log ratio histograms.

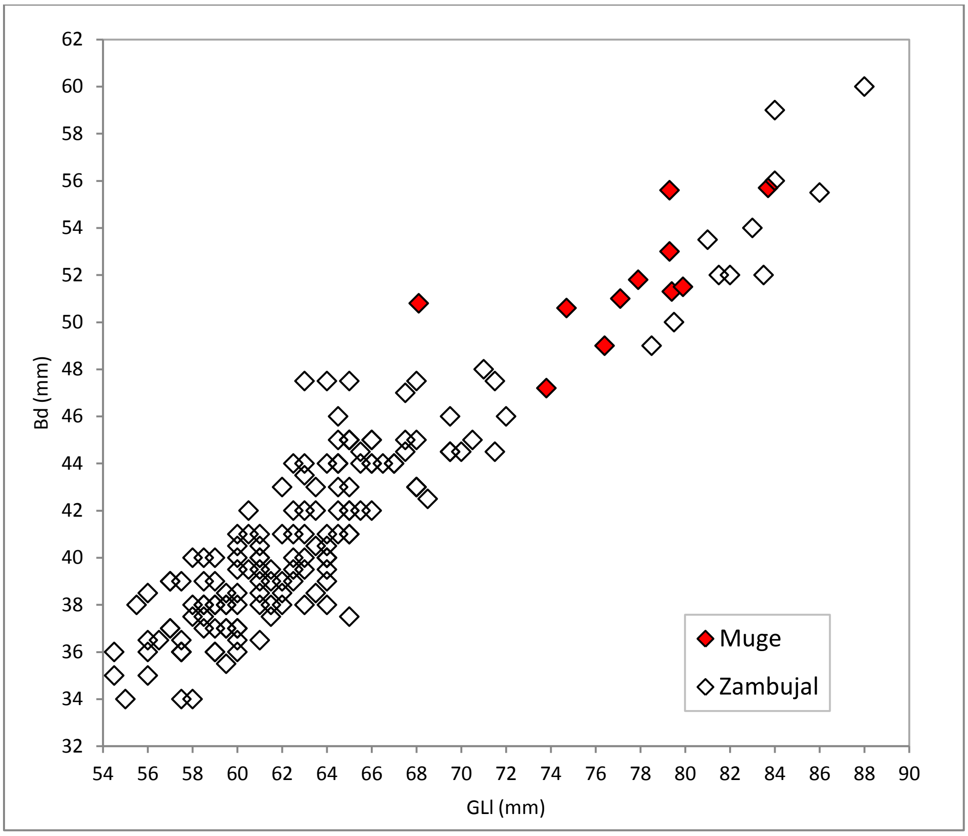


Figure 3.4.2: Scatterplot of astragalus measurements from the Portuguese Mesolithic sites of Muge (Cabeço da Arruda, Cabeço da Amoreira and Moita do Sebastião) and the Chalcolithic site of Castro do Zambujal (GLl = greatest length of the lateral side; Bd = breadth of the distal end).

Portuguese astragalus measurements show an overall increase with time, which is more perceivable in length than breadth (Figure 3.4.2). Material from Zambujal forms two groups, a larger and a smaller group, which could represent wild and domestic animals. The separation is clear within the Chalcolithic material, but some Mesolithic specimens plot very close to the potential 'domestic' group meaning that overall wild and domestic may not be so easily be separated. This pattern suggests that wild cattle got smaller going into the Neolithic period, before shifting to a larger size again at a later date – sometime before the Chalcolithic.

In order to see if this pattern was also seen for measurements on other bones, all postcranial measurements from each period were combined on log ratio diagrams (Figure 3.4.3). When analysing these results, it must be taken into account that calcaneum and tibia measurements from ‘domestic’ animals at Zambujal were not available, the ‘domestic’ population is represented by astragalus and metapodial measurements only.

Log ratios show that when all measurements are combined there is, on average, still a slight shift to larger animals in the Chalcolithic wild group. Although the mean for the Chalcolithic dataset is smaller, and this is greatly affected by the domestic animals in this group, the smaller peak of larger animals does peak at a larger size than the Mesolithic dataset does. It is possible that the overall smaller size of the Mesolithic animals could be caused by a higher proportion of female animals in the Muge assemblages, which may be biasing the pattern and exaggerating the shift to larger animals in the Chalcolithic, although the pattern may instead be a reflection of the measurements chosen for inclusion in the log ratio analysis – as we have seen in other geographical areas, this will become clearer when we look at the individual measurements contributing to the pattern. Measurements from specimens identified as deriving from domestic animals are much smaller, with minimal overlap, therefore confirming the astragalus data. The larger overall decrease in size, between the Mesolithic and Chalcolithic periods, due mainly to the large domestic dataset in the Chalcolithic sample is reflected by a highly significant result when they are tested statistically (Table 3.4.3).

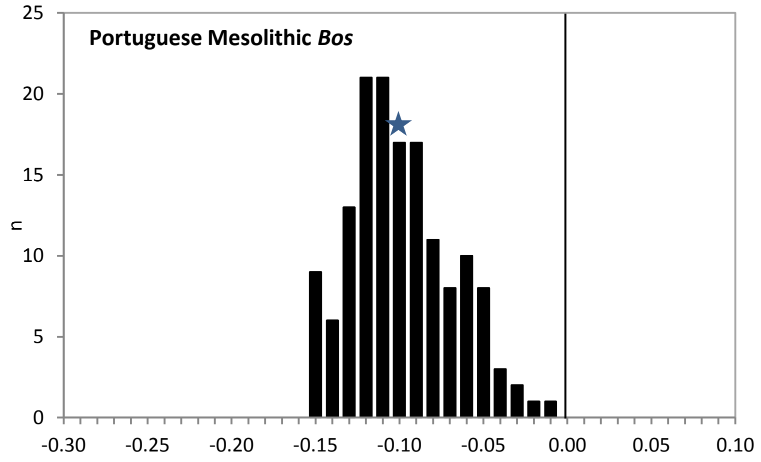
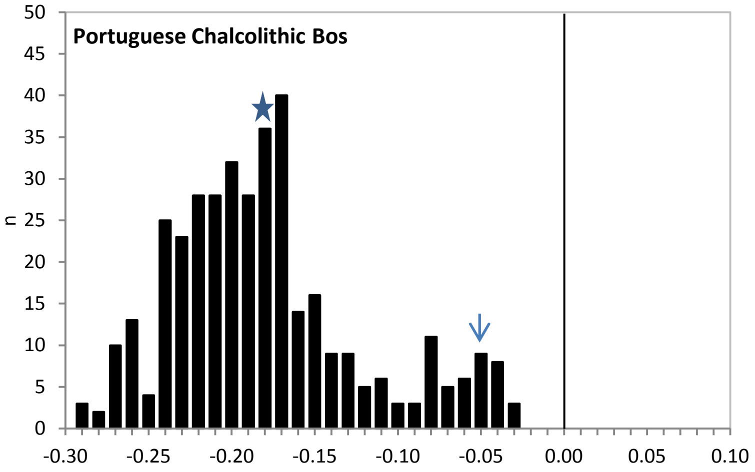
	n= 148 mean = -0.10
	n= 380 mean = -0.18 (Peak of potential wild group= -0.05)

Figure 3.4.3: Log ratios combining postcranial measurements from the Portuguese Mesolithic (top diagram) and Chalcolithic (bottom diagram). Means are indicated with a star. The very rough peak of the 'wild' group in the Chalcolithic dataset is shown using an arrow.

To see the potential effect of sexual dimorphism, and try to separate this from other factors, log ratios showing individual measurements from different bones were compared (Figures 3.4.4-3.4.7). Metapodial distal breadth measurements (Figure 3.4.4) are most useful for detecting sex groups, whereas astragalus, calcaneum and tibia measurements are likely to be less sex dependent. For the reasons explained above only specimens identified as 'wild' or 'probably wild' were included in this analysis.

Not enough metapodial measurements were available from the Chalcolithic period to compare to the material from the Mesolithic, but this does not prevent the analysis of the Mesolithic sample itself. Two potential groups can be identified in the plots of both metacarpals and metatarsals, and they may constitute sex groups (Figure 3.4.4). Should this be indeed the case, it would follow that females are better represented in the assemblage than males, which, assuming an equal sex representation for the Chalcolithic group, may explain the difference between the two periods.

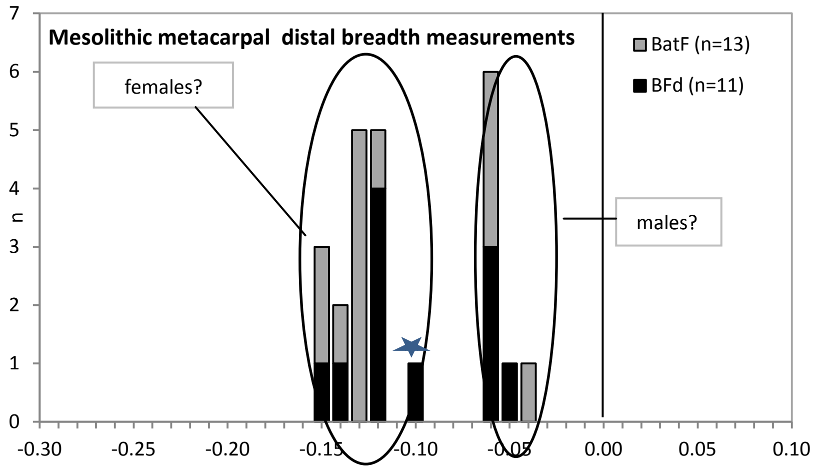
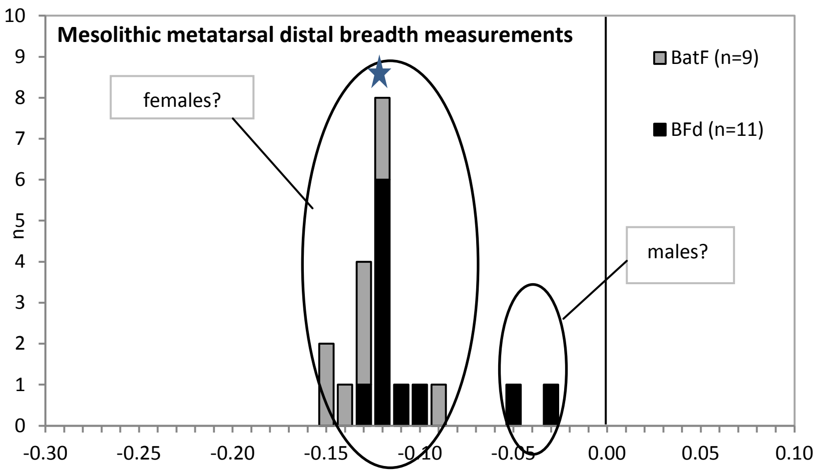
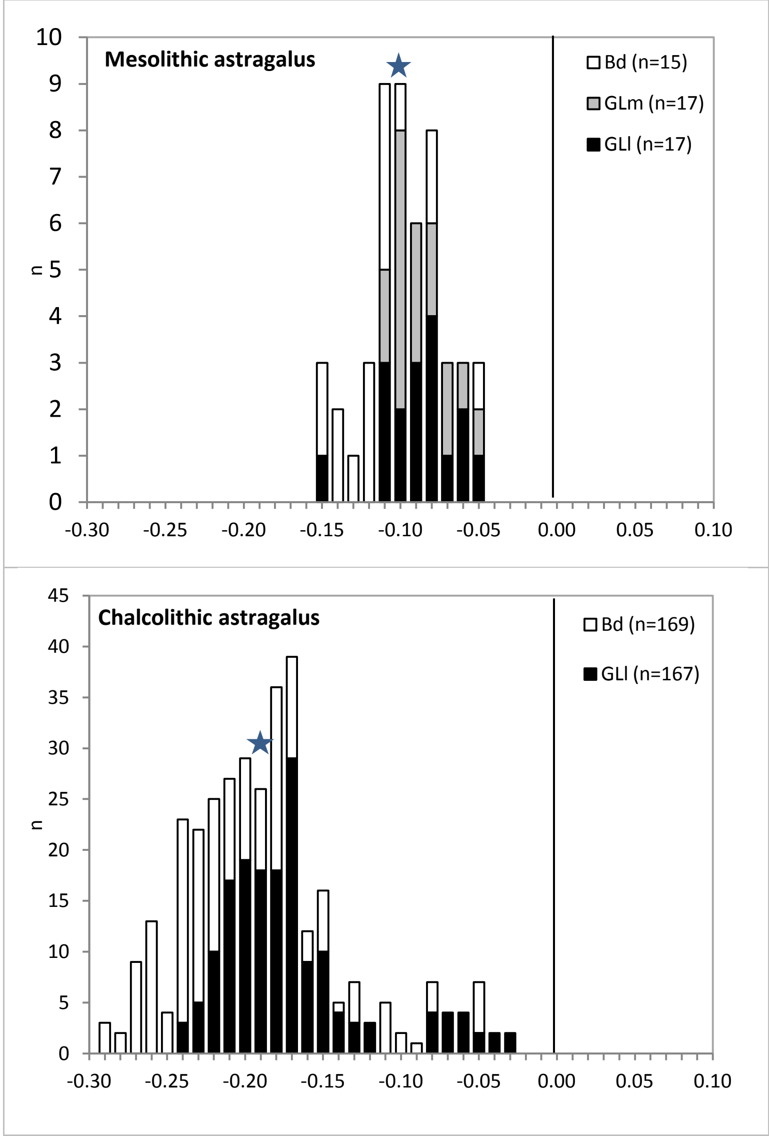
	n= 24 mean = -0.10
	n= 20 mean= -0.12

Figure 3.4.4: Metapodial distal breadth measurements from the Portuguese Mesolithic assemblage. BFd= breadth of the distal end, BatF= breadth at the distal line of fusion.

Log ratio diagrams showing astragalus measurements (Figure 3.4.5) confirm the data from the scatterplot (Figure 3.4.2) indicating some larger measurements in the Chalcolithic than in the Mesolithic. Unlike the metapodials, little sex related bimodality can be seen in the distribution of either period, which is not surprising, considering the likely lower degree of sexual dimorphism of this bone. However, astragalus breadth measurements are slightly more bimodal than length measurements, which show a very small degree of variation in comparison and stack on top of each other. If the Mesolithic pattern is mostly comprised of length measurements, this could be creating the skewed pattern.

Astragalus breadth measurements also tend to plot further away from the standard than length measurements, this is the case in both time periods, but is particularly noticeable in the Chalcolithic domestic group. This suggests that Holocene *Bos* astragali were slenderer than British Pleistocene *Bos* astragali, and that domestic cattle were slenderer still. This is a common pattern that has been seen in this study across the whole of Europe. Interestingly here, in the Mesolithic distribution, breadth measurements do not seem to plot quite as far from the standard as they do in other geographical areas. This will be explored in more detail in Chapter 4. Both the calcaneum (Figure 3.4.6) and the tibia (Figure 3.4.7) have some specimens which exceed the size of those from the Mesolithic, and therefore confirm the pattern identified for the astragalus, though the Chalcolithic tibia sample is very small.



n= 49

mean= -0.10

n= 336

mean= -0.19

Figure 3.4.5: Log ratio diagrams displaying astragalus measurements from Mesolithic and Chalcolithic Portugal. (GLl = greatest length of the lateral side, GLm= greatest length of the medial half, Bd= distal breadth).

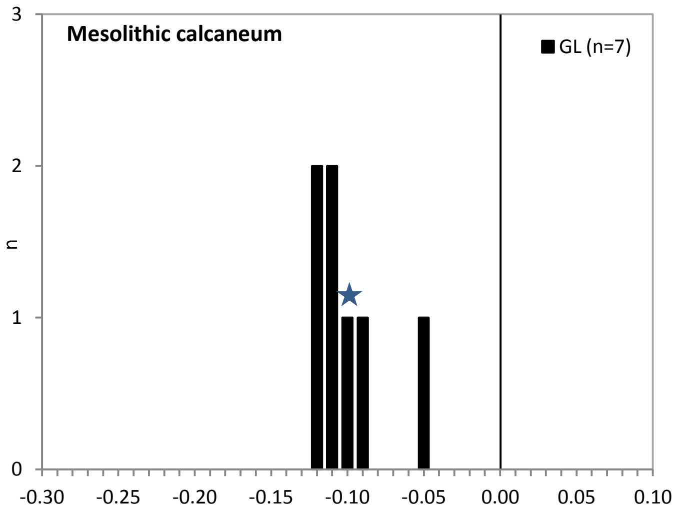
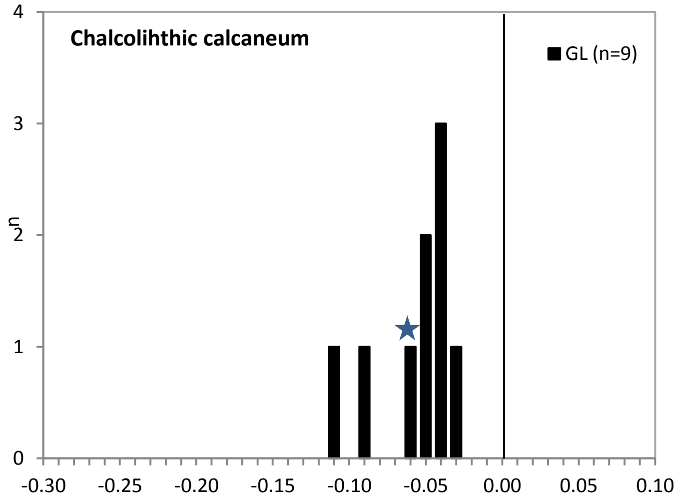
	n=7 mean= -0.10
	n=9 mean= -0.04

Figure 3.4.6: Log ratio diagrams displaying calcaneum length measurements from Mesolithic and Chalcolithic Portuguese sites. GL= greatest length.

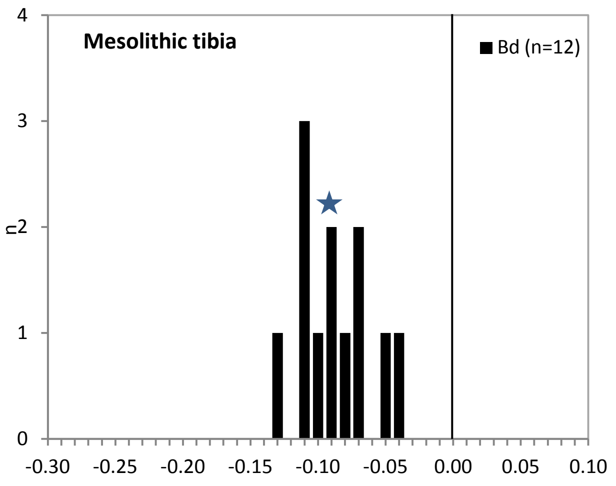
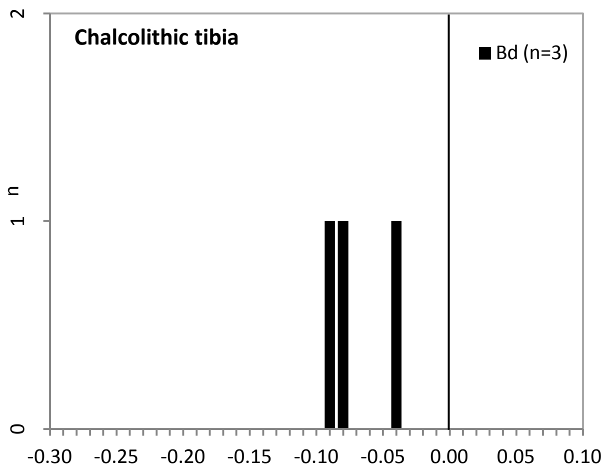
	n= 12 mean= -0.09
	n= 3 mean= sample too small

Figure 3.4.7: Log ratio diagrams displaying tibia measurements from Mesolithic and Chalcolithic Portuguese sites. Bd= distal breadth.

Overall, all individual measurements that it was possible to plot indicate a slightly larger size of the Chalcolithic aurochsen. The small size of the Chalcolithic samples means that these trends must be interpreted cautiously, but the larger sample obtained through the log ratio technique supports the suggestions of a size increase. The analysis of the highly sexually dimorphic metapodials suggests that in the Mesolithic the assemblage may contain more females than males, although only slightly, so this may not be enough to explain the bimodality seen in the overall plot. Alternatively, the pattern in the plot could be created by the selection of measurements that have been used to make the log ratio (i.e. a predominance of length measurements which have less variation than breadth and depth measurements). Taking into account the patterns seen in other areas of Europe, where this kind of pattern appears quite regularly, it does seem that this is the more likely explanation.

3.4.2.2 Spain

As has been the general trend throughout biometrical analysis in this project, the most common measurements were length measurements from the astragalus. Unfortunately many of the measurements from Cerro de la Virgen could not be split between the Chalcolithic and Bronze Age so for the analysis that involves these data the two time periods have been combined into one group

The only data available from the Middle Palaeolithic site of Solano del Zamborino were summary measurement ranges and means. The astragalus provided enough measurements to be able compare ranges from this site to those from the Mesolithic, Neolithic and Chalcolithic. No other elements provided enough data spanning a number of periods in order for them to be compared. To compare ranges has its limitations, but it was the only way of using the Pleistocene data.

Astragalus measurement ranges (Figure 3.4.8) show that the Middle Palaeolithic assemblage contains the largest specimens, but the mean value of this assemblage is actually slightly smaller than that of the Mesolithic. This suggests that it is actually only very few of the Palaeolithic specimens that are large and that these specimens make up only a small proportion of the assemblage. This is very interesting, when considered alongside the pattern seen in Italy (see Section 3.5 and Chapter 4) where a decrease in the body size of the aurochs seems to have taken place within the later Pleistocene itself, rather than at the very start of the Holocene. Of course the lack of individual measurements from Solana del Zamborino, restricts a more in depth analysis of the aurochs at this site, and the sample sizes here are also small.

There is an overlap between the Mesolithic, Neolithic and Chalcolithic size ranges, but the Neolithic range extends to measurements that are quite a lot smaller than those from the Mesolithic. The Chalcolithic range indicates that it contains some specimens that are larger than those from both the Neolithic and Mesolithic. The mean values reflect this, with all of the Chalcolithic means being larger than those from the Neolithic group. Neolithic and Chalcolithic samples show the largest ranges, which is what would be expected with the appearance of domestic cattle during the Neolithic. The Mesolithic sample shows the smallest range, but also has the smallest sample size.

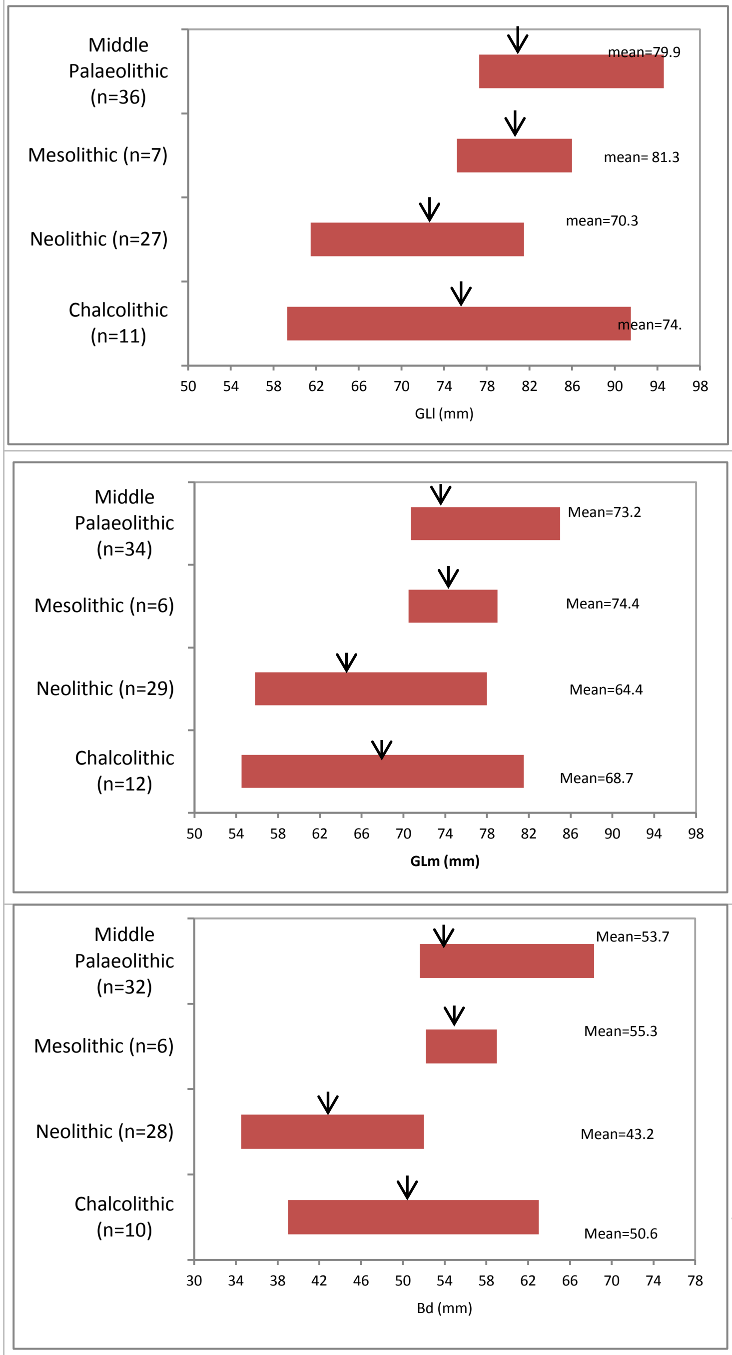


Figure 3.4.8: Astragalus measurement ranges from the Middle Palaeolithic to the Chalcolithic in Spain. GLl= greatest length of the lateral half, GLm= greatest length of medial half, Bd=distal breadth

The summary statistics for the Holocene of Spain (Table 3.4.2) indicate a reduction of the mean during the Neolithic period, and then and an increase going into the Chalcolithic period – similar to the pattern displayed by the calcaneum length (GL) for Portugal. Chalcolithic samples also display the greatest range, as indicated by the coefficient of variation. The Neolithic period clearly needs more investigation, because the coefficient of variation value lies midway between the Mesolithic and Chalcolithic values, and it is unclear if this population contains both wild and domestic animals. It is important, therefore to look at the spread of measurements using scatterplots and log ratio histograms.

Individual measurements provide a better opportunity for exploring the variation within an assemblage or time period. According to the scatterplot of astragalus length measurements (Figure 3.4.9 – top diagram) it is difficult to split the spread of specimens into clear wild and domestic groups as it was for the Portuguese material. It is probably safe to say that the majority of Neolithic, Chalcolithic and Bronze Age specimens that plot to the bottom end of the size range are from domestic cattle, but distinguishing where the wild specimens start is more problematic.

Specimens towards the top end of the range are likely to be wild, especially those that are an equal size to, or larger than the Mesolithic specimens. These include some Neolithic and some Chalcolithic/Bronze Age specimens. This pattern is seen in both length and breadth measurements. When the material from Cerro de la Virgen is removed (Figure 3.4.9 - middle diagram) it is clear that only one of these large specimens is potentially from the Bronze Age, and all of the rest are from the Chalcolithic or Neolithic. Some Chalcolithic specimens are larger than those from the Mesolithic. There is only one Neolithic specimen that is at all similar in size to the large Chalcolithic specimens.

Breadth measurements of specimens from the Mesolithic and the larger specimens from the Chalcolithic are especially large compared to the rest of the specimens. This means that where breadth measurements are displayed (Fugure 3.4.9 - bottom diagram) some of the Mesolithic specimens stand out more obviously than they do when just length measurements are plotted (top two diagrams).

These results hint at a similar increase in the size of wild cattle by the Chalcolithic period as seen in the Portuguese material. In the astragalus at least this increase is not evident in the Neolithic material, although it must be remembered that we do not have data for the Late Neolithic here so this does not rule out a size change prior to the Chalcolithic period.

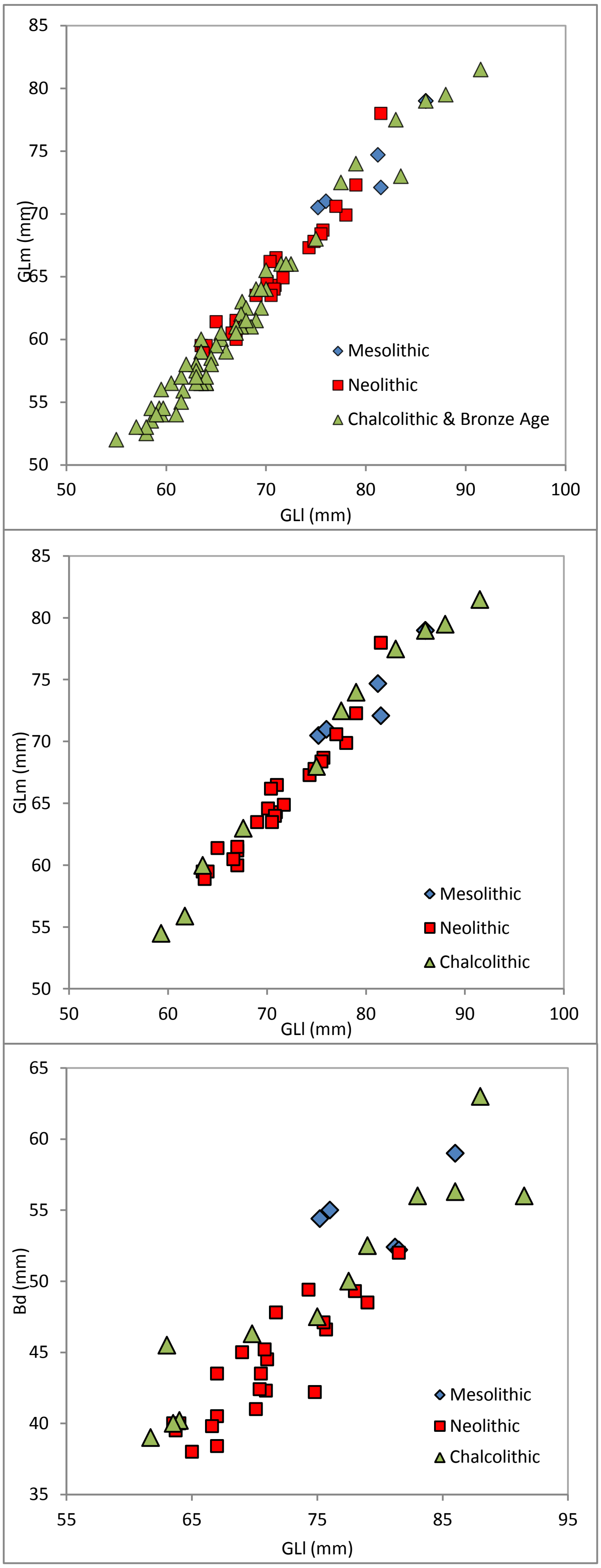


Figure 3.4.9: Spanish *Bos* astragalus measurements over time according to length measurements (top two graphs) and length vs. breadth measurements (bottom graph). GLl= greatest length of the lateral side, GLm= greatest length of the medial side, Bd=distal breadth.

Specimens from Cerro de la Virgen are included on the top graph, but excluded from the bottom two.

In the middle diagram specimens from Cerro de la Virgen are removed leaving a group made up entirely of specimens from the Chalcolithic period.

Log ratios combining all measurements (Figure 3.4.10) show that there are some particularly large specimens in the Chalcolithic compared to both the Neolithic and Mesolithic samples, therefore confirming the pattern seen in the scatterplots. This pattern suggests that the phenomenon may affect more than just astragalus measurements. The Neolithic measurements appear to plot unimodally, which is suggestive of a relatively low admixture of populations. In view of this, and their smaller size in comparison with Mesolithic aurochsen, most of the Neolithic specimens are likely to be domestic, although the distribution does overlap slightly with that of the Mesolithic, suggesting that the occurrence of a few potential wild specimens in this sample cannot be ruled out. The coefficient of variation results, also suggest that the Neolithic sample may contain a mix of wild and domestic, although not to the extent of the Chalcolithic sample (Table 3.4.2). In the Chalcolithic period there is a much greater variation (the extent of the range is similar to the Neolithic, despite the smaller sample size) and there is no peak, but a rather even spread of measurements. This distribution would be consistent with a combination of domestic and wild specimens though it does not seem to be possible to draw a line between the two. Interestingly, the larger specimens exceed the size of the Mesolithic aurochsen, therefore confirming the pattern already seen for Portugal. When the Spanish distributions are compared statistically, all tests result in statistically significant results, and this is unsurprising considering the obvious differences between them.

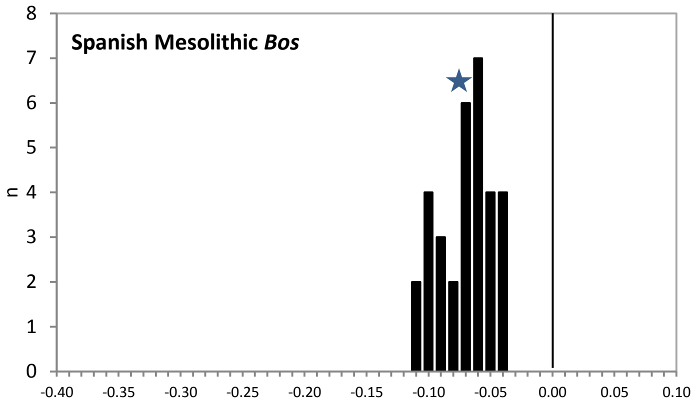
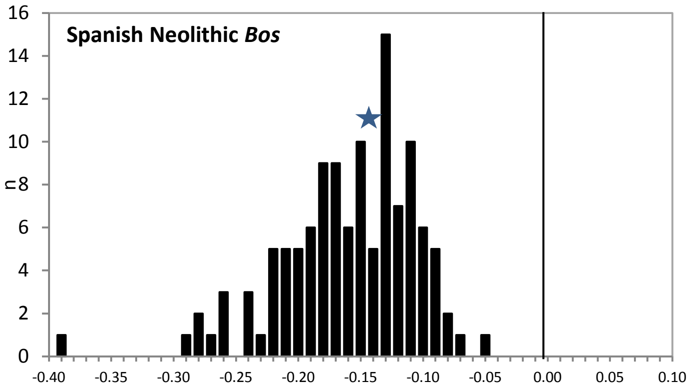
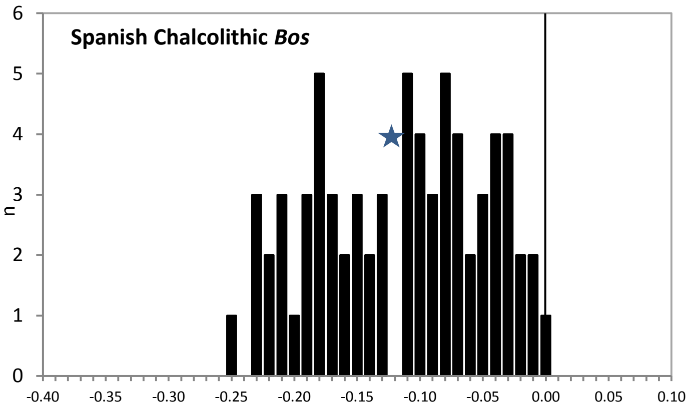
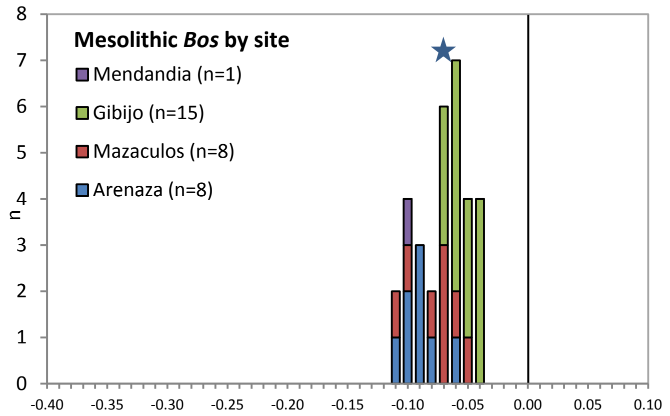
	n=32 mean= -0.07
	n= 120 mean= -0.14
	n=70 mean= -0.12

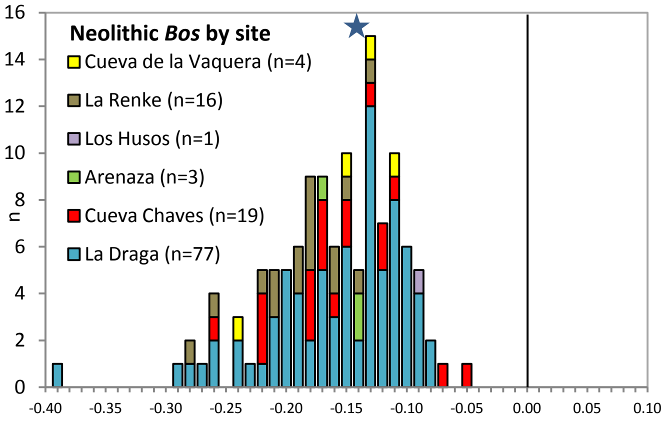
Figure 3.4.10: Log ratios combining all postcranial measurements from the Spanish Mesolithic (top), Neolithic (middle) and Chalcolithic (bottom).

When the same diagrams are displayed distinguishing measurements of specimens from different sites (Figure 3.4.11) it is possible to see that the majority of larger Mesolithic measurements come from one site (La Sierra de Gibijo). This is important, because in this case all of these measurements actually come from one articulated skeleton which has been identified as a male animal. Taking this into account, the few larger Neolithic specimens may have more significance as they are not just overlapping with female aurochsen. These specimens are mostly from the site of Cueva de Chaves. The larger Chalcolithic measurements are mostly from the same site - Los Castillejos - but there are also some specimens from Fuente Flores in this group. The other Chalcolithic sites included have very small sample sizes in comparison to Los Castillejos.



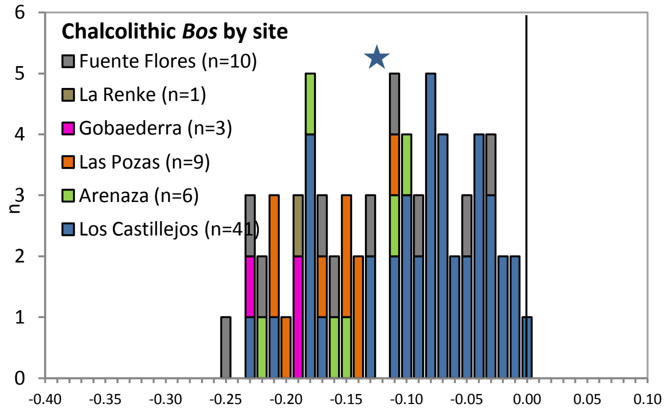
n= 32

mean= -0.07



n= 120

mean= -0.14



n= 70

mean= -0.12

Figure 3.4.11: Log ratio diagrams combining measurements from all postcranial remains for each time period, and splitting them according to site.

The large size of specimens in the Chalcolithic can be observed when log ratios are produced showing individual measurements (Figures 3.4.12 - 3.4.14). A number of measurements from different bones are larger than those from the Mesolithic.

The Chalcolithic astragalus sample contains length and breadth measurements large than any from the Mesolithic, and there are also tibia and femur measurements which plot outside of the Mesolithic range. Of all the bones with enough measurements to display, it is just those from the metapodials that do not show these patterns, although this could be due to sample size.

As seen in other geographical areas, breadth measurements are more variable and change more rapidly than length measurements. Both astragalus length and breadth measurements form two groups during the Chalcolithic period, which could represent wild and domestic animals. As seen in other geographical areas astragalus breadth measurements tend to plot further from the standard population in comparison to length measurements from the same period. This is especially prominent during the Neolithic in Spain, and suggests more slender animals during this period. Interestingly some of the large Chalcolithic animals are represented by large breadth measurements from the astragalus and tibia, which may reflect the especially plastic nature of these measurements. The pattern suggests that some Chalcolithic wild cattle did not have particularly slender bones, as you might expect from Holocene aurochs. The largest breadth measurements are very close to the standard population in size.

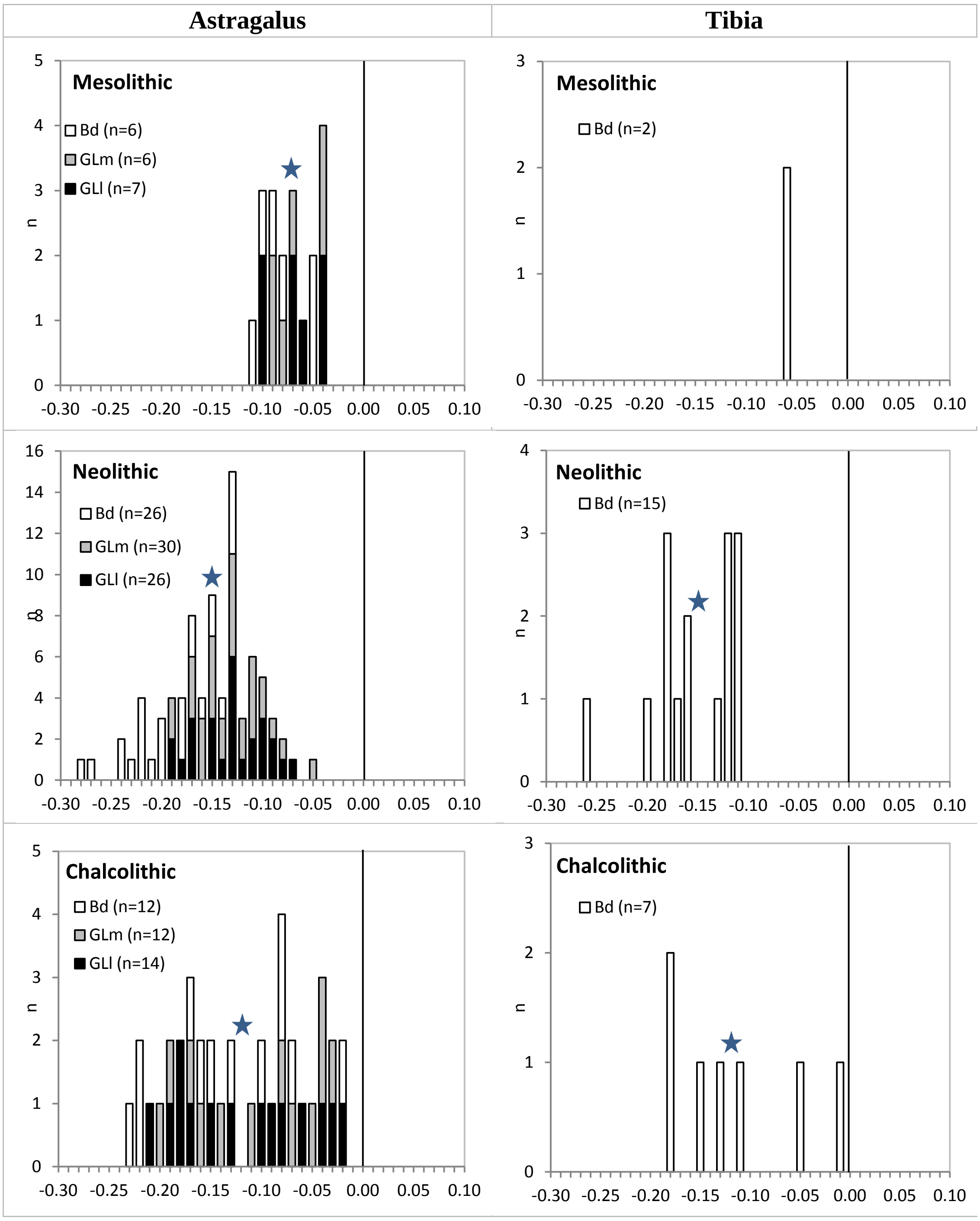


Figure 3.4.12: Log ratio diagrams displaying astragalus and tibia measurements from the Spanish Mesolithic (top), Neolithic (middle) and Chalcolithic (bottom).

