CHAPTER 2:

PAST USES OF BIOMETRY IN ARCHAEOLOGY

'Biometry is a complex but useful subject that has been reduced to a bland and merely descriptive exercise in too many archaeological works of the last two or three decades' (Albarella 2002: 61)

2.1 INTRODUCTION

Archaeozoologists have been measuring bones for many years with a variety of aims, which have ranged from determining what a particular group of animals may have looked like in comparison to the animals we know today, to investigating the timing and nature of domestication of a particular species. This chapter will attempt to summarize some of the main issues that have been covered by biometric studies in archaeozoology over the years, and hopefully illustrate that since the quote from Albarella (2002) above, the application of biometry has been made with evermore interesting results. The chapter has been divided into three main sections covering genetic issues (such as the problem of domestication or the distinction of closely related species), economic issues that relate to matters of animal husbandry or hunting practices, and finally environmental issues and how biometry has been used to examine (for example) changes in landscape or climate. As will be seen from the following review, there is a great deal of overlap between these three areas of interest and often distinguishing the effects of genetics from, say, those of environment is very difficult indeed, highlighting the complex nature of bone growth, animal size and archaeozoological biometry.

2.2 GENETIC ISSUES

One of the key uses of biometry in archaeology has been the use of measurements and the indices calculated from these to aid distinction of closely related species that may otherwise be indistinguishable from one another on the basis of overall morphology. A particular and ongoing problem has been the distinction of sheep and goat bones at sites where both species are likely to occur. One potential solution or at least helping hand in this was offered by Payne (1969). He took two measurements of the distal metacarpals, the width of the condyle and the width of the trochlea. When these were presented as a scatterplot, two groups would be formed if both sheep and goats were present due to goats having relatively wider condyles than sheep. Payne did however point out that this method was only a useful indicator where groups of bones were present and certainly could not be used to identify single specimens; it was also noted that where possible other supporting evidence should be sought (*ibid*.). A similar method was put forward by Boessneck (1969).

Further work on sheep and goat metapodials was undertaken by Rowley-Conwy (1998) which confirmed the usefulness of Payne's (1969) and Boessneck's (1969) methods, applying them to both the metacarpals and the metatarsals; however, Rowley-Conwy (1998) noted that the metacarpals provided better separation of the two species. Rowley-Conwy also introduced the use of breadth and depth measurements of the proximal metatarsal to support morphological methods of separation (*ibid*.).

Small mammals are also often difficult to tell apart, particularly if only post-cranial elements are present. Graham and Saunders (1978) used a variety of measurements of the femora and humeri to examine differences between a variety of small mammal species including *Apodemus sylvaticus* (wood mouse) and *Microtus agrestis* (field vole). Employing discriminant analysis, they were able to examine several dimensions at once and found an 80-100 percent success rate in identifying modern specimens of known taxa. They then applied this discriminant analysis to archaeological specimens from Bacon Hole cave site and tentatively identified some species and sub-species that had not previously been identified from the site using the teeth.

Staying with the rodent theme, Armitage *et al*. (1984) managed to successfully determine the presence of black rat (*Rattus rattus*) in Roman deposits from Fenchurch Street in London. This was achieved through the use of an index of diastema measurements which allowed black rat mandibles to be distinguished from those of the brown rat (*Rattus norvegicus*). This proved significant, as the 3rd century AD date for the well deposits in which the rat bones were found was an earlier date than had previously been attributed to the introduction of the black rat into Britain (*ibid*.).

Biometry was also employed in assisting in the re-identification of bird bones from Fishbourne Roman palace (Allen 2009). Here, some bones had previously been identified as great bustard (*Otis tarda*), but in more recent work they were re-identified as bones of the common crane (*Grus grus*). Had whole bones been present,

their identification may have been made easier as the bones of the latter species are considerably longer, however no complete bones were available. While measurements of humerus breadths for the two species do greatly overlap, the measurements of the archaeological specimens came out at the top of the range for the crane and above that for the great bustard, aiding in the re-identification of the bones.

