

An Experimental Approach to Archaeomorphometrics

With Special Reference to Metapodials
of Artiodactyls in Sri Lanka

Kalangi Rodrigo

Kelum N. Manamendra-Arachchi



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To the cherished memory and unchallenged legacy of Dr. Siran Upendra Deraniyagala

Contents

Acknowledgements	1
Abstract	2
Introduction	3
Global Synthesis	4
The Sri Lankan Synthesis	4
Species Description	8
<i>Cervus unicolor</i> (Artiodactyl: Cervidae)	8
<i>Sus scrofa</i> (Artiodactyl: Suidae) (See Appendix 3)	9
<i>Muntiacus muntjak</i> (Artiodactyl: Cervidae)	10
<i>Axis axis</i> (Artiodactyl: Cervidae)	10
<i>Axis porcinus</i> (Artiodactyl: Cervidae)	11
<i>Moschiola meminna</i> (Artiodactyl: Tragulidae)	11
<i>Bubalus Bubalis</i> (Artiodactyl: Bovidae)	12
Methodology of the study	13
General description of terminology used (see Appendix 2)	14
Description of the metacarpals	17
Description of the metatarsals	18
Results	20
Results of metacarpals	20
Descriptive statistics: BP, DP, BM, BL, BS, GL, BD1, BC, BD2	20
Principal component analysis: BP, DP, BM, BL, BS, GL, BD1, BC, BD2	20
Eigenanalysis of the correlation matrix	20
Eigenvectors	20
Discriminant analysis: species versus BP, DP, BM, BL, BS, GL, BD1, BC, BD2	21
Linear method for response: species	21
Summary of classification	22
Correct Classifications	22
Squared distance between groups	22
Linear discriminant function for groups	23
Summary of misclassified observations	23
Factor analysis: BP, DP, BM, BL, BS, GL, BD1, BC, BD2	24
Unrotated factor loadings and communalities	24
Rotated factor loadings and communalities	24

Item analysis of BP, DP, BM, BL, BS, GL, BD1, BC, BD2	27
Correlation matrix	27
Covariance matrix.....	27
Item and total statistics.....	27
Cronbach's alpha	27
Omitted item statistics	27
Results of metatarsals.....	29
Descriptive statistics: BP, DP, BM, BL, BS, GL, BD1, BC, BD2.....	29
Principal component analysis: BP, DP, BM, BL, BS, GL, BD1, BC, BD2.....	29
Eigen analysis of the correlation matrix	29
Discriminant analysis: species versus BP, DP, BM, BL, BS, GL, BD1, BC, BD2.....	31
Groups.....	31
Squared distance between groups.....	31
Linear discriminant function for groups.....	31
Factor analysis: BP, DP, BM, BL, BS, GL, BD1, BC, BD2	32
Unrotated factor loadings and communalities	32
Rotated factor loadings and communalities.....	33
Quartimax rotation	33
Factor score coefficients	33
Item analysis of BP, DP, BM, BL, BS, GL, BD1, BC, BD2	35
Correlation matrix	35
Covariance matrix.....	35
Item and total statistics.....	35
Cronbach's alpha	35
Omitted item statistics	36
Interpretation of the Results.....	37
Appendix 1: Primary data set of bone measurements.....	41
Metacarpals	41
Metatarsals	42
Appendix 2: Bone terminology	44
Appendix 3: Summary report for BP, DP, BM, BL, BS, GL, BD1, BC, BD2	50
Appendix 4: Exclusion of <i>Sus scrofa</i>	55
References	57

List of Figures

Figure 1: Bone measurement criterion – carpal view (Bovidae metacarpal, right)	15
Figure 2: Bone measurement criterion – anterior view (Bovidae metacarpal, right).....	15
Figure 3: Bone measurement criterion – lateral and tarsal view (Bovidae metacarpal, right)	16
Figure 4 Metacarpal proximal morphology	17
Figure 5 The medial epicondyle is circle-sector shaped and larger, and the lateral epicondyle is smaller and triangular	17
Figure 6 Capral view of metatarsal (L).....	19
Figure 7: Score plot for metacarpals	21
Figure 8: 3D scatterplot of BP vs DP vs GL for metacarpals.....	21
Figure 9: Score plot for factor analysis (quartimax rotation).....	26
Figure 10: Score plot for factor analysis (equimax rotation)	26
Figure 11: Matrix plot for metacarpal measurements	28
Figure 12: Score plot for metatarsals	30
Figure 13: 3D Scatterplot of BD vs DP vs GL for metatarsals	30
Figure 14: Score plot for factor analysis (quartimax rotation).....	34
Figure 15: Score plot for factor analysis (equimax rotation)	34
Figure 16: Matrix plot for metatarsal measurements	36
Figure 17: Scatterplot of metacarpal GL vs metatarsal GL in tenths of millimetre taken along same axis.....	39
Figure 18: Scatterplot of metacarpal BD1 vs metacarpal GL in tenths of millimetre taken along same axis.....	39
Figure 19: Scatterplot of MC BD1 vs MT BD1	40
Figure 20: Cervus unicolor metacarpal - anterior view (L)	44
Figure 21: Cervus unicolor metacarpal - posterior view (L).....	45
Figure 23: Cervus unicolor metatarsal - tarsal view (L)	47
Figure 24: Cervus unicolor metatarsal - posterior view (L).....	48
Figure 25: Cervus unicolor metatarsal - anterior view (L)	49
Figure 26: Articulation of metapodials: Cervidae vs Suidae (K. Manamendra-Arachchi del).....	55
Figure 27: Human third and fourth left metacarpals (anterior views) are compared to adult pig left third and fourth metacarpals (dorsal views).....	55
Figure 28: Human third and fourth left metatarsals (superior views) are compared to adult pig left third and fourth metatarsals (dorsal views)	56