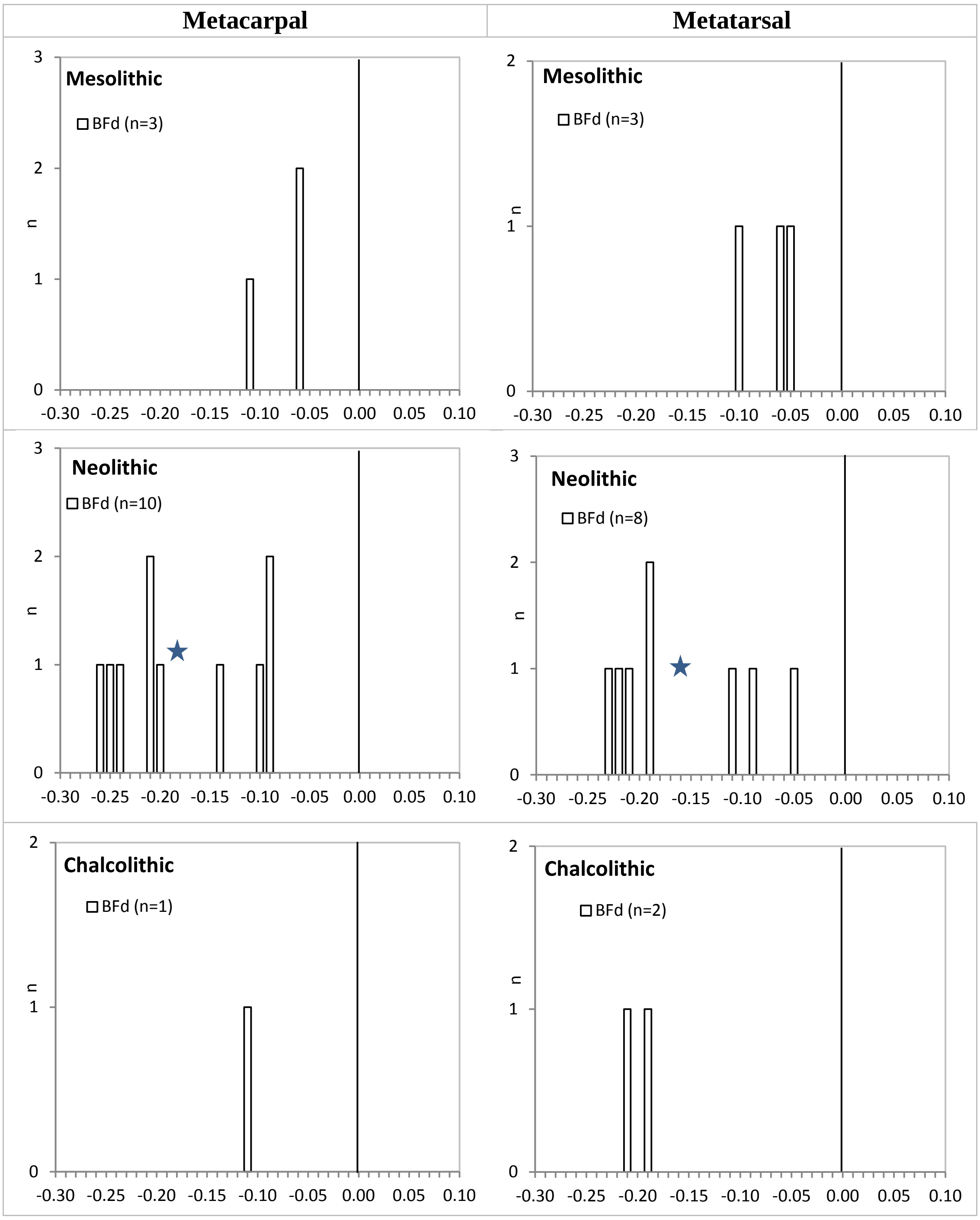


Figure 3.4.13: log ratio diagrams displaying postcranial breadth measurements from the Spanish Mesolithic (top), Neolithic (middle) and Chalcolithic (bottom).

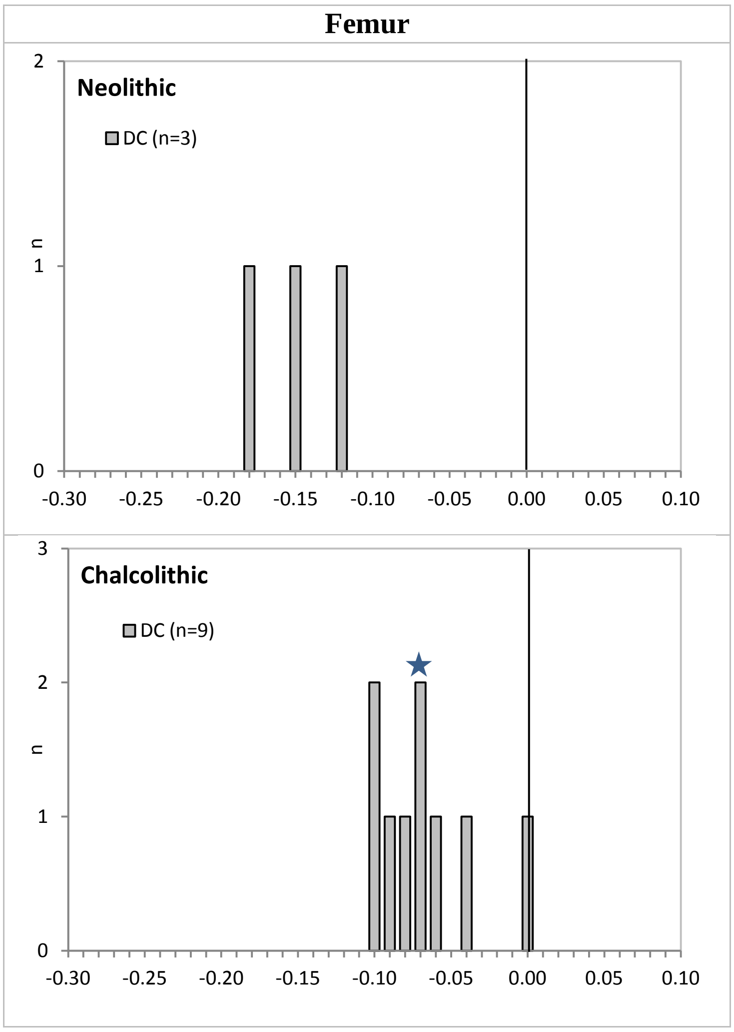


Figure 3.4.14: log ratio diagrams displaying postcranial depth measurements from Spanish Neolithic (top) and Chalcolithic (bottom) sites.

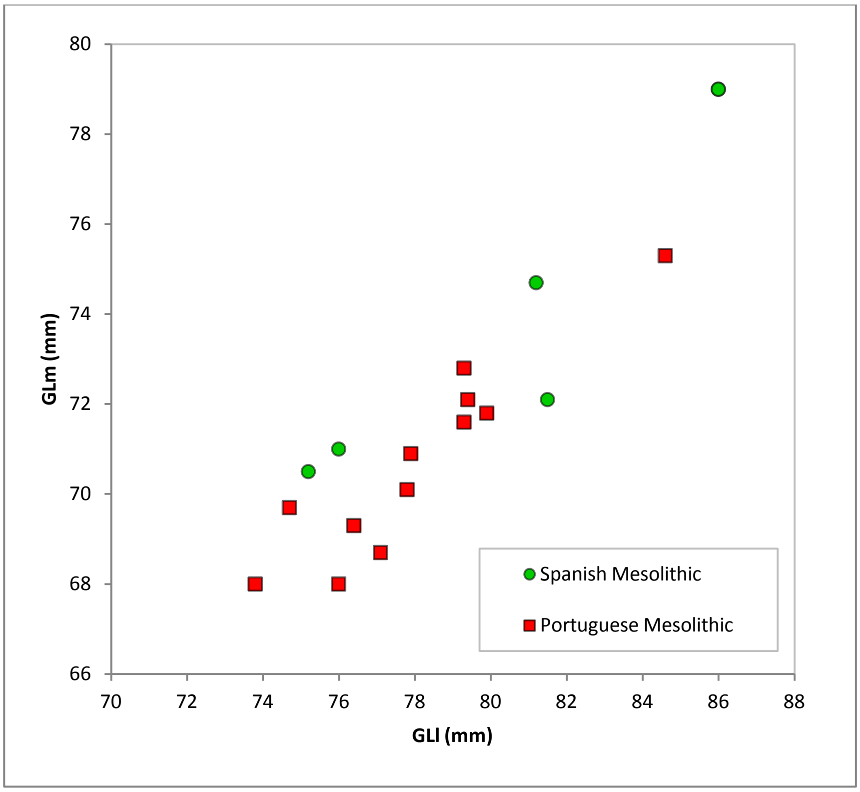


Figure 3.4.15: Scatterplot of astragalus measurements from the Spanish and Portuguese Mesolithic.

The pattern seen for the Spanish data complements that of the Portuguese material, and adds extra information from the Neolithic and Palaeolithic periods that was not available from the west of the Iberian Peninsula. However, there are some differences between the Portuguese and Spanish patterns. There are some differences between the Mesolithic groups. Figure 3.4.15 shows that the Spanish (Early Mesolithic) may be larger than the (Late Mesolithic) Portuguese material from Muge, which has some quite small specimens.

The size increase going into the Chalcolithic in Portugal is most obvious in length measurements from the astragalus and calcaneum, whereas for the Spanish data the pattern is most obvious in breadth measurements from the astragalus and tibia, and depth measurements from the tibia and femur. A scarcity of calcaneum measurements in the Spanish data means that it is not possible to see if this bone would have shown a size change. When astragalus lengths and breadths are compared between Spanish and Portuguese Chalcolithic samples (Figure 3.4.16) the pattern is very similar.

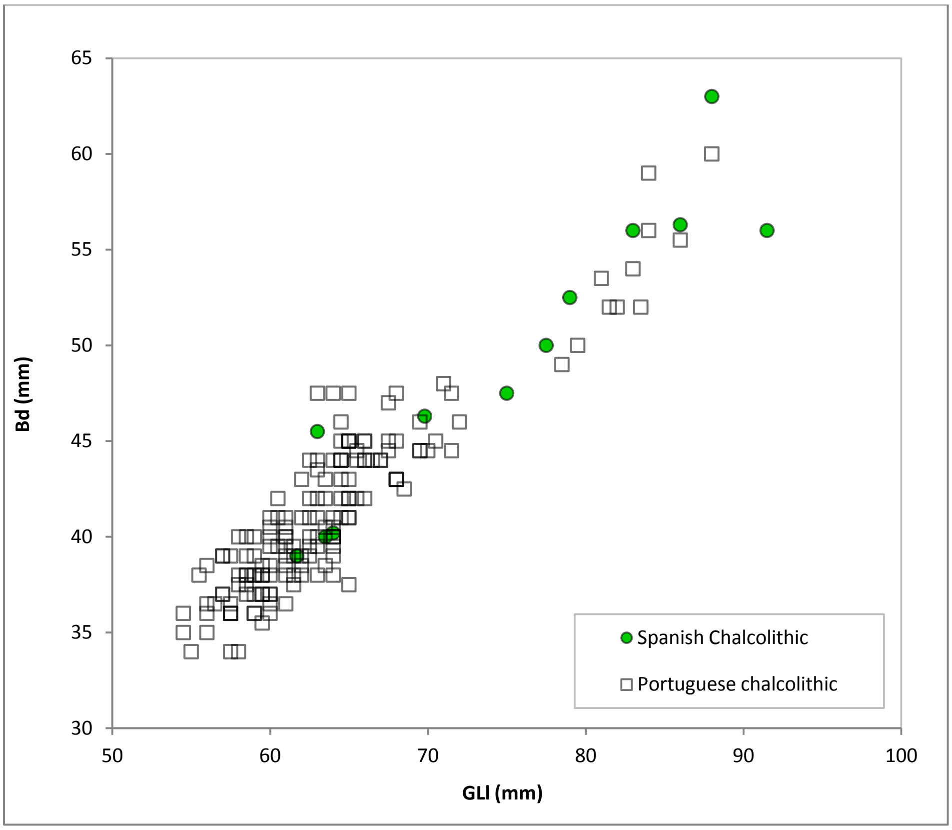


Figure 3.4.16: Scatterplot comparing Spanish and Portuguese astragalus length and breadth measurements. GLl= Greatest length of the lateral half, Bd= distal breadth

Most of the bones used in these analyses are relatively unaffected by age. They are also not particularly sexually dimorphic with the exception of metapodials. As a result in general the patterns they show are most likely to reflect external factors such as climatic change, or the effects of human impact, such as domestication or hunting pressure. In view of a Chalcolithic size increase in Spain as well as Portugal it seems unlikely that the change in Portugal is purely dependent on different sex ratios between the different periods. The change appears to affect a broad geographic area and it is unlikely to be dependent on the specific circumstances of a population, a site or even a geographically restricted group of sites.

The changes at the bottom end of the size range seem most likely to be related to domestication. This is most clear in the Chalcolithic assemblages, where there is a large amount of variation considering the sample sizes available. There is no peak, but a rather even spread of measurements. This pattern is not so clear for the Spanish Neolithic material which gathers towards the smaller end of the scale, implying that very few wild specimens are present. There is some overlap between the Neolithic dataset and those from the Mesolithic and Chalcolithic, suggesting the potential presence of a small number of wild specimens. Separating wild from domestic is, however, extremely difficult, with perhaps only two measurements from Cueva de Chaves being large enough to claim with any degree of confidence that they may be from wild animals.

The changes between time periods at the top end of the size range are going to be unaffected by domestication, so perhaps we can exclude this factor. Here the climatic deterioration may be having an impact, as the Chalcolithic period in Iberia falls after 3000 cal BC. Unfortunately we have a lack of data from the time period immediately after the onset of the climatic change, which would correspond with the Late Neolithic. All of the Neolithic data included here is too early to be affected by this change. The Chalcolithic material, on the other hand, is at the correct time to have been affected. These data could therefore provide evidence that *Bos primigenius* began to increase in size in reaction to this climatic deterioration.

Of course this body size change may not be the result of just one factor and other potential events must also be taken into account. An alternative that has previously been suggested and should be explored is the impact of human hunting pressure. Some previous studies have looked to a relaxation of hunting pressure after the onset of domestication as an explanation for the increase of size in red deer in Portugal (Davis 2006) and wild boar in Italy (Albarella *et al.* 2006) after the Mesolithic.

These results can be discussed in more detail with the aid of more contextual information and by their comparison with previous work on other animals done for these areas.

3.4.3 Iberian *Bos* and *Sus* results in comparison

The interpretation of the results from Portugal and Spain may be further enhanced by comparing the *Bos* results with those seen for *Sus* remains from some of the same sites, and the way that they have been interpreted. *Sus* data are available for a number of the sites included in this section and they will be discussed here. In all of these diagrams potential domestic and wild animals are combined, creating one ‘*Sus*’ group.

3.4.3.1 Portugal

The *Sus* measurements presented here are those discussed in Albarella *et al.* (2009) and derive from Castro do Zambujal and the Muge middens. The raw data were subsequently kindly passed on to the author.

Scatterplots of *Sus* humerus measurements from Muge and Zambujal show a less clear distinction between wild and domestic specimens in comparison to *Bos* astragalus measurements (Figure 3.4.17). The sample from Muge plots in a similar place on the diagrams for both *Bos* and *Sus*, but the sample from Zambujal shows a clear separation between wild and domestic; for *Bos*, whereas for Sus it is more mixed. Of course these diagrams are not of the same bones and are not absolutely comparable, but the similarity in the overall pattern is interesting, as is the presence of a number of particularly large specimens at Zambujal for both species.

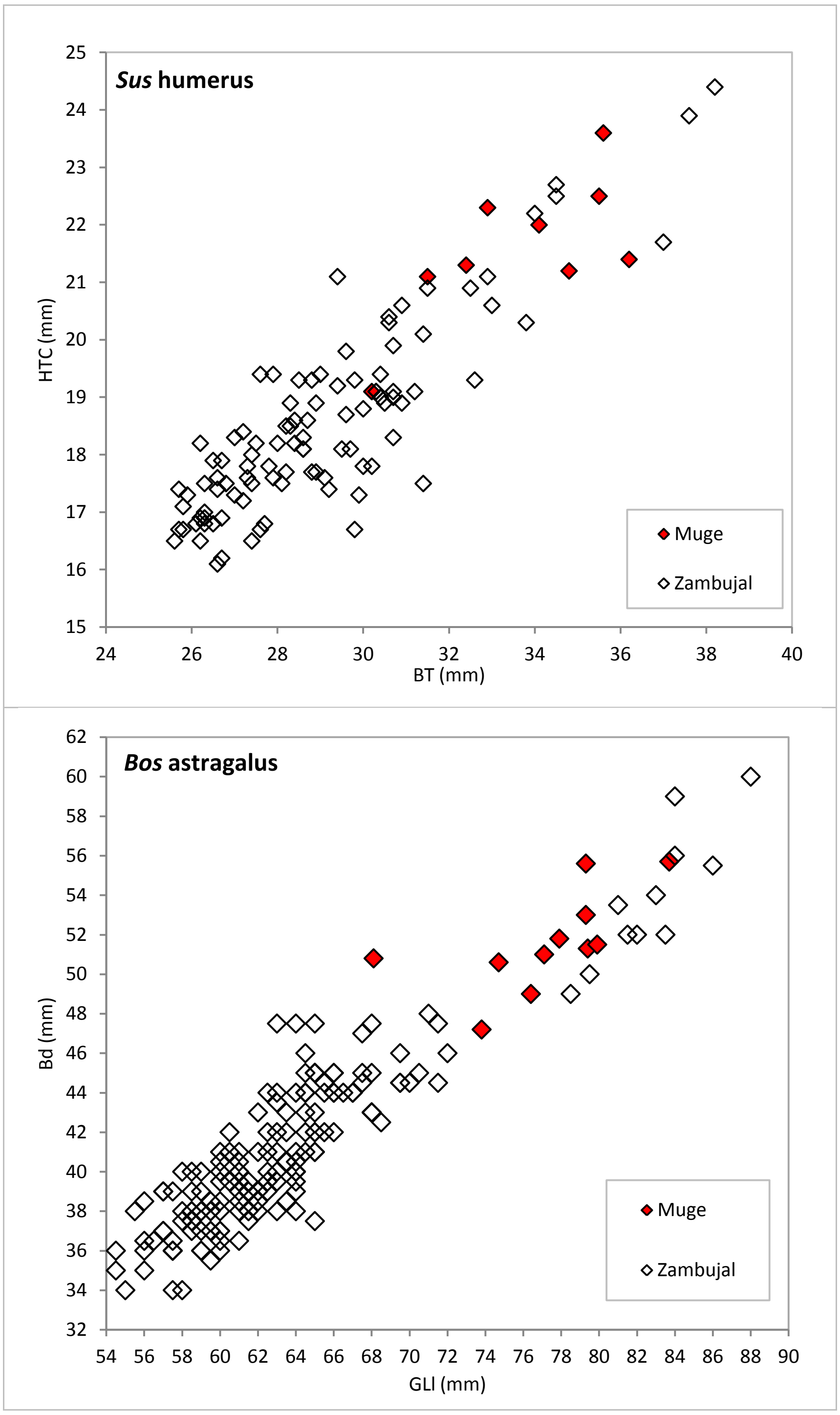
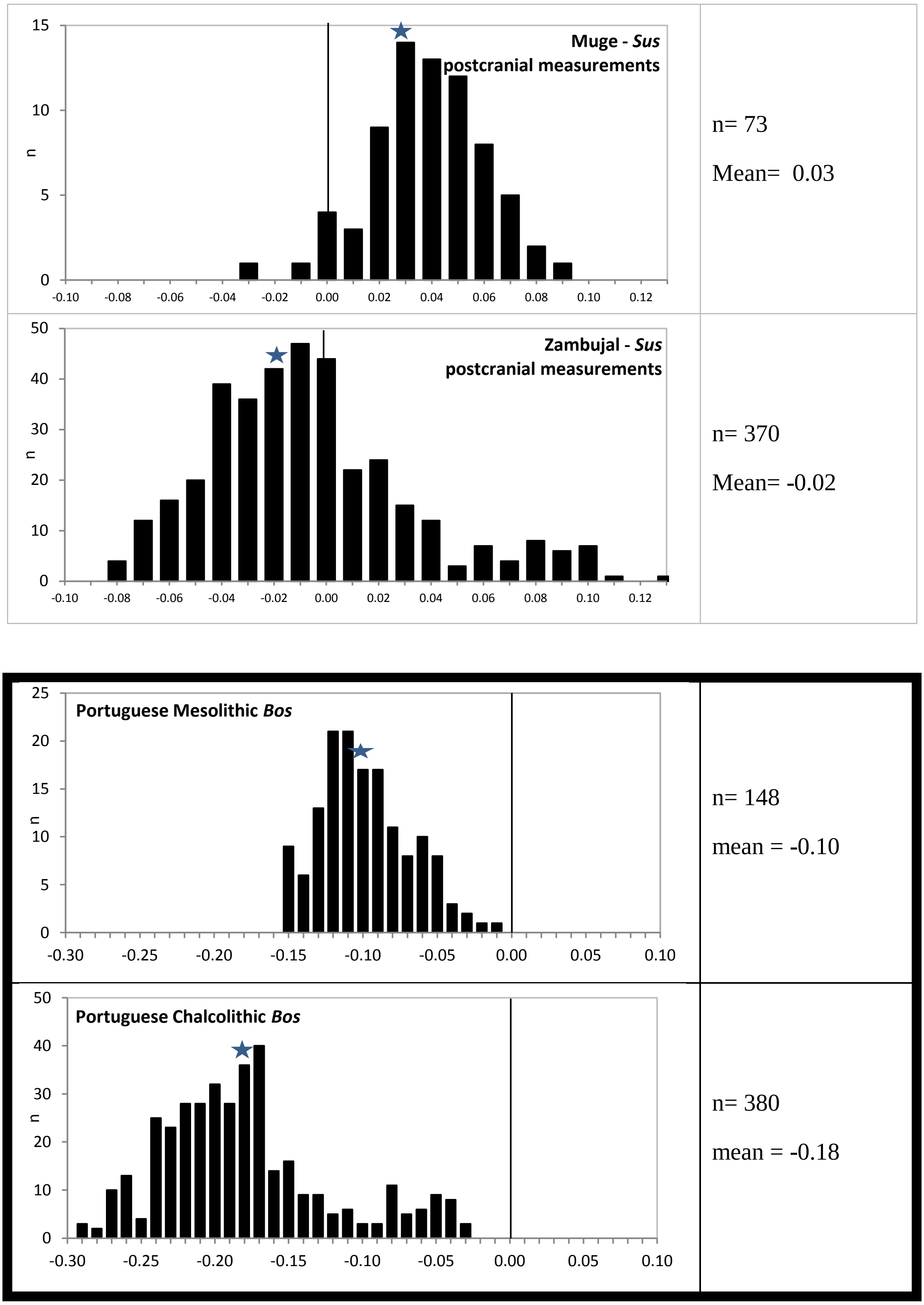


Figure 3.4.17: Scatterplot of *Sus* humerus and *Bos* astragalus measurements from the Mesolithic site of Muge and the Chalcolithic site of Zambujal. (BT= breadth of the trochlea; HTC= height of the trochlea restriction; Bd= (breadth of the distal end); GLl= (greatest length of the lateral side).

The creation of log ratios (Figure 3.4.18) helps little in distinguishing between wild and domestic, but overall the pattern is similar to that seen for *Bos* (bottom diagram). Both *Bos* and *Sus* log ratios from Zambujal show two peaks indicating a wild and domestic group but there is overlap between them. Of course the *Bos* domestic group contains relatively few specimens and is mainly made up of astragalus measurements because not all measurements were available, but the two peaks are still visible. The main difference between the *Bos* and *Sus* results is that there are clearly a few *Sus* measurements from Zambujal that are larger than all of the Mesolithic measurements. This pattern is present for *Bos*, but only when individual bones are displayed.



n= 73

Mean= 0.03

n= 370

Mean= -0.02

n= 148

mean = -0.10

n= 380

mean = -0.18

Figure 3.4.18: Log ratios of *Sus* (top diagrams) and *Bos* (bottom diagrams inside thick border) postcranial measurements from the Mesolithic sites at Muge and the Chaclolithic site of Zambujal. Note that *Sus* and *Bos* diagrams are not on the same scale and do not have the same standard, the *Bos* diagrams are provided for the comparison of the overall pattern only.

Another similarity between the *Bos* and *Sus* results is that the Mesolithic *Sus* sample also peaks to the left of the top end of the Chalcolithic distribution. The similarity of the *Bos* and *Sus* patterns makes the sex explanation less likely, as this would rely on the fact that for both species female animals were being specifically targeted above males. Explanations for this pattern in *Sus* are potentially much the same as those for *Bos*. If the size increase in *Bos* were indeed due to the climatic deterioration of the 3rd millennium BC, it would make sense that this phenomenon was not restricted just to one animal.

Von den Driesch and Boessneck (1976) interpret the gap between domestic and wild *Bos* seen at Zambujal (Figure 3.4.2 and 3.4.3) as evidence of a lack of 'transitional' sized cattle, and therefore as evidence that this was a population unaffected by local domestication. They interpret the lack of clear groups for the *Sus* pattern as a result of Spanish wild boar being smaller than those from central and eastern Europe. These explanations are not necessarily incorrect, but a number of other, potentially more plausible possibilities must also be taken into account. As Zambujal is a Chalcolithic site, any inferences concerning the beginning of the domestication process must be treated cautiously, as by this time domestication already had a long history. By the Chalcolithic period domestic and wild populations may have developed different and well-distinguished characteristics, whether domesticates had originally been imported or not. This would have particularly been the case if hybridization did not occur on a regular basis.

If hybridisation (or lack of it) is a possible explanation for the difference between the two different species, then perhaps a more likely scenario is a difference in the treatment of *Bos* and *Sus* populations at Zambujal. If *Sus* were more often kept as free-range animals than *Bos* were, then domestic and wild animals would have had more opportunity to interbreed. Alternatively the size overlap in the *Sus* population could be related to sexual dimorphism within both the domestic and wild *Sus* groups. This could be exacerbated by the fact that humerus measurements are more likely to be affected by sexual dimorphism than astragalus measurements.

3.4.3.2 Spain

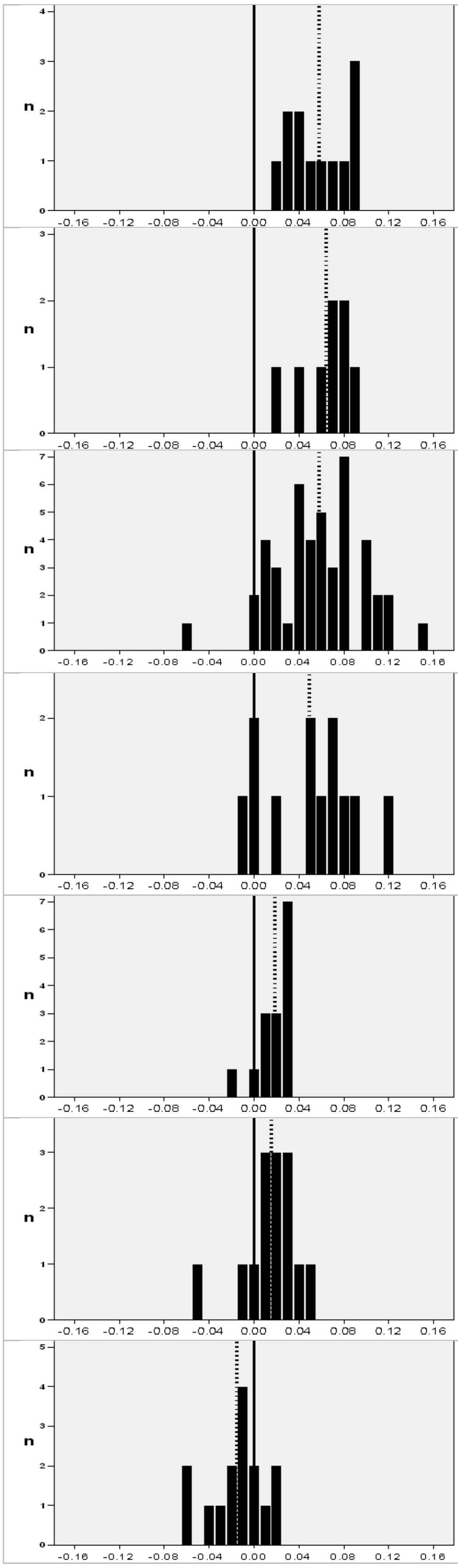
The situation is more complicated in Spain, partly as a consequence of the greater diversity of sites. It is worth bearing in mind that work on Spanish *Sus* remains has demonstrated that different Neolithic sites had very different characteristics in terms of the occurrence of wild and domestic forms, with an obvious difference between open and cave sites (Hadjikoumis 2010). This information may help in the interpretation of the cattle data.

Most of the Spanish Neolithic samples included in the study of *Bos* are small, with the exception of La Draga and Cueva de Chaves. The smaller samples do not show much evidence of potential wild specimens, but are also so small that it is not worth analysing their individual patterns in detail. The part of the *Bos* Neolithic distribution that represents larger specimens and overlaps with the Mesolithic distribution is dominated by specimens from La Draga and Cueva de Chaves, with two specimens from Cueva de Chaves extending further than those from La Draga, and reaching the extent of the Mesolithic specimens from the male skeleton at Sierra de Gibijo. These are the sites that will be dealt with here.

Cueva de Chaves is an Early Neolithic cave site where domestic species, according to the interpretation of the original researcher, dominate the faunal assemblage (Castaños 2004). Subsequent biometrical analysis of *Sus* remains from the site has, however, highlighted the overall large size of these animals compared with other sites from the Spanish Early Neolithic such as Cueva de la Vaquera and La Draga (Hadjikoumis 2010) - see Figure 3.4.19. This pattern has been interpreted as a sign that the *Sus* remains at Cueva de Chaves contain a mixture of wild and domestic forms, possibly as a consequence of a population that was (perhaps partly) locally domesticated but had not yet fully developed the morphological traits that are characteristic of domestic animals (Hadjikoumis 2010). The presence of the two large *Bos* specimens, along with much smaller specimens from the same site (Figure 3.4.11) raises the possibility that the *Bos* assemblage too may comprise both domestic and wild forms.

The larger *Bos* specimens from La Draga (Figure 3.4.11), which is an open-air site, do not stand out in the same way as those from Cueva de Chaves, and do not overlap so much with the Mesolithic male from Sierra de Gibijo, but they do still overlap with other Mesolithic aurochs specimens and so the identification of some of these specimens as wild cannot be completely excluded. In fact the larger *Bos* specimens from La Draga overlap with the Mesolithic sample to a greater extent than the *Sus* specimens do (compare Figure 3.4.11 with Figure 3.4.19). *Sus* from La Draga were seen to be quite a lot smaller than those from Cueva de Chaves and this is interpreted to be evidence of a dominance of domestic animals at the site, in contrast to the more mixed situation at Cueva de Chaves (Hadjikoumis 2010:91).

Overall the size differences between Cueva de Chaves and La Draga are not as clear for *Bos* as they are for *Sus*. There is a slight hint that Cueva de Chaves may have yielded a higher proportion of wild specimens, but the larger *Bos* specimens at La Draga might also be wild, while the pigs form this site are consistent with all being domestic (Figure 3.4.19).



Final/Advanced Magdalenian (combined sites)

n= 12

mean= 0.06

Epipalaeolithic/Mesolithic (combined sites)

n= 8

mean= 0.06

Cueva Chaves (Early Neolithic)

n= 45

mean= 0.06

Cova Fosca (Early Neolithic)

n= 12

mean= 0.05

La Draga (Early Neolithic)

n= 15

mean= 0.02

Cueva de la Vaquera (Early Neolithic)

n= 15

mean= 0.02

Late Neolithic (combined sites)

n= 15

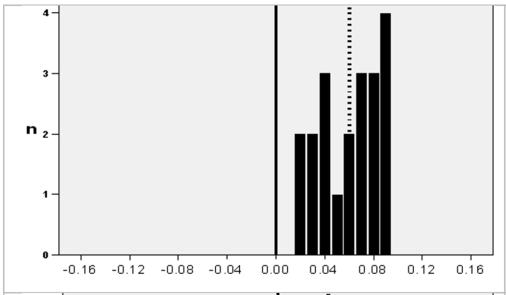
mean= - 0.02

Figure 3.4.19: Log ratios of *Sus* postcranial remains from Spanish sites, including the breakdowns of Early Neolithic sites (taken from Hadjikoumis 2010: 70, with permission – Figure 3.22). The standard population is the solid line and the mean is indicated by the dashed line.

The majority of the specimens in the *Bos* Chalcolithic sample are from the site of Los Castillejos. Castaños (1997) has identified the majority of these specimens as aurochs as opposed to domestic cattle. There is a clear presence of wild animals at the site, with a large proportion of red deer identified, although more domestic pig has been identified than wild boar. Aurochs have been identified based on measurements from a number of bones but only measurements from the first and second phalanges are presented as scatterplots in the original report. Issues of identifying anterior from posterior phalanges are mentioned but wild and domestic are still identified on this basis. The presentation of measurements as log ratios in this study, however, agrees in general with the potential for most of the specimens to be wild. Most of the specimens either overlap with, or are larger than those from the Mesolithic (Figure 3.4.11). Castaños (1997) suggests that this pattern may indicate locally domesticated cattle in an 'initial state' of domestication, but this pattern could just as easily stem from a predominance of the consumption of hunted wild cattle in comparison to domestic cattle at the site. Either way, the large size of some of the specimens beyond the size of the Mesolithic sample cannot be disputed. This pattern is not mirrored in the *Sus* Chalcolithic sample from Los Castillejos, or in fact in any of the other Chalcolithic *Sus* datasets (Hadjikoumis 2010) see Figure 3.4.20 below. However, there is evidence of a similar size change by the Bronze Age, where there are a number of specimens that are larger than any from the pre-Neolithic group (Figure 3.4.20).

Overall, there is evidence for similar processes occurring in both *Bos* and *Sus* in the Iberian Peninsula between the Mesolithic and Bronze Age. The Portuguese samples especially show a lot of similarities. The study of Spanish sites by Hadjikoumis (2010) highlights the variation that can exist between different Neolithic sites, and that is often difficult to interpret patterns when many sites are combined. This is a similar situation to that emphasised by the German Early Neolithic sample, which also demonstrated a large amount of variation between sites. It seems that a diversity of husbandry practices was taking place during the Early Neolithic, which may have been related to how isolated the domestic populations were, and may be directly related to the location of the sites in question.

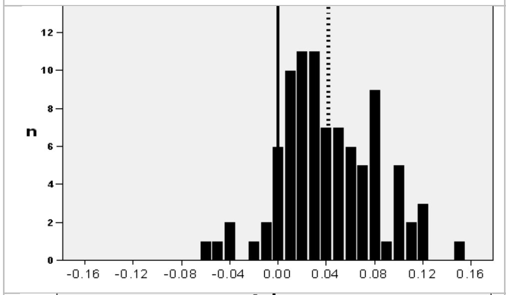
Both *Bos* and *Sus* remains indicate an increase in size after the Neolithic period, with this becoming evident in some bones from both animals during the Chalcolithic period, and then even clearer for *Sus* in the Bronze Age. This change in size is concurrent with a similar change seen in wild boar in Italy (see the following chapter for further discussion of this), and it is thought that the most likely explanation for this is related to the post-Mesolithic climatic deterioration (Albarella *et al.* 2006), which has been the focus of much of the analysis in this project.



Pre-Neolithic (combined sites)

n= 20

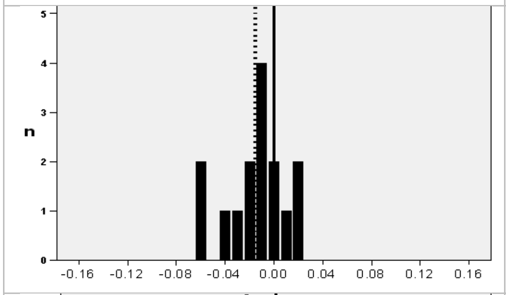
mean= 0.06



Early Neolithic (combined sites)

n= 91

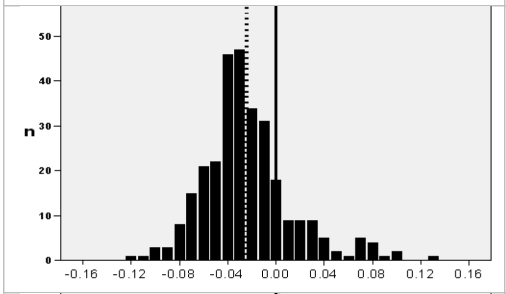
mean= 0.04



Late Neolithic (combined sites)

n= 15

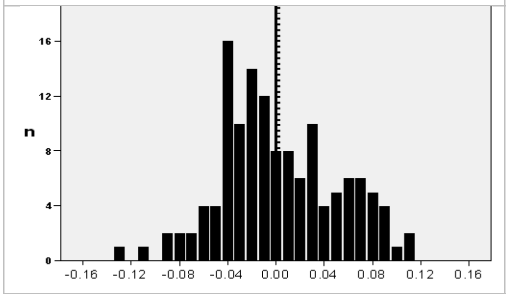
mean= - 0.02



Copper Age (combined sites)

n= 298

mean= - 0.02



Bronze Age (combined sites)

n= 133

mean= 0.00

Figure 3.4.20: Log ratios of *Sus* postcranial remains from Spanish sites by time period (taken from Hadjikoumis 2010: 167, with permission – Figure 4.91). The standard population is the solid line and the mean is indicated by the dashed line.

Table 3.4.1: Summary statistics for archaeological *Bos* from Portugal. Only archaeological material is included. Samples of less than 5 were excluded.

Measurement	No.	Min	Max	Mean	Standard deviation	Coefficient of variation
Astragalus GLl						
Mesolithic	17	68.1	84.6	77.96	4.16	5.34
Chalcolithic	167	54.5	88	64.53	7.37	11.42
Astragalus Bd						
Mesolithic	15	47.2	59.8	51.65	3.34	6.47
Chalcolithic	169	34	60	42.20	5.60	13.27
Calcaneum GL						
Mesolithic	7	149	174	155.29	8.85	5.70
Chalcolithic	9	152	183	171.56	10.44	6.09
Metacarpal BFd						
Mesolithic	11	65.9	81.9	73.86	6.13	8.29
Chalcolithic	11	49.5	70	58.36	6.10	10.45
Metatarsal BFd						
Mesolithic	11	60.9	76.4	65.05	5.02	7.71
Chalcolithic	9	52	76	61.28	9.76	15.93

Table 3.4.2: Summary statistics for archaeological *Bos* from Spain. Only archaeological material is included. Samples of less than 5 were excluded.

Measurement	No.	Min	Max	Mean	Standard deviation	Coefficient of variation
Astragalus GLl						
Mesolithic	5	75.2	83	79.38	3.53	4.45
Neolithic	26	61.5	81.5	70.56	5.54	7.85
Chalcolithic	14	59.3	91.5	73.49	10.81	14.71
Astragalus GLm						
Neolithic	30	55.8	78	64.31	4.88	7.59
Chalcolithic	12	54.5	81.5	68.65	9.94	14.48
Astragalus Bd						
Neolithic	26	35	52	43.25	4.41	10.19
Chalcolithic	12	39	63	49.36	7.62	15.44
Tibia Bd						
Neolithic	15	50	71.8	64.46	6.17	9.57
Chalcolithic	7	60	89	70.79	10.75	15.19

Table 3.4.3: Results of the Mann-Whitney tests on *Bos* postcranial log ratios from Iberia. Significant results (<0.05) are marked with an * and highly significant results (<0.01) are marked with **. Only archaeological material has been included in the statistical analyses. Samples of less than 20 were excluded.

Group	n.	Group	n.	U	z	Sig.
Portugal Mesolithic	70	Portugal Chalcolithic	199	2053.00	-8.78	0.000**
Spain Neolithic	57	Spain Chalcolithic	39	747.50	-2.72	0.007**
Portugal Mesolithic	70	Spain Neolithic	57	651.00	-6.54	0.000**
Portugal Mesolithic	70	Spain Chalcolithic	39	1189	-1.116	0.264
Portugal Chalcolithic	199	Spain Chalcolithic	39	2314.00	-3.99	0.000**

3.5 Italy

Italy is the only country with a large enough sample of tooth measurements to be able to compare with postcranial remains in this study, with the exception of the small Danish tooth sample. Changes in tooth measurements can be compared to those of postcranial remains to see if bones and teeth reacted similarly to different factors.

Pleistocene data are much more numerous in the Italian dataset than for any other country in this study. These data provide a valuable comparison with the Holocene data, but must be treated with caution due to the numerous climatic fluctuations that took place during the Middle and Late Pleistocene. To try and deal with this issue, Pleistocene sites have mostly been presented separately rather than in one 'Pleistocene' group. Luckily most of the Pleistocene sites have yielded relatively large samples of *Bos primigenius* remains to allow for some splitting of the datasets without excessively compromising their reliability.

Compared with Portugal and Spain, data from the Italian Holocene are relatively scarce. There is very little evidence for the presence of *Bos primigenius* beyond the Neolithic period, and Mesolithic and Neolithic samples are very small. Of all of the Holocene sites yielding potential *Bos primigenius* remains, one site stood out as having the most numerous specimens – Rendina (Bökönyi 1982). Attempts were made to both physically access this material and to get the raw biometrical data recorded by other researchers, but unfortunately neither of these was possible. In future hopefully these data can be recovered because they could prove to be very important in the identification of Neolithic *Bos primigenius* specimens in Italy.

The data analysis included in this section has been conducted in the same way as most of the data analysis in this project, with almost all data being combined into one *Bos* group. Presenting the data in this way means that there are no preconceptions about domestic and wild groups when undertaking the analysis. There is one exception to this. Individual measurements were not provided for the bones identified as domestic at the late Neolithic site of Santa Maria in Selva (Wilkens *unpublished report*). In most diagrams only the wild specimens are shown, but one scatterplot shows the area in which the domestic specimens would have been.

Pleistocene sites included in this study for which the animal bones and teeth were recorded by the author are: Castel di Guido, Grotta del Fossellone, Canale Mussolini, Grotta Paglicci, Santa Croce, Riparo L'Oscurusciuto, and Grotta Romanelli. Further data were acquired from the literature regarding the site of Vado all'Arancio (Boscato 1996) and a Sicilian 'dwarf' form of aurochs, known as *Bos primigenius sicilae* from the site of Grotta dei Puntali, dated to the last interglacial period (Brugal 1987). Dates and references for all Pleistocene sites included can be found in Table 3.5.1.

Table 3.5.1: Sites from the Italian Pleistocene included in this study and their dates. All radiocarbon dates have been calibrated using calibration programme Calib 6.0 (after Stuiver and Reimer, 1993)

Site name	Marine isotope Stage (MIS)	C14 date BP	Calibrated date	Cultural sequence	Reference
Castel di Guido		327-260 ka BP (dated by Uranium-thorium dating)			Michel *et al.* (2001; 2008)
Grotta di Puntali	Last interglacial period (MIS 5) (c130 ka -75 ka BP)				Brugal (1987)
Canale Mussolini	MIS 5a-3 (c85-60 ka BP)				Farina (2011)
Santa Croce	MIS 4 (c71-60 ka BP)			Mousterian	Boscato *et al.* (2010)
Grotta del Fossellone				Late Mousterian – Aurignacian (all postcranial measurements included here are from the Aurignacian level)	Alhaique *et al.* *(*1996)
Grotta Paglicci		28100±400 - 28300±400	30276-29539 cal BC	Early Gravettian	Boscato (1994; 2004)
Vado all'Arancio		11300±50 - 11600±130	11319-11118 cal BC	Epigravettian	Boscato (1996)
Grotta Romanelli		10740±100 – 9790±80	10863-10571 cal BC	Epigravettian	Tagliacozzo (2003)

All Mesolithic and Neolithic data have been taken from the literature. An attempt was made to choose sites that had at least some *Bos primigenius* identified, although this was quite difficult during the Neolithic period. Mesolithic sites included are: Grotta delle Mura (Bon and Boscato 1993); and Grotta dell'Uzzo (Tagliacozzo 1993). Neolithic sites are: Favella (Tagliacozzo and Pino Uria 2009), Cornuda (Riedel 1988), Santa Maria in Selva (Wilkens *unpublished report*) and Arene Candide (Rowley-Conwy 1997). At both Favella and Arene Candide all *Bos* remains had previously been identified as domestic.