Another taxonomic group where biometry is a useful tool in determining between species is the canids. The ability to distinguish between dogs and wolves is extremely important in terms of studying the domestication of the dog and telling the two species apart when they may both be present on an archaeological site. Benecke (1987) used measurements from known domestic dogs and wolves, including some that had been raised in zoos, and used cranial and mandible measurements to distinguish them via discriminant function analysis. Following this, canid remains from a variety of early northern European sites were examined using the same discriminant analysis. The results showed that many of the archaeological specimens came out nearest to the zoo wolves and so were interpreted as being wolves that possibly represented the very earliest stages of domestication (*ibid*.).

Due to the fact that domestic mammals are considerably smaller than their wild counterparts, biometry has been widely used, as above, in order to determine the timing and nature of domestication. The use of size reduction in mammals as a tool for pinpointing the timing of the beginning of domestication has recently been brought into question (see discussion in Section 3.3.2); however, it has been used

many times as an identifier of the presence of domestic species, most often in more modern studies in conjunction with other forms of evidence.

Uerpmann (1978) recognised that an overall change in the size of sheep in the Middle East would not be a reliable marker of the presence of domesticated sheep, as other environmental factors could cause a reduction in bone size. However he argued that in areas where domestication was taking place there would be split in the size of the sheep population, with the wild element staying the same size and the domesticated part becoming changed (reduced) in size resulting in greater size variability overall (*ibid*.). Changes in size variability such as those described above were identified at the Çayönü Jarmo, Pre-pottery Neolithic B site dating to 7500-6500 BC. Uerpmann did recognise that these changes may not be the start of animal domestication but asserted that they showed some form of change in the relationship between man and sheep (*ibid*.).

More recent studies have taken a far more multidisciplinary approach to the problem with Haber and Dayan (2004) recognising that domestication was a gradual process and not something that happened, metaphorically speaking, overnight. At the site of Hagoshrim they noted changes in both the size and proportions of pigs and a gradual change in size of cattle in association with changes in kill off patterns for both species; caprines which had already been domesticated by the beginning of the time period being studied at the site did not show any significant changes over time (*ibid*.).

A similar approach was taken by Arbuckle (2008) at the Neolithic site of Suberde in Turkey. Previous studies of the site had interpreted it as a hunting village, but Arbuckle closely examined both the biometrical evidence and the age data, which showed a slight size diminution in caprines and an age profile that suggested the selection of animals at particular ages for slaughter (*ibid*.). Arbuckle acknowledged that the kill off pattern was not one indicating a 'typical' management strategy, i.e. where there is a high incidence of kill off of young males, but he interprets this as an 'experimental' management system practised by an early sedentary human population where perhaps full domestication had not been achieved. Although these interpretations may seem tenuous in light of Zeder's (2008) assertion that size diminution comes at a late stage in the domestication process, the work of Hongo *et al*. (2009) would appear to support Arbuckle's (2008) interpretation.

Hongo *et al.* (2009) also took an integrated approach, looking at size change, kill off patterns and stable isotope data, at another site in Turkey. From this they found evidence for a two stage process of domestication, the first of which was very similar to that identified by Arbuckle (2008) above: an appearance of some smaller individuals accompanied by a slight change in the kill off pattern and the beginning of a steady change in carbon and nitrogen isotope values in *Bos*. As a check to ensure that these changes were not simply brought about by environmental fluctuations, data for red deer, also present at the site, were examined and showed none of the changes observed in cattle or the other 'pro-domestic' taxa (sheep, goat and pig) (Hongo *et al*. 2009). The second stage of the domestication process was seen as a much more marked reduction in body size and a change in demography to show a

much greater proportion of females (*ibid*.). However it should be noted that the increase in females was also identified through biometry, and as the data was not presented it is difficult to say if there really was an overall size reduction and an increase in females present or if there was only an apparent size reduction due to a greater exploitation of females. While the distinction is important, it may not change the interpretation of this being a stage in the domestication process: after all Zeder (2008) noted that any apparent size reduction seen at the very early stages of domestication was likely to be due to a shift to a greater exploitation of adult females over adult males.