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Abstract

Taxonomic identification is a primary objective of zooarchaeology and has traditionally been facilitated by specimen morphology. As the discipline evolved newer methods, such as DNA analysis and geometric morphometrics, have become a part of the zooarchaeological toolkit. Therefore, morphometrics holds tremendous potential to fundamentally change how zooarchaeologists conduct analysis and the questions they ask. This publication presents the first attempt of the use of principal component analysis to interpret morphological differences between taxa. Despite being morphologically identified for over two decades, bones have never been examined by statistical approach. In a Sri Lankan context, using morphometrics to differentiate taxa on both prehistoric and historic sites has not been pursued with the vigour that it deserves. This research is a preliminary attempt at addressing this complex issue. The volume presents a new analytical method that aims to broaden our knowledge of the application of statistical and quantitative methods in archaeology. In addition, methods for inter-species comparison will be developed in order to determine whether morphological and morphometric characteristics varied among temporally synchronous but ecologically disparate groups. The results are promising, yielding a better comprehension of statistics and bone assemblages. How much dimensions of different bones and parts of bones vary, how they are related to each other and also how they might reflect the condition of the animal in life are key questions addressed by the research. An understanding of the relations between different measurements taken on animal bones can serve as an aid in deciding which are useful and which produce merely redundant information. Overall the work presents an in-depth analysis of morphological and dimensional features to classify the genera of hoofed animals and to create a solid base for the inclusion of metapodial characteristics in future phylogenetic analysis, which is highly informative in relation to zooarchaeological analysis.

Introduction

Faunal remains, recovered from systematic archaeological excavations, comprise much of the archaeological assemblage. These are found in various quantities and qualities that depend on the type of site and preservation status. Faunal remains provide evidence in reconstructing the human past, chronology, and climate change in paleoenvironments. Also, faunal remains provide a unique insight into the behavior and cultural adaptations of past societies. Archaeologists must provide the most accurate information possible, and it is, therefore, important to consider the methods for investigating, analysing, and interpreting faunal remains from archaeological assemblages. The foremost purpose of this book is to highlight and investigate different methods of faunal analysis and how to interpret faunal assemblages with statistics. It is aimed at archaeologists with little or no experience of statistical approaches for dealing with large datasets of faunal assemblages and will hopefully provide some insight into the importance of quantitative analytical methods and what information may be derived from the assemblage. It should be stressed that the case study covers the metapodials of artiodactyls only.

Animals formed an important part of people's lives in the past and the bones from archaeological sites may provide information on not only diet but also on care, hygiene, climate, status, seasonal occupation, hunting methods, butchery methods, industries, trade, and even religion. A wide variety of species may be recovered from sites such as fish, amphibians, reptiles, birds, and mammals. Through identification of morphological features (shape), it is possible to identify the skeletal elements and to what species they belong. Some bones may allow the identification of the sex of the species, either through measurements or through sexually dimorphic features such as the canine teeth of pigs and the presence of spurs on the tarso-metatarsus of birds, to provide a couple of examples. Ageing mammals is best done through dental wear and eruption as well as bone development and growth (i.e. stages of bone fusion). Other species, such as fish, grow throughout life and their bones do not fuse; however, these may be aged by other means such as incremental growth. Discerning patterns of seasonality may be possible from certain species such as fish, where the otoliths (ear bones) are excellent indicators of seasonal patterns. The shedding of antlers is likewise an indication of season as this happens in a yearly cycle.

It may be possible to extract additional information from animal bones. For example, butchery methods can be assessed from chop and cut marks on the bones as well as evidence of scavenging (Binford 1981). On most archaeological sites, the information extracted may at least provide a ratio of the different species present and which parts of the animals are present. This may help identify the type of site; by identifying the different elements present it may be possible to establish whether the site was used primarily for butchery or whether the butchered remains were deposited there after cooking and consumption of meat.

Indeed, investigating external morphological characters of animal bones is a credible advancement of taxonomic identifications in zooarchaeology. In recent advances in zooarchaeology and related fields, osteometrics can be a potential source for gathering information in an anthropological and archaeological context. In that sense, osteometrics could be further describe as 'the study and measurement of animal or human skeletons'. This is an innovative way of examining human and animal bones through a statistical approach. The examination of osteometrics is routinely carried out by either bioarchaeologists or physical anthropologists to retrieve information such as the biological profile, pathological conditions, anthropometrical purposes, and cause of death. The ultimate goal of this pilot spectroscopic study is to access sets of measurements retrieved from particular sets of bones to determine whether dynamics are predictable and quantifiable. In this case, a relationship between

the measurements and ecological correlations may be established, allowing us to reliably profile faunal remains. The ability to accurately estimate changes in species and ecological settings through bones will have an immediate and invaluable impact on zooarchaeological studies.