In contrast to the Spanish data, some of the Neolithic data included in this analysis were from a time period after the onset of the climatic deterioration at around 3000 cal BC. These include specimens from the site of Santa Maria in Selva and Cornuda, both of which have some large potentially wild specimens. There are also some domestic specimens from Arene Candide from this time period. For this analysis, any Neolithic material from after the onset of the climatic deterioration (so, dated to 3000 cal BC or later) is considered as Late Neolithic. Some material is also included from the Chalcolithic/Bronze Age levels at Arene Candide, although these have all been previously identified as domestic cattle (Rowley-Conwy 1997).

3.5.1 Ageing

Only Pleistocene sites were recorded by the author, and Holocene sites produced very few data anyway. Just three of the Pleistocene sites produced enough data to look at ageing through epiphysial fusion. The results can be seen in Figure 3.5.1. Canale Mussolini had 100% fused bones. This site did not contain fossilised bones, but was excavated in the early/mid 20th century and the potential for selective sampling cannot be ignored. This sample is also relatively small, the fusion results being calculated using just 51 specimens, and the combination of all of these factors is likely to have led to this result. The material from Castel di Guido contains some unfused later fusing bones, although a relatively small percentage in comparison to Grotta Romanelli, which contains the most unfused bones. All Pleistocene and Mesolithic sites for which ageing by epiphysial fusion has been possible in this project have shown a relatively similar pattern, with very small proportions of unfused early fusing bones, and therefore few very young animals. The pattern at Romanelli is most similar to that seen at Star Carr, which is the closest site in age for which ageing by epiphysial fusion was possible. As with all sites that have this pattern, it will result in smaller sample sizes of later fusing bones, such as the proximal femur and the calcaneum, available for use in the biometrical study.

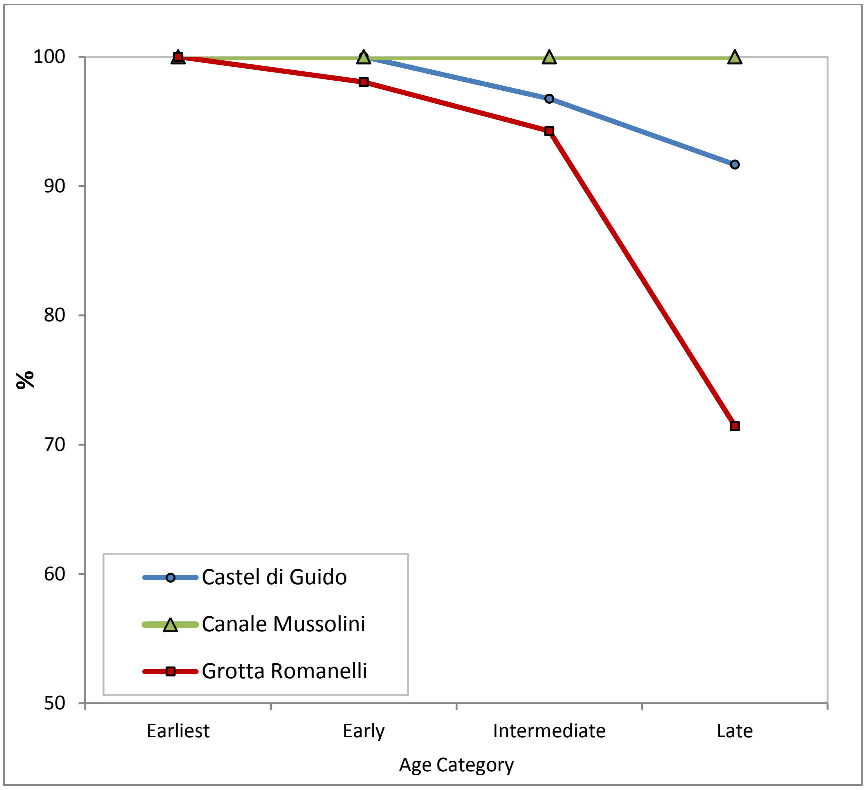


Figure 3.5.1: Fusion of *Bos* bones from Italian Pleistocene sites.

3.5.2 Biometry

Summary statistics for both postcranial and tooth samples are provided at the end of this section (Tables 3.5.2 and 3.5.3). All measurements show a reduction in their mean over time. Most coefficient of variation values are low. In order to investigate the patterns further the spread of measurements within these samples will be plotted using scatterplots and log ratio histograms.

3.5.2.1 Postcranial remains

When astragalus measurements are placed on a simple scatterplot, divided according to broad time periods (Figure 3.5.2), it is possible to see a clear difference in size between Pleistocene and Holocene animals (despite the small sample size from the Holocene). There is just one Pleistocene specimen that plots away from the rest of this group. Both Mesolithic specimens are smaller than the majority of the Pleistocene specimens and plot between them and all of those from later periods. Because none of the Neolithic/Copper Age specimens overlap with those from the Mesolithic it is possible that none of them are from wild cattle. In fact all of these specimens were identified as domestic cattle in the original reports.

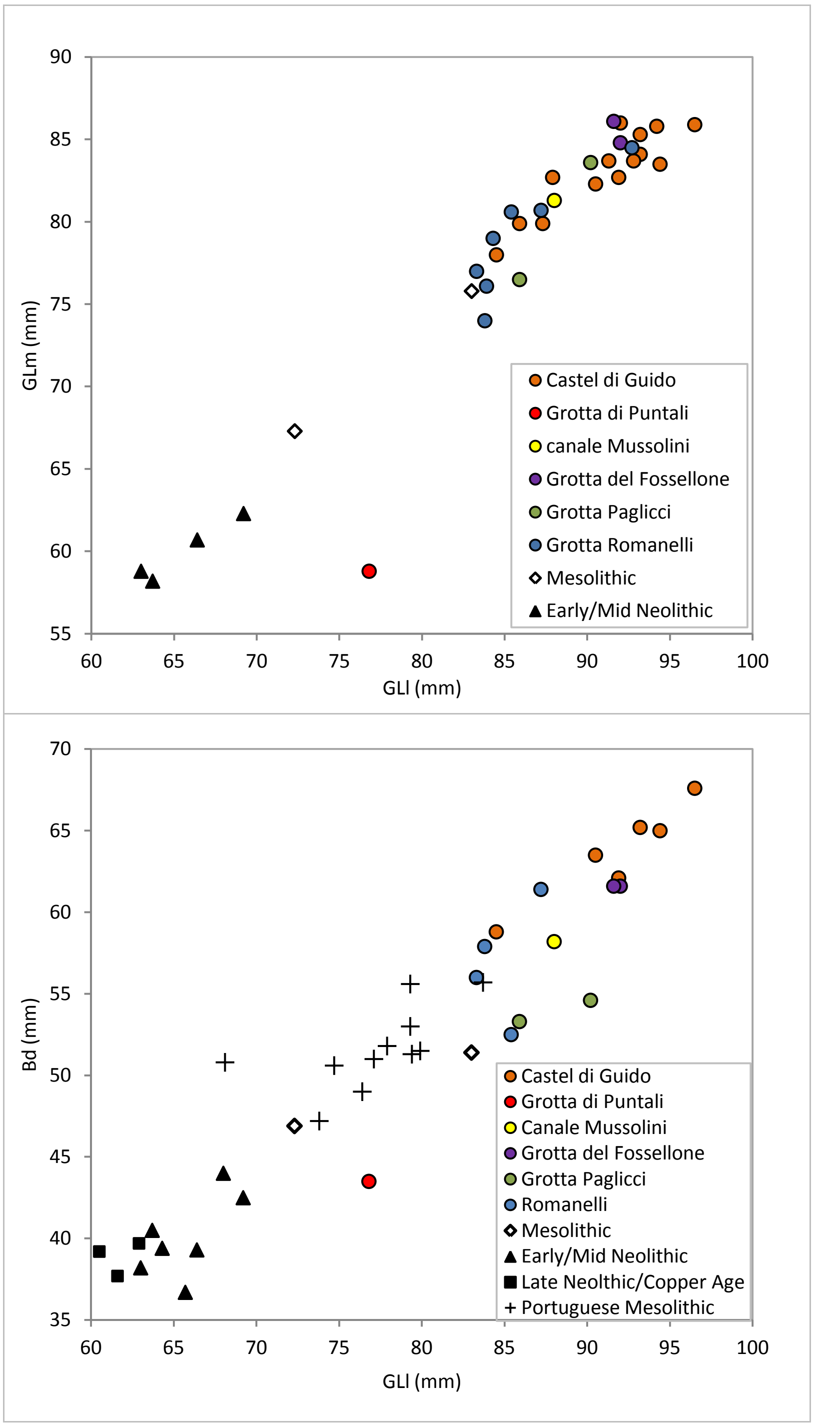


Figure 3.5.2: Scatterplots of Italian *Bos* astragalus measurements according to time period. GLl = greatest length of the lateral side; GLm= greatest length of the medial side; Bd= distal breadth.
Pleistocene sites have been plotted by site due to the long timescale that they span, and in the hope that climate fluctuations within this time span might be spotted.
Portuguese Mesolithic specimens have been included on the second diagram to show their close proximity to the few Italian Mesolithic specimens
Early/Middle Neolithic and Late Neolithic/Copper age sites have been separated in order to have a representation before and after the climatic deterioration of c3000 cal BC. There were no suitable Late Neolithic/CopperAge specimens available with both length measurements.

The specimen from Grotta dei Puntali stands out as being much smaller than the others from the Pleistocene and does not correlate with the other astragali. This has previously led to its being named a specific ‘dwarf’ subspecies of *Bos primigenius* (*Bos primigenius sicilae*) potentially caused by the geographical isolation of the population after the submersion of the land bridge between Sicily and mainland Italy (Brugal 1987). It is especially interesting that the measurements from the Puntali astragalus do not seem to correlate with all of the other astragali, with the lateral length not being as small, relative to the other specimens, as the medial length and the distal breadth. This suggests an astragalus with a greater difference between medial and lateral lengths (so potentially a less symmetrical shape overall) but also an astragalus that is overall relatively narrow for its length compared to those from other *Bos* in Italy.

The astragali from Castel di Guido tend to plot to the larger end of the range of Pleistocene specimens, and the astragali from Grotta Romanelli at the smaller end, with specimens from other sites plotting somewhere in-between. The difference between the specimens from Castel di Guido and Grotta Romanelli indicates a size reduction by the time of the Younger Dryas, when Grotta Romanelli was occupied.

A similar pattern is seen for the Pleistocene material in the tibia scatterplots (Figure 3.5.3). Again Castel di Guido and Grotta Romanelli provide the largest sample sizes and Grotta Romanelli plots to the smaller end of the Pleistocene range. Castel di Guido provides the largest specimens, but does seem to have a greater range compared with the astragali due to some relatively small specimens. Unlike the astragalus, the tibia specimen from Grotta di Puntali does not stand out as being smaller than the rest of the Pleistocene material, and does correlate with all of the other specimens, tucking nicely into the Pleistocene group.

The pattern is different for Holocene tibia measurements compared to the astragalus, as some of the Holocene specimens plot in the same area as those from the Pleistocene. This includes two Late Neolithic/Copper Age Italian specimens and all of the Mesolithic aurochsen from Portugal. Both breadth and depth measurements correlate with the smaller end of the Pleistocene group and especially overlap with the specimens from Grotta Romanelli. The two large Italian Holocene specimens are from the Late Neolithic site of Santa Maria in Selva, and were identified in the original report as wild (Wilkens *unpublished report*). The other, small, Late Neolithic/Copper Age specimen is from the Copper/Bronze Age levels at Arene Candide, and was identified as domestic. All of the Holocene specimens that plot outside of the Pleistocene group were previously identified as domestic cattle, whereas those that overlap were identified as wild. With this in mind, the original identifications that were given to these bones make sense. The two specimens from Santa Maria in Selva plot in the middle of the Mesolithic distribution from Portugal, suggesting that there is not enough evidence in the Italian sample for a post-Mesolithic size increase, as observed for Spain and Portugal. We will come back to the issue of wild and domestic cattle in the Holocene a little later after looking at the Pleistocene in greater detail.

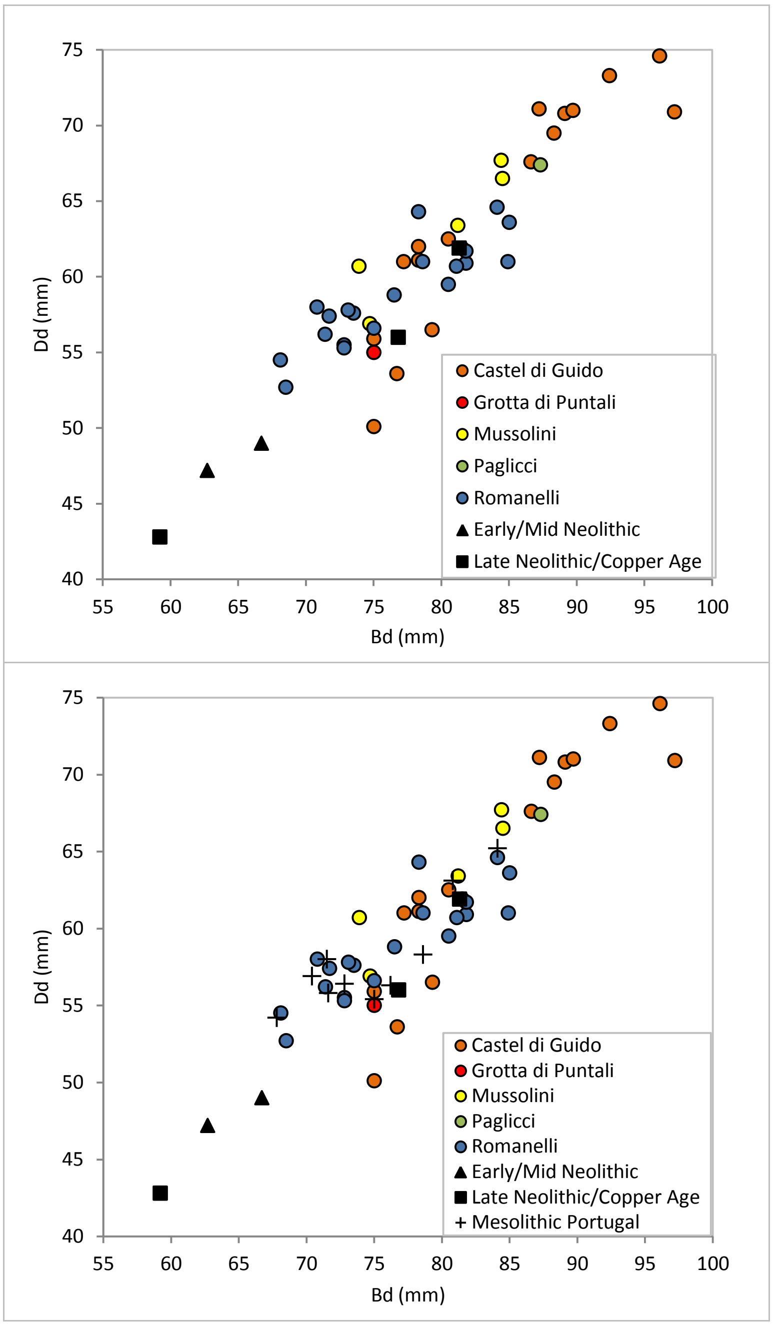


Figure 3.5.3 Scatterplots showing Italian *Bos* tibia distal breath vs. distal depth measurements according to time period. Bd= greatest breadth of distal end, Dd=greatest depth of distal end. Pleistocene sites are shown in colour and Holocene in black. There are no Mesolithic tibia measurements available, and so no Mesolithic measurements are included on the top diagram, whereas in the bottom diagram Portuguese specimens were plotted as a proxy for those from Italy (astragalus measurements from Mesolithic Portugal plotted in a very similar area to those from Italy).

Portuguese Mesolithic measurements are from the shellmiddens at Muge and were recorded by the author.

Early/Middle Neolithic data is from Arene Candide (measurements from Rowley-Conwy 1997).

Late Neolithic and Copper age data are from Arene Candide (Rowley-Conwy 1997) and Santa Maria in Selva ('wild' measurements only, from Wilkens *unpublished report*).

Log ratios showing postcranial remains from all of the Pleistocene sites for which there were enough specimens have been displayed (Figure 3.5.4) in order to try to see change over time and potential differences between warm and cold phases. Castel di Guido peaks the closest to the standard population of all of the sites and also contains some of the largest specimens. It also has a relatively compact range in comparison to some of the other sites considering its large sample size. Canale Mussolini has a quite a large range considering its relatively small sample size with some very large specimens but also a few that are quite small. This sample has a similar mean to the sample from Grotta Romanelli, although Grotta Romanelli has a more compact range. Unfortunately the sample from Canale Mussolini was too small for a statistical comparison between the two.

Both Castel di Guido and Grotta dei Puntali are from warmer interglacial periods (see Chapter 1 for a discussion of the climatic changes that took place over this time period), but the material from Grotta dei Puntali is smaller overall than the material from Castel di Guido, and indeed has the smallest mean of all of the other samples here. This suggests that the small size of the cattle at this site is unlikely be solely related to climate, and lends some support to the dwarfism interpretation. The situation will become even clearer when this site is compared to contemporary sites from other areas of Europe in Chapter 4. Canale Mussolini spans a long time period which includes some substantial oscillations in climate and this could be one explanation for the size variability within this sample.

Of all of the Italian Pleistocene sites included in this study Castel di Guido has the largest mean, despite the fact that the dating of this site places it almost entirely in a warm phase (MIS 9). All other sites are from during or after the last interglacial period. This suggests that size change did not take place completely in line with climatic changes that took place over this period. The situation at Grotta Romanelli is especially noteworthy, as the cold climate of the Younger Dryas seems to have had no impact at all on body size and shape.

Only Castel di Guido and Grotta Romanelli had large enough samples to be tested statistically, and this gave a significant result (Table 3.5.5). This is entirely in line with the changes that can be seen in the log ratio patterns.

Overall there do seem to be some differences between the samples, which may have some correlation with climate. The data from Grotta di Puntali are especially interesting in this light. The interpretation of the small size of these specimens as dwarfism, stemming from geographical isolation, should also take into account the climatic context of this site. Although there are no interglacial sites from mainland Italy here to compare it with, the pattern at Canale Mussolini suggests that *Bos primigenius* body size may have been vulnerable to climate change, and its impact cannot be discounted at Grotta dei Puntali.

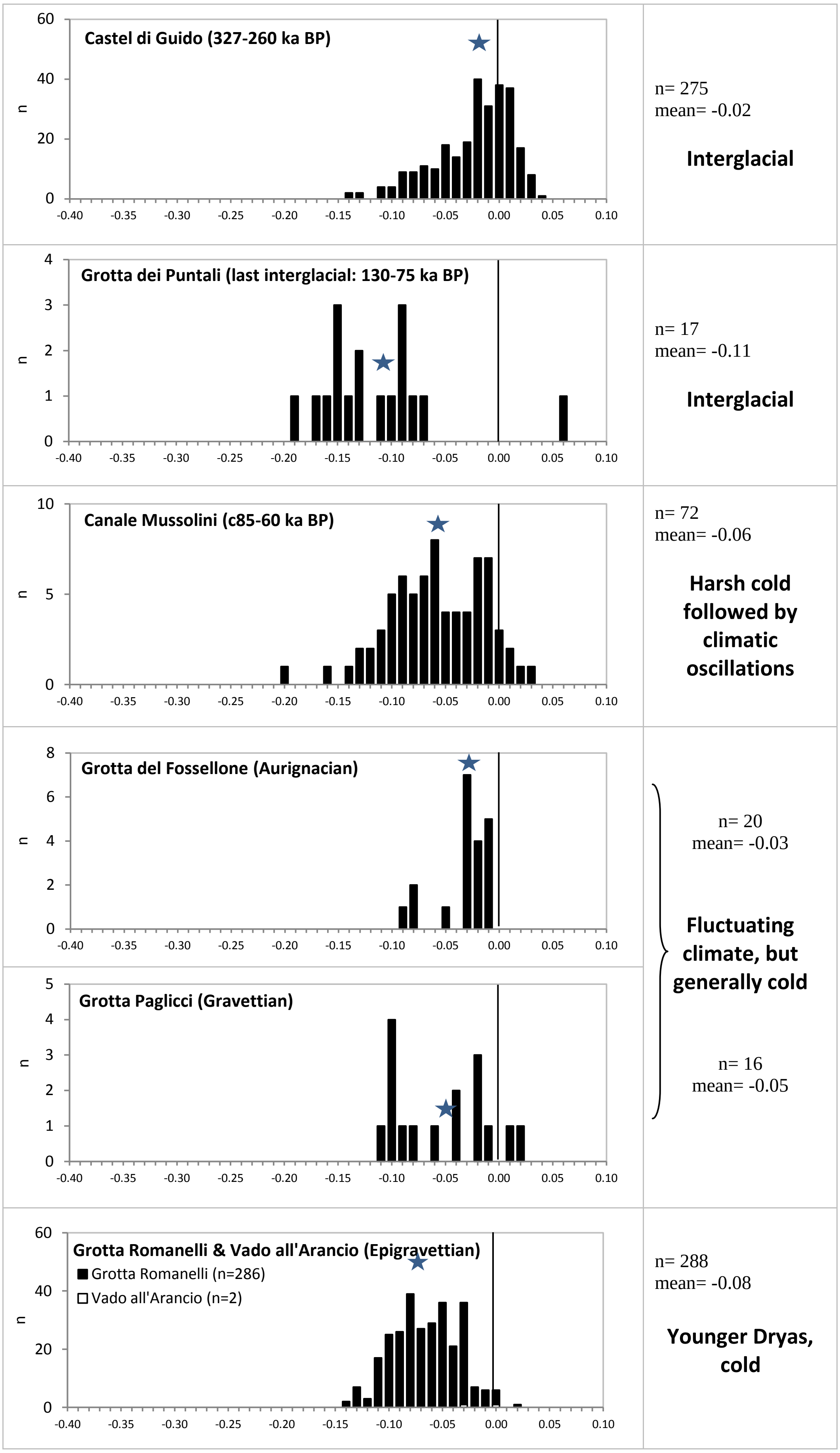


Figure 3.5.4: Log ratio diagrams showing postcranial measurements from Italian Pleistocene sites, presented in chronological order.

When individual measurements are displayed on Log ratio diagrams, the astragalus measurements (Bd and GLm) from Grotta dei Puntali stand out as being particularly small in comparison to all other measurements (Figure. 3.5.5). This astragalus clearly has a strange shape, which has not been displayed by any others in this study. None of the other bones from Grotta dei Puntali display a shape change different to the kinds of changes seen in other bones, although they are all to the smaller end of the range (except for the one particularly large femur measurement).

There is an overall decrease in size between all bones from Castel di Guido and those from Grotta Romanelli (Figures 3.5.5 - 3.5.7); astragalus breadth measurements from Romanelli plot further away from the standard than for Castel di Guido. This is a common pattern that has been seen throughout this study. These results demonstrate that this change had taken place by the Younger Dryas in Italy. Metacarpal length measurements do not seem to decrease in size as fast as breadth measurements, resulting in slenderer metacarpals, and this again is a pattern that has been seen in other areas.

Metacarpal and humerus measurements display the most variation (Figure 3.5.6), and this may be related to the fact that these are more sexually dimorphic bones. There are quite a few measurements from both of these bones in the Canale Mussolini sample, and may go some way to explaining the larger variation here, although even without these bones the variation is large considering the sample size.

The particularly large femur measurement from Grotta dei Puntali is particularly strange (Figure 3.5.7), and it seems unlikely that this bone can be representing an animal from the same population as the others included here. This would suggest that either this measurement is a mistake, or that there was a mixture of dwarf and non-dwarfed forms at the site. With only one specimen it isn’t possible to make any conclusions about this.

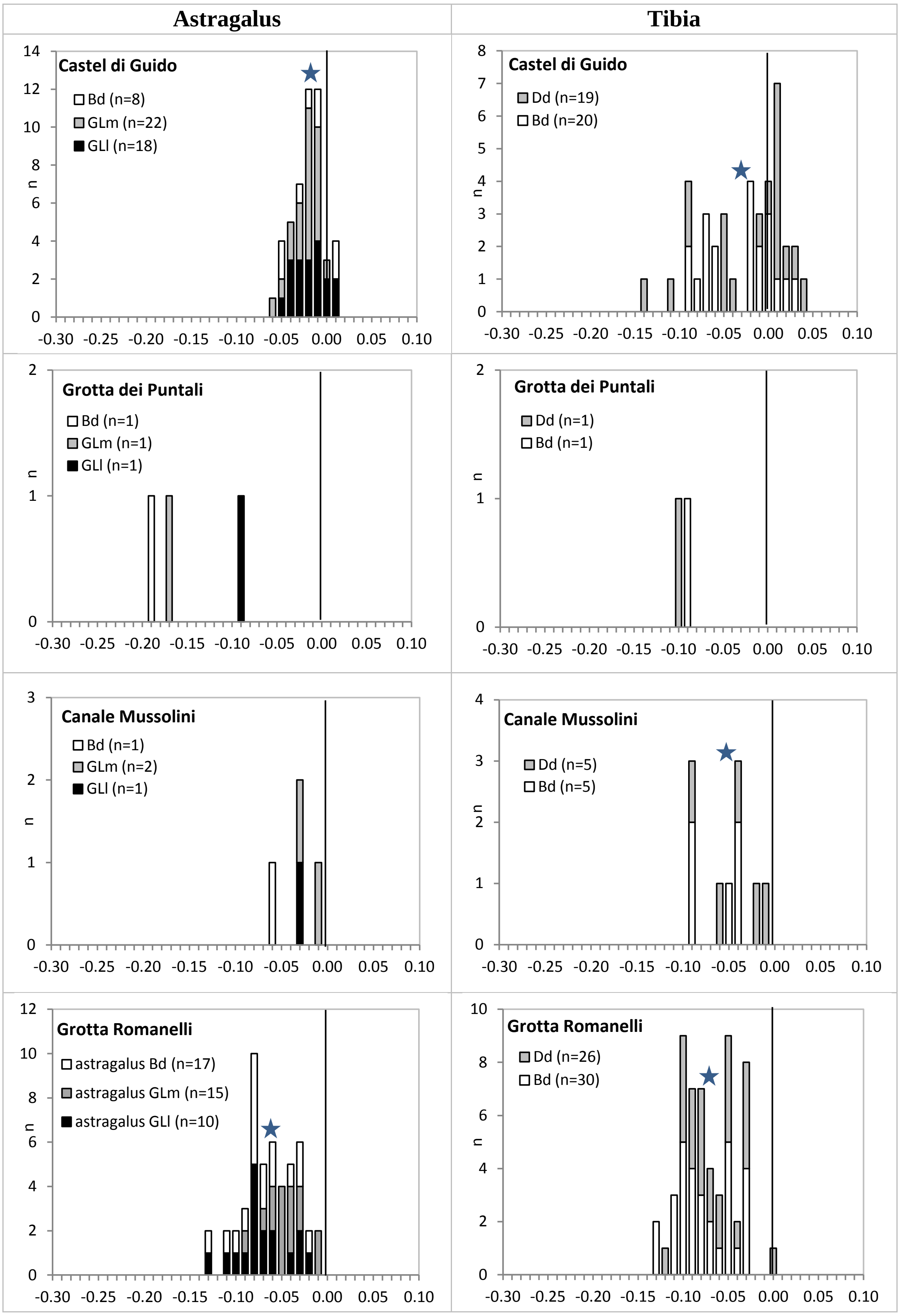


Figure 3.5.5: Log ratios of astragalus and tibia measurements from Italian Pleistocene sites.

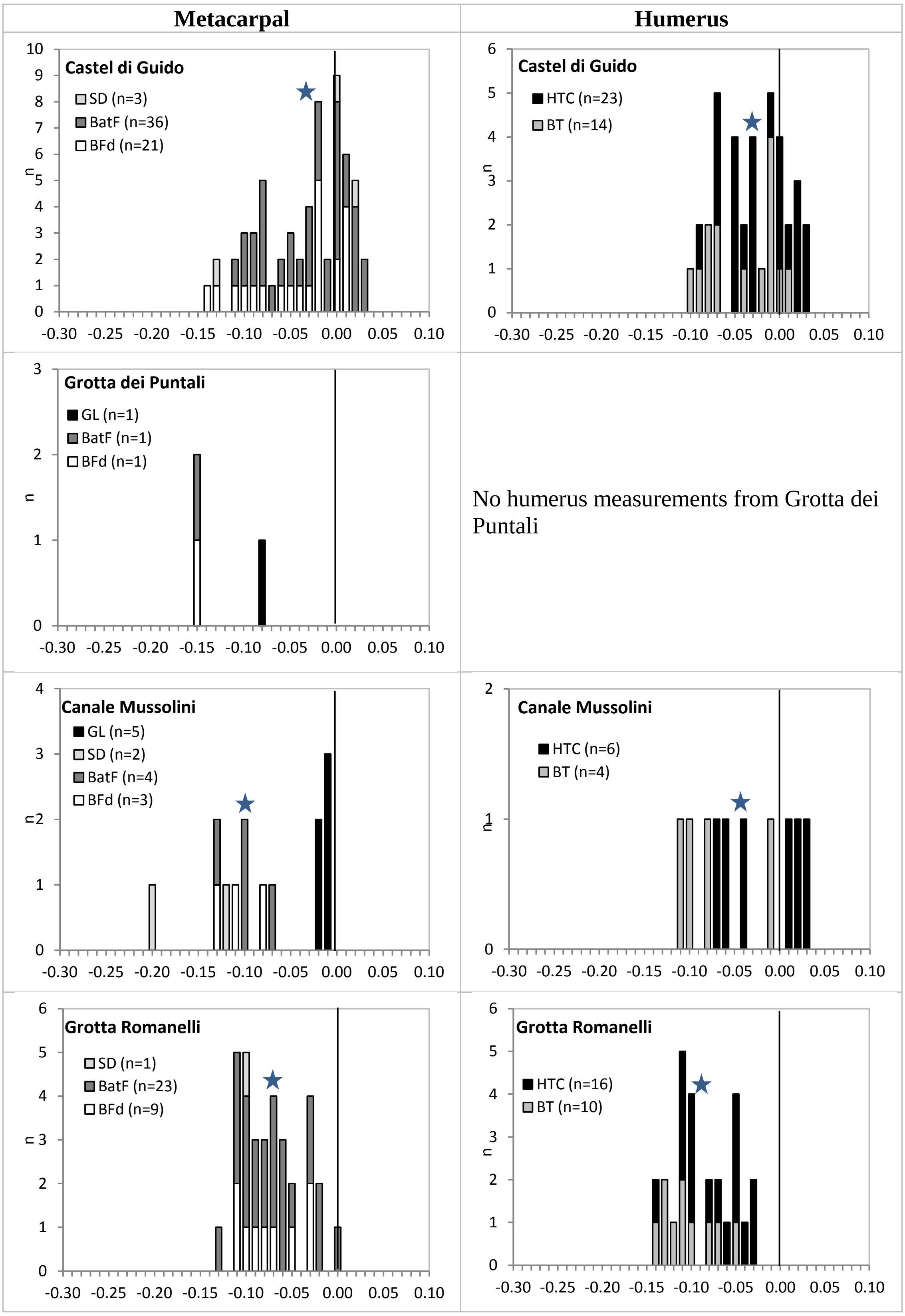


Figure 3.5.6: Log ratios of metacarpal and humerus measurements from Pleistocene sites.

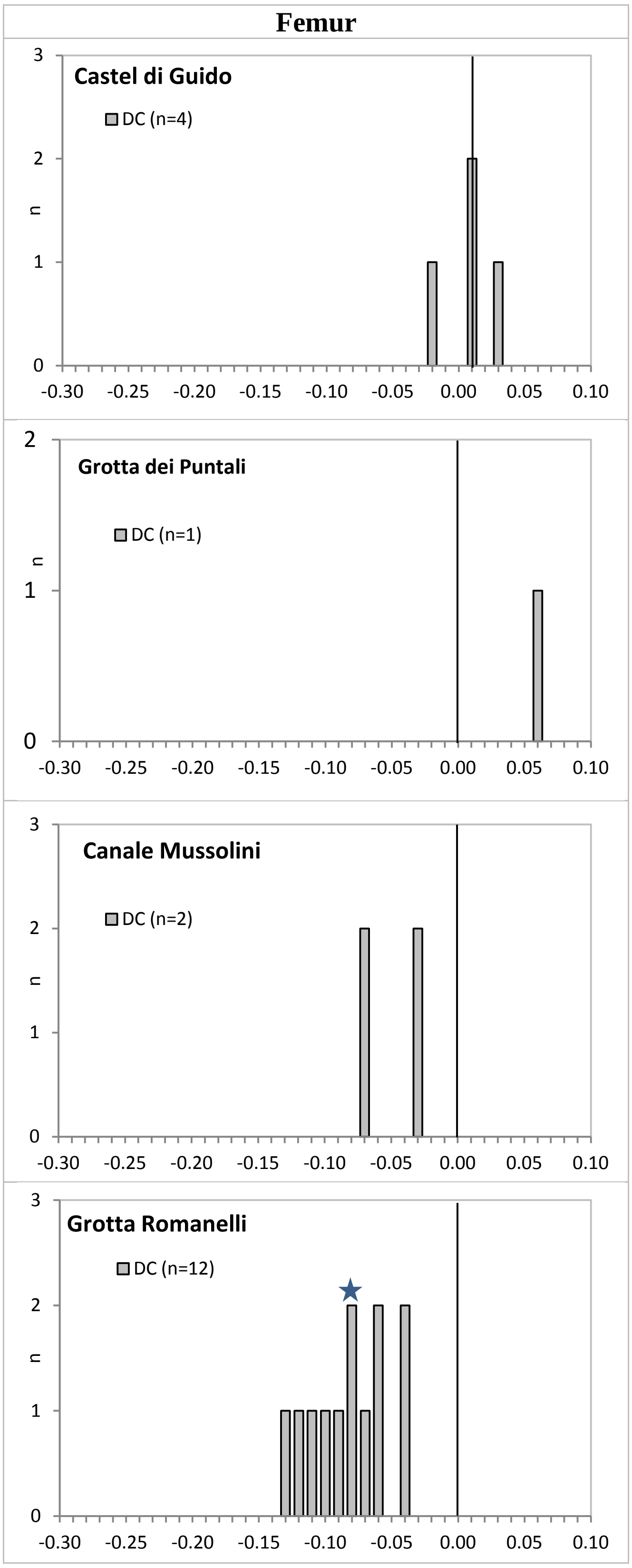


Figure 3.5.7: Log ratios of femur measurements from Pleistocene sites.

Bos postcranial remains at Grotta dei Puntali are smaller overall even than those from the Mesolithic, occupying a range closer to the postcranial remains from the Neolithic (Figure 3.5.8). This does not necessarily rule out a climatic explanation for the small size of the bones from Grotta dei Puntali. There are no precise dates for the material from Puntali and this material could come from any time during the last interglacial. Some parts of the last interglacial may have been warmer than it was during the early Holocene and the *Bos* from Grotta dei Puntali may have lived after a longer period of climatic warming than those from the early Holocene. The comparison of the material from Grotta dei Puntali with other material from the last interglacial in the Chapter 4 will shed light on whether this is a distribution that one would expect during this period.

There are no specimens from after 3000 cal BC that are larger than those from the Mesolithic, so the pattern is not the same as that seen in Portugal and Spain, although we must bear in mind that this sample size is very small. There are, however, specimens from this period that are larger than all of the Neolithic specimens from before the climatic deterioration. All of the specimens included from the Early and Middle Neolithic have been identified as domestic cattle in previous work. As there is no clear bimodal pattern in these data there is little evidence to suggest that these have been misidentified beyond the fact that a few of these specimens do overlap with those from the Mesolithic and earlier. The coefficient of variation results for the Early Neolithic period reflect a small amount of variation and therefore support the idea that all of these animals are domestic (see Table 3.5.3). The specimens from after 3000 cal BC seem to be separated more clearly into two groups: a larger potential wild group and a smaller domestic group.

Figure 3.5.9 shows that the larger specimens in the later Neolithic sample are from the sites of Cornuda and Santa Maria in Selva. Cornuda is an unusual Neolithic site in having a majority of bones from wild species (Riedel 1988). The pattern at Cornuda suggests that there may be a clear gap between domestic and wild specimens at this site, but sample size is too small to make a clear interpretation. A scatterplot of Neolithic tibia measurements, including the area in which the domestic specimens from Santa Maria in Selva would have been found shows that at this site there is a similar pattern (Figure 3.5.10).

Including data from the Copper and Bronze Ages does nothing to make this pattern clearer (Figure 3.5.9). These specimens have all previously been identified as domestic (Rowley-Conwy 1997) and there is nothing here to suggest that these identifications are not correct. There is therefore no evidence here of large specimens in the Italian Copper Age, as there is in Iberia.

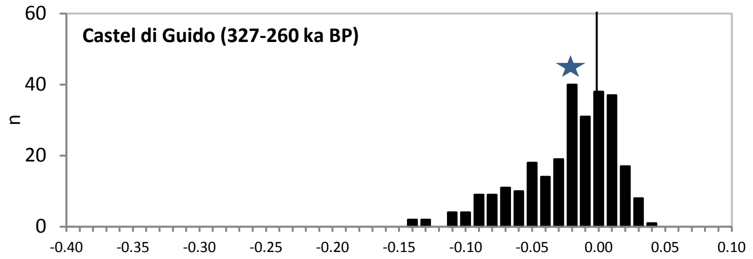
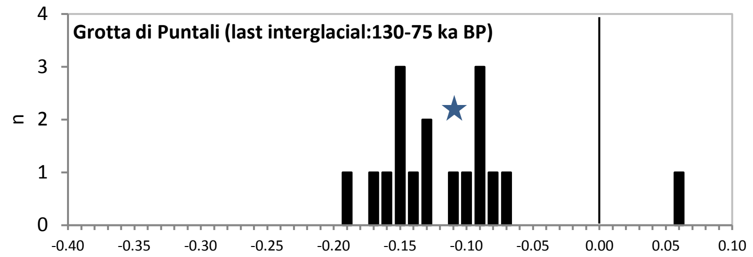
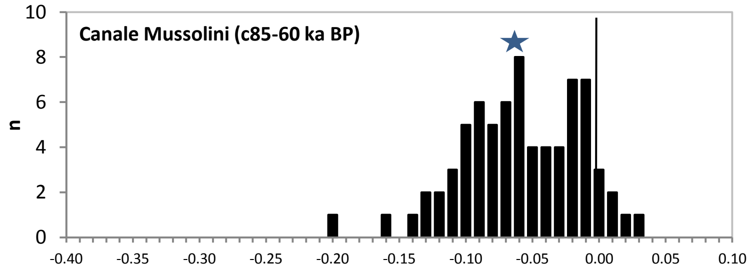
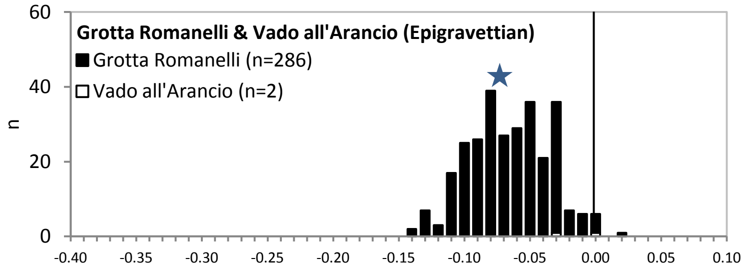
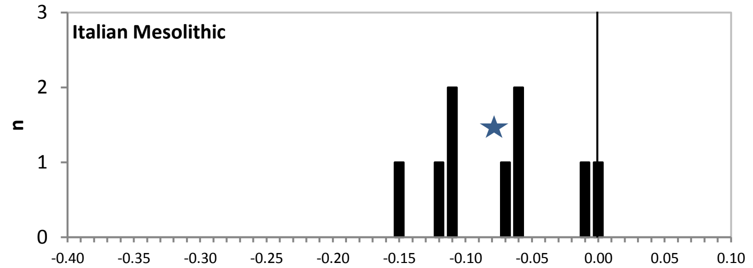
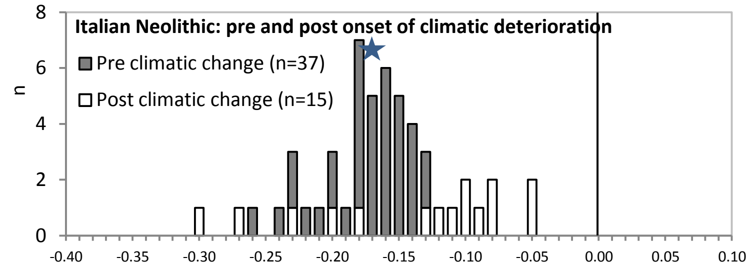
	n= 275 mean= -0.02
	n= 17 mean= -0.11
	n= 72 mean= -0.06
	n= 288 mean= -0.07
	n= 9 mean= -0.08
	n= 52 mean= -0.16

Table 3.5.8: Log ratios showing postcranial measurements from a selection of Pleistocene sites and the Mesolithic and Neolithic samples.

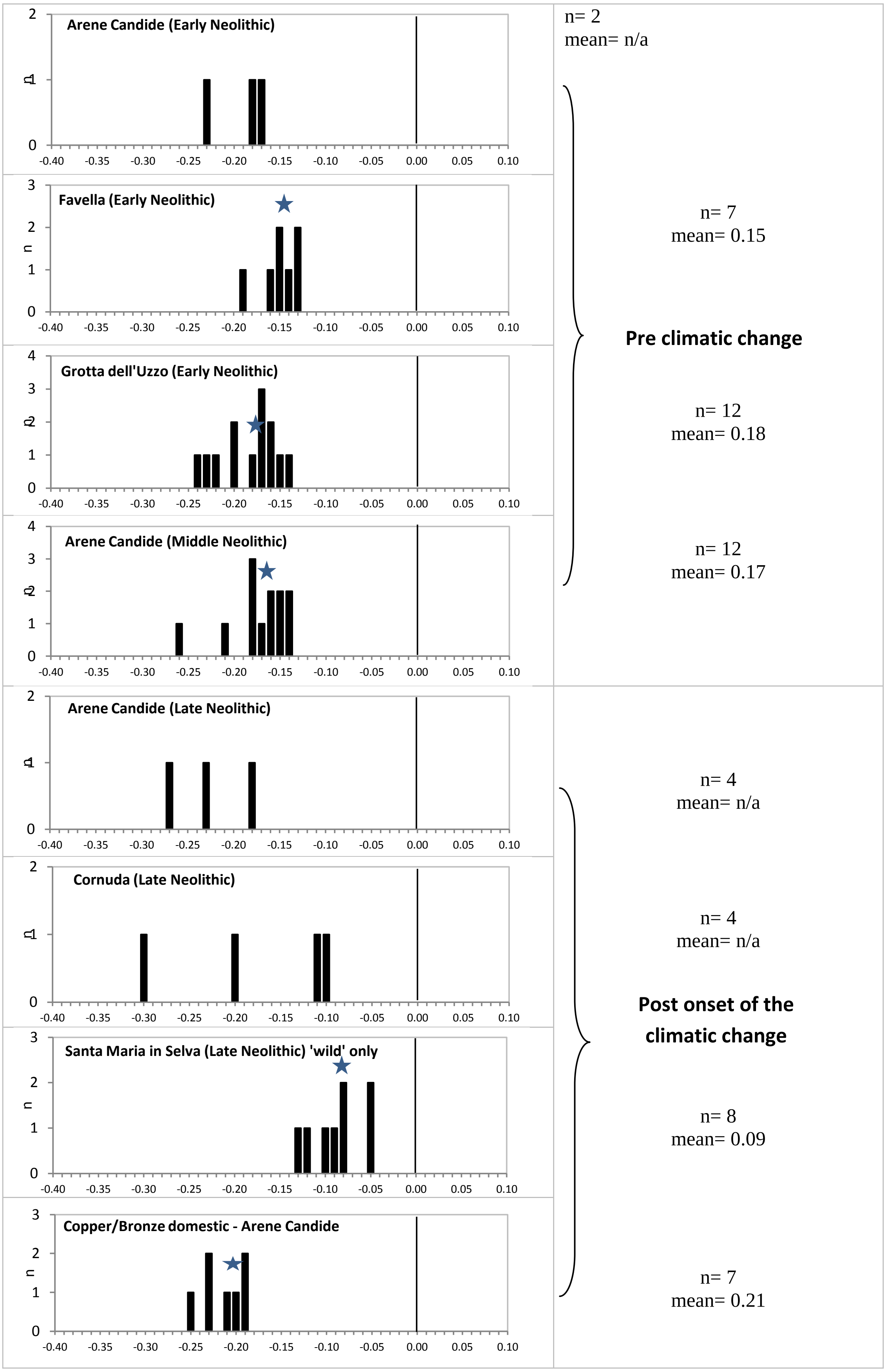


Figure 3.5.9: Italian Neolithic and Copper & Bronze Age cattle specimens per site.