The last two papers discussed have both noted 'slight' size changes in the bones examined and interpreted these as an early stage in the domestication process. This approach, where applied to cattle and pigs in Germany and Portugal has attracted criticism (Rowley-Conwy 1995). Rowley-Conwy argues that in some cases where individual small bones have been claimed to be from early domestic animals this need not be the case (*ibid*.). In a number of cases, bones that have fallen below the known size range for wild specimens have been called domesticated or 'transitional' animals whereas, as Rowley-Conwy points out, the full size range for a wild species in a particular area may not, and in fact is likely not known (*ibid*.). In addition, many domesticates and their wild counterparts often have considerable overlap in their size ranges. For instance, female aurochsen (*Bos antiqus*) have a very similar size range to domesticated male cattle (*Bos taurus*) and therefore distinguishing one from the other on the basis of the size of a single bone is unrealistic (*ibid*.). Based on this argument, Rowley-Conwy (1995) determined that several specimens from northern

Germany and Portugal, previously claimed to be early domestic specimens, were in fact probably just wild specimens from the small end of the size range.

Biometrics have also been used to determine the 'types' or breeds of animals present at archaeological sites. For example Noddle (1974) examined a variety of sheep bone measurements from the site of Dun Mor Vaul on Tiree and determined that the sheep were of a primitive, northern, short-tailed type that is still present in Scotland today in the form of the Soay and the Orkney (North Ronaldsay). She makes a similar comment about the sheep from Skara Brae, which she interpreted as a Northern Isles race of sheep and which apparently had a different appearance to the sheep from elsewhere in Britain (Noddle 1978). Although it is quite possible that a difference in stature could have been induced in the Skara Brae sheep by their marginal location, it does appear that at least some of the difference was due to genetic variation: they not only differed in stature but also in the position of their nutrient foramen on the femur (*ibid*.).

Finlay (1984) also used metrical analysis to look at the 'types' of sheep present from a variety of sites in the Western Isles (incidentally much of this data is included in the present study). At the site of the Udal, Finlay suggested that the measurements indicated a small slender animal that did not change significantly in its proportions throughout the prehistoric period (*ibid*.) (but see Section 6.4.1). For Northton, she noted that the sheep were 'generally of the same type as those from Udal and other sites' (*ibid*.: 53) and at the site of Sollas she also notes a similar slender limbed sheep

that 'compares closely with the bones of the 'primitive' Mouflon type surviving today in the Shetland breed' (*ibid.*, 61).

In York, O'Connor (1988) examined cattle horncore morphology through the use of basal diameter and horn length. From this it was determined that there was the likely presence of some 'Celtic Shorthorn' cattle in the Roman period. He also explored dimensions of the metapodials and determined that a larger type of cattle was also present alongside the native cattle (*ibid.*). A similar situation was also indicated for sheep with the presence of a mix of small, 'native' animals and larger, possibly introduced animals (*ibid.*).

Work carried out on medieval deposits from York (Bond & O'Connor 1999) noted changes in cattle horncores between the Anglo-Scandinavian and later medieval deposits and thought that this was likely due to an overall size change over time. However, when post-cranial elements were examined these did not show any significant differences between the two periods - indicating that a change had occurred that affected the horncores but not overall body size and shape. Possible interpretations were a genetic drift or change in the supply source of cattle into the city (*ibid.*).

Examination of goat horncores from two medieval sites in York, Aldwark and Skeldergate, also by Bond and O'Connor (1999) showed that although for both sites bimodal distributions of horncore measurements were present, indicating the presence of males and females, those from Aldwark were notably bigger, particularly

the males. It was suggested that the horncores from the two sites came from phenotypically different populations of goats. It was also of interest that the Aldwark site was interpreted as a horn working area and hence the larger horncores found there were likely to provide more attractive material to a horn worker than the smaller horncores found at Skeldergate (*ibid*.).