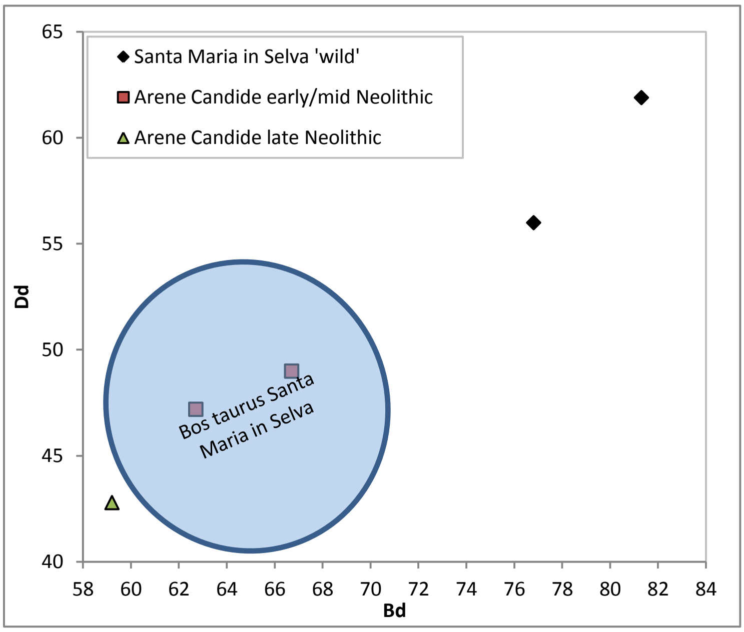


Figure 3.5.10: Scatterplot showing all tibia measurements available from Italian Neolithic sites. The blue area indicates where the 'domestic' specimens from Santa Maria in Selva would have been located.

The potential split between wild and domestic is also clear when length, breadth and depth measurements are split (Figure. 3.5.11). Measurements were combined like this due to the very small sample sizes. Tibia and metapodial breadths and tibia depths make up the wild group. Only metapodials split between the two groups on the same diagram.

Overall the small sample sizes involved with the analysis of the Italian Holocene postcranial data prevent confident interpretations from being made. The larger size of some *Bos* specimens after the onset of the climatic change, is probably due to their wild status while all earlier Neolithic appear to be domestic. To evaluate size changes in aurochs before and after the climatic worsening after 3000 cal BC it would be necessary to have larger sample sizes and also ideally some Early Neolithic wild specimens. At the moment, however, the similarity in size between the Mesolithic and Late Neolithic aurochsen does not support the hypothesis of a climatic effect on body size during the Holocene in Italy.

The Neolithic remains overlap most closely with the remains from Grotta di Puntali which could be smaller than the other Pleistocene remains simply because they are from an interglacial period and therefore reflect a warmer climate, or their small size could be related to some kind of 'dwarfism' caused by the geographical isolation of the population in Sicily. Evidence for dwarfism firstly comes from the fact that the assemblage at Puntali reflects animals which are so much smaller than even those from other Pleistocene interglacials, such as the assemblage from Castel di Guido, as mentioned above. However, the strangely shaped astragalus none of the other bones from Grotta di Puntali suggests that something more complex could have been taking place. Without more data from bones identified as *Bos primigenius sicilae*, and *Bos primigenius* data from mainland Italy during this warm time period to compare it with, no firm conclusion can be drawn.

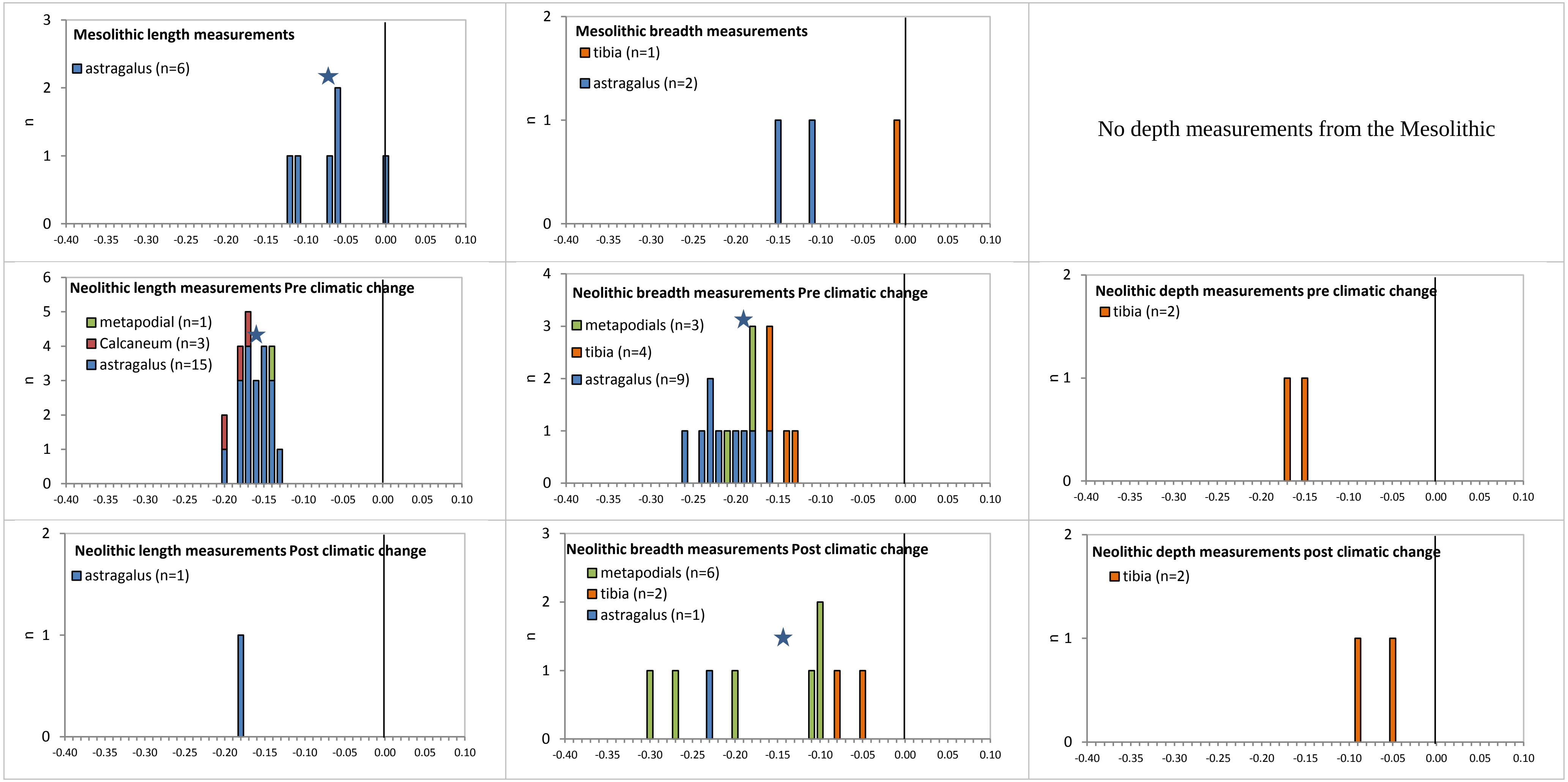


Figure 3.5.11: Length, breadth and depth measurements from Italian Holocene sites.

3.4.2.2 Teeth

Only tooth measurements from Pleistocene sites were available, but this still provides a good opportunity to compare postcranial patterns with those from teeth, albeit before the time of the advent of domestication.

Teeth from Grotta Romanelli dominate the scatterplot and samples from all other sites are small (Figure 3.5.12). Despite this it is still possible to see that the smallest specimens come from Grotta Romanelli, giving similar results to the postcranial remains. The few specimens from Castel di Guido plot predominantly to the larger end of the range which also fits the previous pattern. Specimens from all other sites plot somewhere in the middle, as was seen for the postcranial remains.

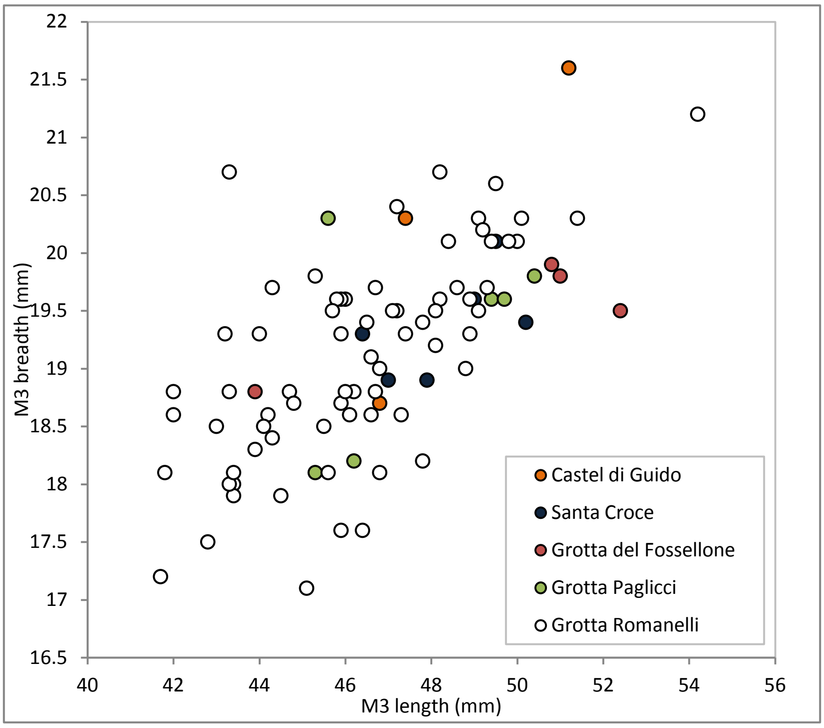


Figure 3.5.12: Scatterplot of Italian Pleistocene third molar length vs. breadth measurements.

Log ratios do not show any clear patterns between sites (Figure 3.5.13). There does not seem to be a difference even between the sample from Castel di Guido (representing a warm phase) and all of the other sites (which are all from cold phases). The sample from Grotta Romanelli does shift slightly to the smaller end of the range compared to the other samples and this could be a reflection of the Younger Dryas not being as cold as previous cold periods, or the Younger Dryas being short and sharp with not enough time for changes to take place. The pattern at Grotta del Fossellone is not caused by some measurements being from the Late Mousterian, the split seems entirely related to length and breadth. Unfortunately sample sizes were too small to be able to perform any statistical analyses on the results.

Breadth measurements tend to plot to the smaller end of the range, suggesting that tooth breadths are generally small in relation to lengths compared with the standard population.

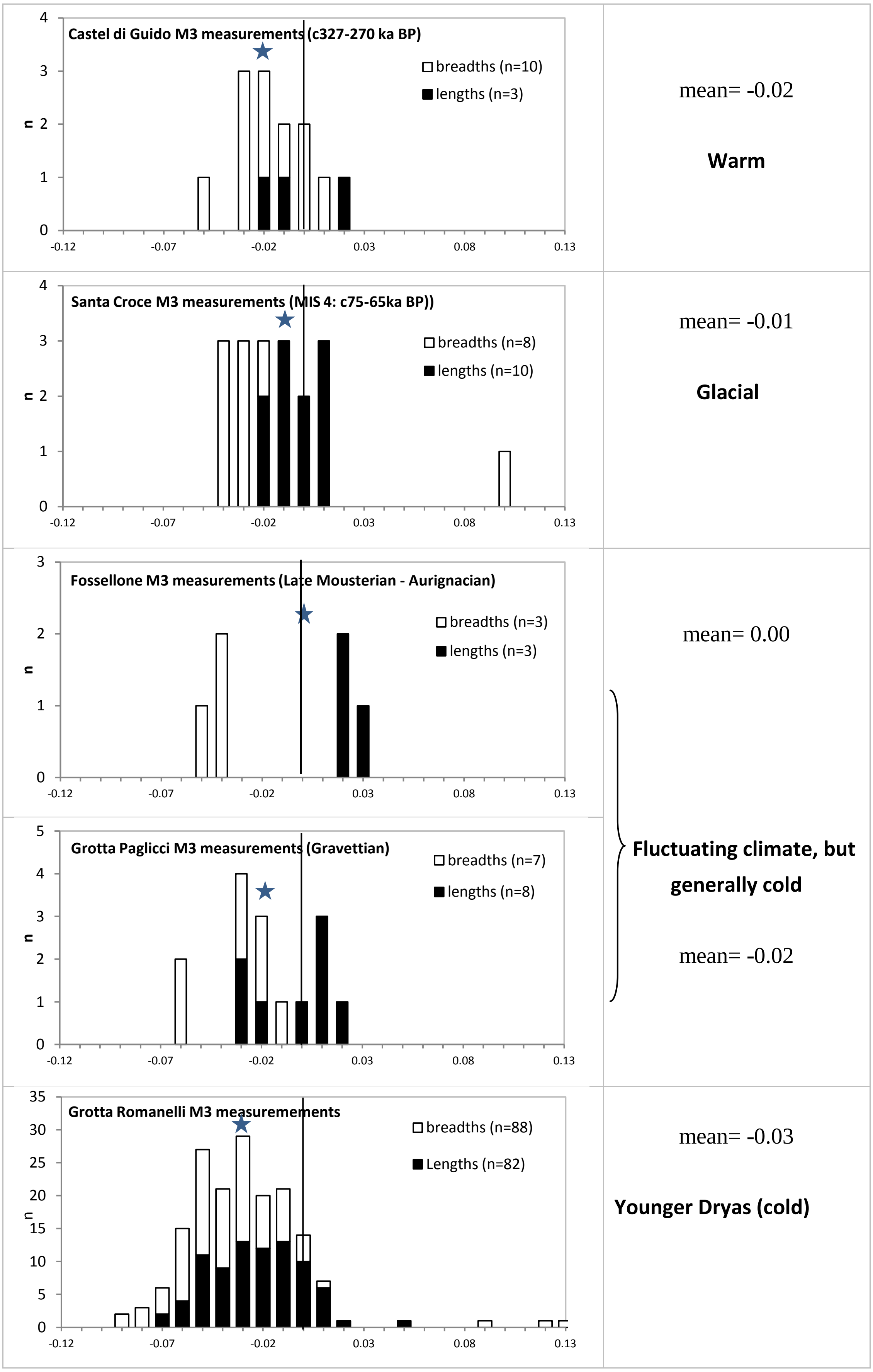


Figure 3.5.13: Log ratios of Italian Pleistocene third molar measurements.

Since most measurements (including the standard) were taken by the author, we can be confident that they were taken consistently across different sites. The pattern is therefore likely to be genuine. The only site at which this pattern is less clear is Castel di Guido. This site is relatively close in age to the standard population (Ilford is dated to MIS 7- the following interglacial – which is thought to have been climatically similar to MIS 9 – see Chapter 1 for a description of climate, and Section 3.2 and Chapter 4 for further discussions of the Ilford population). This suggests that the process of teeth becoming slender started after MIS 9 and before MIS 4.

Overall there are smaller differences between the tooth samples than between the postcranial samples. This can be seen in the less clear separation between sites both on the scatterplot and on the log ratio diagrams. This could partly be a reflection of sample size, but also reflects the lower plasticity of teeth in comparison to postcranial remains. The coefficient of variation results reflect the low variation seen in tooth measurements (Table 3.5.3). The only site which displays a high score is Santa Croce, and this must be related to the one particularly large breadth outlier that can be seen on the log ratio distribution, and so therefore does not reflect the overall pattern.

3.5.3 Italian *Bos* and *Sus* results in comparison

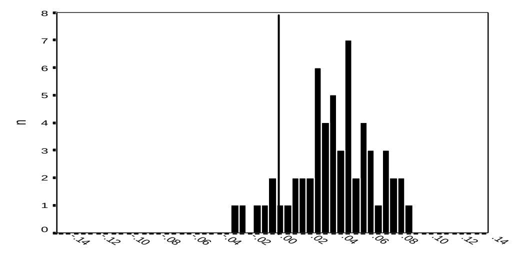
Extensive work has been done on the biometry of Italian *Sus*, mostly focussing on the early Holocene period (Albarella *et al.* 2006). Some of the sites included are those that have provided *Bos* data for this project, although potential *Bos primigenius* remains are far fewer than those from *Sus scrofa*. Figure 3.5.14 displays *Sus* results from sites included in this study, and Figure 3.5.15 provides *Sus* results from other Italian sites.

Although *Bos* sample sizes are much smaller, there are some similarities with the pattern seen in the *Sus* remains. Firstly looking at the sites for which there are *Bos* data in this study (compare Figure 3.5.9 with Figure 3.5.14), the largest specimens appear on the later sites for both *Bos* and *Sus*. In the *Sus* samples, some very large specimens appear in the Middle Neolithic sample from Arene Candide, but these are at the top end of an approximately unimodal distribution, which also includes much smaller specimens. Cornuda has both large *Sus* and *Bos* specimens, although none of the *Bos* specimens from Cornuda are as large in comparison to other sites as those from *Sus*. Some *Sus* specimens at Cornuda are larger than those from Mesolithic Grotta dell'Uzzo, which is not the case for *Bos*.

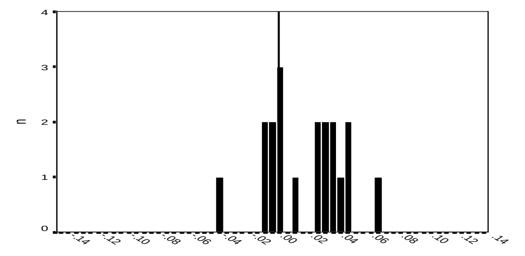
On the other sites for which there are no *Bos* to compare with (Figure 3.5.15), in the Early and Middle Neolithic the specimens appear to be similar in size to those from the Mesolithic. In the Eneolithic of Conelle, however, very large wild boar - much larger than those from the Mesolithic - can clearly be distinguished from the smaller domestic pigs.

It is clear that wild boar is far more common than aurochs on Italian early Holocene sites. A large size variation or a bimodal pattern can be seen in many of the *Sus* samples (suggesting both wild and domestic animals are present) whereas this is not the case for *Bos*. The Early Neolithic *Bos* samples included in this study show little evidence of containing wild animals, it is only in the Late Neolithic samples that any relatively large specimens are present. One big difference between the *Bos* and *Sus* results is that Neolithic *Sus* specimens are much more similar in size to those from the Mesolithic, whereas Neolithic *Bos* specimens show a more sudden change to a smaller size compared to the Mesolithic.

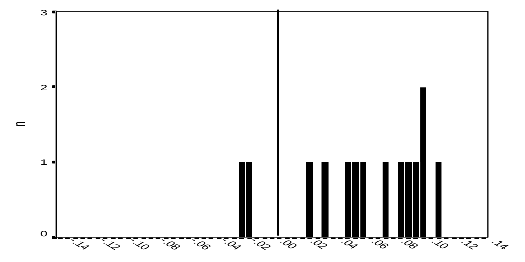
There is no evidence in the *Bos* results for an increase in size of *Bos* during the Neolithic period which could be linked to climatic change, but for wild boar it is possible to see an increase in size in the Middle and Late Neolithic. This is similar to what has been shown for both the aurochs and wild boar in Portugal and Spain.



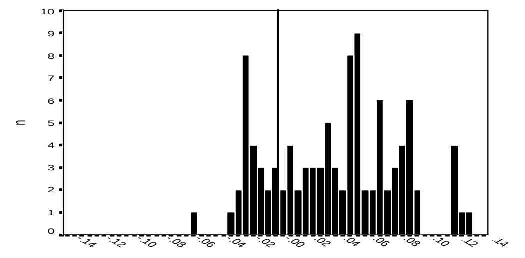
Grotta dell'Uzzo
(Mesolithic and transition)
n= 57
mean= 0.04



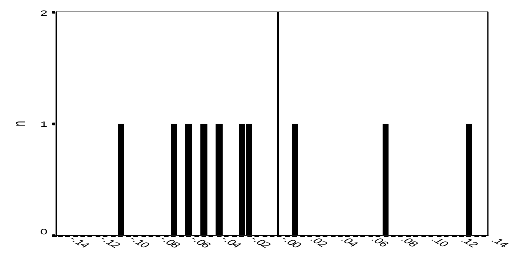
Grotta dell'Uzzo
(Early Neolithic)
n= 19
mean= 0.02



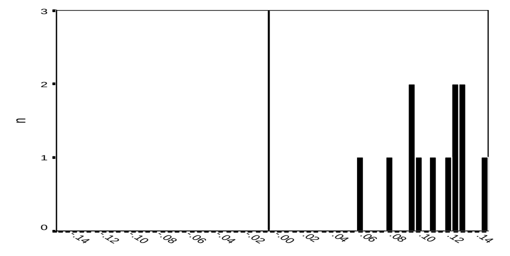
Arene Candide
(Early Neolithic)
n= 14
mean= 0.06



Arene Candide
(Middle Neolithic)
n= 101
mean= 0.04



Arene Candide
(Late Neolithic)
n= 10
mean= -0.01



Cornuda
(Late Neolithic)
n= 12
mean= 0.11

Figure 3.5.14: Log ratio diagrams showing *Sus* postcranial remains from sites included in this project (taken from Albarella *et al.* 2006, with permission).

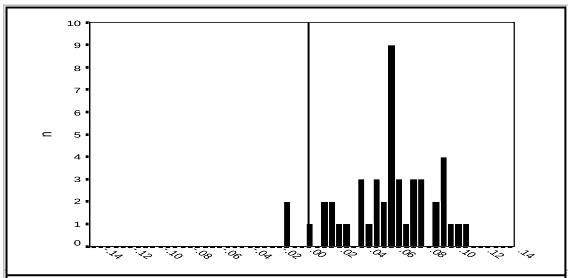
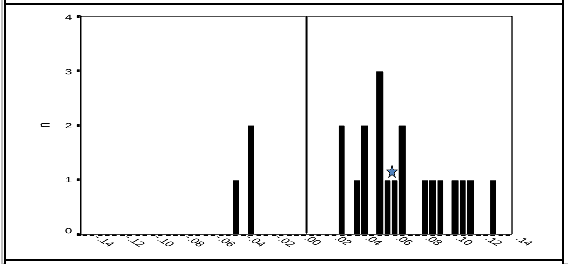
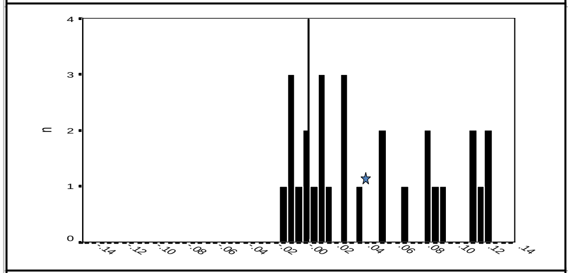
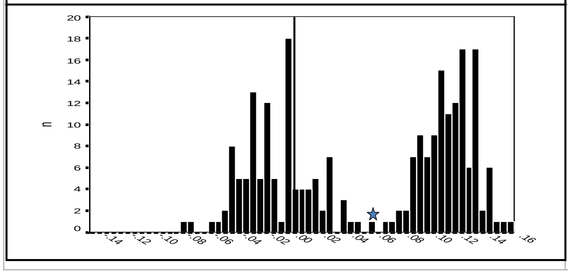
	Grotta delle Madonna (upper Palaeolithic & Mesolithic) n= 46 mean= 0.06
	La Marmotta (Early Neolithic) n= 22 mean= 0.06
	Rivoli (Middle Neolithic) n= 28 mean= 0.05
	Conelle (Eneolithic) n= 237 mean= 0.06

Figure 3.5.15: Log ratio diagrams showing Sus postcranial remains from Italian sites not included in this study – note the slightly different scale used for Conelle (taken from Albarella *et al.* 2006, with permission).

What this analysis does highlight is that after the end of the Pleistocene the aurochs became very rare in Italy. The measurements that we have from the Mesolithic do not show much of a change in size compared with the Epigravettian. There is then a shift to a much smaller size for *Bos* in the Early Neolithic, providing evidence that domestic cattle were present in Italy from the Early Neolithic, and it is likely that they were far more common than wild cattle. The small amount of evidence that we do have for wild cattle during the Neolithic period suggests that it occupied a similar size range to those in the Mesolithic and Epigravettian periods.

These results contrast with the results for *Sus* in terms of the domestication debate. *Sus* samples show no dramatic change in size between Mesolithic and Neolithic animals, instead the change seems to happen slowly and gradually throughout the Neolithic period. This has been used as evidence to suggest that local domestication of wild boar could have taken place in Italy (Albarella *et al.* 2006). There is no evidence in the *Bos* results for a slow and gradual change from wild to domestic cattle, instead there is a distinct and abrupt reduction in size between the Mesolithic and Early Neolithic samples. This suggests the possibility of a different domestication process for *Bos* compared to *Sus*. This is interesting in the context of genetic research which has provided evidence which is not inconsistent with local cattle domestication in Italy (e.g. Beja-Pereira 2006; Mona *et al*. 2010) - see discussion in Chapter

1. Some aurochs specimens from sites included in this analysis were shown to have the T haplotype, which is typical of domesticated cattle across Europe. These include three specimens from Grotta Paglicci and two specimens from Grotta delle Mura. Both the domestic and wild haplotype (P) were found in aurochs bones from Vado all'Arancio. The occurrence of the T haplotype in wild cattle from Italy means that domestic cattle with that same haplotype may be consistent with a local domestication event, though this cannot be proven. Equally of course these domestic cattle may be of an introduced origin as Middle Eastern aurochsen (and domestic cattle) are characterised by the T haplotype (e.g. Troy *et al*. 2001; Edwards *et al*. 2007).

If cattle domestication was a local event in Italy, you might expect to see a more gradual change over time, such as that seen for pig. Therefore the results of the *Bos* biometrical analysis lean more towards an introduced domestication event, providing a new contribution to an issue that could not be solved by genetic analysis. We must however be cautious, as the Mesolithic sample is small, partly due to the rarity to the aurochs in Italy during this period. This in itself makes the Italian aurochs an unlikely candidate for domestication, as common and widespread species are more likely to have developed a close relationship with human communities. At the site of Grotta dell'Uzzo, the aurochs is represented by only one specimen in the Mesolithic-Neolithic transition phase (and there are also no specimens attributed to domestic cattle in this phase either), therefore suggesting the introduction of domestic cattle in the Early Neolithic (Tagliacozzo 1993). A priority for the future is to collect more metric data for the Italian Mesolithic aurochs, possibly from different regions, in order to assess how size could have varied according to local environmental conditions.

Table 3.5.2: Summary statistics for postcranial measurements from Italian *Bos*. Only archaeological material is included. Samples of less than 5 were excluded.

Measurement	No.	Min	Max	Mean	Standard deviation	Coefficient of variation
Astragalus GLl						
Castel di Guido	18	84.5	96.9	90.9	3.64	4.00
Grotta Romanelli	10	82.4	92.7	86.8	4.11	4.73
Early Neolithic	9	63	71	66.5	2.66	4.00
Astragalus GLm						
Castel di Guido	22	76.3	87.4	83.1	2.85	3.43
Grotta Romanelli	15	70.2	85.2	78.5	3.73	4.76
Early Neolithic	6	58.2	63	60.8	1.96	3.23
Astragalus Bd						
Castel di Guido	8	58.8	68.2	63.7	3.59	5.63
Grotta Romanelli	17	49.8	63.4	56.7	3.88	6.84
Early Neolithic	9	36.7	46	41.0	2.98	7.25
Tibia Bd						
Castel di Guido	20	75	97.2	85.6	7.29	8.52
Canale Mussolini	5	73.9	84.5	79.7	5.15	6.46
Grotta Romanelli	30	68.1	85.7	77.1	5.22	6.77
Tibia Dd						
Castel di Guido	19	50.1	75.4	65.8	7.69	11.69
Canale Mussolini	5	56.9	67.7	63.0	4.39	6.96
Grotta Romanelli	26	52.7	69	59.6	3.99	6.70
Metacarpal BFd						
Castel di Guido	21	66.9	95.7	84.6	9.13	10.78
Grotta Romanelli	9	71.5	85.8	78.1	5.65	7.24
Metatarsal BFd						
Castel di Guido	20	69.1	86.2	81.3	5.05	6.21
Grotta Romanelli	18	67.7	85.8	76.0	5.09	6.70
Humerus BT						
Castel di Guido	14	91.9	117	105.1	8.82	8.40
Grotta Romanelli	10	83.9	102	90.5	5.83	6.44
Humerus HTC						
Castel di Guido	23	41.4	54.3	48.0	3.92	8.17
Canale Mussolini	6	43.3	53.7	48.6	4.85	9.99
Grotta Romanelli	16	36.5	47	42.3	3.21	7.60

Table 3.5.3: Summary Statistics for tooth measurements from Italian *Bos*. Only archaeological material is included. Samples of less than 5 were excluded.

Measurement	No.	Min	Max	Mean	Standard deviation	Coefficient of variation
M3 Breadth						
Castel di Guido	10	18.7	21.6	20.1	0.84	4.21
Santa Croce	8	18.9	26.5	20.3	2.55	12.58
Grotta Paglicci	7	18.1	20.3	19.4	0.87	4.49
Grotta Romanelli	88	17.1	28.3	19.4	1.74	8.94
M3 length						
Santa Croce	10	46.4	50.2	48.4	1.26	2.60
Grotta Paglicci	8	45.3	50.5	48.3	2.20	4.56
Grotta Romanelli	82	41.7	54.2	46.3	2.48	5.35

Table 3.5.4: Results of the Mann-Whitney tests on *Bos* postcranial Log Ratios from Italy. Significant results (<0.05) are marked with an * and highly significant results (<0.01) are marked with **. Only archaeological material has been included in the statistical analyses. Samples of less than 20 were excluded.

Group	n.	Group	n.	U	z	Sig.
Castel di Guido	112	Grotta Romanelli	81	1488.0	-7.98	0.000**

3.6 Summary

This chapter has presented the results from the first part of the biometrical study, looking at each geographical area across time, and has provided evidence for differences between different areas.

Britain and Italy were the only areas for which it was possible to present data from the Pleistocene to compare with the Holocene. As expected there is evidence for a general overall reduction in body size of the aurochs between the Pleistocene and Holocene, but this study has also highlighted changes that took place within the Pleistocene itself, with the largest animals present in Marine Isotope Stages 9 and 7, and potentially the most distinct reduction in size taking place at around Marine Isotope Stage 5. In Italy at least, we can see that the aurochs was similar to its Early Mesolithic size by the time of the Younger Dryas, and potentially even earlier.

There are indications of a reduction in size of the aurochs between the Early and Late Mesolithic in Denmark, demonstrated by both postcranial and tooth remains, and the same pattern is not seen in any other areas of Europe, although this could be partly related to a general lack of late Mesolithic assemblages from many areas.

Some Iberian Chalcolithic sites provide evidence for an increase in size of the aurochs, in at a similar time to the increase in size that has previously be highlighted for red deer (Davis 2006; Davis and Mataloto 2012) and wild boar (Albarella *et al.* 2006; Albarella *et al.* 2009), but this pattern is not widespread across Europe.

Some interesting patterns have also become clear in terms of the way that different bones change over time. Breadth measurements seem to display more plasticity, and reduce in size more readily than length measurements, causing a slendering of a number of bones over time. This is something that begins to take place during the Pleistocene, and therefore cannot be linked entirely to the process of domestication. Breadth measurements also display more sexual dimorphism, which means that this complicates things when trying to identify wild and domestic groups.

In terms of the introduction of domestic cattle, we can see different patterns in different areas. In Britain, Spain and Italy there is an abrupt change during the Early Neolithic, with very few aurochsen present during this period, whereas in Germany, and potentially Denmark the change may have been more gradual. The kind of abrupt change seen in Britain, Spain and Italy has previously been interpreted as evidence for the introduction of domesticated cattle from elsewhere (e.g. Viner 2010), but the presence of higher proportions of wild cattle seen in Germany does not necessarily mean that local domestication was happening. Splitting the German sample by site demonstrated that different things may have been happening in different places.

The next chapter deals with some of the same data sets, but presents a comparison across space rather than time.

Chapter 4

Morphological Variation Across Europe by Broad Time Period

Thus far size and shape variation of *Bos primigenius* remains have been investigated in each geographic area individually. This section aims to bring together the results from each of these areas in order to form a picture of variation across space. In order to do this an attempt has been made to group material based on chronology rather than archaeological period. This will mean that chronologically contemporary material can be directly compared even when it derives from different cultural horizons. Chronological groups have also been chosen taking into account climatic changes. Table 4.1.1 outlines the chronological groupings used for this analysis.

Deciding which sites to compare was most problematic for the Pleistocene, because of the extreme climatic variability during this period, and as a result of this it has not always been possible to compare material from exactly the same climatic period. An attempt has been made to include as many of the larger assemblages as possible in this study.

For the Holocene, three chronological groups were defined, based on broad climatic and cultural changes. The first, which covers the period from 10000-5500 cal BC, roughly correlates with the Mesolithic period and reflects a generally warm period, leading into the Climatic Optimum of the current interglacial which occurred between c9ka and 4ka BP (c7000-3000 cal BC) . There are a couple of climatic changes that take place during this time (notably the 11.2 and 8.2 ka BP events), but these were short and sharp and the data that we have do not provide enough resolution to be able to see their effects, if there were any; there is thought to be only weak evidence for a significant climate change during the 8.2 ka BP event outside of the North Atlantic region, for example (Thomas *et al.* 2007). The second chronological group (5500-3000 cal BC) represents a continuation of this warm climate, but also the time period when we begin to see cattle domestication across Europe. The third chronological group (3000-500 cal BC) begins at the start of the late Holocene climatic deterioration which has been discussed throughout this thesis. The climatic deterioration continues up until approximately 500 cal BC (Bell and Walker 2005:93), so this group continues until this date.

Table 4.1.1: Chronological groupings used for the analysis of aurochs body size and shape across space in Europe.

Time period	Approximate archaeological periods	Climate
Pleistocene		
MIS 9	Late Lower Palaeolithic (Acheulean)	Warm interglacial
MIS 7	Middle Palaeolithic	Warm interglacial
MIS 5/6	Late Middle Palaeolithic	Last interglacial
Younger Dryas	Late Upper Palaeolithic/Epigravettian	Cold phase
Holocene		
1. 10000-5500 cal BC	Mesolithic	Warming
2. 5500-3000 cal BC	Late Mesolithic/Early Neolithic	Warm - climatic optimum
3. 3000-500 cal BC	Late Neolithic/ Chalcolithic/ Bronze Age	Climatic deterioration

This is also an opportunity to include some material from areas that were not included in the previous analysis, such as France and Switzerland, where there was not enough material spanning a wide enough chronology in order to include the areas individually. French material included in this section is from the Middle Palaeolithic site of La Borde (some data was taken from Jaubert *et al.* 1990, and some unpublished data was kindly provided by Jean-Phillipe Brugal), and the Mesolithic sites of La Montagne (8298-7944 cal BC – data taken from Helmer & Monchot 2006), and Noyen-sur-Seine (7234-6090 cal BC - recorded by the author). The Neolithic Swiss site of Seeburg, Burgäschisee-Süd (data from Stampfli 1963) is also considered here.

Only postcranial bones have been included in this analysis, due to the lack of comparable tooth data from different geographical areas, and only archaeological material has been used, and no partial skeletons, in order to avoid biases caused by having many bones from the same animal in a distribution.

4.1 The Pleistocene

As has been already noted, trying to compare contemporary sites from the Pleistocene is problematic due to the constant climatic fluctuations that took place during this period. Table 4.1.2 lays out the sites from the Pleistocene included in this study and the climatic fluctuations that they coincide with. Some sites span more than one marine isotope stage (MIS) and therefore may contain material from both warm and cold periods. These sites are difficult to include in a cross Europe comparison because of the potential variation which may be present. The Italian site of Canale Mussolini is a good example of this, and the previous analysis of the aurochs from this site in this thesis (see Section 3.4) demonstrates the impact that a fluctuating climate can have on an assemblage. Some sites included here have been dated according to the presence of tool cultures, or according to the animal species present at the site. This can sometimes be problematic. The British Pleistocene sites of Grays Thurrock and Ilford have been assigned to MIS 9 and 7 respectively, based on a detailed analysis of the mammalian biostratigraphy at British Pleistocene sites (Schreve 2001). A number of the more recent sites (such as Grotta Romanelli) have been subject to radiocarbon dating, which provides more precision in their dating.

Table 4.1.2: Pleistocene sites included in this project and their coinciding climatic phases.

Marine Isotope Stage – dates are ka BP (after Bassinot *et al.* 1994)	Climate	Britain	France	Spain	Italy
9 (334-301)	Interglacial	Grays Thurrock			Castel di Guido (327-260)
8 (301-242)	Glacial				
7 (242-186)	Interglacial	Ilford			
6 (186-127)	Glacial				
5 (127-71)	Interglacial - warm - climatic oscillations		La Borde	Solana del Zamborino	Grotta di Puntali Canale Mussolini (c85-60)
4 (71-57)	Glacial - cold and harsh	Coygan cave			
3 (57-24)	Fluctuating, but warmer				Grotta del Fossellone (c40-30) Grotta Paglicci (c28)
2 (24-11)	Glacial - cold and harsh - last glacial maximum				vado all'Arancio (c13) Grotta Romanelli (c12-10.5)
1 (11-1) Holocene	Interglacial				

4.1.1 Marine Isotope Stage 9

Two assemblages come from this warm interglacial period: Grays Thurrock (Britain), and Castel di Guido (Italy). The dates for Castel di Guido actually stretch into MIS 8, and therefore we cannot exclude the possibility that there is some material from a colder period in this sample. Nevertheless these two datasets provide an opportunity to compare aurochsen from northwest Europe to those from the Mediterranean during an approximately similar period.

Summary statistics from MIS 9 (Table 4.1.3) show that the samples from Grays Thurrock all display a higher mean than Castel di Guido, suggesting that there may be some differences that could be correlated with climate during this period. The populations from these sites will be plotted on scatterplots and log ratio histograms in order to investigate the variation further.

When displayed on a scatterplot (Figure 4.1.1), astragalus measurements from Castel di Guido plot to the smaller end of the range, whereas there are some especially large specimens from Grays Thurrock. The smallest tibiae are also from Castel di Guido, but the pattern is more difficult to read here due to the likely impact of sexual dimorphism creating two groups in the Italian sample. It could be that male animals are predominant in the sample from Grays Thurrock.

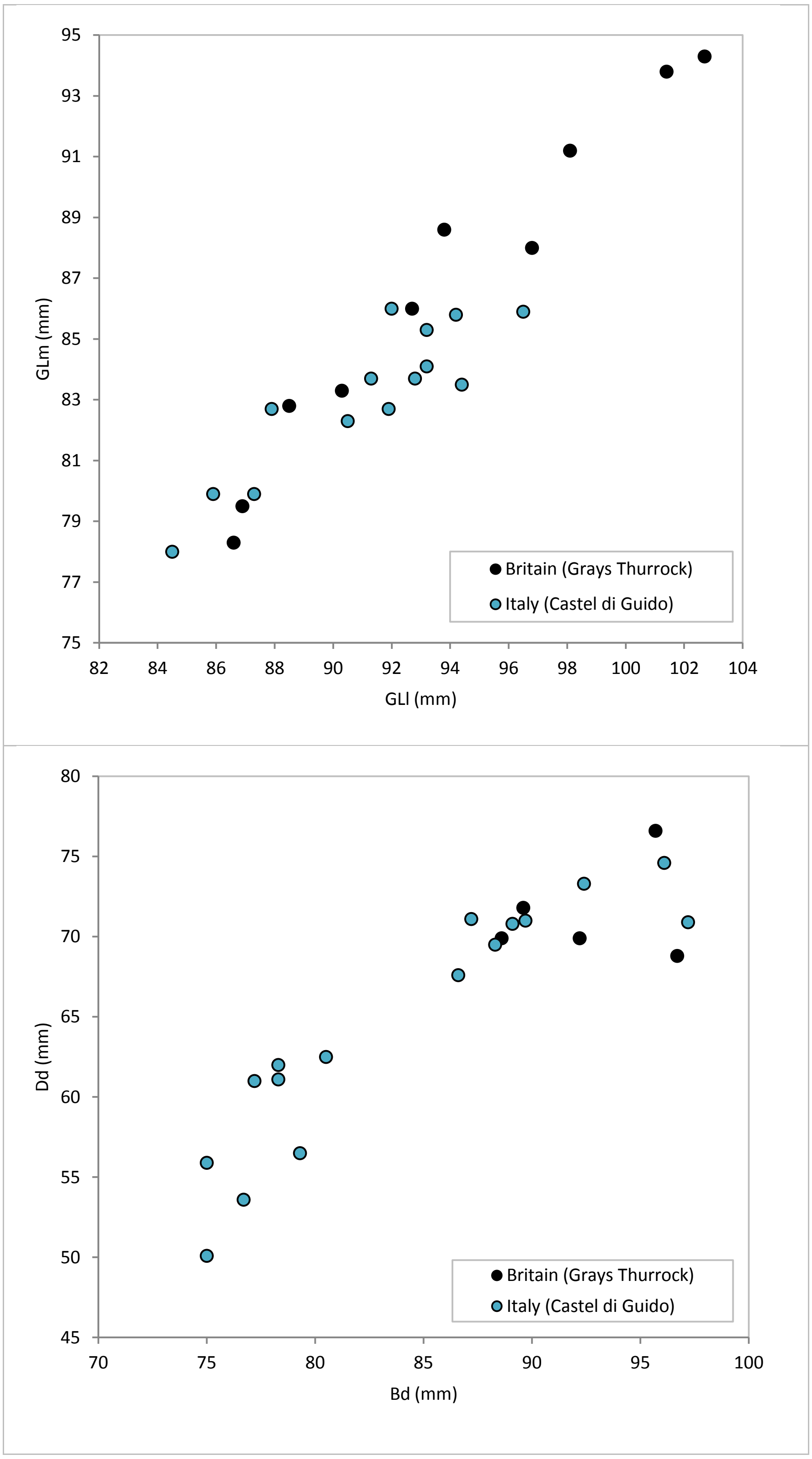


Figure 4.1.1: Scatterplots showing astragalus and tibia measurements from Britain and Italy in MIS 9.

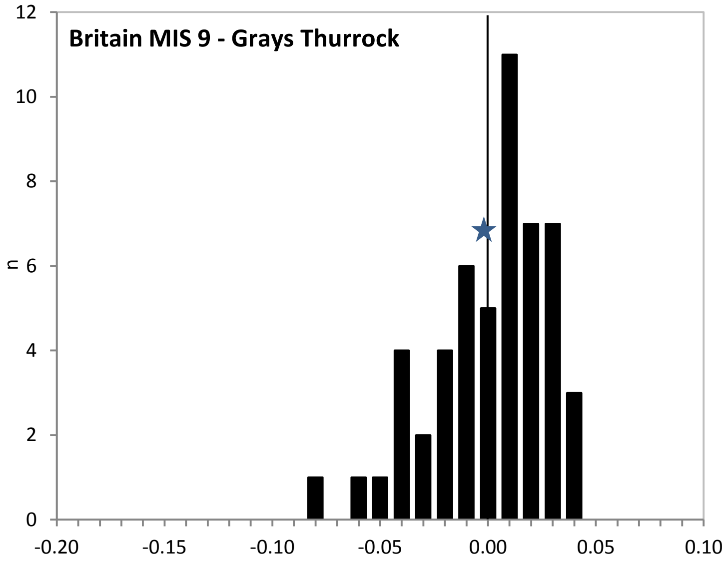
A slightly smaller mean at Castel di Guido, compared to Grays Thurrock is demonstrated by the log ratio patterns (Figure 4.1.2). There are a number of different explanations for this pattern. Firstly it could be a true reflection that aurochsen in Italy at this time were on average smaller than those in Britain – a pattern that would not be altogether unsurprising as Italy is so much further south. Alternatively it could be a reflection of the material from Castel di Guido potentially originating from a mix of climatic contexts. This would imply that the average size of the aurochs in the warmer MIS 9 would have been even smaller. It would also suggest that the animals from the colder period did not get larger than those at Grays Thurrock. Alternatively the pattern could be related to a predominance of males in the assemblage from Grays Thurrock. The scatterplot results suggest that this is unlikely, unless all of the plotted astragali from Castel di Guido are from females.

It is also possible that the pattern has been affected by the particular measurements included in the log Ratio analysis, as seen in many of the log ratio distributions in this project. Length measurements have tended to plot closer to the standard line, so if there is a predominance of length measurements in an assemblage it may indicate that there are more larger animals. The Castel di Guido diagram contains more measurements from the metapodials and humerus which tend to be more sexually dimorphic and therefore show more variation – these would plot further from the standard line than the sample from Grays Thurrock, which contains very small metapodial samples, and is mostly comprised of length measurements from the astragalus and calcaneum.

Despite the number of different factors which could be affecting the interpretation of these patterns, the assemblage from Castel di Guido, which is the much larger sample of the two, does not contain many very large measurements, and this in itself could be evidence that the Italian aurochs tended to be smaller than British aurochs at this time.

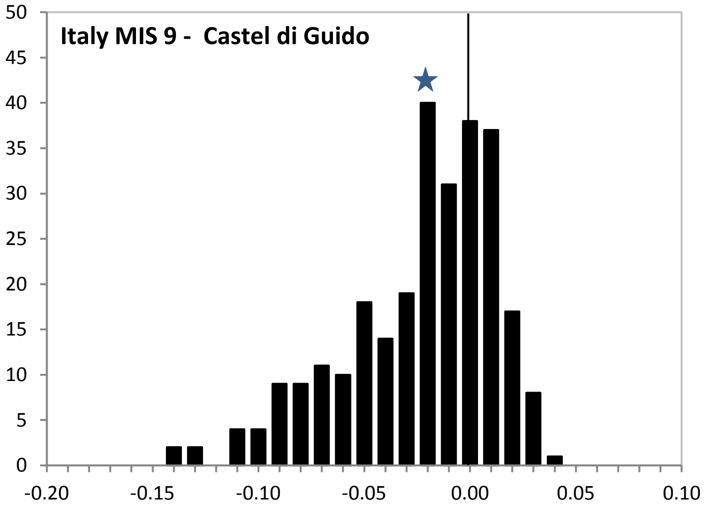
In order to enhance the picture of this part of the Pleistocene, the log Ratio distribution for the sample from Ilford has also been included here. This site is dated to MIS 7, which at its peak may have reached similar temperatures to MIS 9 (see Figure 1.3 in Chapter 1). Ilford has an identical mean to Grays Thurrock, which confirms the similarity of these two interglacials, but also provides another comparison to the material from Castel di Guido.

Compared to both Grays and Ilford, Castel di Guido reflects an aurochs population with a smaller average size, despite the fact that some of the included material may be from a colder period. This provides evidence of the presence of a north-south cline in aurochs body size during the Middle Pleistocene in Europe. Although Grays Thurrock did not have a large enough sample size to be included in a statistical analysis, a comparison of the samples from Castel di Guido and Ilford (Table 4.1.4) (which could act as a proxy for Grays, considering the similarity between the two samples) provides a significant result, confirming the differences between the two distributions.



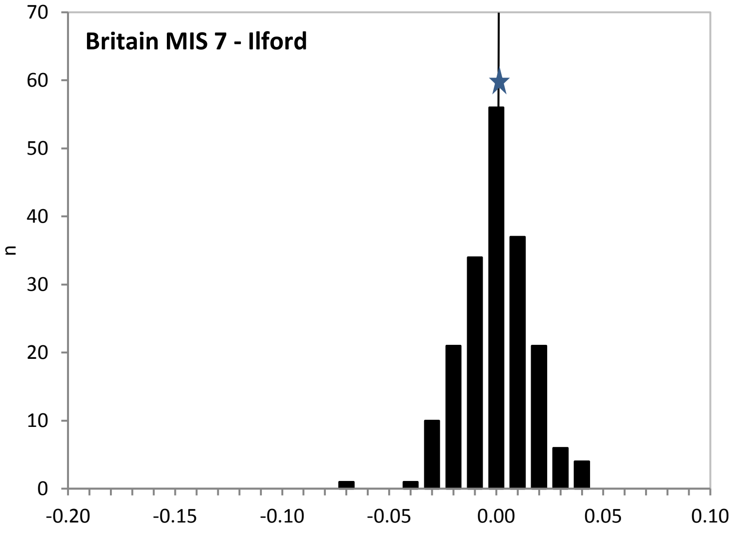
n= 52

Mean= 0.00



n= 275

Mean= -0.02



n= 191

Mean= 0.00

Figure 4.1.2: Log Ratio diagrams from MIS 9 (Grays Thurrock and Castel di Guido) and MIS 7 (Ilford).

4.1.2 Marine Isotope Stage 5

Grotta dei Puntali (Italy), La Borde (France) and Solana del Zamborino (Spain) have all been broadly dated to the last interglacial, which corresponds with MIS 5. Individual measurements are not available from Solana del Zamborino and therefore this site has only been included on the scatterplots using a green rectangle covering the range of measurements from the site.

A scatterplot of astragalus measurements indicates that aurochs from Solana del Zamborino and La Borde were similar in size, whereas the one animal from Grotta dei Puntali is much smaller. All sites have much smaller measurements than Ilford, here included to provide a baseline from an older interglacial. The difference is likely to be due to geography (the north-south cline) and climate (MIS 5 being warmer then MIS 7).

Aurochs remains from Grotta dei Puntali, which is located in Sicily, have previously been considered to be from a dwarf form, which became so due to its isolation from mainland Italy (Brugal 1987). This was discussed in Section 3.5. This further analysis confirms that this specimen is a very different size and shape from other astragali from the same interglacial in other areas of Europe, and therefore may indeed have been subject to insular dwarfism.

Unfortunately too few measurements from other bones were available for comparison using scatterplots.

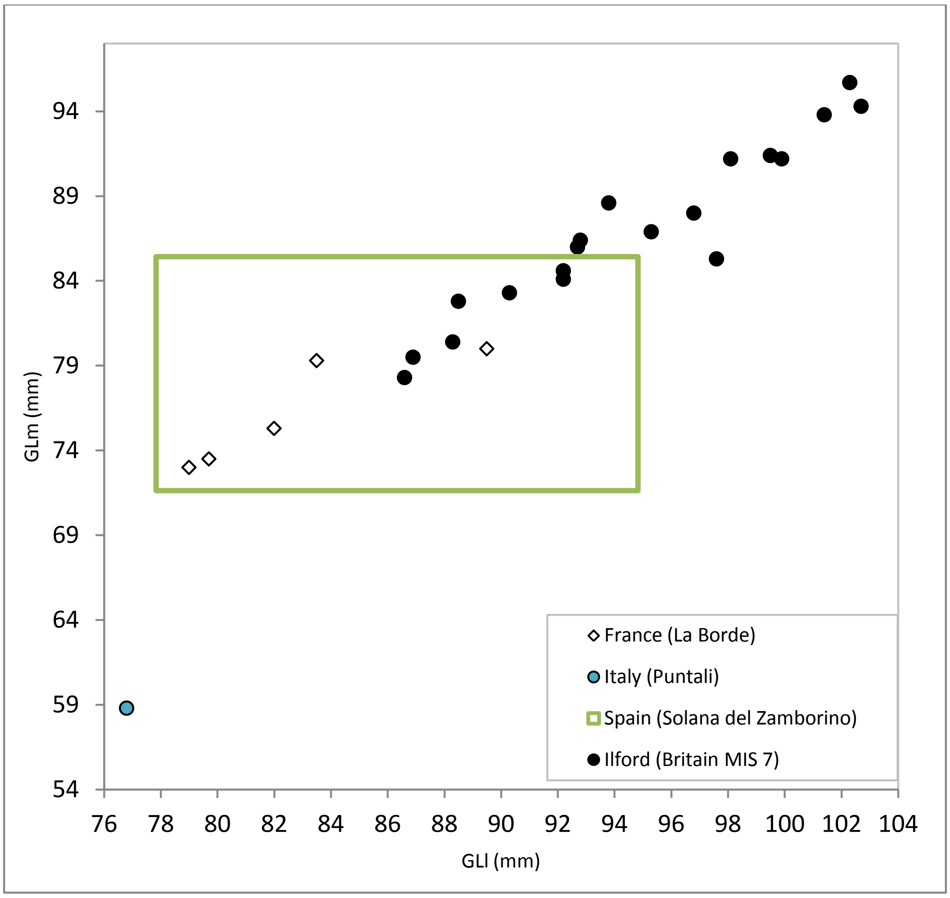
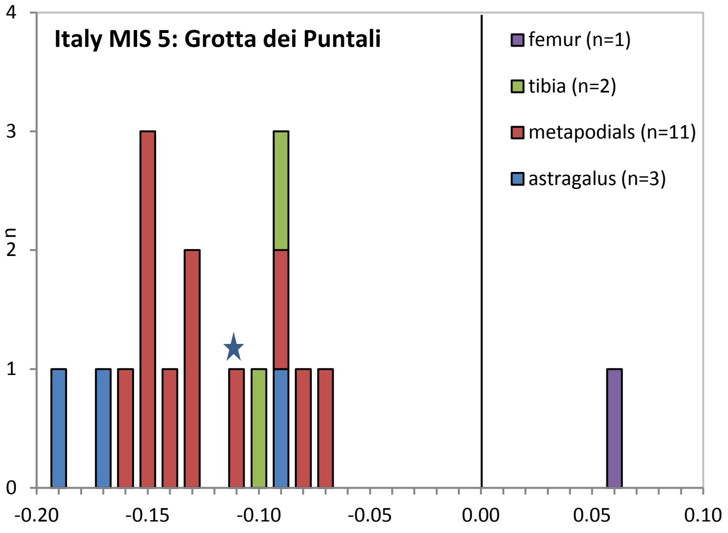


Figure 4.1.3: Scatterplot of astragali from sites dated to MIS 7: La Borde (France), Grotta dei Puntali (Italy), and Solana del Zamborino (Spain). Astragali from Ilford (Britain) have also been included in order to provide a comparison from MIS 7.

Log ratio distributions confirm the pattern seen in the astragalus scatterplot (Figures 4.1.4 and 4.1.5). The specimens from Grotta dei Puntali plot consistently to the smaller end of the distribution, and although some of the astragalus measurements are the smallest, a number of metapodial measurements are also very small. The one very large femur measurement is particularly intriguing. It is unlikley that this measurement comes from the same remains as the other specimens from this site and its presence suggests that the non-dwarfed form may have co-existed with the dwarfed-form, or it is a more recent intrusion. The similarity of this femur measurement to some others from *Bos primigenius* in other places in Europe suggests that this measurement isn't likely to be a mistake. This is something that needs to be further investigated through looking at different, larger samples.

The sample from La Borde plots in between the samples from Grotta dei Puntali and Ilford, and its mean is actually closer to that of Puntali. This confirms the decrease in body size between MIS 7 and 5, and that the sample from Grotta dei Puntali may derives from a particularly small sized aurochs population.



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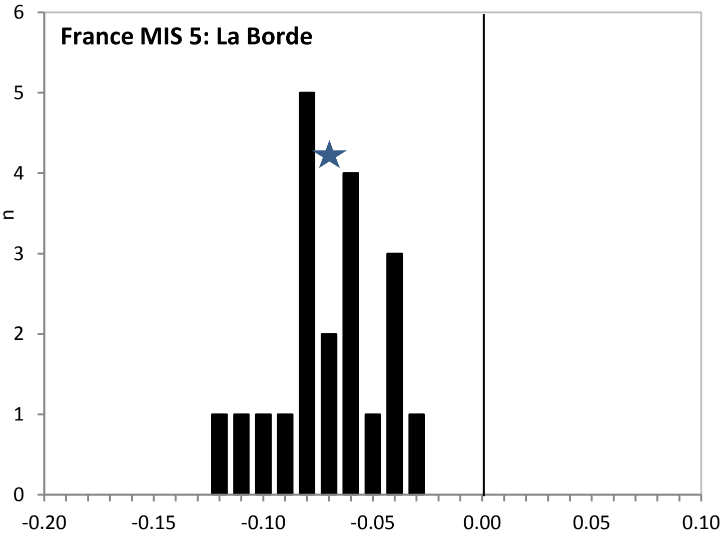

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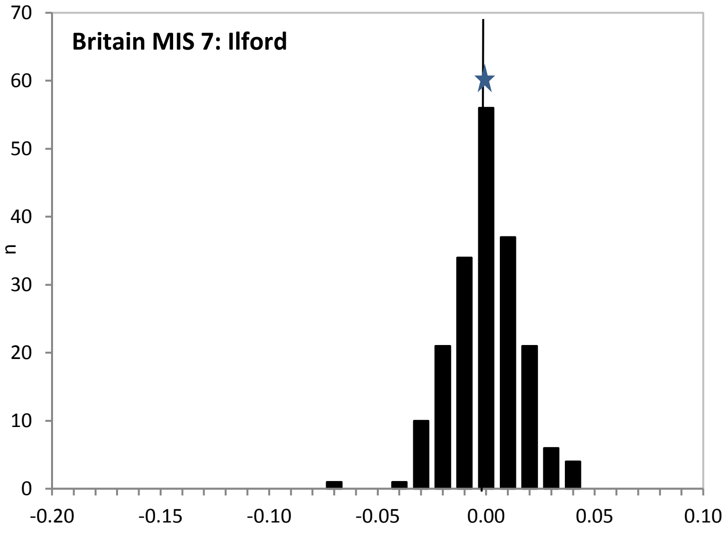
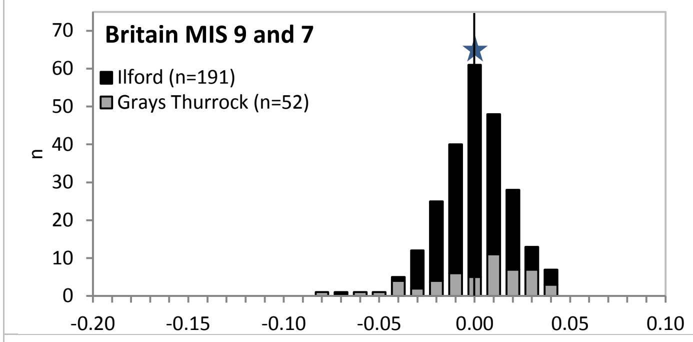
mean= -0.07



n= 191

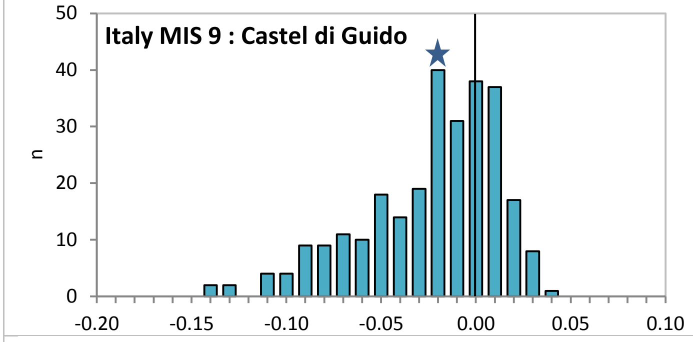
mean= 0.00

Figure 4.1.4: Log Ratio diagrams for sites from MIS 5. The distribution from Ilford (MIS 7) is also included for comparison.



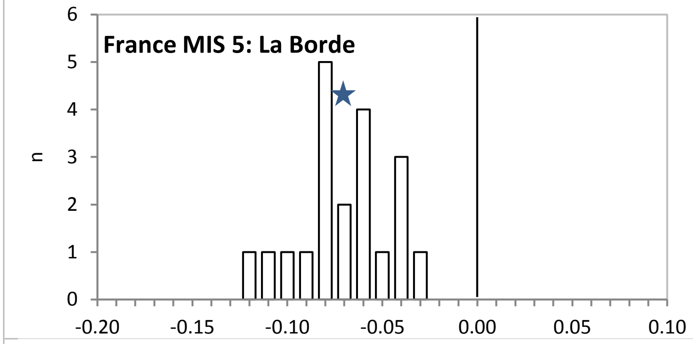
n= 243

mean= 0.00



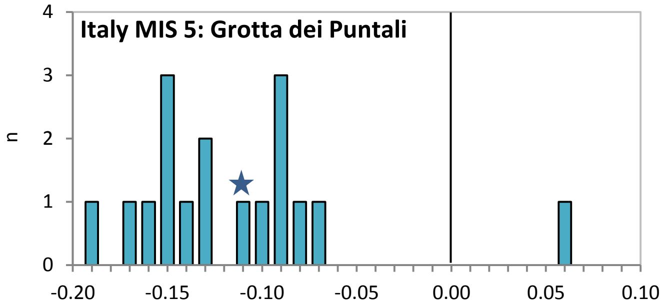
n= 275

mean= -0.02



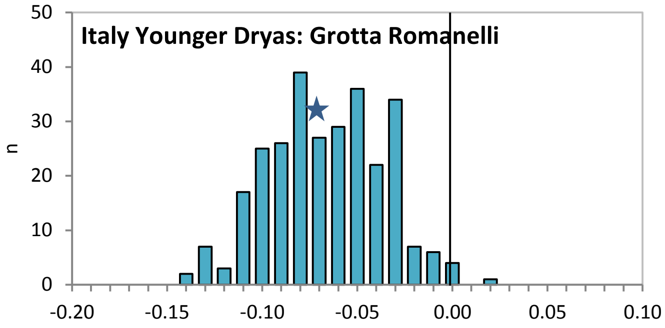
n= 20

mean= -0.07



n=17

mean= -0.11



n= 286

mean= -0.07

Figure 4.1.5: Log Ratio diagrams for all of the sites included in this analysis. Northern European assemblages are in black, grey and white, and southern European assemblages are in colour.

Finally the distribution from Grotta Romanelli is also included to compare with the sites already discussed, and to see the pattern of change over time. This site mostly dates to the Younger Dryas and can therefore be considered as representing aurochs from a cold climate, although it was not as cold as the last glacial maximum. There is no sign of an increase in the size of the animals here, compared with those from previous periods during the Pleistocene, as might be expected in accordance with Bergmann's rule. This material overlaps most with that from La Borde and also with some of the material from Grotta dei Puntali. It is significantly smaller than the specimens from Castel di Guido, despite the fact that it is from a far colder period (Table 4.1.4).

Overall, a reduction in size can be seen over time. The last Pleistocene interglacial (MIS 5) is thought to have been warmer than the previous two interglacials (MIS 9 and 7), and, assuming the material from La Borde is a suitable proxy for material from this phase, it indicates a reduction in size compared with previous periods. There is no real sign of an increase in size again during the Younger Dryas, particularly if we assume that the material from Grotta dei Puntali is small mainly because of insularism rather than climate.

Where it is possible to compare across space, southern European material does seem to be slightly smaller than northern European material, but essentially this analysis is limited by a lack of material from the same time period which is contemporary enough to be compared. In many ways this situation was inevitable, because the aurochs was mainly restricted to southern areas during glacial times.

Table 4.1.3: Summary statistics for Pleistocene *Bos*. Samples of less than 5 were excluded.

Measurement	No.	Min	Max	Mean	Standard deviation	Coefficient of variation
Astragalus GLl						
Grays Thurrock	12	86.6	102.7	94.9	5.85	6.17
Castel di Guido	18	84.5	96.9	90.9	3.64	4.00
Ilford	10	88.3	102.3	95.2	4.50	4.73
La Borde	5	79	89.5	82.7	4.18	5.06
Grotta Romanelli	11	82.4	92.7	86.7	3.90	4.50
Astragalus GLm						
Grays Thurrock	10	78.3	94.3	86.6	5.61	6.48
Castel di Guido	22	76.3	87.4	83.1	2.85	3.43
Ilford	9	80.4	95.7	87.3	4.65	5.32
La Borde	6	73	80	76.5	2.97	3.89
Grotta Romanelli	15	70.2	85.2	78.5	3.73	4.76
Astragalus Bd						
Grays Thurrock	8	55.6	72.5	66.8	5.89	8.82
Castel di Guido	8	58.8	68.2	63.7	3.59	5.63
Ilford	6	62.2	71.1	66.7	2.83	4.24
La Borde	6	52.5	61	56.5	3.04	5.38
Grotta Romanelli	17	49.8	63.4	56.7	3.88	6.84
Tibia Bd						
Castel di Guido	20	75	97.2	85.55	7.29	8.52
Ilford	7	88.6	96.7	91.6	3.38	3.69
Grotta Romanelli	30	68.1	85.7	77.1	5.22	6.77
Tibia Dd						
Castel di Guido	19	50.1	75.4	65.8	7.69	11.69
Ilford	6	58.4	76.6	69.2	5.99	8.65
Grotta Romanelli	26	52.7	69	59.6	3.99	6.70

Table 4.1.4: Results of Mann-Whitney test on *Bos* postcranial log ratios from Pleistocene sites. Significant results (<0.05) are marked with an * and highly significant results (<0.01) are marked with **. Samples smaller than 20 have been excluded. Only one measurement from each bone was included, and samples of under 20 were excluded.

Group	n.		n.	U	z	Sig.
Castel di Guido	112	Ilford	57	1775.0	-4.76	0.000**
Castel di Guido	112	Grotta Romanelli	81	1488.0	-7.98	0.000**
Ilford	57	Grotta Romanelli	81	40.0	-9.84	0.000**

4.2 Holocene

For the Holocene, three chronological groups were defined, based on broad climatic and cultural changes; c10000-5500 cal BC, c5500-3000 cal BC and c3000-500 cal BC. Tables 4.2.1, 4.2.4 and 4.2.7 lay out the sites for each of these periods within their broad chronologies.

4.2.1 10000-c5500 cal BC

This period coincides roughly with the Mesolithic, and the material included in this section is considered to be from prior to the onset of domestication in most areas of Europe. This material is from a relatively warm period which leads into the Climatic Optimum of the last interglacial. This is a period for which data are available from across a wide area of Europe, although some of the southern European samples are small. It is worth bearing in mind throughout this analysis that there are some gaps in chronology within this period for certain geographical areas. The British material is fairly early in date (see Table 4.2.1) (i.e. pre-8000 cal BC), as is the majority of the German sample. The Danish dataset contains some material that has not been securely dated, but the dates that are available are from the later part of this period. The material from the Portuguese Muge middens is also late in date (in fact these sites may also have had some occupation after c5500 cal BC (Bicho *et al.* 2012), although the majority is from before this date. The general climate is not thought to have changed a great deal during this time period, but it is worth bearing in mind that sites which are not entirely contemporary are being compared. It is also important to consider the potential impacts of more localised climatic events which would not have been recorded in the Greenland ice core data.

The material from Cherhill has not been included here or in the following Early Neolithic section, due to the fact that this site has mixed material and it was unclear which was Mesolithic and which was Neolithic (Sarah Viner-Daniels *pers. comm.*).

Summary statistics (Table 4.2.2) show a reduction in mean values between northern and southern areas, which might provide a similar climatic pattern as seen during the Pleistocene. Samples from Denmark and Sweden display the largest ranges, and this may be a reflection of the fact that these samples contain material from a number of sites as opposed to samples such as Portugal, where all of the material is from one site. The spread of measurements within each population will now be explored further using scatterplots and log ratios.

Astragali provide the most specimens suitable for plotting on a scatterplot, and provide samples from across most geographical regions (Figure 4.2.1 – top diagram). The northern European sample clearly contains, on average, larger animals than the southern European sample, which plots to the smaller end the range. The samples from Denmark and Sweden, Britain, Germany and France (these specimens all come from the site of La Montagne, in southern France) all plot in a very similar area on the diagram, and this material potentially forms two groups, most prominent according to breadth measurements, which could be representative of male and female animals. This pattern is not visible for the southern European material, perhaps as a consequence of the smaller sample size. There is also a slight hint in the southern European material that astragali breadths are large for their length (Figure 4.2.1 – bottom diagram), in comparison with the northern European sample. The French sample also hints at this pattern, although the sample is small. This pattern is particularly obvious in some of the Iberian specimens. Regression lines have been added to the top diagram for the samples from Denmark and Sweden, France and Portugal in order to demonstrate this, and the bottom diagram is specifically designed to highlight shape change.

Far fewer tibiae were suitable for inclusion on a scatterplot, so sample sizes here are very small in comparison to the astragalus. The pattern indicates a less distinct difference in size between the northern and southern aurochs (Figure 4.2.2). The Danish sample still contains the largest specimens, but some British and French specimens are especially small. Of particular interest is the one very small French specimen, which is from the site of Noyen-sur-Seine (in the Paris basin). The identification of this bone has been checked by the author when it was recorded in Paris, and was subsequently double checked (thanks to Angelos Hadjikoumis for this). This site is situated near to Paris in the north of France, whereas the other French tibia included here is from the site of La Montagne, which is situated much further south in the Bouches-du Rhone. This suggests that this difference in size is not related to climate. The fact that it is so much smaller than the Portuguese specimens also confirms this. It has been suggested that this specimen could potentially be very early evidence for cattle domestication in Middle Mesolithic France, or alternatively is intrusive (Jean-Denis Vigne *pers. comm.*). A radiocarbon date for this specimen is clearly desirable.

Table 4.2.1: Broad chronology for the sites included in the 10000-5500 cal BC group.

Chronology	Climate	Britain	Denmark	Germany	France	Spain	Portugal	Italy
10000-9000 cal BC	Warming	Star Carr		Bedburg Königshoven		Cueva de Mazaculos Cueva de Arenaza		
9000-8000 cal BC	Warming							
					La Montagne			
8000-7000 cal BC	Warming							
			Holmegaard Mullerup Ulkestrup Lyng	Hohen Vichelen	Noyen-sur-Seine			Grotta delle Mura
7000-5500 cal BC	Warming							Grotta dell'Uzzo
							Muge middens	

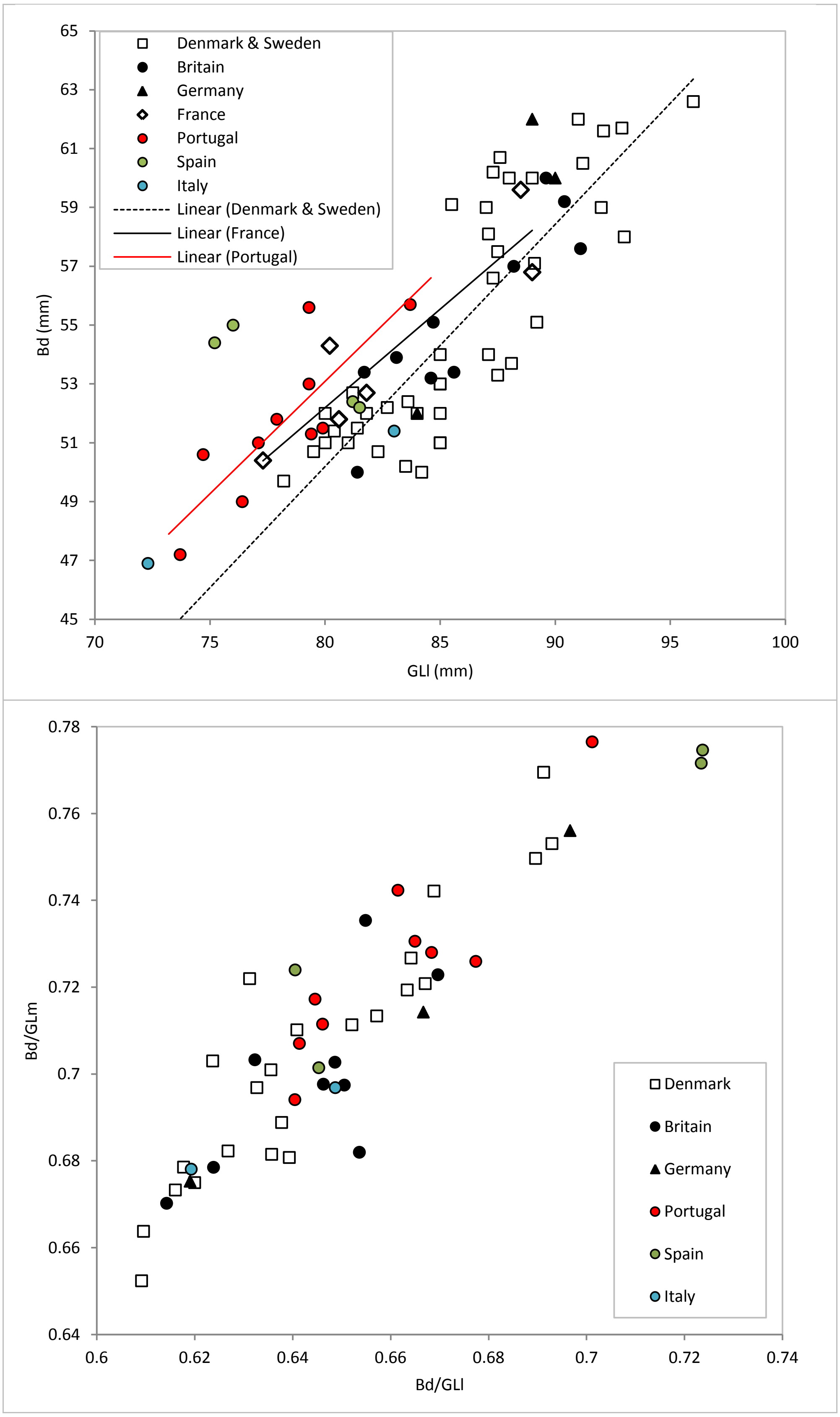


Figure 4.2.1: Scatterplots of astragali looking for size change (top diagram) and shape change (bottom diagram) from sites across Europe dated between 10000 and 5500 cal BC. Northern European countries are in black and white, and southern European countries in colour. (Note: all potential elk specimens – as discussed in the preceding results chapters – have been excluded here in order to avoid potential confusion.)

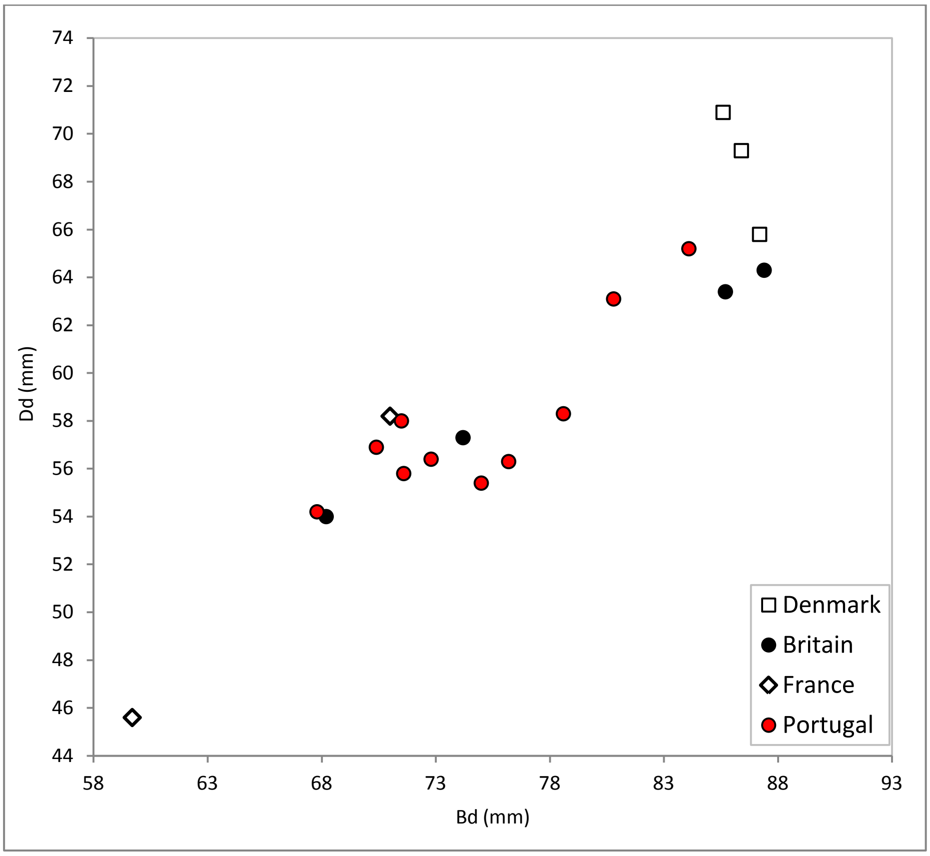


Figure 4.2.2: Scatterplots of tibiae from sites across Europe dated between 10000 and 5500 cal BC. Northern European countries are in black and white, and southern European countries in colour.

Log ratio results (Figure 4.2.3) demonstrate the overall similarity of the samples from Denmark and Sweden, Britain and Germany, which all have very similar means. The German sample shows a slightly different distribution, but its sample size is far smaller, so it could be a reflection of this. The one small specimen in the German sample is a metapodial SD, which has often proven to be a very variable measurement in this study, so it may not be particularly significant.

The French sample contains a number of very small measurements for the Mesolithic, the majority of which are from Noyen-sur-Seine. These measurements include those from the tibia on the scatterplot above, and also measurements from the humerus. The sample from La Montagne plots in a similar position to Portugal rather than with the northern European samples which may reflect the southern location of this site in France, and may be therefore better grouped with the southern and Mediterranean areas. However this site also has some very small measurements. These are breadth measurements from the distal metacarpal. When the French and Portuguese samples are compared statistically, there is a non-significant result, compared with a significant result when compared with northern areas (Table 4.2.3). This is unsurprising considering the overlap between the material from La Montagne and the Portuguese sample on the Log Ratio results, but it must be treated with caution until the status of the very small measurements in the French sample is resolved.

There is a clear difference in size between the northern samples from Denmark and Sweden, Britain and Germany, and the southern sample from Portugal, with both the mean and the peak of the Portuguese dataset being lower. The pattern is not reflected to the same degree by the Spanish and Italian samples. They display lower means than the northern European samples, but not to the extent of the Portuguese sample. However, these regions have very small sample sizes, and cannot be fully relied upon.

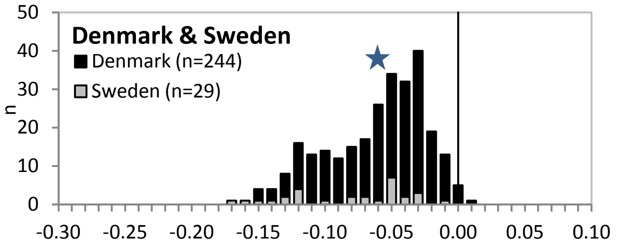
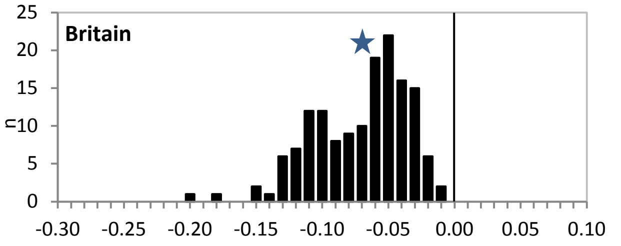
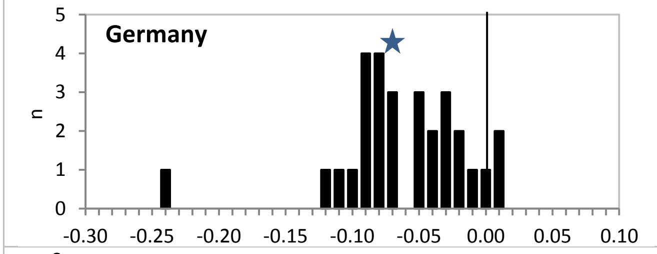
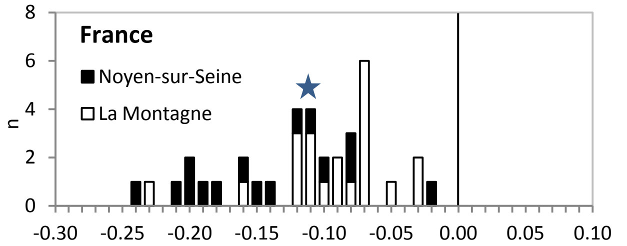
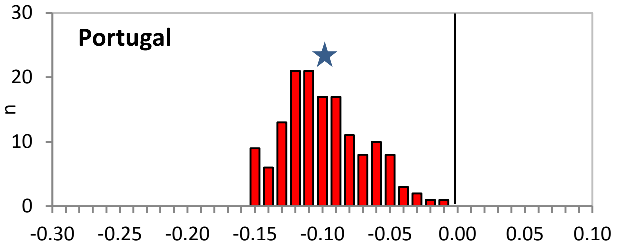
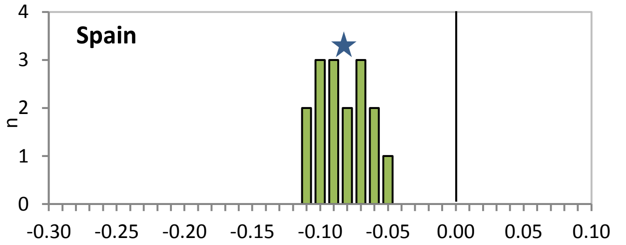
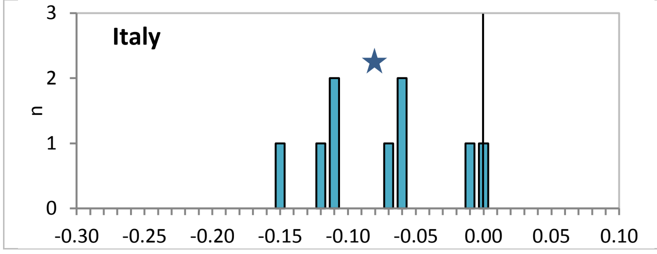
	n= 273 mean = -0.06
	n= 145 mean= -0.07
	n= 37 mean= -0.07
	n= 36 mean= -0.11
	n= 148 mean= -0.10
	n= 16 mean= -0.08
	n=9 mean= -0.08

Figure 4.2.3: Log ratio diagrams of material from different European countries during the period 10000-5500 cal BC.

Displaying the results by selected individual measurements allows us to see where in the body change is taking place (Figures 4.2.4 and 4.2.5).This is particularly useful during the Mesolithic period, because there are no domestic cattle present in the samples which will confuse the patterns. For the astragalus the most distinct difference between north and south is a reduction in length measurements. A difference in the size of length measurement has regularly been interpreted as a true size change in this project, due to their lesser variability, and therefore greater reliability in assessing the average body size of a population, compared to breadth measurements. Here, however, breadth measurements do not reduce at the same rate, resulting in a pattern in the Portuguese sample where there is little bimodality compared with the samples from northern Europe, with most breadth measurements plotting at a similar distance as lengths from the standard population. Astragali in Portugal are therefore a more similar proportion to the astragali making up the standard population (Pleistocene Ilford), but are just much smaller. These astragali would have been less slender than those from northern Europe.

The lack of good comparable length measurements across space for the tibia and metacarpal hinders our ability to look at slenderness in these other bones, but it is possible to see size change in particular measurements. Tibia breadth measurements are clearly overall smaller in Portugal than in the northern areas, and there is a slight overall decrease in metacarpal breadth measurements in the Portuguese sample too.

The distributions for the French sites have been included in order to see where the main differences in size lie. Astragalus measurements from La Montagne fit very well with the pattern for other areas of Europe; this sample plots mid-way between the northern European and Portuguese samples. This makes absolute sense considering this site is in southern France – and supports the idea that the differences between north and south are related to climate.

Measurements from other body parts show a different pattern, with some particularly small measurements being present in the samples of tibiae, metacarpals and humeri. The clearest shift is in the humerus measurements from Noyen-sur-Seine, which are all particularly small compared to humerus measurements from both Denmark and Portugal. This suggests that the differences are not related to climate. Tibia measurements are particularly interesting as there are small measurements from both French sites, not just Noyen-sur-Seine. This hints that there may have been a particular situation in France, although of course there may also be the possibility of intrusive modern cattle at either site. This situation is certainly not resolved by this analysis, and further work on French Mesolithic cattle remains is needed, including clearer dating of some of the smaller bones in order to determine if this pattern is indeed the result of modern intrusions.

Overall, there does seem to be some evidence of a difference in size between northern and southern regions of Europe during the Mesolithic period, with southern areas having aurochs which were, on average, smaller than those in the north. When the samples are tested statistically, there is consistently a significant difference between northern and southern samples, and when the overall combined northern group and southern group were compared statistically, there was also a significant result (Table 4.2.3). The French material was not included in the overall group, but the log ratio results and the statistical analysis of these results suggest that the site of La Montagne shows more similarity with the southern samples than those from northern areas. Astragalus measurements suggest that this bone may have been wide for its length (less slender) in the south compared with the north. This is an interesting pattern as most size reductions seen in this project, whether thought to be related to climate or domestication, have caused more slender bones.