O'Connor's (1988) work, mentioned above, discusses the likelihood of Roman introductions of cattle into York and, not surprisingly, other likely Roman livestock introductions have been identified through the use of biometrical methods at a variety of other sites around England. Albarella (2007) noted that one aspect of the transition in animal husbandry that took place at the end of the Iron Age and the beginning of the Roman period was an increase in mean cattle size associated with an increase in size variation; indicating the presence of small Iron Age type cattle with the addition of a number of larger cattle. It is also noted that this increase in size is a very sudden one and is therefore thought likely to be due to new types of cattle being introduced from the Continent (*ibid*.).

Albarella *et al*. (2008) also noted this trait at the site of Elms Farm and showed that size increases were present in teeth (lower 3rd molar), astragali and metatarsals. Examination of horncore data demonstrated that males and females were present in both the Late Iron Age and Early Roman periods and no significant size change was seen after this initial one until the 5th century (*ibid*.). As the teeth changed in size, not just the bones, it was thought most likely that the size increase was due to the introduction of new stock or possibly the evolution of a different genotype.

Interestingly, size change in cattle from Colchester showed a much slower increase, taking place over several centuries. This was thought to be the result of this large urban centre being supplied from a variety of different areas, providing animals of differing levels of improvement (*ibid*.).

Size changes were also seen later on in Britain. Dobney *et al*. (no date) noted size increases in cattle and sheep from Lincoln, particularly in the later Post Medieval period, thought to be due to the introduction of new stock and also some local improvements. There also seems to be evidence for a considerable degree of genetic variability, which as inferred above is to be expected in an urban centre being supplied from a variety of sources (*ibid*.). Albarella (1997a) also found evidence for Post Medieval cattle imports at the site of Launceston Castle through the examination of cattle metapodial size and shape.

Although the detection of the import of animals into a site through the use of biometry is essentially the identification of genetic variations within a sampled population, it is clear that such an introduction of new animals would have economic ramifications. The following section looks at further issues of economy and animal husbandry.

2.3 ECONOMIC ISSUES

One of the key topics of study when examining archaeozoological assemblages is the determination of sex, and as animals such as sheep and cattle display reasonable levels of sexual size dimorphism, biometrical data can be used to elucidate such

issues. The determination of sex ratios present in a population is important as it can inform on the economic practices being carried out (e.g. Payne 1973). Some examples of the application of biometry to the determination of sex ratios are given below.

O'Connor (1991) examined cattle astragalus measurements from a variety of time periods at the site of Fishergate in York. He observed that there was little change in the size and distribution of these measurements over the majority of the phases being examined; however, one time period showed a positive skew in the dataset indicating a greater number of smaller animals. O'Connor took this to signify that a higher number of females were present in this phase than the others (*ibid*.). The interpretation of such a shift is however difficult in an urban situation, where animals are likely to have been provided from a variety of sources and for a variety of reasons.

At the sites of Skeldergate and Walmgate, also in York, O'Connor (1984) examined two samples of metacarpals, looking at both length and breadth measurements. Very little difference was seen between the two samples when breadth measurements were examined, however, a significant difference was found between the mean length measurements of the two samples. This was interpreted as a greater number of castrates being present in the group with the larger mean length.

At the Anglo-Saxon site of Flixborough, Dobney *et al*. (2007) also examined measurements of metapodials and found specific groupings to be present. One was a

group of animals of small stature that varied greatly in length but much less so in breadth, and the other a group of larger individuals which varied much more, with a wider range of breadth values present. Evidence was also seen for bimodality in tibia breadth measurements, although for one of the phases (4-5b) this bimodality was much less distinct due to the presence of a greater number of intermediate measurements. The groupings of metacarpal plots for this phase also show a great deal more 'blurring' than for the other phases and this pattern is interpreted as a great deal more oxen (castrated males) being present in this phase than the others examined (*ibid*.). It is also noted that this phase contains a high proportion of elderly cattle, a greater number in fact than any other age group. These data are interpreted as the presence of oxen as draught animals: a valuable commodity in Anglo-Saxon England (*ibid*.: 156).