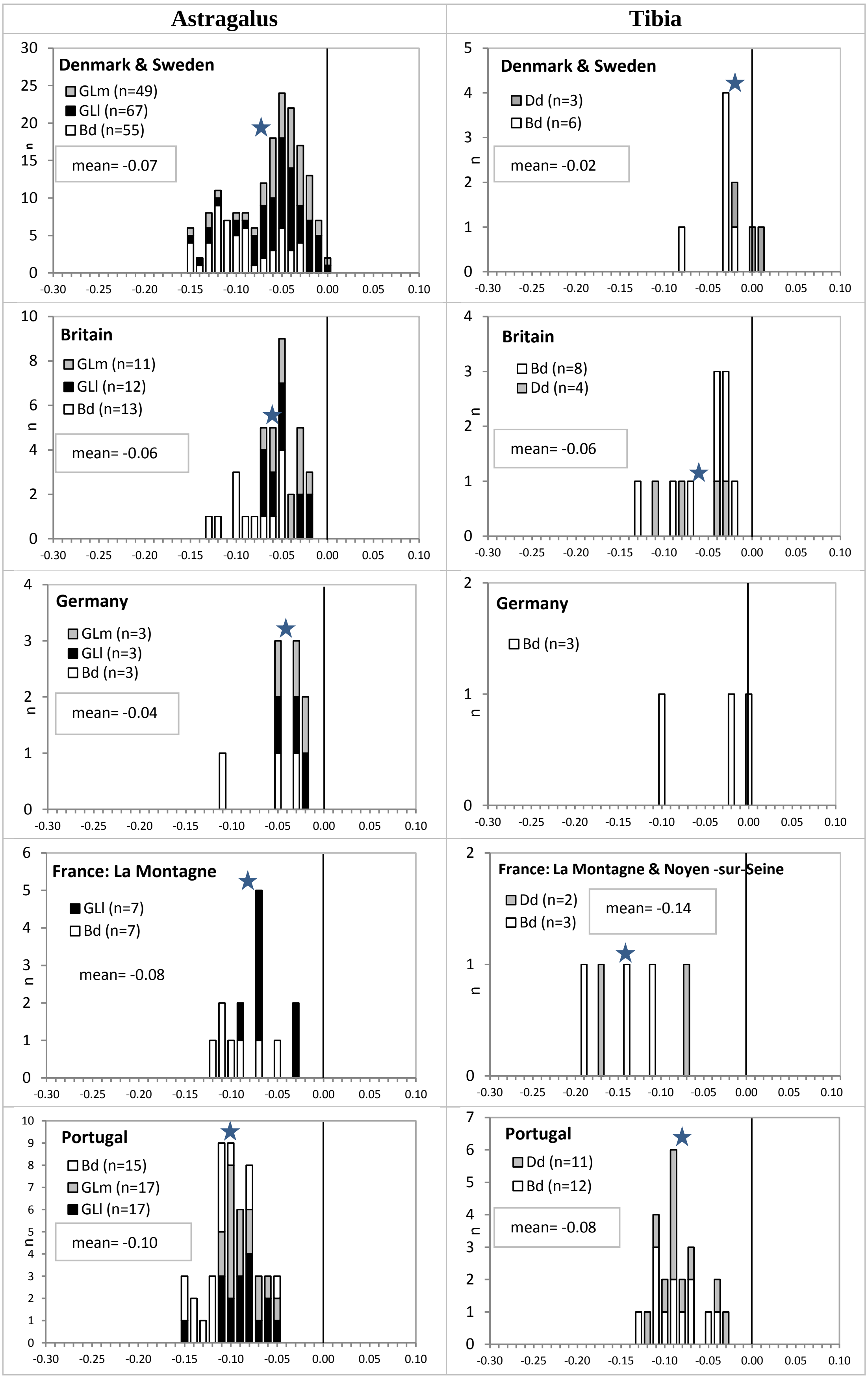


Figure 4.2.4: Log Ratio diagrams displaying astragalus and tibia measurements from different areas of Europe during the period 10000-5500 cal BC.

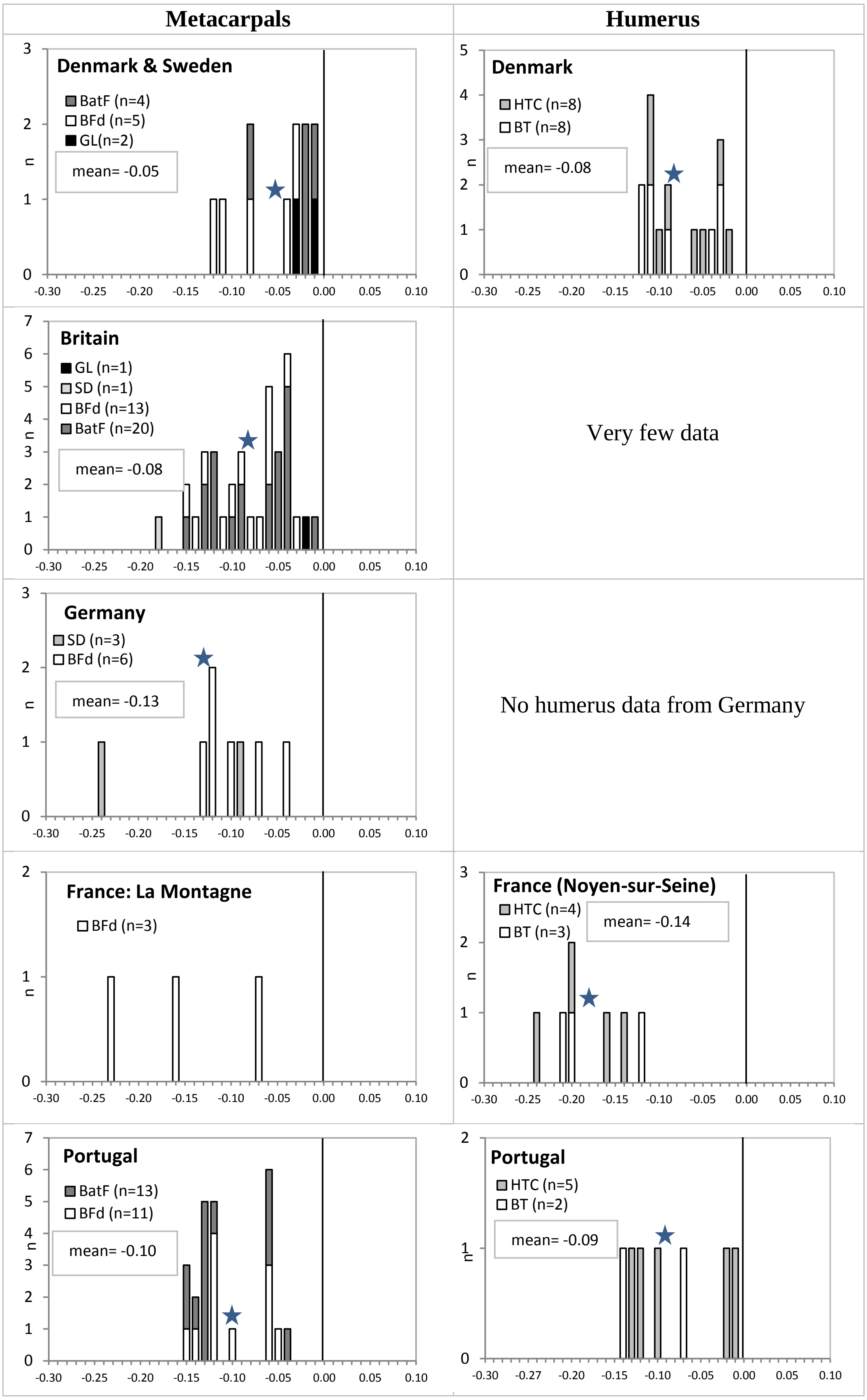


Figure 4.2.5: Log Ratio diagrams showing metacarpal measurements from different areas of Europe during the period 10000-5500 cal BC.

Table 4.2.2: Summary statistics for *Bos* during the period 10000-5500 cal BC. All the French material is from the site of La Montagne only.

Measurement	no.	min	max	mean	standard deviation	coefficient of variation
Astragalus GLl						
Denmark &Sweden	64	67.8	96.0	85.1	5.59	6.58
Britain	11	81.4	91.1	85.8	3.49	4.07
France	7	77.3	89.0	82.6	4.44	5.38
Portugal	17	68.1	84.6	78.0	4.16	5.34
Spain	5	75.2	83.0	79.4	3.53	4.45
Astragalus GLm						
Denmark &Sweden	49	62.3	88	77.79	5.56	7.15
Britain	11	74.6	83.0	79.3	2.79	3.52
Portugal	17	68.0	77.6	71.3	2.76	3.87
Astragalus Bd						
Denmark & Sweden	52	47	62.6	54.44	4.21	7.74
Britain	13	50.0	60.1	55.6	3.45	6.21
France	7	50.4	59.6	53.9	3.25	6.04
Portugal	15	47.2	59.8	51.6	3.34	6.47
Tibia Bd						
Denmark & Sweden	6	77.0	87.2	84.5	3.76	4.45
Britain	8	68.2	87.4	80.9	6.84	8.45
Portugal	12	67.8	84.1	75.1	4.69	6.24
Tibia Dd						
Portugal	11	52.1	65.2	57.4	3.77	6.56

Table 4.2.3: Results of Mann-Whitney tests on *Bos* postcranial Log Ratios from the period 10000-5500 cal BC. Significant results (<0.05) are marked with an * and highly significant results (<0.01) are marked with **. Only La Montagne is included in the French sample. The Northern Europe group contains Denmark & Sweden, Britain, and Germany. The Southern European group contains Portugal, Spain, and Italy. Only one measurement from each bone was included, and samples of under 20 were excluded.

Group	n	Group	n	U	z	Sig.
Denmark & Sweden	106	Britain	63	2755.0	-1.81	0.700
Denmark & Sweden	106	Germany	23	922.0	-1.78	0.750
Denmark & Sweden	106	France	21	503.0	-3.94	0.000**
Denmark & Sweden	106	Portugal	70	1455.5	-6.78	0.000**
Britain	63	Germany	23	632.0	-0.90	0.367
Britain	63	France	21	344.0	-3.28	0.001**
Britain	63	Portugal	70	1078.0	-5.08	0.000**
Germany	23	France	21	157.5	-1.98	0.047*
Germany	23	Portugal	70	523.0	-2.53	0.012*
France	21	Portugal	70	664.5	-0.67	0.504
N. Europe	192	S. Europe	83	4062.0	-6.42	0.000**

4.2.2 5500-3000 cal BC

This period roughly covers the very late Mesolithic and the earliest part of the Neolithic up until the onset of the late Holocene climatic deterioration which has been regularly discussed throughout this study (see Table 4.2.4). It is worth bearing in mind that the Neolithic begins at different times in different areas of Europe, essentially beginning earlier in southern Europe than in northern Europe. Therefore different parts of Europe will have been in different cultural periods at the same chronological times. It is from this time period that domesticated cattle appear in the archaeological record and begin to confuse the pattern. This period includes material from sites linked to the Ertebølle culture, and as for previous analyses, sites from the very northern tip of Germany in the state of Scheswig-Holstein (Rosenhof and Neustadt LA) have been included in the Danish dataset.

Confidence in the results will need to consider that Germany has a very large dataset from this period, whereas some other areas, such as Britain, have small samples. This must be remembered when attempting to interpret the patterns that arise.

Summary statistics (Table 4.2.5) indicate larger means in northern areas compared to southern areas, but also quite a few measurements display wide ranges, so the presence of domestic animals in the samples may be a factor here. Italy displays the smallest coefficient of variation for all measurements, which reflects that all of these animals are likely to be domestic. The ways in which the measurements are spread within these populations will allow further interpretation, so they will be plotted on scatterplots and log ratio histograms in order to investigate this.

The scatterplot of astragali (Figure 4.2.6) demonstrates the large size of the German sample in comparison to the other geographical areas. Specimens from Germany cover almost the whole size range, whereas all of the other samples cover smaller parts of this area. This may be an indication that sample size is impacting the pattern. It is difficult to split the German sample into potential wild and domestic groups – something that was mentioned when the German sample was previously examined (Section 3.3), as was the case with Spain. Some of the other individual geographic areas do show more of a distinction such as Britain, Denmark, and especially Switzerland, but when combined together this is difficult to spot. This is an indication that attempting to identify wild and domestic animals based upon measurements from areas of Europe that are not pertinent to the one being investigated is likely to lead to inaccuracies. Nevertheless it seems likely that all of the Italian specimens included here are domestic animals (this has been discussed in Section 3.5), whereas all of the other areas contain at least one wild animal.

The largest specimens on the diagram are most likely to be wild, and almost all of the largest specimens are from Germany. Denmark, Switzerland and Poland also have some fairly large individuals. Spain and Britain have some specimens which are likely to be wild, but are at the smaller end of the wild cattle range. One explanation for this is that the German sample contains a particularly large number of male animals compared to these other areas. Alternatively this is a reflection of a difference in the size of the aurochs across Europe at this time. The British sample can probably be excluded from this interpretation, as it is very small, but it is possible that the larger Spanish specimens are in fact from wild male cattle. There is no indication that domestic cattle from southern Europe are any smaller than domestic cattle from northern Europe during this period. The smallest Italian and Spanish specimens are a similar size to the smallest specimens from Germany. This could indicate that the difference in climate between these areas is not affecting body size, or alternatively it could indicate that climate factors are less likely to have had an impact on domestic animals. This is a possibility, as domesticates who relied on food provided by humans may have been less affected by climatic and environmental factors.

The pattern displayed by the Swiss sample is especially interesting. This assemblage splits clearly into two groups, and the smaller (potentially domestic) group is made up of astragali which are especially small – all of them plot to the very bottom, or beyond the bottom of the range covered by other areas. The clear distinction between the two groups could be related to the fact that this sample only includes material from one site, which may have had a specific husbandry regime – for example one which kept domestic and wild cattle very strictly apart, although this would not explain the especially small specimens. Alternatively the pattern could be related to a methodological issue. There is no indication that any of the measurements could have been taken from light or porous astragali, which would have been young (see Stampfli 1963), but this is of course possible. Perhaps the most likely explanation is related to the husbandry practices employed at this particular site, and this is a further reminder of the large amount of variation in cattle husbandry practices that was likely to have been present during the Early Neolithic period (as was discussed throughout the preceding chapters). Inclusion of all of the postcranial measurements from this site on a log ratio diagram may help to shed light on this further.

Table 4.2.4: Broad chronology for the sites included in the 5500-3000 cal BC group.

Chronological	Climate	Britain	Denmark	Sweden	Germany	Poland	Switzerland	Spain	Italy
5500-4500 cal BC	Warming	Goldcliff East	Dyrholmen Norslund Braband Sø Krabbesholm		Rosenhof Neustadt LA Künzig Unternberg Meindling Straubing-Lerchenhaid	Żuławka Mała Grabie Bochien Bozejewice Łojewo Gniechowice		La Renke Cueva de la Vaquera La Draga Cueva de Chaves	Favella Grotta dell'Uzzo Arene Candide
4500-3500 cal BC	Warming	Eton Rowing Lake	Hjerk Nor Kolind Havnø		Schernau Bruschal-Scheelkopf Ehrenstein Hüde I		Burgäschisee-Sud		
3500-3000 cal BC	Warming		Bundsø Lidsø	Lindängelund Alvastra				Cueva de Arenaza	

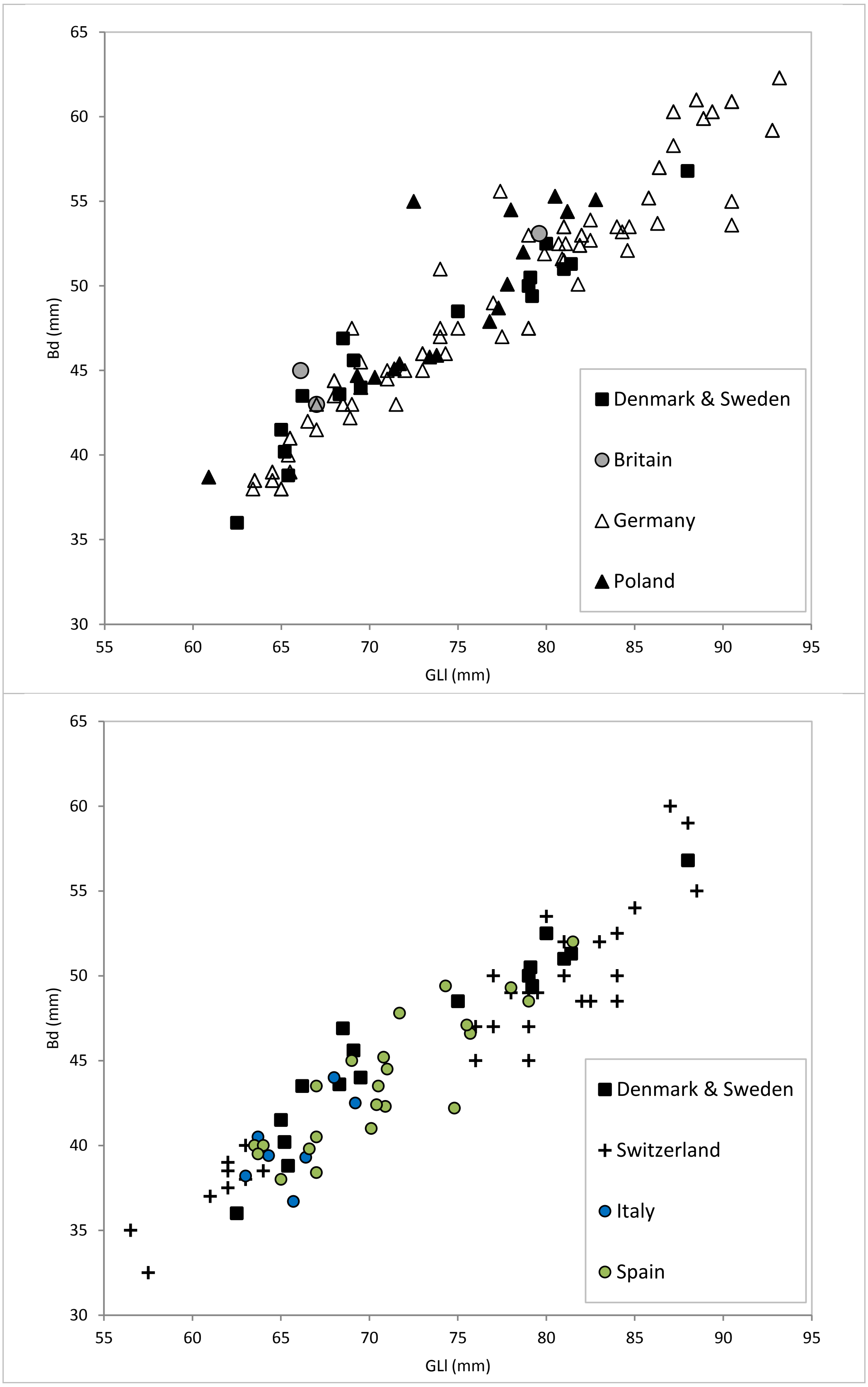


Figure 4.2.6: Scatterplots of astragali from different European countries dated between 5500-3000 cal BC. Astragali have been split between two graphs for a clearer visual comparison.

Log ratio diagrams (Figure 4.2.7) confirm the difficulties of being able to separate wild from domestic in a number of areas during this period, and highlight the difficulties of looking specifically at the wild form when this separation cannot be performed. A partial exception to this is the sample from Denmark and Sweden, which displays a more bimodal pattern, but still a large amount of overlap. Referring back to the previous analyses of this material (Section 3.1) the larger peak represents specimens from Late Mesolithic/ Early Neolithic, potentially male, wild cattle. These specimens represent some of the earliest material included from this time period, but are no larger than a number of the measurements from Germany and Poland. This indicates that the size of the largest wild cattle did not vary much across different areas of northern and central Europe during this time period.

The Spanish sample does not contain measurements that are as large as some of those from Germany, Denmark, or Poland. However the peak of the Spanish sample is closer to the standard than the peak of the Italian sample, which is likely to be made up of domestic cattle only. This may be an indication that there are a number of wild animals in the Spanish distribution, which overlap in size with the domestic cattle and therefore do not stand out as their own group. In previous analyses the overlapping wild animals have generally been considered to be female. This pattern therefore suggests that there are very few male animals in the Spanish sample, and that the difference in size seen on the scatterplot may be more likely to be related to this rather than the impact of a warmer climate in southern Europe.

The pattern displayed by the Swiss sample is mixed compared to the other geographical areas, and is not the pattern expected after looking at the very distinct astragalus scatterplot results. It is likely that both wild and domestic animals are present in the assemblage, and the pattern indicates that domestic animals display a large amount of variation. This kind of pattern is most similar to some of the Log Ratio results from more recent periods in Germany and Poland and may indicate some kind of intensive husbandry practice. Alternatively it could be a reflection of particular climatic conditions in the local area; although this particular site was not located in the most mountainous region of the country, it was still subject to sub-alpine conditions.

Sexually dimorphic bones (metapodials and humeri) were too few to be able to gain much from a comparison across Europe, and previous analyses in this study have shown the complications of interpreting Log Ratio diagrams with very few measurements attributable to either wild or domestic animals, and therefore individual measurements have not be analysed here.

The coefficient of variation results (Table 4.2.5) show an increase in variation across the board in comparison to the previous period. The only exceptions are the scores from Italy. This pattern confirms the suggestion that all of these samples include both wild and domestic animals, except for Italy which is likely to only contain domestic animals.

The Mann-Whitney test results (Table 4.2.6) indicate that quite a few regional groups are significantly, or even highly significantly, different from each other. As discussed above, this is probably due to the relative proportions of wild and domestic animals, as well as females and males, in different groups, rather than a genuine body size difference of populations living in different geographic areas. Switzerland has been excluded from the north versus south comparison (Table 4.2.6) due to its unusual pattern and most likely different climate which is not compatible with any other countries included.

Overall most areas do not show a clear distinction between wild and domestic animals, no matter how they are displayed. Specimens at the largest end of the distribution are likely to be aurochsen and those at the smaller end are almost certainly domestic cattle, but there is also a problematic intermediate group. The combination of different measurements on the same scale (Figure 4.2.7) is valuable because it allows us to look at larger samples, but the inevitable loss of resolution also leads to greater variation and less neat distribution (see for instance the difference in the Swiss pattern between Figures 4.2.6 and 4.2.7).

The difficulty of separating wild and domestic forms is also likely to be due to the great variation of the latter, likely to be a consequence of a great differentiation in husbandry practices that may have been employed in different areas This therefore makes the combination of material from sites over a wide area rather problematic.

All in all there is limited evidence of a clear difference in the size and shape of cattle remains from northern and southern Europe during this period, although this does not mean that, once specific sites are considered, this may not emerge. Unlike pre-Neolithic times we cannot, however, make a general statements about the occurrence of larger aurochsen (or domestic cattle) in the north of Europe.

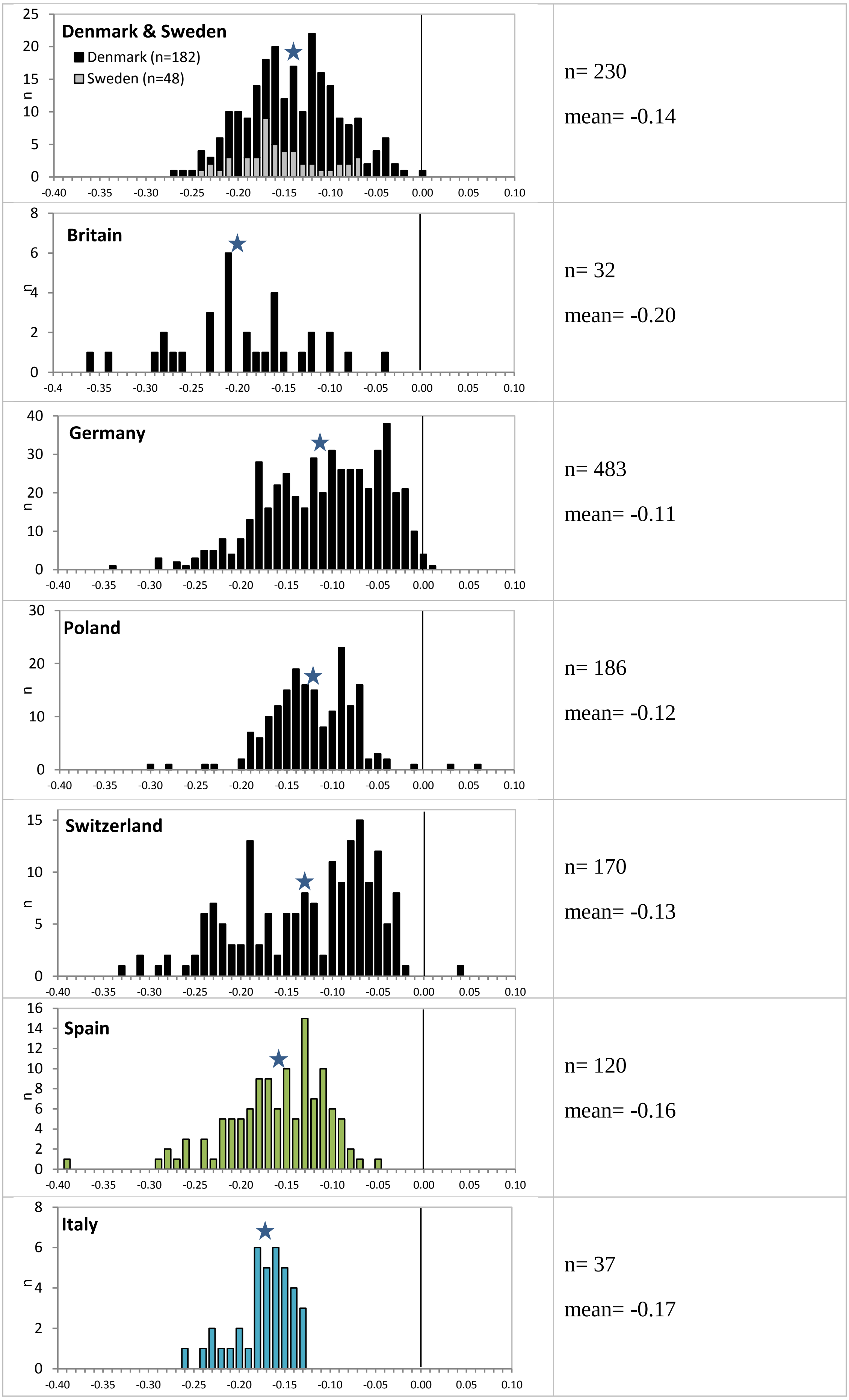


Figure 4.2.7: Log ratios of postcranial measurements from European sites during the period 5500-3000 cal BC.

Table 4.2.5: Summary statistics for *Bos* during the period 5500-3000 cal BC. Samples of less than 5 were excluded.

Measurement	No.	Min	Max	Mean	Standard deviation	Coefficient of variation
Astragalus GLl						
Denmark & Sweden	48	60.0	88.0	68.8	6.27	9.11
Germany	78	61.6	93.2	77.5	8.98	11.60
Poland	42	60.9	82.8	73.7	5.75	7.80
Switzerland	35	56.5	88.5	76.2	9.53	12.50
Spain	26	61.5	81.5	70.6	5.54	7.85
Italy	8	63.0	71.0	66.6	2.84	4.27
Astragalus GLm						
Denmark & Sweden	22	56.6	81.5	65.0	6.70	10.31
Germany	78	45.0	85.7	69.4	9.28	13.37
Poland	20	56.3	76.1	69.6	4.91	7.05
Switzerland	34	52.0	81.5	70.3	9.05	12.87
Spain	30	55.8	78.0	64.3	4.88	7.59
Astragalus Bd						
Denmark & Sweden	20	36.0	56.8	46.1	5.48	11.88
Germany	128	34.0	66.0	49.5	7.43	14.99
Poland	18	38.7	55.3	49.6	5.08	10.23
Switzerland	32	32.5	60.0	46.8	6.93	14.81
Spain	26	35.0	52.0	43.2	4.41	10.19
Italy	8	36.7	46.0	41.4	2.97	7.19

Table 4.2.6: Results of Mann-Whitney tests on *Bos* postcranial Log Ratios from the period 5500-3000 cal BC. Significant results (<0.05) are marked with an * and highly significant results (<0.01) are marked with **. The northern European group contains Denmark & Sweden, Britain, Germany and Poland. The southern European group contains Spain and Italy. Only one measurement from each bone was included, and samples of under 20 were excluded.

Group	n	Group	n	U	z	Sig.
Denmark & Sweden	135	Germany	308	9836.5	-8.84	0.000**
Denmark & Sweden	135	Poland	129	5600.0	-5.02	0.000**
Denmark & Sweden	135	Switzerland	87	4463.5	-3.02	0.003**
Denmark & Sweden	135	Spain	57	3747.0	-0.29	0.775
Germany	308	Poland	129	13458.5	-5.34	0.000**
Germany	308	Switzerland	87	10436.0	-3.16	0.002**
Germany	308	Spain	57	3876.5	-6.71	0.000**
Poland	129	Switzerland	87	5388.0	-0.50	0.619
Poland	129	Spain	57	2459.0	-3.61	0.000**
Switzerland	87	Spain	57	1813.0	-2.73	0.006**
N. Europe	587	S. Europe	76	13468.0	-5.633	0.000**

4.2.3 3000-500 cal BC

This period covers the time from the onset of the late Holocene climatic deterioration to roughly into the Iron Age (Table 4.2.7), after which aurochs remains become so scarce that cross-European comparisons are no longer possible. Climatically this group represents a time period when the climate was worsening. It is not until the early Historical period that the climate recovered again (Bell and Walker 2005: 93).

Summary statistics (Table 4.2.8) do not show very clear patterns between different geographical areas, but it is clear that the Spanish sample contains some particularly large astragalus specimens, indicating that some of the large Spanish Chalcolithic aurochsed wer not just large in Spain, but compared to other areas as well. The variation within these populations needs to be investigated further using scatterplots and log ratio histograms.

The scatterplot of astragali (Figure 4.2.8) shows a slightly different pattern to the previous time period. It is easier to separate potential wild and domestic animals in each geographical area, but it is clear that combining all of the measurements from the whole of Europe confuses the pattern due to geographic variation. The clearest split is in the Portuguese material. The German sample is still large and spans almost the whole size range, but the Spanish and Portuguese samples have some very large sized specimens which are larger than all of the German ones. Only two Polish specimens are of a similar size to these large specimens. German cattle cover a similar range during this period than they did during the previous period, whereas Iberian cattle extend their range at the larger wild end, although not at the smaller, domestic end.

Table 4.2.7: Broad chronology for the sites included in the 3000-500 cal BC group.

Chronological group	Climate	Britain	Germany	Poland	Spain		Portugal	Italy
3000-2000 cal BC	Deterioration	Durrington Walls North Marden Mount Pleasant	Griesstetten Riekofen		Cueva de Arenaza Las Pozas Fuente Flores		Castro do Zambujal	Cornuda Santa Maria in Selva Arene Candide
2000-1000 cal BC	Deterioration	Snail down Eton Rowing Lake		Bruszczewo Gniechowice	Los Castillejos Gobaederra	Cerro de la Virgen		
1000-500 cal BC	Deterioration		Dresden-Coschutz	Łęki Majątek Smuzewo				

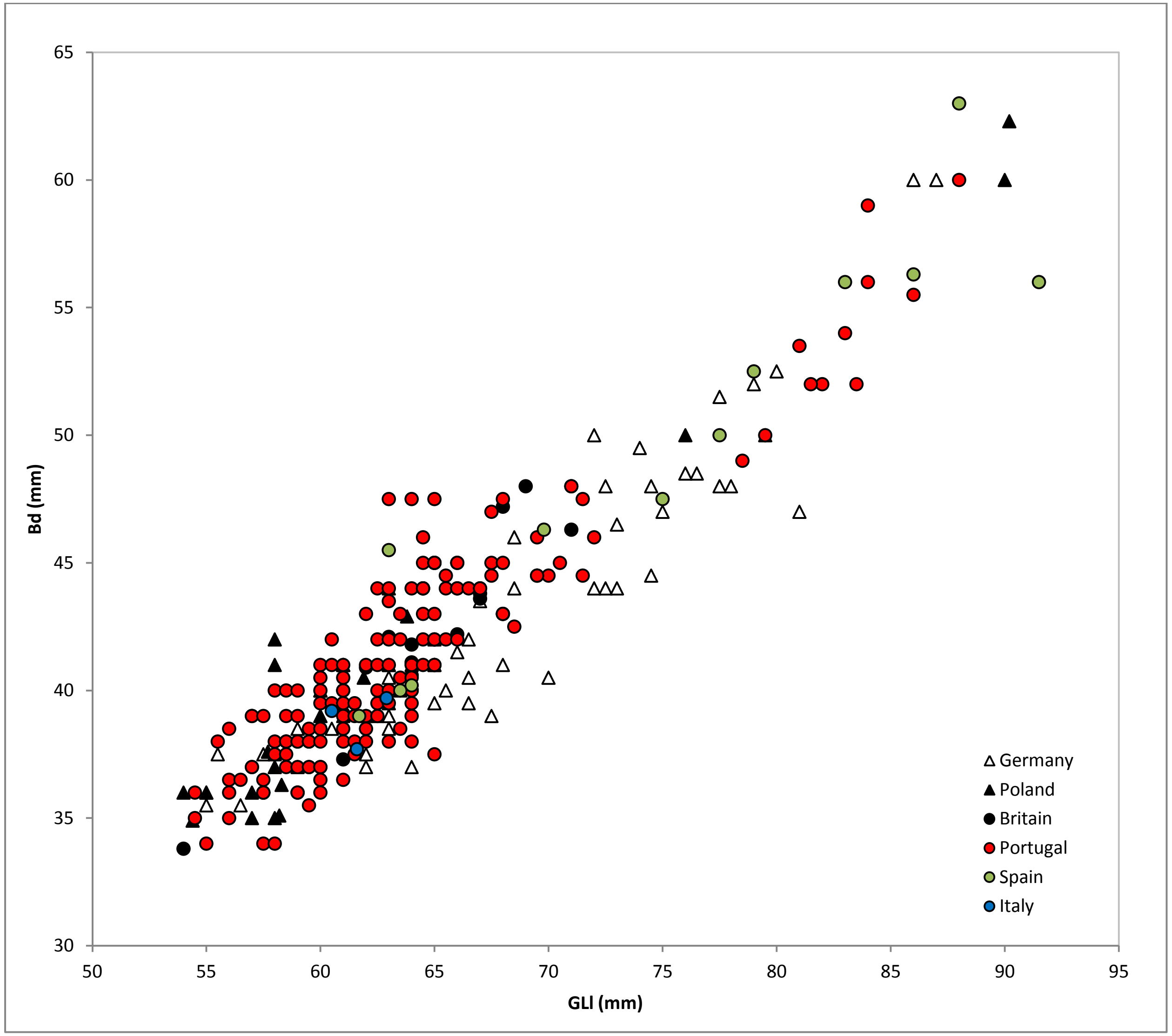


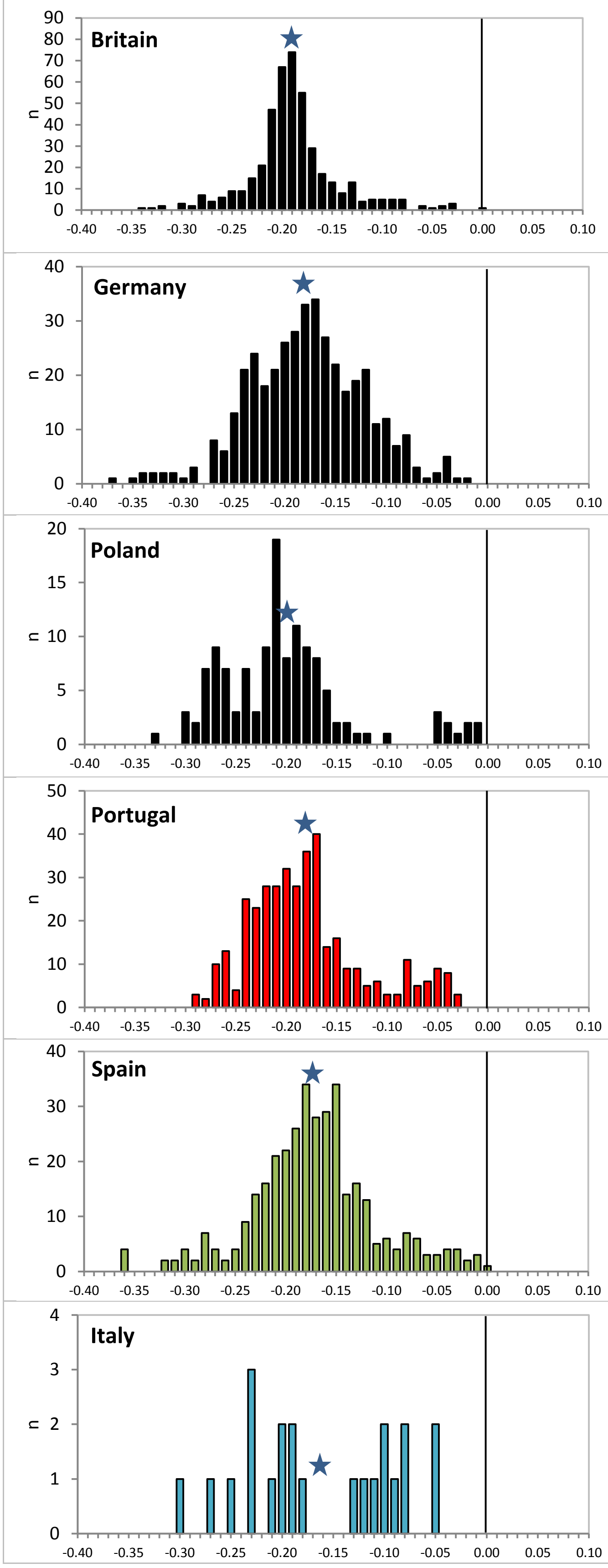
Figure 4.2.8: Scatterplot of astragali from across Europe between approximately 3000 and 500 cal BC.

The distributions shown in the log ratio diagrams (Figure 4.2.9) confirm the pattern suggested by the astragali, in that it is generally easier to distinguish between potential wild and domestic groups in most geographical areas in comparison to the previous period. This is discussed in more detail in the individual chapters for each area.

The Italian sample is small but both the Portuguese and Spanish distributions have similar ranges to the northern European samples. The increase in size of the Iberian wild animals, whatever its cause, has served to decrease the difference in size between northern and southern areas that was seen in the 10000-5500 cal BC study above. All of the geographical areas have wild populations which plot in a very similar place, perhaps with the exception of Poland which contains some particularly large measurements. This may tentatively suggest a size increase along an east-west cline, as demonstrated for wild boar, but more evidence is needed to test this hypothesis.

As for the previous time period coefficients of variation have only been calculated for the bones included on the scatterplots (Table 4.2.8). Here again most coefficient of variation results are higher than in the pre-domestication periods, indicating a mixture of wild and domestic animals in the samples.

As for the previous period the Mann-Whitney test results are heavily affected by the relative proportion of wild and domestic animals in the different groups and therefore have limited use in assessing differences between population body sizes (Table 4.2.9). The Polish group spears to be consistently different from the others, probably as a consequence of its very large aurochsen.



n= 436

mean= -0.19

n= 404

mean= -0.18

n= 128

mean= -0.20

n= 380

mean= -0.18

n= 355

mean= -0.17

n= 22

mean= -0.16

Figure 4.2.9 Log ratio diagrams of postcranial measurements from European sites between approximately 3000 and 500 cal BC.

Table 4.2.8: Summary statistics for *Bos* during the period 3000-500 cal BC. Samples of less than 5 have been excluded.

Measurement	No.	Min	Max	Mean	Standard deviation	Coefficient of variation
Astragalus GLl						
Britain	29	54.0	88.0	66.2	7.51	11.35
Germany	72	55.0	88.5	68.2	7.86	11.52
Poland	26	54.0	90.2	62.1	9.34	15.04
Portugal	167	54.5	88.0	64.5	7.37	11.42
Spain	61	55.0	91.5	66.6	7.84	11.77
Astragalus GLm						
Britain	11	55.7	79.2	61.8	6.57	10.63
Germany	84	49.5	80.5	61.8	6.72	10.87
Poland	7	50.9	80.4	57.9	10.26	17.73
Portugal	7	69.0	78.0	73.4	2.94	4.00
Spain	65	52.0	81.5	61.0	6.70	10.99
Astragalus Bd						
Britain	21	33.8	48.0	41.8	3.59	8.58
Germany	70	35.5	60.0	43.0	5.27	12.26
Poland	26	34.9	62.3	40.8	6.95	17.02
Portugal	169	34.0	60.0	42.2	5.60	13.27
Spain	12	39.0	63.0	49.4	7.62	15.44

Table 4.2.9: Results of Mann-Whitney tests on *Bos* postcranial Log Ratios from the period 3000-500 cal BC. Significant results (<0.05) are marked with an *. The Northern Europe group contains Britain, Germany and Poland. The Southern European group contains Portugal, Spain and Italy. Only one measurement from each bone was included, and samples of under 20 were excluded.

Group	n	Group	n	U	z	Sig.
Britain	199	Germany	204	16430.0	-3.31	0.001*
Britain	199	Poland	68	5154.0	-2.93	0.003*
Britain	199	Portugal	199	15629.5	-3.64	0.000*
Britain	199	Spain	39	1603.5	-5.79	0.000*
Germany	204	Poland	68	4563.5	-4.23	0.000*
Germany	204	Portugal	199	19848.5	-0.39	0.701
Germany	204	Spain	39	2112.5	-4.65	0.000*
Poland	68	Portugal	199	4160.5	-4.74	0.000*
Poland	68	Spain	39	493.0	-5.40	0.000*
Portugal	199	Spain	39	2314.0	-3.99	0.000*
N. Europe	471	S. Europe	249	45035.500	-5.126	0.000*

4.3 Summary

The results presented in this chapter have shown some interesting and important patterns with regards to differences in the size and shape of *Bos* remains in different areas of Europe, and in the contexts of the broad climatic changes that have occurred over the last 350,000 years. The climatic fluctuations which took place throughout the Pleistocene considered here make it difficult to find contemporary assemblages from different areas to compare. Where it was possible (for example in MIS 9) there is some evidence of a size increase along a south-north cline, when comparing British and Italian assemblages. The results of this study, along with the previous section on Italy (Section 3.5) have also provided more evidence that the greatest decrease in size, may have taken place during the last interglacial. The material from the Younger Dryas included in this study does not contain any particularly large specimens, and overall fits best with the kind of distributions seen in the Mesolithic period, rather than assemblages from the earlier Pleistocene, but we need to consider that this is based on only one substantial assemblage belonging to this period.

The material from Grotta dei Puntali continues to be perplexing. The astragalus included in this study is clearly a very different shape than other astragali included from any other area or time period. This could be a result of dwarfism, but even if this is the case the shape difference is unexpected. As an example, modern wild boar from island populations on Sardinia and Corsica form a very distinct, smaller, size group, compared to wild boar from the rest of Europe, but there is no shape difference, they are merely a smaller version of wild boar elsewhere (Albarella *et al*. 2009). In order to solve the mystery of *Bos primigenius siciliae* a larger sample size must be found.

The Mesolithic period provides some interesting patterns, with the hint at an increase in size along a south-north cline here as well. This is something which is also seen in Mesolithic Pigs (Albarella *et al.* 2009). The Portuguese sample dominates the southern European *Bos* sample, but the measurements that are available from Spain and Italy do not refute the idea. Of particular interest is the shape difference between the northern and southern samples, of a nature that has not been seen in any other part of this analysis. It is difficult to go into a more detailed analysis of this here, when measurements from bones other than the astragalus are so few, but is definitely something which is worth bearing in mind if the southern European sample can be increased in the future.

Once domestic animals start appearing in the distributions the patterns become quite complex, and difficult to read. Certainly for the earlier Neolithic group there do not seem to be any clear patterns, and it is clear not only that wild and domestic overlap in size in most areas during this period, but also that combining material for a number of sites where husbandry techniques may have been very different does not help to split wild and domestic animals. Distributions where only one site is included on the plot, such as from Switzerland, are far easier to split than those that contain a number of different assemblages which have previously been shown to reflect different husbandry practices (for example in Germany).

The splitting of wild and domestic animals becomes slightly easier during the later Holocene periods, but the splits are still not clear cut. Again in samples made up of material from just one site it is much easier to discriminate between wild and domestic animals (for example, the Portuguese sample from Zambujal), which suggests that there is still a lot of variation within the broad geographical areas. The variation may not just be related to the employment of different husbandry practices, but could also reflect the effects of microclimates within the broad geographical areas discussed.

There is evidence of some particularly large animals in southern Europe in this later phase, which brings the size of *Bos primigenius* back in line with the sizes seen in northern Europe. There is no evidence that there was an increase in size of the animal in northern regions, and this contrasts with the evidence for pigs, where Britain and Switzerland show some increase in size. However there is the hint of a size increase in the Polish *Bos primigenius* during this period, which could be related to similar factors as the large size of modern eastern European wild boar (Albarella *et al.* 2009). This size cline in wild boar is most prominent in the Russian sample, which of course has not been included in the scope of this *Bos* project, and maybe an area for further research in future.