Examination of sex ratios, while extremely important in the interpretation of farming economies can also shed light on hunting strategies. Morrison and Whitridge (1997) used data from modern, known age and sex caribou (*Rangifer tarandus groenlandicus*) to develop a discriminant analysis to determine sex from mandibular measurements; they were also able to determine age from tooth crown height. They applied this discriminant analysis to an archaeological data set from a series of Arctic Inuit sites of varying dates, and were able to show that little selection in terms of age and sex was made during hunting. This is until the introduction of firearms into the area c. 1870 at which point there was evidence for the targeting of larger, prime age animals (*ibid*.).

Weinstock (2000) also used bone measurement data to examine hunting strategies. He used a variety of different bone measurements to look at sex ratios from a reindeer (*Rangifer tarandus*) hunting site in northern Germany and noticed that different bones gave different sex ratios: those from later fusing bones showing progressively higher proportions of females in the sample (*ibid*.). Upon inspection it was found that this demographic profile (the older end of the age spectrum being dominated by females) reflected that of the natural population. This tends to be due to males dying at a younger age than females as a result of entering the winter months with lower fat reserves following virtual starvation during the rut. Weinstock concluded that, as the death assemblage reflected the age and sex structure of the natural population, it had accumulated as the result of a catastrophic mass hunting event (*ibid*.).

One of the other key applications of biometrics to archaeozoology is that of estimating the quantity of meat that may be available from an animal and hence determining the economic input that it may have into a society. Noddle (1973) addressed this question by looking at the relationship between a number of bone measurements and the fat-free carcass weights of a variety of modern cattle breeds in order to assess which measurements gave the closest correlation between the dimension measured and the carcass weight. Reasonable correlations were found between the area of the proximal surface of the metatarsal and fat-free carcass weight, and a multiple of the mid-shaft width and depth of the metatarsal and fat-free carcass weight (*ibid*.). The closest correlation found however was between a multiple of the medial and lateral lengths, and distal breadth of the astragalus and

this multiple divided by carcass weight: thus there is an indirect relationship between the weight of the astragalus and the animal (*ibid*.). Noddle then used these relationships between bone dimensions and fat-free carcass weight to extrapolate to live body weight and made a pilot study of bones from a number of archaeological sites around Britain (*ibid*.). One point of note (although Noddle did point out that the work was still in its early stages), was that the archaeological material live weight estimated from the astragalus multiple appeared to be generally larger than those calculated from other bone measurements from the same site (*ibid*.).

Bartosiewicz (1984a) re-analysed Noddle's (1973) data and applied the results to a group of astragali excavated from a pit at a Bronze Age hill fortress in Hungary. Before the application of Noddle's (*ibid*.) data Bartosiewicz (1984a) employed cluster analysis and discriminant analysis in order to distinguish three bone groups within the astragalus data set: these he took to represent males, females and juveniles. Following this he used Noddle's data to reconstruct carcass weights and gave estimates for each of the three groups. Using comparisons with modern Holstein Friesians he determined that the average live weight of the cattle from the pit was likely to have been in the region of 500-550 kg (Bartosiewicz 1984a).

O'Connor (1988) took a more straightforward approach to estimating live body weight of sheep from the General Accident site in York. Using long bone length measurements, he calculated withers heights and then compared these to data from modern Soays to give an estimate of live body weight. The reliability of this method is questionable, as bone length seems less well correlated with carcass weight than

bone breadth (e.g. Pálsson & Vergés 1952a). However if the sheep bones from York could be seen to be of similar proportions to those of modern Soays then this would be a valid comparison.

Bond and O'Connor (1999) took another slightly different approach and used distal radius measurements to determine live body weights through the use of a regression equation derived from a range of modern breeds of varying 'primativeness'. They then combined the live weight data with calculated withers heights and determined that the sheep from medieval Coppergate in York were similar in size and proportions to modern Welsh Mountain sheep; however, it was pointed out that this did not indicate a genetic relationship between the two (*ibid*.).