Chapter 5

The Morphometric Variability of the European Aurochs: Discussion, Conclusions and Reflections on the Study

This final chapter will bring together all of the evidence presented for the morphometric variability of the aurochs in order to address the original research questions set out in Chapter 1. Variability across time and then space will be discussed, within the context of previous patterns of body size and shape change seen both in the aurochs, and in other animals. The potential for picking apart size and shape changes related to different factors is also discussed. The potential contributions of this work to the identification of wild and domestic cattle bones, and to future genetic studies is also considered. Finally some potential directions for future research are highlighted, and some reflections on the overall project are also laid out.

5.1 Morphometric variability of the aurochs across time

5.1.1 Differences within the Pleistocene, and between the Pleistocene and early Holocene.

A number of previous studies have reported a size decrease in the aurochs between the Pleistocene and Holocene in various different areas of Europe (e.g. Fraser and King 1954; Degerbøl and Fredskild 1970; Bökönyi 1974; Davis 1981; Grigson 1969; Ekström 1993; Estevez and Sana 1999; Viner 2010). These studies have often lacked sufficiently detailed data to detect precisely when this size change(s) took place, and this has resulted in the general assertion that the Pleistocene aurochs was larger than the Holocene aurochs. This statement is, in a general sense, correct, but it usually tends to be presented without much reference to glacial and post-glacial periods within the Pleistocene itself, usually because of a lack of data representing these climatic stages.

Most of these studies suffer from small sample sizes or chronological gaps in their data. In Denmark, for example, this assertion was based on the size of one particularly large skull dating to the Younger Dryas (Degerbøl and Fredskild 1970). In Sweden the size change was based on the size of one (juvenile) skeleton also from the Younger Dryas (Ekström 1993). In these cases the samples are so small that they cannot represent the variability that would have been present within each population, and they cannot take into account issues of sexual dimorphism. The Danish specimen is thought to be from a male animal, due to its large size, but there are no potential ‘female’ skeletons from this time period for comparison. The Swedish specimen is thought to be a female, but is also a juvenile, which, although large for its age, cannot be fully relied upon for predicting adult body size. The comparison by Fraser and King (1954) of the size of skulls from Star Carr to a small number of large undated ‘Pleistocene’ skulls is problematic, not just because of sample size, but due to the fact that it is not known what part of the Pleistocene the skulls are from, and therefore whether they represent warm or cold phases.

The scope of this study has allowed for a more detailed approach, and a more complex picture has been uncovered. The large sample from Grotta Romanelli in Italy, which dates to the Younger Dryas, has been an instrumental source of information for this cold phase. This dataset has provided evidence that, in Italy at least, aurochsen from the Younger Dryas were overall of a very similar size to aurochsen from the early Holocene (there may have been some differences in the size of the astragalus, but the sample size from the Mesolithic is really very small). The small sample from Coygan Cave in Britain has demonstrated that aurochsen from the cold phase taking place c.60 ka BP were also of a more similar size to those at Early Mesolithic Star Carr, than they were to the samples from earlier in the Pleistocene at Ilford and Grays Thurrock. By comparing the samples from La Borde (France) and Solana del Zamborino (Spain) which represent MIS 5, to Ilford (Britain), Grays Thurrock (Britain) and Castel di Guido (Italy) representing MIS 9 and 7, the pattern suggests that the most distinct size decrease may have actually taken place sometime around the last interglacial. This fits with previous work by Cerilli and Petronio (1991) who concluded, by looking just at metapodials, that the aurochs initially increased in size until it reached its maximum dimensions in the Riss Ice Age (c. 130 ka BP).

The sample from the Italian site of Canale Mussolini, with its very broad date covering a number of climatic periods (c. 85-60 ka BP) indicates, however, that body size may have increased again during some of the subsequent cold periods, and the sample from Grotta Paglicci – the only site in the study which is contemporary with the last glacial maximum - also contains some large specimens, but both of these samples display a more similar mean to that of Grotta Romanelli than to Castel di Guido.

Both the last glacial period and the Younger Dryas are climatic events that need more investigation. In Italy the Younger Dryas did not seem to have a great impact on body size, but without comparative samples from across Europe it is difficult to know what happened elsewhere. There is some evidence of large aurochsen during the last glacial maximum in Portugal (although this is according to just one tooth – Simon Davis *pers. comm.* 2013), and there is also some limited evidence from outside of Europe, where Davis (1981) records a reduction in the size of the aurochs at around 12 ka BP in the Near East. Of course the lack of aurochs remains from these glacial periods may be related to the very fact that they are cold, and so the geographical distribution of the animal would have been restricted to more southern, warmer areas.

The available data unfortunately are insufficient to be able to see differing size changes in different geographical areas, but contemporary samples from each time period are similar enough to suggest that a similar pattern took place across the whole of Europe (except perhaps for Sicily – see Section 5.2.3).

This general diminution in size between the Pleistocene and Holocene has also been recorded for other animals, such as red and roe deer (Fraser and King 1954; Jensen 1991; Davis 2002; 2006), and wild boar (Davis 1981; Albarella *et al.* 2009) and some of these studies have the precision to be able to look more closely at the changes that took place before the end of the Pleistocene.

There is clear evidence of a size reduction in red deer at the end of the Pleistocene in Iberia (Davis 2002; Klein and Cruz-Uribe 1994; Mariezkurrena and Altuna 1983). Davis (2002) provides evidence from the Portuguese site of Gruta del Caldeirão of a size decrease between the Magdalenian and the Mesolithic, demonstrating a pattern for which we have no appropriate data for the aurochs. Evidence from Spain is more abundant and demonstrates a clear fluctuation in red deer size between glacial and post-glacial times during the Pleistocene, including a size reduction since the Last Glacial period (Mariezkurrena and Altuna 1983).

Despite the large amount of Holocene wild boar data available (e.g. Albarella *et al.* 2009), only a small amount of data are available from earlier periods; and as a result, data comparing wild boar body size from the Pleistocene and the Holocene have only been presented from the Middle East (Davis 1981; Albarella *et al.* 2009). This work has provided evidence of a general reduction in size between the Pleistocene and Holocene, which is thought to be related to climatic changes, and particularly the rise in temperature. There are indications that the picture was probably more complex, and that there were fluctuations within this pattern (Albarella *et al.* 2009).

More data are available from European red deer than for aurochs or wild boar for investigating body size changes that took place between the Pleistocene and Holocene. These data demonstrate the kinds of patterns that could be possible if more aurochs data were available from the late Pleistocene. The pattern in the Middle Eastern aurochs is similar enough to that of red deer and wild boar to suggest that a general diminution in size was likely to have taken place. However, the expanded datasets available for red deer and wild boar also demonstrate the kind of more complex patterns that may be excluded from detection by using small samples. The datasets from other animals conform to the idea that the Younger Dryas did not have a large impact on body size, as there is no evidence for size change during this period. It seems likely that the most prominent changes in body size took place prior to this.

Little evidence of shape change has been presented in the literature for the comparison between Pleistocene and Holocene, for any animal, as the focus has always concentrated on size change. It is worth mentioning here that the kind of shape change that has been noticed most prominently for domestic cattle – a general slendering of the bones - is evident to a limited extent during the Pleistocene as well. This change is manifested in the movement of breadth measurements from bones such as the astragalus and the metapodials away from the standard line on log ratio diagrams, whilst length measurements stay near the standard size. This process is detectable in the Younger Dryas in Italy at Grotta Romanelli and there is also a slight hint of it at Coygan Cave in Britain at around 60 ka BP. More data from the end of the Pleistocene will be needed to confirm the extent of this change, but it is worth bearing in mind that the slendering process may not have been restricted to the Holocene.

5.1.2 Evidence for a decrease in size during the early Holocene

Degerbøl (1963; 1970) referred to a reduction in the size of the aurochs during the earlier Holocene in Denmark, and a change in size between the Mesolithic and Ertebølle groups can also be seen in the investigation of this geographic area in this study. A slight reduction in size is evident for both astragalus and calcaneum length measurements, and is further shown by the pattern provided by third molar measurements (this is also mentioned by Degerbøl 1970: 87 - Figure 17). Although new dates have now meant that some of the sites that Degerbøl included in his Ertebølle group extend further into the Neolithic than was previously thought (for example, Krabbesholm, Mejlgaard and Havnø), more securely dated Late Mesolithic sites such as Dyrholmen and Norslund consistently show smaller measurements than seen in the earlier Mesolithic, and this anaylsis has shown that Havnø (Denmark) and Neustadt LA (northern Germany) are the only sites that contain reliable evidence for domestic cattle in this Ertebølle group, which suggests that these specimens may in fact come from Neolithic contexts.

Very few of the geographical areas included in this project have comparable data from both the Early and Late Mesolithic. Goldcliff East provides the only Late Mesolithic material in Britain, and this sample is very small, although it plots entirely within the distribution from Early Mesolithic Star Carr. The Late Mesolithic material from the Muge middens in Portugal indicates relatively small animals, but without earlier Mesolithic material from the same region to compare it with it is not possible to say that this material represents a size decrease since the earlier Mesolithic. There is some evidence, however, of a size difference between Later Mesolithic Portugal and Early Mesolithic Spain which could indicate a size reduction during this period, although this could be a reflection of the climatic context of the Muge middens in comparison to other sites in Iberia (see Section 3.4). There are also indications of a decrease in size between the earlier Mesolithic and Early Neolithic in Spain, but this may be related to a small sample of aurochs in the Early Neolithic distribution, which may not represent the full spectrum of aurochs body size. In Northern Europe it is only in Denmark that there is evidence of a size decrease going into the Early Neolithic, with the aurochs not reaching the size that it did during the Mesolithic. In Britain and Germany there is no evidence of a size decrease in the aurochs until the Late Neolithic.

As concerns other species, there is no sign of a size decrease in wild boar between Mesolithic and Ertebølle sites in Denmark, or Mesolithic and Early Neolithic sites in any of the geographical areas for which data have been analysed (Britain, Spain and Italy).

This study has provided some evidence of a size decrease in aurochs during the early Holocene, but this is not very clear in any geographical region except for Denmark. The attempt to look for these changes has highlighted a couple of potential problems with spotting these kinds of changes. Firstly, beyond the end of the Mesolithic, investigating patterns of aurochs change becomes particularly complex, due to the overlap in size between wild and domestic animals. Because of this, the only reliable way that we can look for a size change is by looking at fluctuations at the top end of the size range and it is not really possible investigate fluctuations at the bottom end. Secondly, there is generally a scarcity of data which can be compared across the Mesolithic itself, meaning that it is not possible to detect changes leading up to the period of domestication with much precision.

5.1.3 Late Holocene size increase

One of the research aims for this project was to look at the effects of the late Holocene climatic deterioration, beginning at around 3000 cal BC (Bell and Walker 2005), on aurochs size. The onset of this deterioration falls very roughly during the Middle or Late Neolithic of Northern European areas, or the Chalcolithic in southern regions such as Iberia, and runs roughly into the Iron Age. This period is of particular interest because a size change has previously been seen at the start of this period in various other animals, such as the wild boar in Portugal, Italy and potentially Britain and Switzerland (Albarella *et al.* 2006; 2009; Davis and Mataloto 2012) and red deer in Portugal (Davis 2006; Davis and Mataloto 2012).

This study has provided some evidence of an increase in the size of a number of different anatomical elements in Chalcolithic samples from both Portugal and Spain. No other areas show a size increase during this period, and in fact the aurochs in both Britain and Germany shows hints of a size *decrease* during the Late Neolithic.

The largest specimens from Spain not only are larger than those from the Iberian Mesolithic, but are also some of the largest potential aurochs from anywhere in Europe during the period from the Late Neolithic to the Iron Age (see Section 4.2.3). The size range of the astragalus from Spain and Portugal, for example, exceeds that from all areas of Europe, with the exception of Poland.

But it is within Portugal and Spain themselves where the size of these bones has the most important implications, because the smaller average body size of the Iberian Mesolithic aurochs indicates that there was a substantial size increase between the Mesolithic and Chalcolithic, as represented by aurochs remains at Castro do Zambujal and los Castillejos. This increase in the size in Iberia results in aurochsen of a much similar size to those previously seen in northern European areas in earlier periods.

The Iberian aurochs size increase does seem to take place during the period of climatic deterioration, and is concurrent with the size increase seen in wild boar at Iberian sites and also in Italy which have been associated with this climatic change (Albarella *et al.* 2006; Albarella *et al.* 2009). However, if the size change is wholly a reflection of the climatic deterioration after the Mesolithic, we might expect to see at least a hint of it in other areas of Europe – as is seen for the wild boar. But sample sizes for the aurochs are generally much smaller than for the wild boar from the Late Neolithic onwards, and even with comparatively large wild boar samples the pattern is only hinted at in Britain and Switzerland. The increase in size of wild boar in Britain is also not necessarily confined to the same period (Late Neolithic/Chalcolithic), and could have taken place any time between after the Mesolithic period up until historic times (Albarella *et al.* 2009).

The small body size of a number of Iberian animals, and in particular the red deer (although the pattern has also been seen in rabbit – Simon Davis *pers. comm.)*, during the Mesolithic period, has been discussed by Davis and Mataloto (2012), who suggest it may be related to its over-hunting rather than to climatic change. The small amount of aurochs data that is available from earlier than the Mesolithic in Spain (from Solana del Zamborino), does indicate a few large specimens, but does not suggest a great deal of difference in the average size of the astragalus between the late Middle Pleistocene and Mesolithic times, and so there is no indication of a great change in hunting pattern here. In Portugal there is a small amount of evidence that large aurochsen were present during the last glacial maximum (Simon Davis *pers. comm.*), but this evidence is currently comprised of just one estimated tooth length measurement, and it would be expected that a size decrease would have taken place in post-glacial conditions anyway . The generally small samples of aurochs therefore inhibit the comparison of the Mesolithic sample from the Muge middens with time periods immediately before and after their occupation. These small samples in themselves may suggest that a reduction in body size due to hunting pressure is unlikely because there is such little evidence for the aurochs being hunted in large numbers during these periods. Even the Portuguese Mesolithic sample is not particularly large, even though it is the largest in southern Europe from this period. In future more Iberian late Palaeolithic post-glacial aurochs need to be found in order to make a useful comparison with the Mesolithic data, because until then it is difficult to determine whether the large size fluctuation between the Mesolithic and Chalcolithic is the result of particular factors affecting the Mesolithic or the Chalcolithic.

The size range of the Portuguese Mesolithic aurochs in comparison to the Mesolithic aurochs in other areas of Europe is not unusual when climatic differences are taken into account. The Muge middens were situated in a warm and dry area, even compared to any of the Spanish Mesolithic sites and this could be a more likely explanation for the small average size of the aurochs in Portugal, and indicates that climate, rather than hunting pressure, could have been the more important factor leading to small body size in the Portuguese Mesolithic aurochs.

It may be worth noting that the Iberian sites at which the largest specimens have been found (Zambujal, los Castillejos and Cerro de la Virgin) were all relatively large settlements during the Chalcolithic period; Zambujal and los Castillejos both have evidence of fortifications (Sangmeister *et al.* 1969; Castaños 1997) and Cerro de la Virgin was considered to be a regional centre (von den Driesch 1972). The other Iberian Chalcolithic sites included in this project, including the cave sites of Cueva Arenaza and Cueva de Gobaederra and the causewayed enclosure at las Pozas, were far smaller. The small size of these other sites has also resulted in smaller faunal assemblages, so sample size could be one explanation for this pattern. Alternatively, it could represent some kind of deliberate hunting of large aurochsen at the larger settlements. In order to take this further, a more in-depth exploration of cattle at different types of Iberian sites would need to be undertaken, similar to that undertaken for pigs by Hadjikoumis (2010).

A predominance of wild animals, and some particularly large wild boar, has been found at the Late Neolithic site of Cornuda (Veneto) in Italy (Albarella *et al.* 2006). Boar bones from this site (along with some other large boar from Chalcolithic Conelle and a few other sites) seem to demonstrate a post-Mesolithic size increase in Italy. The cattle assemblage from Cornuda did have some large wild specimens, but none outside of the Mesolithic range – although the sample was small.

The increase in body size indicated by faunal assemblages at a number of Late Neolithic and Chalcolithic sites can be demonstrated for the aurochs in Iberia, and for a number of other animals across Europe. Because it occurs in a number of different places across Europe at the same time it is unlikely to be related to local factors, although it is intriguing that often the sites with the larger specimens seem to have characteristics in common. This said, some of the sites that provide evidence for a larger body size do have larger than average proportions of wild animals, in which you might be more likely to capture a fuller picture of the size range of an animal population. The generally small sample size of aurochs suggests that pressure on aurochs populations was unlikely to have been so great that there was a reduction in body size – as suggested by Davis and Mataloto (2012) - although this could be a valid argument for some of the other animals which display this pattern. The most likely factor to have caused the large jump in size between the Mesolithic and Chalcolithic periods in Iberia is climatic change.

5.1.4 Size reduction from the Early Neolithic – the impact of domestication

From the beginning of the Neolithic period, smaller cattle appear in all of the areas considered in this study, and this pattern is in agreement with the situation previously recorded for cattle across Europe and beyond (e.g. Grigson 1969; Degerbøl and Fredskild 1970; Davis 1981). The most prominent factor contributing to this change is unquestionably domestication. In some areas such as in Spain, Italy and Britain, smaller cattle dominated quite suddenly during the Early Neolithic, whereas in other areas, such as Denmark, Germany and potentially Poland, the transition was more gradual. These patterns provide various insights about the ways in which cattle domestication was adopted throughout Europe. Although an investigation of the nature of cattle domestication was not a research aim of this project, the ways in which it affects our understanding of wild cattle populations during the Neolithic has implications for our interpretation of the changes in aurochs morphology.

In Italy, Spain and Britain it is difficult to find sites from the Early Neolithic which have aurochs represented in any great number in their faunal assemblage. The situation in Italy is particularly intriguing. During the Early Neolithic the evidence for aurochs is so small that it was not possible to find any sites with useful measurements during this period, and therefore the size change after the Mesolithic appears to be very abrupt in the biometrical analysis. This could serve as evidence that domesticated cattle were not locally domesticated in Italy, and that instead they were introduced. The situation is very well reflected at Grotta dell'Uzzo, where the aurochs is almost absent in the Mesolithic/Neolithic transitional level and cattle reappears in a domesticated form during the Early Neolithic therefore leading to the interpretation that these were introduced domesticates (Tagliacozzo 1993). The pattern for cattle is in contrast to the pattern seen for *Sus*, which seems to change in size more gradually and therefore may have potentially been locally domesticated (Albarella *et al.* 2006).

The predominance of domestic animals during the Early Neolithic in Italy has been mentioned previously (e.g. Tagliacozzo 2005/06), and although some cave sites do provide evidence of hunting, the evidence for aurochs is sparse. At Grotta dell'Uzzo, for example, there is evidence for the hunting of red deer throughout the Early Neolithic, but no trace of the aurochs, or at least of any specimen that can be identified as such (Tagliacozzo 1993). The only Early Neolithic sites that do seem to have a larger proportion of wild cattle are those at Rendina: 'Rendina lake 3' (Wilkens 1996) and 'Rendina' (Bökönyi 1982). Neither the material nor the data from these assemblages could be accessed for this project, but perhaps in future these sites will yield important information that will contribute to our knowledge about the morphological variation of the aurochs in Early Neolithic Italy.

The evidence for aurochs in Early Neolithic Spain is also sparse. The log ratio distribution from this period does not indicate any particularly large animals, nor does it provide a bimodal pattern. The overlap with the Mesolithic distribution, and the high coefficient of variation scores suggest that it may contain a mixture of wild and domestic animals, but if it does, there are likely to be few wild animals. Cave sites such as Cueva de Chaves contain larger proportions of wild animals, but, as in Italy, aurochsen are always rarer than other wild animals, such as wild boar. The abrupt change to a smaller size of cattle during the Early Neolithic in Spain, combined with the apparent rarity of aurochs during the Mesolithic could be interpreted as evidence for introduced domestic animals in Early Neolithic Spain. In contrast the Spanish Early Neolithic *Sus* distribution only shows and abrupt change to a smaller body size at a few settlement sites, whereas at cave sites such as Cueva de Chaves the wild and domestic pig populations are not easily distinguished from each other. This indicates that a combination of introduced and local domestication may have occurred in Spain (Hadjikoumis 2010). Conversely it is possible that, for cattle, introduction represented the sole mode of developing husbandry in the area, though larger assemblages and more sites will have to be analysed to clarify the situation fully.

Very few aurochs remains have also been found from the British Early Neolithic. In this study Eton Rowing Lake did provide some evidence of aurochsen, but only very few specimens. In addition, other sites which have not been included here such as Hambledon Hill (Legge 2008) and Runnymede (Done 1991; Serjeantson 2006) have also yielded very few aurochs remains. All of the available evidence points towards an abrupt change in size between the Mesolithic and Neolithic periods, in concurrence with a relatively sudden dominance of domestic animals in the Early Neolithic. This pattern has previously been interpreted as evidence for the introduction of domesticated cattle, with no local domestication in Britain (Viner 2010), thought the large time gap between available assemblages for the Late Mesolithic and the Early Neolithic must be considered.

The distributions from Denmark and Germany during the Early Neolithic seem to contain larger proportions of wild animals compared with those from Italy, Spain and Britain. Smaller cattle do appear in these assemblages but the aurochs seems to still be economically important at these times. The large dataset from Germany highlights differences between Early Neolithic sites, with Hüde I and Bruschal-Scheelkopf displaying a dominance of wild animals and sites such as Ehrenstein displaying more domesticates. Sites such as Künzig-Unternberg and Straubing-Lerchenhaid display a much more mixed pattern. Almost all sites have some evidence of wild animals whether they are predominant or not. Even though it is obvious that wild animals are still present, when all sites are combined there is no clear distinction between the wild and domestic groups.

More can be discovered through looking at individual sites in Early Neolithic Germany, as there seems to be such a stark difference between their distributions. Künzig-Unternberg and Straubing-Lerchenhaid display a mixed pattern in comparison to some of the later Early Neolithic sites. Although these samples are generally small, there are still some particularly large specimens of a similar size to Mesolithic aurochs. This is a situation in contrast to that seen in Early Neolithic Spain and Italy, where large specimens are not present. At sites with later Early Neolithic dates, such as Bruschal-Scheelkopf and Hüde I, the aurochs seems to increase in proportion, and there are indications that it is more numerous than domestic cattle. This could indicate some kind of change in economic strategy at this time. This would fit with the interpretation set out by Steppan (1999) who considers the increase in aurochs numbers during the later Early Neolithic as a reflection of an intensification of hunting activity, due to a climatically induced crisis.

The high proportion of wild animals during this period is not something restricted to Germany, as the phenomenon is also seen at sites in France and Switzerland (Schibler *et al.* 1997). With this in mind, the geographic pattern that emerges for central Europe could also explain the relatively large proportion of wild cattle at the Swiss site of Seeburg Burgäschisee-Sud (Stampfli 1963, and Section 4.2.2 of this thesis).

Interpretation of the Danish situation is frustrated by the fact that the Early Neolithic dataset is made up almost entirely of measurements from individual skeletons, and any archaeological remains appear on sites which also have a potential Ertebølle component. The pattern is indicative, though, that the situation was more similar to the earliest Neolithic of Germany than to Spain or Italy. In fact, because some of the earliest evidence for domesticated cattle appears at sites which may have been in use in both the Late Mesolithic and very Early Neolithic periods, is a prime opportunity to look for continuity on the cattle populations there. Neustadt LA is the only site included here which may have both domestic and wild cattle bones (Havnø only seems to have domestic cattle, and all others only wild). The evidence from Neustadt LA has been considered to represent some of the earliest evidence for domestic cattle in southern Scandinavia (Glykou *in press*).

Evidence for aurochs from the very earliest Neolithic has meant that it is often very difficult to determine if the process of domestication was taking place in local wild cattle, or if new populations of already domesticated cattle were being brought in. In Britain, Spain and Italy there is an abrupt change to a smaller size of cattle during this period, compared with the Mesolithic, indicating the likelihood of an incoming population of domesticated cattle (although of course Late Mesolithic samples for comparison are lacking), whereas in Denmark and Germany the situation may be more complicated, as there is more continuity between the two periods. It is clear that these populations are made up of a mixture of wild and domesticated cattle, but this does not necessarily imply that local domestication was taking place.

5.1.5 Climate versus human impact

The above discussions have demonstrated the difficulty in determining which factors have caused differences in the size and shape of the aurochs across time. The onset of domestication suggests a continuation of the kind of changes that had taken place previously – a general reduction in size, and a reduction of robustness. Both of these changes seem to have taken place to some degree during the Pleistocene, and then may have continued at certain points leading up to the Neolithic, when there is generally an increased size decrease as a consequence of domestication.

It would seem most likely that the body size and shape changes that took place during the Pleistocene were related to temperature changes. There does seem to be some correlation with glacials and interglacials, and it is especially worth noting that the most prominent reduction in size prior to the onset of domestication may have taken place during the warmest phase – at around the time of the last interglacial. Of course changes in temperature may also be linked to factors such as food availability, environmental differences and different patterns of behaviour in both aurochs and human populations. At the moment it is hard to say which of these factors, if any, may have played the greatest role.

Hunting pressure is something that has previously been linked to body size change (e.g. Davis 1981; Milkowski and Wojcik 1984; Albarella *et al.* 2006) so it is worth bearing in mind the kind of pressures that the aurochs would have faced from predators. Alongside humans, the aurochs was likely to have faced the greatest threat from predators such as wolves, bears, wild cats, wolverines and hyenas (van Vuure 2005), however most of these animals prefer to exploit smaller prey (Rodriguez *et al.* 2012), so it seems unlikely that pressure from these prey animals would have had a drastic effect on body size. Humans would have constituted the other predatory threat to the aurochs. We know that the actions of domestication, at least, did have an impact on aurochs morphometry, but it is unclear if other activities such as hunting might have had a large impact. As mentioned above (Section 4.1.3), it has been suggested that the small size of the Mesolithic aurochs in Portugal could have been caused by some kind of over-hunting (Davis and Mataloto 2012), although this is not the only explanation offered for this change, which could be more likely related to climatic change. None of the sites included in this study have yielded a very large sample size, especially during the Holocene, which suggests that humans were not relying heavily on this animal economically. A couple of Pleistocene sites, such as Castel di Guido (Italy) and La Borde (France) have yielded some of the largest proportions of aurochs, but these are much earlier sites dated to MIS 9 and 5 respectively. Overall it would seem unlikely that hunting pressure from the humans and pre-human hominins would have had a large impact on aurochs populations during either the Pleistocene or Holocene.

The general lack of tooth data, either due to the rarity of teeth in archaeological assemblages, or to incompatibility of published tooth measurements, means that it is not possible, in most cases, to compare postcranial changes with those of the teeth, and this may have hindered our ability to unpick the kinds of factors that were affecting size and shape change. Teeth generally show less variability than postcranial remains (Degerbøl 1963), and it has been shown that for pigs, tooth measurements, being less variable than postcranial measurements, are most useful for identifying different geographic groups (Albarella *et al.* 2009: 114). Because tooth measurements are less variable, the pattern that they produce may provide slightly more precision than postcranial remains. In this study, with the exception of some small samples from the Mesolithic of Denmark, it was only really possible to look at changes in aurochs teeth during the Italian Pleistocene, and these do seem to show a similar pattern to the postcranial remains. The population from Grotta Romanelli displays, on average, the smallest body size of all of the other Pleistocene sites included, including Castel di Guido which is dated to a warm phase. This confirms the pattern detected in the postcranial samples, and indicates that the pattern is not purely related to the increased variability seen in postcranial measurements. For the period when domestication occurred the dental evidence is unfortunately lacking and we must rely almost entirely on postcranial bones. The small sample of tooth data from Mesolithic Denmark, does, however confirm the reduction in size seen between the Early and Late Mesolithic in Danish postcranial remains.

5.2 Morphometric variability of the aurochs across its European range

5.2.1 North versus South

5.2.1.1 Pleistocene

This work has shown that there is likely to have been a difference in size between aurochsen in northern and southern areas of Europe during at least some parts of the Pleistocene and during the Early Holocene.

Although the sites from the Middle Pleistocene do not overlap in time exactly, their distributions suggest that the aurochs was larger in northern areas compared to southern areas. The relatively large interglacial samples from Castel di Guido in Italy, and Grays Thurrock and Ilford in Britain have been instrumental for spotting these patterns. The south-north cline is not really surprising when you take into account the likely climatic differences between Italy and Britain in MIS 9 and 7. Indications from MIS 5 in Southern France (La Borde) and Spain (Solana del Zamborino) are that aurochsen in these areas were of a similar size and shape during this interglacial period. The overall size of aurochsen at La Borde and Solana del Zamborino, in the last interglacial, is small compared to all aurochsen from the interglacials at MIS 9 and 7, whether they be from northern or southern areas, but then the last interglacial was a warmer period than these previous interglacials, which could explain the pattern.

A south –north cline in body size has traditionally been associated with temperature, as laid out by Bergmann'sRrule (1847). Whether the pattern is related directly to differences in temperature – i.e. animals with a large body mass being more able to retain heat in a cold environment (Schmidt-Nielsen 1984) - or to climate through the impacts of factors such as seasonality and food availability (Geist 1987), is uncertain.

5.2.1.2 Holocene

A size and potential shape difference between north and south has also emerged for the early Holocene. In the Mesolithic southern European aurochsen tend to be smaller than those from northern Europe, and some differences in shape, as highlighted by an analysis of the astragali, have also been detected.

There are a number of complicating factors in the interpretation of this pattern. Firstly the sample sizes from some areas of southern Europe are quite small. The Portuguese sample is far larger than any others from southern Europe, and constitutes most of the evidence for the south-north size and shape differences, although the tiny samples from Italy and Spain do seem to plot in a similar area. The Portuguese sample is made up of specimens from the Mesolithic Muge middens, which were excavated in the early 20th century and so have an unclear chronology. Recent dating has suggested that the material is likely to be from relatively late in the Mesolithic - c8000-7450 cal BP (between approximately 6300 and 5500 cal BC) (Bicho *et al.* 2012) - which is later than comparable specimens from Britain and

Germany which come from the Early Mesolithic. Because of this, the size difference could be related to a change over time rather than a difference between north and south. Arguments for a reduction in the size of various animals during the Mesolithic (e.g. Davis and Mataloto 2012) may support this. The lack of clear dating for many of the Danish sites does not help the situation, but it does seem likely from the information available that some of this material is from the later part of the Mesolithic – potentially closer in date to some of the material from the Muge middens. Holmegaard, for example is thought to date to c7000-6600 cal BC (Fischer 2007) and Mullerup to only slightly earlier (Leduc 2010). The Danish Mesolithic dataset plots in a consistently larger range than that from Portugal, Spain and Italy for most bones, though, there is some evidence for a reduction in the size of the aurochs in Denmark during the Late Mesolithic, from Ertebølle assemblages.

The French sample from La Montagne in southern France plots in an intermediate position between the northern and southern groups as you might expect if there were a south-north cline. This material is dated to c8298-7974 cal BC (Helmer and Monchot 2006), which is closer in date to Star Carr than to the Muge middens. This, along with the small amount of Early Mesolithic data from Spain, provides some evidence pointing towards a difference between north and south during the earlier Mesolithic.

As discussed above, the lack of aurochs biometrical information from the Early Mesolithic and the late Pleistocene in Portugal means that it is very difficult to ascertain whether the small body size seen in the biometrical distribution of the aurochs at Muge reflects a size change over time or a size difference between south and north during the Mesolithic period. Contemporary size reductions in other animals, such as red deer, suggests that it might be more likely to be some kind of change over time, but large specimens from Denmark, and a hint at a size cline within the Early Mesolithic suggests that it could be related to a true size difference between regions. It is likely that both of these factors may play a part in the formation in this pattern.

The shape differences seen between astragali from different areas of Europe are particularly interesting. Breadths seem to be particularly large for their depths in both the Portuguese and Spanish samples. This means that, whilst throughout most of this study astragalus breadths have tended to reduce in size faster than lengths, in the Portuguese and Spanish Mesolithic samples lengths may have reduced faster than the breadths, or at least a similar rate. This is an unusual pattern and indicates that it is predominantly astragalus length that is different in size between north and south. No other bones seem to show this pattern; tibia, metacarpal and humerus measurements seem to all reduce at a similar rate to each other, although there are very few length measurements from any other bone apart from the astragalus. Because this pattern seems to be present in both Portugal and Spain, and therefore is present in both the Early and Late Mesolithic, it could reflect a true difference between south and north during the Mesolithic.

Although there are limitations in a pattern of shape difference that is only identified on one anatomical element, this is nonetheless an indication of yet another difference, in addition to size, between the Iberian Mesolithic populations of aurochs and those from central/northern

Europe. It acts as a reminder that in archaeological interpretations we cannot use aurochs morphometry as a homogenous variable across all chronological and geological ranges.

5.2.2 East versus West

Less evidence seems to be available for size and shape differences between east and west, although this may be partly to do with the fact that Poland is the only eastern European area that has been included in this study. There is no pre-Neolithic material from Poland included either, so it is difficult to judge what the situation was before domestication took hold. The sample from Mesolithic Germany contains some of the largest specimens from the Holocene, although this sample also contains the earliest dated material from this period, so the pattern may reflect chronology rather than geography. Germany and Poland also contain some of the largest specimens from the Early Neolithic (5500-3000 cal BC) - Germany has some particularly large astragali, at least - but the samples are quite small. In the Bronze and Iron Age there are indications that the Polish aurochs may be larger than others in Europe. Again the sample is small, but there is an indication that domestic and wild cattle are particularly separate here compared to other areas, perhaps also as a consequence of different sex ratios in the compared datasets.

A west-east size cline has previously been identified in a number of different animals, including modern wild boar (Genov 1999; Magnell 2004; Albarella *et al.* 2009), as well as the brown bear and the reindeer (Weinstock 2000). All of these species tend to increase in size going from west to east. Temperature, continentality, and distance from the sea may all play a part in this phenomenon (Albarella *et al.* 2009). In the most in-depth study of wild boar size and shape (Albarella *et al.* 2009) the largest European wild boar specimens came from Belarus and Russia, an area for which we do not have a comparable dataset for the aurochs, and further east than any of the data presented here. Additionally the west-east cline has not been identified in ancient wild boar, only in modern populations. Wild boar body size during the Mesolithic period seems to have been more affected by climatic differences between north and south, rather than east and west (Albarella *et al.* 2009). It is therefore not particularly surprising that no very clear west-east cline has been identified for the aurochs in this study. The very slight hint of it during later periods, hints that, as for the wild boar, differences between western and eastern aurochsen may have become more pronounced during more recent periods.

5.2.3 Island versus mainland

The other particularly interesting pattern that stands out in the Pleistocene is that of the supposed ‘dwarf’ aurochsen (*Bos primigenius sicilae*) in Sicily at Grotta dei Puntali during the last interglacial. Most of the bones attributed to this species at this site are particularly small - overlapping more with domestic cattle than with the aurochs - and the one astragalus found also displays a very different shape compared to all of the other astragali in this study. Such a small sample size is very hard to interpret, but it does hint that there may have been some kind of geographic isolation of the aurochs population in Sicily at this time.

The geographic isolation is likely to be due to the separation of Sicily from the mainland during the upper Pliocene and lower Pleistocene. The exact nature of subsequent geographical fluctuations in the area is unclear but it is known that a land bridge had eventually formed between Sicily and the mainland by the Upper Pleistocene (Bonfiglio *et al.* 2002).

Bos primigenius sicilae has also been identified on at least one other site on Sicily – San Teodoro cave (Mangano *et al.* 2005; Bonfiglio *et al.* 2008; Mangano 2011), where it is described to be "within the range of variation" of the remains found at Grotta dei Puntali (Mangano *et al.* 2005: 74). Larger numbers of bones attributed to this species than at Grotta dei Puntali were recorded at San Teodoro cave, but unfortunately it was not possible to access the material in order to compare the metric data with others from this study. It would be extremely interesting to investigate whether the shape difference in the astragalus is something that also appears in this assemblage, and if any of the other bones also display a shape change. Interestingly, although there are no precise dates, it is thought that the assemblage at San Teodoro cave is from the following glacial period (MIS 4) to the material from Grotta dei Puntali. If the *Bos primigenius sicilae* remains here are of a similar size to the preceding interglacial, then this suggests no climatically related size change in Sicily at this time.

Insular dwarfism is a well-known zoological phenomenon (e.g. Foster 1964; van Valen 1974; Lomolino 1985; Lomolino *et al.* 2013). Explanations for it have primarily focused on issues of food limitation, competition and predation (e.g. Sondaar 1977; Masseti and Mazza 1996). This kind of dwarfism does seem to be particularly common in Sicily and other Mediterranean islands, such as Corsica and Sardinia, where dwarfed versions of various different animals have been found, including a number of different Proboscideans, deer, bison and wild boar (e.g. Carpasso Barbato 1990; Palombo 2007; Albarella *et al.* 2009). At San Teodoro cave endemic sub-species of red deer (*Cervus elaphus sicilae)* and bison (*Bison priscus sicilae)* have been identified in addition to the dwarfed aurochs (Mangano *et al.* 2005; Bonfiglio *et al.* 2008; Mangano 2011). Whilst a number of papers report the presence of dwarf forms, it is very rare for biometrical information to be published, so the exact nature of the dwarfism cannot really be discussed. Certainly in the case of wild boar, there is no indication of a shape change alongside the size reduction seen in animals on Corsica and Sardinia (Albarella *et al.* 2009). In this context it is not at all surprising that a dwarf form of the aurochs has been identified at Grotta dei Puntali, although evidently more investigation is needed to explore the nature of the possible change in astragalus shape.

5.3 Potential contributions of this work to the morphometric identification of wild and domestic cattle bones

Numerous studies have demonstrated the difficulties of separating wild and domestic cattle biometrically (Jewell 1963; Degerbøl and Fredskild 1970; Grigson 1969; 1978; Rowley-Conwy 1995; Kyselý 2008), and this project has not set out to solve this problem, but it was hoped that some comments could be made on how to perform these distinctions more reliably.

The first thing to highlight is the real problem with attempting to determine wild from domestic animals based upon measurements from animals from areas not local to the population you are studying. This was especially evident when trying to make distinctions between wild and domestic animals looking at data from across Europe in the Early Neolithic (Section 4.2.2). Some countries showed much clearer distinctions between groups than others, but in others no clustering of measurements could be detected with any clarity. Even within smaller geographical areas this problem still arose. In Germany, for example, variations in the kinds of husbandry employed at different sites have created a situation where wild and domestic animals are really very difficult to split, unless you look at the data at an individual population level. It is therefore important to bear in mind the origin of any data used as a comparison for determining wild from domestic cattle, and if the measurements used for comparison are actually appropriate for what you are trying to achieve.

Various aspects of methodology useful for distinguishing wild from domestic animals are also worth mentioning. The particular technique of displaying log ratio results according to individual bones has allowed a thorough investigation of the ways in which different measurements were changing, whether they were related to a change within the aurochs population itself, or to the process of domestication. Changes in different measurements can be compared to each other in order to see how size change was taking place, and if there was any shape change of the bones.

The measurements chosen to be a part of this study were selected on the basis that they would be most useful for investigating patterns of change over time. Rowley-Conwy (1995) highlighted the problems with using certain bones for distinguishing between wild and domestic animals. With this in mind, measurements from bones such as the scapula, which continues in its growth even after fusion, were not used in the biometrical analysis, and were excluded from log ratio diagrams. By doing this, some of the uncertainties about the variation of postcranial measurements were dulled.

Breadth measurements tend to be particularly plastic compared to length measurements, which tend to linger around the standard line on log ratio diagrams for longer, when other measurements are getting smaller. This may mean that breadth measurements are potentially of more use for determining wild from domestic animals. This is complicated, however, by the fact that breadth measurements tend to be more affected by sexual dimorphism, resulting in a large amount of variation. Degerbøl (1970) mentions that length measurements from a number of limb bones show less overlap than breadth measurements, but this study has not identified this as a clear pattern across Europe.

Metapodial diaphysis measurements tend to be of little use for distinguishing wild from domestic cattle, due to their large variability, which was particularly highlighted by the especially small measurements recorded at Eton Rowing Lake. This indicated that this measurement can become increasingly variable within a specific population, making it incomparable with other assemblages. These measurements should probably be excluded from log ratio diagrams in order to reduce the chances of confusion.

Depth measurements tended to have quite small sample sizes, and they seemed to vary in the amount of variation that they displayed. There were a few instances where femur proximal depth measurements stood out as being particularly large, and this indicates that this measurement can be quite variable, but this was not a consistent pattern. Overall depths seemed to have similar variability to breadth measurements, therefore providing similar challenges when used for separating wild and domestic forms.

Sexual dimorphism is much clearer in some measurements than others. As mentioned above, breadth measurements are generally more sexually dimorphic than length measurements, but also some specific measurements, such as those from the distal metapodials and the distal humerus are particularly sexually dimorphic, and this must be taken into account when attempting to use these measurements to distinguish wild from domestic animals. Degerbøl (1970) mentioned that measurements from the tibia display a large amount of sexual dimorphism, and it has to be said that this has not been particularly clear in this study. Even where there are larger samples the data does not form distinct groups which could be related to sex. That said, there does seem to be quite a lot of variation in both breadth and depth measurements, which could be related to sexual dimorphism, an interference in attempts to separate wild from domestic animals.

There is also some evidence of a change in shape between wild and domestic cattle. A number of bones tend to be more slender in domestic cattle than in the aurochs, and this pattern becomes especially clear in the latest periods (as seen by the German and Polish Roman and medieval assemblages), when selective breeding becomes common. However, this pattern may easily be confused with other processes. There is a hint that this kind of change may have taken place by the Younger Dryas in Italy, for example. This means that other forces, such as temperature change, may have similar impacts on the shape of bones as domestication.

Finally, coefficients of variation for many measurements have been displayed (as suggested by Rowley-Conwy 1995). This enables the detection of particularly mixed samples which are likely to contain both wild and domestic animals, even if each individual bone in a sample could not be identified. Of course, it is important to bear in mind that many of the samples contain bones from a number of different sites, and this will automatically increase the variation, but even then some of the more mixed samples can be spotted. The southern Scandinavian Ertebølle sample is a good example of this. Length measurements from the astragalus and calcaneum display particularly high values compared to both the Mesolithic (wild) and Middle Neolithic (domestic) samples. Values are near to or above 10, which indicates particularly mixed groups (Simpson *et al.* 1960:91). Interestingly in this instance, the coefficient of variation scores from breadth measurements from the astragali and metacarpals do not show such a clear pattern, which might suggest that the generally higher variation of breadth measurements across all time periods makes for a less reliable indicator of mixed assemblages.

5.4 Potential contributions of this work to palaeogenetic studies

The background of genetic work investigating cattle domestication, partly through the analysis of aurochs material has been outlined in detail in Section 1.5.2. Much of this work has pointed out to a single origin for European domesticated cattle, which is suggested to have take place in the Near East (Troy *et al.* 2001; Edwards *et al.* 2007; Bollongino *et al.* 2012), but the possibility of some variation, and potential exceptions to this has also been discussed in the literature (e.g. Edwards *et al.* 2007; Stock *et al.* 2008; Mona *et al.* 2010).