Biometrics have also been used by a number of researchers to determine differences in husbandry practices over time or between sites. Teichert (1984) used univariate methods to examine differences in cattle size between Germania Romana and Germania Libera. To do this a variety of measurements were taken and their ranges and means plotted. The two regions were then examined in particular in terms of the minimum and maximum values for bone measurements. In general the results showed there to be much more variation in cattle from the Roman sites than on the Germanic ones; bones at the smaller end of the scale were found on sites from both regions, whereas the majority of the larger animals were found on the Roman sites (*ibid*.). Withers heights were also calculated and showed a similar pattern to the raw bone measurements. Teichert (*ibid*.) thought that this size increase may have been

caused either by the buying in of specially bred bulls to breed with the existing stock, or better husbandry and increased food supply at the Roman sites.

Dobney *et al*. (no date) noted a slight increase in the breadth of sheep metacarpals over time in the city of Lincoln, but without a corresponding increase in length. A similar increase was also seen in the breadth of the trochlea in the humerus. This was thought to possibly indicate that some selective breeding for larger animals had taken place, or that possibly new larger stock had been introduced (*ibid*.).

Albarella (1997b) used zooarchaeological data to examine agricultural change in late medieval England in particular at the sites of Launceston Castle, West Cotton and Castle Mall, Norwich. All of the assemblages demonstrated size increases in the animals over time; this was also associated with distinct changes in the kill-off patterns of sheep and cattle (*ibid*.). In combination these two lines of evidence were taken to indicate an economic change at the sites from a focus on the production of resources such as milk and wool towards a greater focus on meat production, with efforts made in improving the conformation of the animals present (*ibid*.).

Davis (2008) examined a variety of measurements of sheep and cattle bones from a number of sites in Portugal and noted that in post Roman times, whilst the country was under Muslim rule, sheep increased significantly in size, particularly in bone breadth measurements. Some of these differences were larger than differences noted between males and females of modern Shetland sheep (Davis 2000) and so were thought to genuinely represent improvement of these animals during Muslim

times. In the following period of Christian rule, sheep size remained static, while cattle size (which had showed no significant change during the Muslim period) increased. These observed size changes were not thought likely due to any climatic change as the two species changed at different times, and changes in sex ratios were also discounted (Davis 2008). The size increases in sheep in Muslim times were attributed to the Muslim love of mutton and the consequent change in sheep exploitation from principally a wool to a meat producer, and it was thought likely that this improvement was brought about at least in part via the import of new stock, possibly from Africa (*ibid*.). The increase in cattle size, in the following Christian period, was thought likely due to the move away from mutton consumption, with a possible greater interest in beef or to the greater use of cattle in traction and hence the need for bigger beasts. Again, it is thought possible that this was achieved by importing animals from elsewhere.

A final example of how husbandry practices may affect bone size comes from a selection of colonial sites in Chesapeake, USA (Arbuckle & Bowen 2004). This work looked at changes in cattle size throughout the colonisation period and identified an initial size increase during the 17th century and then a decrease at the beginning of the 18th century. These size changes were linked to the nature of the somewhat 'relaxed' husbandry practices, where cattle were very much left to fend for themselves, and changing uses of land for arable agriculture (*ibid*.). During the 17th century extensive tobacco farming allowed for large amounts of fallow land and these areas provided the free ranging cattle with a good supply of food, allowing them to increase in size (*ibid*.). In the following century agricultural production

diversified and a wider variety of crops was grown, which led to much more intensive land use with far fewer fallow fields. However, no change was made to the cattle husbandry system and cattle were still left to fend for themselves on the much reduced fallow acreage, consequently becoming much reduced in size (*ibid*.).

Although the size change seen in this last example can be directly attributed to the nature of local cattle husbandry, it is evident that the size change seen in the cattle was due to a change in their environment (the fields they grazed in), in particular the quantity of nutrition available to them. The following section will examine similar situations where a change in environment has brought about a change in body proportions.