In order to more clearly define the nature of cattle domestication, further genetic studies need to provide the most accurate information possible, including the most appropriate samples. They must also be based on a clear understanding of the current zooarchaeological knowledge on the spread of domestication across Europe. With this in mind, the expertise of zooarchaeologists is instrumental to the success of genetic studies dealing with ancient wild and domestic cattle remains. Our role should be to select the most appropriate specimens to best answer the research questions of a particular study, and also to take a role in the analysis of the results, by providing contextual information. The guidelines for best distinguishing wild from domestic cattle remains should be heeded when selecting bones. If a study wishes to test the genetic differences between wild and domestic cattle, the best bones to choose to investigate an aurochs haplotype would be those from Pleistocene or Early Mesolithic cattle, in order to absolutely avoid the contamination of domestic bones. Domestic bones should be chosen from populations where there is no question of aurochs bones being included, such as those which appear to be homogeneous (e.g. with low coefficients of variation) or from periods when the aurochs is regarded to have been extinct. Naturally, in order to investigate the earliest advent of domestication, there will be an interest in analysing Early Neolithic material, when both wild and domestic forms co-existed. For this period, however, particular care must be taken to have a full understanding of the morphometric variabilities of both aurochs and domestic cattle in a given region, before assumptions are made regarding the domestic or wild nature of the animal from which the analysed bone derived. In terms of the distinction of wild and domestic forms more than a century of zooarchaeological research is more likely to lead the way than less than two decades of, still hotly disputed, ancient genetic analysis.

This study has made some important contributions to the debate; it has demonstrated that the difficulty of separating wild from domestic cattle varies depending on geographical area, and according to time period. The Early Neolithic period seems to be a particularly problematic time for distinguishing wild and domestic animals, as already demonstrated for *Sus* (Albarella *et al.* 2006). In some areas the aurochs is represented by very few bones (e.g. Spain, Italy and Britain) so it is unclear what the full body size spectrum would have been, and in other areas (such as Germany) there seems to be much overlap between the wild and domestic groups.

After this period wild and domestic animals become easier to separate in all areas of Europe included in this study, but there still is some overlap and this leads to some uncertain identifications, especially if the reference material is from a different geographical region. The only way to completely exclude the possibility of morphological uncertainty is to wait until after the extinction of the aurochs in the area one is studying. Clearly bones at the extreme of the size range (either the smallest or the largest) may also be worth selecting for genetic analysis as they are likely to represent domestic cattle and aurochs respectively. In many cases, however, sample sizes will not be large enough to provide a complete understanding of the size variability attested in an assemblage. These are the cases in which great caution must be exercised in the selection of specimens for genetic analysis and in the interpretations.

Genetic studies to date have been relatively good at selecting appropriate bones for trying to detect wild and domestic haplotypes; with samples predating the onset of domestication being used for the former, and modern samples from after the extinction of the aurochs for the latter (e.g. Bradley *et al.* 1996; Beja-Pereira *et al.* 2005; Mona *et al.* 2010 Edwards *et al.* 2010). However, in more wide ranging investigative studies where Neolithic and Bronze Age samples have been included, the basis on which the bones were identified as wild or domestic is rarely described, and, if it is, there are often references to Degerbøl and Fredskild (1970), even if the specimen is not from Denmark (see for example the supplementary information from Edwards *et al.* 2007). This is not surprising, considering that there was little other work that could have been used in order to more thoroughly investigate aurochs morphology until now. It highlights, however, the possibility that samples included in genetic studies may not have been identified using the most appropriate comparisons, simply due to the lack of regional knowledge on aurochs and cattle morphometry.

Finally, it is worth mentioning briefly the work that has attempted to distinguish morphologically uncertain bones as wild or domestic through genetic analysis, on the basis that the ‘T’ haplotype is domestic and the ‘P’ haplotype is wild (for example by Scheu *et al.* 2008 at Rosenhof). In the light of studies that have raised doubts about the fact that all European cattle and aurochsen respectively fit into the ‘T’ or ‘P’ groups (e.g. Beja-Pereira *et al.* 2005; Edwards *et al.* 2007; Achilli *et al.* 2008; Mona *et al.* 2010) it seems unwise to distinguish wild and domestic forms on mitochondrial DNA bases. In fact the in-depth biometrical work presented here and in previous papers (e.g. Rowley-Conwy 1995 on the specimens at Rosenhof) is, at present, potentially more reliable. Sometimes it is necessary to accept the limitations of the methods available to us, rather than always strive for an unambiguous answer, which may in fact be inaccurate.

Overall the results of this study do not necessarily question the integrity of the genetic studies that have been previously undertaken, but provide spatial and temporal information on aurochs morphometry that has previously not been available, and that is important to take into account during future studies. This work should act as a reminder that it is necessary to take care not only when identifying cattle bones as domestic or wild, but also when providing contextual information about the nature of domestication in different areas of Europe, which may be used in order to interpret the results of genetic studies.

5.5 Reflections on this study, and potential future directions

5.5.1 Sample size

One of the largest problems faced was the generally small sample sizes of aurochs assemblages, especially during the Holocene. This was not unexpected, but resulted in small biometrical samples, and also meant that it was also often difficult to collect much ageing information. It was a challenge to try and get the most out of the data that were available, without over-interpreting the patterns that became apparent during analysis. Of course not a lot can be done about the size of the samples themselves, but there are a variety of different ways of presenting the data which can help to make them more useful. The method of highlighting individual measurements on log ratio diagrams, and providing diagrams for individual bones (also using a log ratio approach) has proved to be a fairly successful way of looking for patterns of size and shape change. This method is potentially more useful than using simple histograms, because measurements and bones can be combined in as many different ways, as they are all presented on the same scale. It also means that samples can be combined in order to increase their size, or reduced in order to look for more specific patterns at a higher resolution.

With a small sample size it is always tempting to try and use every single piece of information that you have, and this has previously been a problem in biometrical studies looking at aurochs remains, where all measurements have been used regardless of how useful they are. Accepting the limitations of your dataset is an important part of a research project, and if it is not taken into account then you can face issues of over-interpretation. This was something highlighted by Rowley-Conwy (1995) when re-assessing the identification of wild and domestic cattle in Denmark and northern Germany. Some of the bones included in the debate were scapulae, which are not a particularly useful bone for a biometrical study (unless you are perhaps trying to look at age), due to the fact that the scapula continues to grow after fusion, and it was therefore suggested that the scapula neck measurement in particular is unreliable in determining between wild and domestic animals. In this project this kind of issue was taken into account from the very beginning, and even though some of the smaller datasets might have originally had more measurements, it was accepted that these measurements would not be useful in addressing the research questions of this project. This was especially the case with measurements from the phalanges, all of which were discarded because of problems of being able to distinguish those from the fore- and hind-limbs. Measurements from the proximal metapodials were also avoided because they can be heavily age dependent. Although this decreased sample sizes overall, it meant that the data used were the most appropriate and reliable for answering the research questions.

5.5.2 Data collection from the literature – the compatibility of different recording systems

It was set out from the start that only a select few places could be chosen in order to record material using the specific methodology designed for the project, and that therefore a large amount of data would have to be collected from the literature. Much of the data has therefore been collected from publications which inevitably had a variety of different research aims, and which have been written in a variety of styles. Different researchers had different ideas about which were the most important measurements to record and publish (if any measurements were published at all), and whilst a number of measurements appear regularly throughout the literature, there are some included in the protocol for this project that are not taken regularly by many others. In many cases this has had an effect on sample size.

Many researchers follow the measurement guidelines laid out by von den Driesch (1976). The advantage of doing this is that it is a standardisation of measurements (although see my note on observer error, below 5.5.3) but this also has a number of disadvantages. Since the publication of the original protocol various people have suggested additional or amended measurements to take, and these should be taken into account, because they generally have been suggested for good reason. Although the original protocol has been instrumental to our examination of animal body size and shape, some of the measurements are inappropriate for getting the most useful information from an assemblage. A number of the more recent measurements used in this project were originally laid out for pigs by Payne and Bull (1988), including the better defined way of taking the humerus trochlea breadth (BT), and tooth measurements. Bull and Payne (1982) also make the suggestion that the measurements that we take should always be subject to change depending on the kind of information that we seek from a study. Nevertheless, the set of measurements provided by von den Driesch (1976) tends to be uncritically applied, which was probably not even in the spirit of this original publication.

This problem has had a particularly large effect on the ability of this project to look at tooth size and shape change over time. Most papers publish length and breadth measurements as described by von den Driesch (1976), who suggests taking them at the occlusal surface. This is a particularly variable part of the tooth, which will change as the tooth wears, and therefore as the animal gets older. Because of this, the protocol laid out in this project instead includes taking these measurements at the widest part of the tooth, as this is likely to be less variable over time. This is likely to be a much more useful measurement, especially if it were to be taken more widely, but because most people take the measurement as defined by von den Driesch, this reduced the sample of tooth measurements available for use in this project. In future it might be interesting to take tooth measurements in both ways; at the widest part of the tooth, and at the occlusal surface, because this would allow a comparison of variation between the two, and although they might not be directly comparable with each other, a judgement can be made as to whether patterns which result from the analysis of the measurement taken at the occlusal surface are worth using whilst bearing in mind the amount of variability that might be present.

Another drawback of using data collected from the literature is that it did not provide much opportunity for ageing analysis. As raw fusion and tooth wear data are not usually given, it was not possible to directly compare the age profiles of sites across Europe using the same method. This meant that it was not possible to investigate potential differences in age profiles between domestic and wild populations.

The recording protocol adopted for this project therefore reflects a compromise between using measurements that could be compared with those generally used in the literature, and also others that could more reliably address the research question relevant to this project.

5.5.3 Observer Error

Another problem with using large amounts of biometrical information from the literature is that even if the same measurement is being taken there will still be the potential for observer error. Researchers may intend to follow the same protocol, but might take the measurement in a slightly different way. This is something that I experienced whilst recording assemblages in a number of different places, and observing how different people handle callipers. This issue is discussed briefly by Johnstone (1999), in which it is suggested that (as might be expected) there is likely to be greater amounts of inter-observer error than intra-observer error.

Davis (1996) attempted to test issues of intra-observer error in the recording of a sheep population, by taking each measurement in his protocol four times on the same bone. This resulted in variation of less than 1% on almost all bones. This is useful in terms of determining how much variation might be present in a dataset that is recorded entirely by the same person, but it does not reflect the kind of observer error which could be present when a number of different people, with different amounts of experience, have taken the measurements. There could be variations in terms of geographical area, lab, or even related to how someone originally learnt to take measurements – if they were taught by an established zooarchaeologist, or if they taught themselves, for example.

Some measurements are especially difficult to take consistently. Davis (1996) found, for example, that some pelvis measurements were more variable than others. Due to this, and also following conversations with a number of other zooarchaeologists, the protocol was designed in order to exclude the most variable measurements. The possibility that variation could exist was also taken into account throughout the analysis of the data.

Another study, based again on sheep, tested intra- as well as inter-observer error, finding unsurprisingly that inter-observer error was slightly higher than intra-observer error (Popkin *et al.* 2012). The level of both inter- and intra-observer error in this project was reported as being “within acceptable levels”, although it is not explained what the definition of ‘acceptable’ is. In addition to these studies, at least one more study is in progress which aims to investigate this further (Lenny Salvagno *pers. comm.*).

In theory, if a protocol is applied accurately, everyone should be taking teach measurement in the same way, but in reality this may not be the case. Also because for most measurements, as much as you define them, there will always be a margin of uncertainty in the way they should be taken. At the moment, the studies that have investigated this have not recorded very high levels of error on any of the measurements that they have tested, so it is unlikely that observer error will have made a large impact on the results of this study.

5.5.5 Geographical Scope

One of the main challenges of this project has been its potential scale, and the acceptance that its coverage would inevitably be punctuated, especially in terms of geography. The most eastern parts of Europe have been excluded, for example, and it was not possible to undertake a diachronic study of the French material. This is related to a number of issues which could not easily be overcome. The project - like all projects - was restricted by finances and time, both in terms of visiting collections and in terms of searching the literature for data. A locality with large enough samples of material for recording could not be identified in the eastern European areas - and much of the literature in which measurements might have been recorded was not accessible. Even the trip to Poland consisted mainly of accessing literature that it would have been very hard to obtain in Britain. Much of the data from Germany could not have been obtained without the help of people in the country with access to the appropriate publications.

Besides the obvious and unavoidable restrictions of time, two particular issues stood out as being most prominent in the restriction of the geographical scope of this project. The first was the ways in which archaeological remains are stored in different areas of Europe. In Germany and Poland, for example, it seemed rare for material to be held by national or regional museums, and instead local museums tended to hold material from the surrounding area. This means that it is impossible to access all of the material that you would like to when you are undertaking a project spanning such a wide geographical area, but it does mean that in theory access to local archaeology by the public is a lot easier. The second is that access to data from certain areas relied a great deal on the kindness and generosity of individual people. Some geographical areas ended up not being investigated because of difficulties in accessing the information. This means that analytical strategies were partly dictated by research priorities, but also by practical issues concerning the ease of access to both material and data.

Overall this experience has highlighted how projects can be biased due to circumstances out of researcher control, and has, in addition to being an incredible learning curve, sparked a real interest in the ways in which bureaucracy, technology and human nature can have a lasting impact on research.

5.5.6 To The Future

Although this study has investigated many of the issues surrounding the morphological variation of the aurochs, a project of this nature is always likely to throw up just as many questions as it deals with. Here I have outlined some of the most prominent ones.

1. As this project has shown, investigating aurochs populations during the Pleistocene is our best opportunity to understand more fully the effects of climatic change on aurochs body size and shape. In order to have a fuller understanding of the way in

which this process works, datasets from specific climatic periods need to be sought out and compared. The last glacial period and the Younger Dryas have been identified as periods for which it would be especially useful to have datasets for, and this is likely to be due to the fact that the geographical distribution of the aurochs was restricted during these cold periods, but more data from southern areas may become available for study.

2. It would be extremely useful to investigate more thoroughly the changes that took place in different areas of Europe within the Mesolithic period. It would be especially useful to identify more southern European datasets, and also more Late Mesolithic datasets from across the whole of Europe. This would enable a more thorough analysis of the small aurochsen in Portugal during the Late Mesolithic.

3. Further investigation of island populations needs to be undertaken in order to more securely confirm the status of populations such as the Sicilian dwarf aurochs. Access to biometrical information from this population needs to be made available in order to perform a thorough study of this aspect.

4. The kind of work undertaken in this project should be extended to more eastern regions of Europe, such as Ukraine, Belarus and Russia, in order to further investigate how body size and shape changes from west to east, and also to investigate further the effect of continentality.

5. The clear differences between Neolithic and Chalcolithic sites in countries such as Spain and Germany have highlighted a need for more in-depth studies looking at cattle exploitation and domestication through the use of biometry, within more distinct areas of Europe, perhaps in a similar vein to the work on Spanish pigs undertaken by Hadjikoumis (2010).

5.6 Conclusions

- Previous assertions that the Pleistocene aurochs was larger than the Holocene aurochs may be overly simplistic. This work has suggested that there was a large amount of variation within the Pleistocene itself, and that the most distinct size decrease may have taken place at around the time of the last interglacial (MIS 5). The most likely factor causing these fluctuations is climate. There is potential for some body size fluctuations between glacial and interglacial periods, but glacial assemblages are generally limited and restricted to southern Europe, probably due to these areas being used as refugia.

- In addition to fluctuations in body size during the Pleistocene, a change in bone shape, reflected by the slendering of some bones also begins during this period, and thus cannot be wholly attributed to the process of domestication. This process is detectable by the Younger Dryas in Italy, and there are also hints of it in earlier assemblages such as Coygan Cave (c60 ka BP) in Britain.

- The reduction in size between the Early and Late Mesolithic in Denmark, previously noticed by Degerbøl and Fredskild (1970) is detectable in this study for Denmark, but not for any other areas of Europe. Further Mesolithic samples are needed to investigate this further.

- The body size decrease seen in all areas during the Early Neolithic period largely, if not entirely due to domestication. In some areas such as Britain, Spain, and Italy, the shift to a smaller size happens quite suddenly with the onset of the Neolithic, whereas in other areas such as Germany and Denmark this happens more gradually. The process of domestication also results in a further slendering of bones, in a continuation of the process that begins during the Pleistocene.

- An increase in the body size of the aurochs can be detected at some Iberian Chalcolithic sites. This is similar to changes that have been seen in the Portuguese red deer (Davis 2006; Davis and Mataloto 2012) and Italian wild boar (Albarella *et al.* 2006) at a similar time. The most likely cause of this is considered to be changes in the climate, as it coincides with the onset of a climatic deterioration. In the case of the aurochs it seems unlikely to be related to hunting pressure, as there is little evidence that the animal was being hunted in large numbers prior to or during this period.

- Differences in body size are detectable between northern and southern Europe during both the Pleistocene and Holocene; Italian populations display a smaller overall body size to British ones during MIS 9 and 7, and Mesolithic Portuguese populations display an overall smaller body size to those in northern Europe.

However, this pattern is no longer detectable after the onset of domestication. These differences between geographical areas are most likely related to climate.

- There is a slight hint of a west-east cline in body size during the later Holocene, with aurochsen from eastern areas displaying a slightly larger body size to those in the west. Further exploration of samples from eastern areas is needed to confirm this.

- There is some evidence suggesting the presence of a dwarf-form of the aurochs on some Mediterranean islands, such as Sicily, during the Middle Pleistocene. Hopefully in future more biometrical data from these animals will become available for further study.

- The kinds of variation that have been detected in this study have highlighted the importance of using comparative data from a relevant geographical (and climatic) area in order to identify aurochs remains.

This study has provided the most thorough and geographically wide ranging study of aurochs biometrical information to date, and has demonstrated the variation that existed in the European animal both prior to and after the onset of domestication. This work has therefore highlighted the importance of using geographically relevant comparative data when identifying aurochs remains in zooarchaeological studies, and the importance of the accuracy of these identifications for future research about the dispersal of wild and domestic cattle, the pattern of domestication events, and the temporal sequence of domestication. This information also benefits those with whom zooarchaeologists collaborate, such as geneticists, who not only need the most appropriate samples for their work, but also our advice when interpreting the results of their work.

It is hoped that this thesis will provide a resource that can be used by zooarchaeologists in future, in order to make reliable biometrical identifications of wild and domestic cattle, and that this will, in turn, result in a better understanding of the history of this animal and human interactions with it.

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Appendices

Appendix I - Recording protocol

The recording protocol employed to record information from *Bos* postcranial bones and teeth for this project was one that allowed the recording of as much useful information as possible related to age, sex, size and shape in a relatively short space of time. The protocol follows a system based on that outlined by Davis (1992), and Albarella and Davis (1996), with some modifications relevant to this project. This system is based on the identification and recording of only specific zones of a number of skeletal elements. The zones recorded are generally those that include information about ageing (such as the epiphysial ends of long bones), and those that yield the most useful biometrical measurements.

Postcranial Bones

Atlas (at least half)

Humerus (proximal and distal) (at least half of an epiphysis)

Radius (proximal and distal) (at least half of an epiphysis)

Scapula (at least half of the glenoid cavity present)

Metacarpal (at least half of the epiphysis)

Pelvis (ischial part of the acetabulum)

Femur (proximal and distal) (at least half of an epiphysis)

Tibia (proximal and distal) (at least half of an epyphysis)

Metatarsal (at least half of the epiphysis)

Astragalus (at least half)

Calcaneum (sustentaculum present)

First, second and third **Phalanges** (at least half of an epiphysis)

Teeth

(with at least half of the occlusal surface present):

Upper and lower permanent molars

Upper and lower fourth deciduous premolars

Upper and lower fourth permanent premolars

Teeth were recorded as either loose or jaws. Jaws are defined by the occurrence of at least one tooth plus at least half of the adjacent tooth/alveolus or equivalent amount of bone. No attempt has been made to separate first and second mandibular molars when isolated. These teeth can generally be separated biometrically in pigs, with M1and M2 width measurements forming two very distinct groups (e.g. Viner 2010), whereas in cattle M1 and M2 measurements overlap and therefore cannot be distinguished so easily (e.g. Beasley et al 1993).

Crania

Crania have also been recorded where horncores (with at least a full circumference) were present, or where any parts of the skull were present on which measurements were able to be taken (see table X below).

Fusion

The state of fusion was recorded for both distal and proximal ends of the bone. Pelvis, Metapodials, atlas, and scapula will be recorded as having only a distal end, while phalanges and calcanea will be recorded as having only a proximal end. Since no fusion data will be available for astragali, all records will include a characterisation as normal, light or porous, entered in the comments box.

The following fusion codes were used:

f - fused
g - fusing
h - fused or fusing
ud - unfused diaphysis
ue - unfused epiphysis
ux - unfused, both diaphysis and epiphysis present

Eruption and wear

Eruption and wear stages were recorded using the system established by Grant (1982).

Measurements

Measurements taken on postcranial bones, teeth and crania are laid out in tables X X and X respectively

Table I – 1: Postcranial measurements included in this project

Element	Code	Description	Reference
Atlas	H	Height	Albarella & Payne (2005)
	BFcr	Breadth of cranial articular surface	von den Driesch (1976)
Scapula	SLC	Smallest width of the collum	von den Driesch (1976)
Humerus	BT	Width of the trochlea	Payne & Bull (1988)
	HTC	Minimum height of the trochlea	
Radius	GL	Greatest length	von den Driesch (1976)
	Bd	Breadth of distal end	
	BFp	Breadth of the humeral articular surface	
	Bp	Breadth of proximal end	
Metacarpus III & IV	GL	Greatest length	von den Driesch (1976)
	SD	Smallest diameter of the diaphysis	von den Driesch (1976)
	BFd	Breadth of the distal end	von den Driesch (1976)
	Dd	Depth of the distal end	von den Driesch (1976)
	BatF	Breadth at the distal fusion line	Davis (1992)
	a	Breadth of medial condyle	Davis (1992)
	b	Breadth of lateral condyle	Davis (1992)
	3	Diameter of the lateral part of the medial condyle	Davis (1992)
	6	Diameter of the medial part of the lateral condyle	Davis (1992)
Pelvis	LA	Length of the acetabulum including the lip	Von den Driesch (1976)
Femur	DC	Diameter of the caput	von den Driesch (1976)
Tibia	GL	Greatest length	von den Driesch (1976)
	Bd	Breadth of the distal end	
	Dd	Depth of the distal end	
Astragalus	GLl	Greatest length of the lateral side	von den Driesch (1976)
	GLm	Greatest length of the medial side	
	Bd	Breadth of the distal end	
Calcaneum	GL	Greatest length	von den Driesch (1976)
	GD	Greatest depth	Albarella & Payne (2005)
Metatarsus III & IV	GL	Greatest length	von den Driesch (1976)
	SD	Smallest diameter of the diaphysis	von den Driesch (1976)
	BFd	Breadth of the distal end	von den Driesch (1976)
	Dd	Depth of the distal end	von den Driesch (1976)
	BatF	Breadth at the distal fusion line	Davis (1992)
	a	Breadth of medial condyle	Davis (1992)
	b	Breadth of lateral condyle	Davis (1992)
	3	Diameter of the lateral part of the medial condyle	Davis (1992)
	6	Diameter of the medial part of the lateral condyle	Davis (1992)

Table I-2: Tooth measurements included in this project

Element	Code	Description	Reference
dP^4	W	Width, taken at the widest part of the tooth	My own definition
M^1	W		
M^2	W		
M^3	W		
dP$_4$	W		
M$_1$	W		
M$_2$	W		
M$_3$	W		von den Driesch (1976) - as for Pig M3
	L	Length, take at the widest part of the tooth	
Mandible	Mand H	Mandible Height in front of the M1 on the buccal side	von den Driesch (1976)

Table I-3: Cranial measurements included in this project

Element	Code or Number (von den Driesch 1976)	Description	Reference
Horncores	Min (46)	Minimum diameter of the base	von den Driesch (1976)
	Max (45)	Maximum diameter of the base	
	GL (47)	Greatest Length	
Cranium	3	Basal length	
	25	Greatest mastoid depth	
	28	Greatest breadth of the foramen magnum	
	29	Height of the foramen magnum	
	30	Smallest occipital breadth	
	32	Smallest frontal width	
	33	Greatest width across the orbits	
	35	Facial breadth	

Database fields

Table I-4: Database field descriptions: Postcranial bones. The measurement GLl will be recorded under the heading GL. DC and GD will both be recorded in the DC column.

Database code	Description
Rec Num	Record number
Country	Country
Site Name	Site name
Site code	Site code (if applicable)
Location	Location of faunal material, or data source
Box Number	Box number
Ctx Num	Context number
Bone Num	Bone number
Museum Num	Museum number
Phase	Phase
Dating	Dating
El	Element
Taxon	Taxon
Fus prox	Proximal fusion state
Fus dist	Distal fusion state
Min diameter	Minimum diameter of horn core
Max diameter	Maximum diameter of horn core
BFcr	Breadth of the cranial articular surface (Atlas) von den Driesch 1976
H	Height (Atlas) von den Driesch 1976
GL	Greatest length (radius, metapodials, tibia, astragalus, calcaneum) von den Driesch 1976
SLC	Smallest width of the collum (scapula) von den Driesch 1976
BFp	Breadth of the humeral articular surface (radius) von den Driesch 1976
Bp	Breadth of the proximal end (radius) von den Driesch 1976
BFd	Breadth of the distal end (metapodials) von den Driesch 1976
BT	Breadth of the trochlea (humerus) Payne & Bull 1988
HTC	Minimum height of the trochlea (humerus) Payne & Bull 1988
BatF	Breadth at the distal fusion line (metapodials) Davis 1992
a	Breadth of medial condyle (metapodials) Davis 1992
b	Breadth of lateral condyle (metapodials) Davis 1992
3	Diameter of the lateral part of the medial condyle (metapodials) Davis 1992
6	Diameter of the medial part of the lateral condyle (metapodials) Davis 1992
LA	Length of the acetabulum including the lip (pelvis) von den Driesch 1976
Bd	Breadth of the distal end (radius, tibia, astragalus) von den Driesch 1976
Dd	Depth of the distal end (matepodials, tibia) von den Driesch 1976
Glm	Greatest length of the medial side (astragalus) von den Driesch 1976
DC	Diameter of the caput (femur) von den Driesch 1976 / greatest depth -GD (calcaneum) Albarella & Payne 2005
Bos/Bison features	Morphological features relevant to *Bos/Bison* identification
Comments	Any extra comments
Photo?	Is there are photo of this?

Reference	Reference the data were taken from (most relevant for data taken from the literature)

Table I-5: Database field descriptions: Teeth

Database code	Description
Rec Num	Record number
Country	Country
Site Name	Site name
Site code	Site code (if applicable)
Location	Location of faunal material, or data source
Box Number	Box number
Ctx Num	Context number
Bone Num	Bone number
Museum Num	Museum number
Phase	Phase
Dating	Dating
X/N	Maxilla or mandible
J/L	Jaw or loose
Taxon	Taxon
dP4	Presence of deciduous 4th premolar and wear stage if appropriate, Grant 1982
dP4W	Width of the deciduous 4th premolar, taken at the widest part of the tooth
P4	Presence of 4th premolar and wear stage if appropriate, Grant 1982
M1	Presence of 1st molar and wear stage if appropriate, Grant 1982
M1W	Width of the 1st molar, taken at the widest part of the tooth
M2	Presence of 2nd molar and wear stage if appropriate, Grant 1982
M2W	Width of the 2nd molar, taken at the widest part of the tooth
M3	Presence of 3rd molar and wear stage if appropriate, Grant 1982
M3L	Length of the 3rd molar, taken at the widest part of the tooth, von den Driesch 1976 – as for pig M3
M3W	Width of the 3rd molar, taken at the widest part of the tooth – von den Driesch 1976 – as for pig M3
M12	Presence of loose 1st/2nd molar and wear stage if appropriate, Grant 1982
M12W	Width of the 1st or 2nd molar, taken at the widest part of the tooth
Mand H	Mandible height, von den Driesch 1976
Bos/Bison	Morphological features relevant to *Bos/Bison* identification
Comments	Any extra comments
Photo?	Is there are photo of this?
Reference	Reference the data were taken from (most relevant for data taken from the literature)

Table I-6: Database field descriptions: Crania

Database code	Description
Rec Num	Record number
Country	Country
Site Name	Site name
Site code	Site code (if applicable)
Location	Location of faunal material, or data source
Box Number	Box number
Ctx Num	Context number
Bone Num	Bone number
Museum Num	Museum number
Phase	Phase
Dating	Dating
El	Element
Taxon	Taxon
Fus prox	Proximal fusion state
Fus dist	Distal fusion state
33	Greatest width across the orbits, von den Driesch 1976
25	Greatest mastoid depth, von den Driesch 1976
32	Smallest frontal width, von den Driesch 1976
3	Basal length, von den Driech 1976
1	Total length of craniaum, von den Driesch 1976
35	Facial breadth, von den Driesch 1976
30	Smallest occipital breadth, von den Driesch 1976
29	Height of the foramen magnum, von den Driesch 1976
28	Greastest breadth of the foramen magnus, von den Driesch 1976
Inter	Intercornudal breadth, von den Driesch 1976
Comments	Any extra comments
Photo?	Is there are photo of this?
Reference	Reference the data were taken from (most relevant for data taken from the literature)

Database entry codes

Table I-7: database entry codes: Postcranial Bones

Code	Description
at	Atlas
sc	Scapula
hu	Humerus
othu	Proximal humerus
ra	Radius
othra	Proximal radius
mc1	Metacarpal (both condyles)
mc2	Metacarpal (one condyle)
pe	Pelvis
fe	Femur

othfe	Proximal femur
ti	Tibia
othti	Proximal tibia
as	Astragalus
ca	Calcaneum
mt1	Metatarsal (both condyles)
mt2	Metatarsal (one condyle)
p1	1st phalanx
p2	2nd phalanx
p3	3rd phalanx
oth	Other, non-countable, specify element in comment.

Table I-8: Database entry codes: Teeth

Code	Description
l	Loose
j	Jaw
x	Maxilla
n	Mandible
u	unknown

Table I-9: Database entry codes: Taxon (as classified by the previous investigator of the material and not by the author)

Code	Description
w	Wild
d	domestic
w/d	Wild or domestic
Bos sp	Unknown Bos species
Bison?	Possible Bison
‘blank’	unknown

Table I-10: Database entry codes: Location

Code	Description
Newport	Newport museum
Wessex Arch	Wessex archaeology
NHM	Natural History Museum (London) zoology
Nat hist Palaeontology	Natural History Museum (London) palaeontology
NHMW	Natural History Museum Wandsworth (London)
GML	Geological museum Lisbon, Portugal
NHMUP	Natural History Museum, University of Porto, Portugal
UA	University of Algarve, Portugal
ZMK Denmark	Zoologisk Museum København (Zoological Museum, Copenhagen),
KU	København Universitet, (Department of Geology, University of Copenhagen), Denmark
NMW	National Museum of Wales (Cardiff)
The Harris Museum	The Harris Museum, Preston

Pigorini	Museo Nazionale Preistorico Etnographico “Luigi Pigorini”, Rome, Italy
Siena	Dipartimento di Scienze Ambientali “G. Sarfatti” U.R. Ecologia Preistorica, Università degli Studi di Siena, Italy
MGPF	Museum of Geology and Palaeontology Florence, Italy
NHMC	Natural History Museum Calci (Pisa), Italy
DAUP	Department of Archaeology University of Pisa, Italy
MNHNP-A	Zooarchaeology lab, Natural History Museum Paris, France
MNHNP-IPH	Institute of Human Palaeontology, Natural History Museum, Paris,
DMdb	Daniel Makowiecki database
DM home lab	measurements taken at Daniel Makowiecki’s lab (Poznan)
DW written notes	Daniel Makowiecki’s unpublished notes
Kurt Grøn	Kurt Gron unpublished data
Steppan UD	Karlheinz Steppan unpublished data

Appendix II – Aurochs standard measurements

Standard Measurements

Standard measurements were calculated from a population of *Bos primigenius* from Ilford, Essex, dated to Marine Isotope Stage 7. Tables X-X lay out the raw data used to calculate the standard measurements. The mean values below each measurement column are the standard measurements used as a source of comparison for the log ratio diagrams produced in chapter 3. Standard measurements were calculated only from samples of more than five specimens.

Table II - 1: Individual measurements used to calculate standard measurements for the astragalus

ID	Country	Site Name	Location	Museum number	El	Taxon	Fus prox	Fus dist	GL	Bd	GLm
113	britain	Ilford	Nat Hist Palaeontology	129	as	w			102		95.7
123	britain	Ilford	Nat Hist Palaeontology	43128	as	w			99.5	71.1	91.4
125	britain	Ilford	Nat Hist Palaeontology	23128	as	w			99.9		91.2
126	britain	Ilford	Nat Hist Palaeontology	45686	as	w			92.8	66.7	86.4
127	britain	Ilford	Nat Hist Palaeontology	45681	as	w			95.3	66.5	86.9
128	britain	Ilford	Nat Hist Palaeontology	45687	as	w			97.6	67.2	85.3
129	britain	Ilford	Nat Hist Palaeontology	45683	as	w			92.2	62.2	84.1
1589	Britain	Ilford	Nat Hist palaeontology	45682	as	w			92.2		84.6
1590	Britain	Ilford	Nat Hist palaeontology	45688	as	w			91.4	66.5	
1591	Britain	Ilford	Nat Hist palaeontology	45684	as	w			88.3		80.4
								mean	**95.15**	**66.70**	**87.33**

Table II- 2: Individual measurements used to calculate the standard measurements for the calcaneum

ID	Country	Site Name	Location	Museum number	El	Taxon	Fus prox	Fus dist	GL	GD
114	britain	Ilford	Nat Hist Palaeontology	45703	ca	w	f		193	77.9
115	britain	Ilford	Nat Hist Palaeontology	45702	ca	w	f		188	72.1
116	britain	Ilford	Nat Hist Palaeontology	45695	ca	w	f		184	71.3
117	britain	Ilford	Nat Hist Palaeontology	45697	ca	w	f		200	75.3
118	britain	Ilford	Nat Hist Palaeontology	45692	ca	w	f		200	78.7
119	britain	Ilford	Nat Hist Palaeontology	45696	ca	w	f		193	75.6
120	britain	Ilford	Nat Hist Palaeontology	45693	ca	w	f		201	77.8
121	britain	Ilford	Nat Hist Palaeontology	45694	ca	w	f		196	77.6
134	britain	Ilford	Nat Hist Palaeontology	45691	ca	w	f		197	76.2
								mean	**194.67**	**75.83**

Table II-3: Individual measurements used to calculate standard measurements for the femur

ID	Country	Site Name	Location	Museum number	El	Taxon	Fus prox	Fus dist	DC
143	britain	Ilford	Nat Hist Palaeontology	45654	fe	w	f	f	68.9
144	britain	Ilford	Nat Hist Palaeontology	45653	fe	w	f	f	67.8
145	britain	Ilford	Nat Hist Palaeontology	45656	fe	w	f	f	67
146	britain	Ilford	Nat Hist Palaeontology	45655	fe	w	f	f	63.9
161	britain	Ilford	Nat Hist Palaeontology	45652	fe	w	f	f	67.2
1587	Britain	Ilford	Nat Hist palaeontology		fe	w		f	
1588	Britain	Ilford	Nat Hist palaeontology		fe	w		f	
1601	Britain	Ilford	Nat Hist palaeontology	45663	fe	w		f	
1602	Britain	Ilford	Nat Hist palaeontology	20799	fe	w		f	
1603	Britain	Ilford	Nat Hist palaeontology	45660	fe	w		f	
1604	Britain	Ilford	Nat Hist palaeontology	45657	fe	w		f	
91	britain	Ilford	Nat Hist Palaeontology	45658	othfe	w	f		63.7
105	britain	Ilford	Nat Hist Palaeontology	45665	othfe	w	f		70.2
106	britain	Ilford	Nat Hist Palaeontology	45606	othfe	w	f		70.2
107	britain	Ilford	Nat Hist Palaeontology	45667	othfe	w	f		67
138	britain	Ilford	Nat Hist Palaeontology	45664	othfe	w	f		69.8
								mean	**67.6**

Table II-4: Individual measurements used to calculate the standard measurements for the humerus

ID	Country	Site Name	Location	Museum number	El	Taxon	Fus prox	Fus dist	BT	HTC
96	britain	Ilford	Nat Hist Palaeontology	45568	hu	w		f	109.6	50.5
137	britain	Ilford	Nat Hist Palaeontology	45561	hu	w	f	f	118.4	52.9
147	britain	Ilford	Nat Hist Palaeontology	45563	hu	w	f	f	114.5	47.4
149	britain	Ilford	Nat Hist Palaeontology	45394	hu	w		f	114.6	55.4
158	britain	Ilford	Nat Hist Palaeontology	45569	hu	w		f	114.4	49.5
159	britain	Ilford	Nat Hist Palaeontology	45567	hu	w		f	113.3	48.6
170	britain	Ilford	Nat Hist Palaeontology	45564	hu	w	f	f	117.4	48.1
171	britain	Ilford	Nat Hist Palaeontology	45565	hu	w		h	116.0	52.9
172	britain	Ilford	Nat Hist Palaeontology	45562	hu	w	f	f	117.1	
174	britain	Ilford	Nat Hist Palaeontology	48049	hu	w	f	f	117.3	49.9
179	britain	Ilford	Nat Hist Palaeontology	20804	hu	w	f	f		
180	britain	Ilford	Nat Hist Palaeontology	45570	hu	w		f		49.0
								mean	**115.3**	**50.4**

Table II-5: Individual measurements used to calculate the standard measurements for metacarpals

ID	Country	Site Name	Location	Museum number	El	Taxon	Fus prox	Fus dist	GL	SD	BFd	BatF	6	1
108	britain	Ilford	Nat Hist Palaeontology	35008	mc1	w	f	f	268.0	56.6	92.8	85.8	42.5	35.8
109	britain	Ilford	Nat Hist Palaeontology	45597	mc1	w	f	f	248.0	55.5		85.6		37.3
110	britain	Ilford	Nat Hist Palaeontology	45599	mc1	w	f	f		54.5		86.1		
111	britain	Ilford	Nat Hist Palaeontology	45602	mc1	w	f	f		51.7		80.2		
124	britain	Ilford	Nat Hist Palaeontology	45596	mc1	w	f	f	257.0	55.7	95.3	85.7	44.9	38.4
132	britain	Ilford	Nat Hist Palaeontology	45600	mc1	w	f	f	253.0	53.4	86.4	80.2	41.8	35.3
136	britain	Ilford	Nat Hist Palaeontology	45595	mc1	w	f	f	269.0	57.5	94.3	88.6	45.5	38.0
163	britain	Ilford	Nat Hist Palaeontology	20805	mc1	w	f	f	251.0	56.0		81.9		38.2
164	britain	Ilford	Nat Hist Palaeontology	45598	mc1	w	f	f	256.0				43.8	37.4
165	britain	Ilford	Nat Hist Palaeontology	45601	mc1	w	f	f		56.3	95.0	81.1	48.6	39.6
								mean	**257.43**	**55.24**	**92.76**	**83.91**	**44.52**	**37.50**

Table II-6: Individual measurements used to calculate the standard measurements for metatarsals

ID	Country	Site Name	Location	Museum number	El	Taxon	Fus prox	Fus dist	GL	SD	BFd	BatF	6	1
92	britain	Ilford	Nat Hist Palaeontology	45716	mt1	w	f	f	292.0	46.6	87.3	79.7	42.4	36.1
102	britain	Ilford	Nat Hist Palaeontology	45708	mt1	w	f	f	302.0	46.3	83.3	79.1	42.2	35.3
104	britain	Ilford	Nat Hist Palaeontology	45718	mt1	w	f	f	299.0	46.0	82.6	76.9	42.4	
122	britain	Ilford	Nat Hist Palaeontology	45719	mt1	w	f	f	296.0	46.4	78.3	77.5	39.7	33.6
130	britain	Ilford	Nat Hist Palaeontology	45718	mt1	w	f	f	300.0	47.1	84.5	78.1	42.4	34.9
131	britain	Ilford	Nat Hist Palaeontology	45714	mt1	w	f	f		47.2	79.8	73.0	40.6	35.5
133	britain	Ilford	Nat Hist Palaeontology	45713	mt1	w	f	f	308.0	49.5	85.9	83.1	44.4	37.1
1592	Britain	Ilford	Nat Hist palaeontology	45720	mt1	w	f	f	293.0	46.1	81.0	74.8		
1593	Britain	Ilford	Nat Hist palaeontology	45709	mt1	w	f	f	287.0	43.4	80.5	74.7	41.6	34.5
1594	Britain	Ilford	Nat Hist palaeontology	45717	mt1	w	f	f	288.0	50.2	82.9	84.2	41.4	35.7
1595	Britain	Ilford	Nat Hist palaeontology	45716a	mt2	w	f	f		48.4				
1596	Britain	Ilford	Nat Hist palaeontology	45722	mt1	w		f			82.4	73.8	40.8	34.2
								mean	**296.11**	**47.02**	**82.59**	**77.72**	**41.79**	**35.21**

Table II-7: Individual measurements used to calculate the standard measurements for the tibia

ID	Country	Site Name	Location	Museum number	El	Taxon	Fus prox	Fus dist	GL	Bd	Dd
98	britain	Ilford	Nat Hist Palaeontology	45678	ti	w		f		88.6	
99	britain	Ilford	Nat Hist Palaeontology	45677	ti	w		f		89.6	71.8
100	britain	Ilford	Nat Hist Palaeontology	45679	ti	w		f		88.6	69.9
101	britain	Ilford	Nat Hist Palaeontology	45676	ti	w		f		89.8	
112	britain	Ilford	Nat Hist Palaeontology	45814	ti	w	f	f	460		58.4
135	britain	Ilford	Nat Hist Palaeontology	45674	ti	w	f	f	481		
148	britain	Ilford	Nat Hist Palaeontology	45680	ti	w	f	f	470		
150	britain	Ilford	Nat Hist Palaeontology	45675	ti	w	f	f	473		
151	britain	Ilford	Nat Hist Palaeontology	45673	ti	w	f	f		95.7	76.6
152	britain	Ilford	Nat Hist Palaeontology	45671	ti	w	f	f	501	92.2	69.9
153	britain	Ilford	Nat Hist Palaeontology	45672	ti	w	f	f	481	96.7	68.8
								mean	**477.67**	**91.60**	**69.23**

Table II-8: Individual measurements used to calculate the standard measurements for the third molar

ID	Country	Site Name	Location	Museum Num	X/N	J/L	Taxon	M3	M3L	M3W
36	britain	Ilford	Nat Hist palaeontology		n	l		j	46	21.7
37	britain	Ilford	Nat Hist palaeontology		n	l		j	49	20.1
38	britain	Ilford	Nat Hist palaeontology		n	l		c	47	18.2
39	britain	Ilford	Nat Hist palaeontology		n	j		e		
43	britain	Ilford	Nat Hist palaeontology		n	l		g	45	21.6
255	Britain	Ilford	Nat Hist palaeontology	22035	n	l		k	51	21
256	Britain	Ilford	Nat Hist palaeontology	22035	n	l		k	48	20.2
257	Britain	Ilford	Nat Hist palaeontology	22035	n	l		k	48	19.5
258	Britain	Ilford	Nat Hist palaeontology	45500	n	l		j	48	
260	Britain	Ilford	Nat Hist palaeontology	45468	n	j	w	l	53	19.6
261	Britain	Ilford	Nat Hist palaeontology	45463	n	j	w	k		20.4
263	Britain	Ilford	Nat Hist palaeontology	45465	n	j	w	k	50	20.4
264	Britain	Ilford	Nat Hist palaeontology	45473	n	j	w	m		24
265	Britain	Ilford	Nat Hist palaeontology	45472	n	j	w	k	50	19.5
268	Britain	Ilford	Nat Hist palaeontology	45466	n	j	w	m	50	23.7
274	Britain	Ilford	Nat Hist palaeontology	45476	n	j	w	k		23.1
								mean	49	20.9

Appendix III – Raw Biometrical Data

A database containing the raw biometrical and ageing data collected for this project can be found on the accompanying CD-ROM. This contains separate tables for bones, teeth and crania recorded by the author, and a separate table containing data collected from the literature. Separate databases of unpublished data, such as that from Durrington Walls and Eton Rowing Lake, have not been included.