2.4 ENVIRONMENTAL ISSUES

Davis (1981) examined a variety of mammal remains from Late Pleistocene and Holocene deposits in Israel and noted that several of the species reduced in size at the end of the Pleistocene. He also noted that modern examples of the same species varied in size in relation to temperature and hence concluded that the size reduction seen at the end of the Pleistocene was related to an increase in temperature (*ibid*.); this interpretation has however been questioned, see Section 3.4.2.

Lister (1995) used bone measurement data in the identification of dwarf red deer (*Cervus elaphus*) on Jersey. Here, single bone measurements were plotted as percentages of a standard and compared across three time periods. The middle of these (Eemian) showed there to be dwarf red deer present on Jersey. The results

showed that bone width measurements of these deer were on average 55.9% smaller than the mean for British Ipswichian deer and the cheek tooth measurements were relatively larger, being only 77.4% smaller than their mainland counterparts. The bones from the proceeding period (Saalian) were found to be within one standard deviation of the measurements of the mainland animals; measurements of antler base circumference showed similar results (*ibid*.). Scatterplots of metapodial lengths versus proximal breadth showed that the shape of the dwarf red deer, as well as size, was different from that of the mainland red deer. It appears that in dwarfing, height decreases more than width and therefore dwarf animals are relatively more robust than their full-sized counterparts (*ibid*.); unfortunately the sample was not big enough to test for statistical significance. Lister (1995) proposed that although initial size reduction was likely due to a reduction in available resources as a result of separation from the mainland by rising sea level, the large (80%) reduction in body size observed must have been partly due to genetic modification (also caused by isolation) and not simply ecophenotypic change, as such a large change in body size is outside the range of the present day ecophenotype. This is explored more fully in Section 3.4.4.

McCormick (2007) noted a similar, although less extreme phenomenon in cattle in Bronze Age Ireland; those from the site of Dún Aonghasa on the Aran Islands were noticeably smaller than those from mainland Ireland. McCormick attributed this to environmental factors, suggesting that the islands were less well suited to cattle rearing than other areas (*ibid*.). It seems likely this was due to the restricted resources that are characteristic of any island setting. A similar pattern was noted for

pigs, whereas for sheep there did not appear to be a difference between the island site and the mainland sites. However the samples for the mainland sites were very small (*ibid*.).

The final case study comes from the Southern Plains of North America where Lewis *et al*. (2010) examined changes in Late Quaternary bison. A variety of metapodial measurements were analysed through principal components analysis to examine the evolution of *Bison bison antiquus* into modern *Bison bison*. A significant reduction in size was found to have occurred in both males and females at some point between 8000 BP and 6500 BP; very little shape change was noted other than a reduction in shaft breadth (*ibid*.). Although the change was almost uniform across the study area, and climatic change may seem the most likely factor in causing such a widely felt effect, examination of temperature changes did not correlate well with the change in bison size: temperature had already begun to increase earlier without any change in bison size and later decreased without a subsequent increase noted in bison size (*ibid*.). One environmental change did however correlate well with the observed reduction in size and that was the change in vegetation - more specifically, the changeover from C_3 grasses to C_4 grasses. The latter of these is less nutritious, having larger cell walls and less protein (*ibid*.), and therefore the reduction in body size appears to have been related to a reduction in available nutrition.

2.5 SUMMARY

As can be seen from the selected case studies above biometry in archaeozoology has a wide variety of applications and is beginning to be employed more and more

frequently for ever more complex problems. Where large datasets are available, complex, multivariate statistical methods can be used, to determine distinctions that may not be otherwise observed through uni- or bi-modal approaches. However where small datasets are available, useful information can still be gained through careful consideration of the data. In order to assist such studies, datasets suitable for use as standards, against which other assemblages may be compared, have been published for some species (e.g. Albarella & Payne 2005; Clutton-Brock *et al*. 1990). What is also clear from the summary above, and must be borne in mind for the rest of this thesis, is interaction between factors affecting bones size and shape and the inherent difficulty in distinguishing between genetic, environmental and economic factors.