Global Synthesis

Although previous studies have attempted to address this issue, this is the first time that an experimental approach based on the uniquely defined set of measurement criteria have involved and it is to the best of the authors' knowledge, the first osteometric analysis from Sri Lanka synthesis. In the light of Processual Archaeology in the 1960s, Joachim Boessneck and Angela von den Driesch (1978) compiled an extensive literature of the effective use of metric data in zooarchaeological contexts. With the aid of several examples and a solid set of measurement standards they showed how biometry can help in addressing important questions regarding species identification, ecological correlations, and social and cultural history. The first major study was done by Albarella (2002), where he emphasizes the importance of biometry in zooarchaeology which will be discussed later in greater detail.

The scaling of animal bone measurements has been addressed by Meadow (1999) and results were defined as 'size index scaling techniques'. The pros and cons and relative variation of these methods have recently been discussed by the same author, who has demonstrated that all these approaches have some validity and that they provide only marginally different results. Meadow (1984) combined different measurements in the same scale to prove size diminution in cattle, sheep, and goat in the Neolithic at Merhgarh, and also that the size of cattle and goat remained stable after that period, whereas sheep size continued to decrease. Using the same approach Grison (1989) identified sex grouping in cattle measurements at Jericho and other sites at Levant. More recently Vigne and colleagues (2000) have proved that pigs from a particular time in Cyprus were significantly smaller than their wild relatives, surely the result of domestication processes. That the Middle East has tended to be the focus of biometric research could result from the fact that this was where domestication was initiated (Albarella 2002).

In Britain, work by Albarella and Davis (1996) and Albarella *et al.* (1997) has shown an enthusiasm towards the use of biometrical studies in zooarchaeological contexts. They have concluded that the size ratio between bones and teeth is thereby a useful index to assess the level of improvement of a pig breed. A similar approach has been adapted by Albarella (1999) for the analysis of sheep measurements from two localities. Outside Britain, a French scholar, Vigne (1999), has showed that size diminution consequent to domestication is a complex process and that the sophistication of biometric analysis can offer important insights into this phenomenon. Moving on to North America, many of the biometrical studies have been carried out in post-Columbian sites. Reitz and Ruff (1994) demonstrated the size of cattle from eastern coast of North America.

The Sri Lankan Synthesis

In Sri Lanka, which is the focus of this study, the situation is different. From the outset, taxonomic identification and major objectives of zooarchaeology have been facilitated by inspecting external morphological characters. However, the analysis of external morphological characters of faunal remains carries a significant degree of uncertainty and does not lead to reliable inferences. Therefore, final interpretation could be interrupted. Due to the opportunities offered nowadays by the sophistication of computer analysis and a better understanding of factors affecting measurement variability, biometry and osteometry can in fact be seen as one of the most 'modern' and effective tools for zooarchaeologists. This research is an initial attempt to address this complex issue in a regional (Sri Lankan) perspective.

The genesis of interest in zooarchaeological studies in Sri Lanka owes itself to P.E.P. Deraniyagala, who

has been the only noteworthy palaeontologist to have worked in Sri Lanka. In his numerous publications on prehistory and palaeontology, his extensively developed tastes were indeed eclectic. Nevertheless, his legacy was so remarkable that the study of natural history in Sri Lanka could aptly be divided into two: before and after Deraniyagala.

Before Deraniyagala, two of the most enigmatic zooarchaeological personalities in the pre-independence era were ‘the cousins’, Paul and Fritz Sarasin, who visited and worked in Sri Lanka from 1884-86, exploring various aspects of zoology, archaeology and anthropology. The Sarasins provided the first detailed knowledge of Sri Lanka’s Stone Age, throwing light on ornaments made from molluscs, and bone tools (Sarasin and Sarasin 1908). Particularly, they identified all teeth and bones (depending on the stature and dental characteristics between the two genera) belonging to genus *Semnopithecus* and *Macacus* from Nilgala Cave (Sarasin and Sarasin 1908). At a time when facilities were not as plentiful as they are today, they must be credited for exploring and studying amid countless obstacles and difficulties. The golden era of any natural history subject in Sri Lanka commenced from 1929, when P.E.P. Deraniyagala began publishing his research. He excavated Bellanbendipelessa open air site (Deraniyagala 1958a, 1963a), Batadombalena at Kuruvita, Ravana-ella cave at Wellavaya, and many other prehistoric sites (Deraniyagala 1944, 1946, 1960a; b) and protohistoric sites (Deraniyagala 1972). The animal remains unearthed by P.E.P. Deraniyagala are described in his scientific papers, many of which are published in *Spolia Zeylanica*. This literature survey is a critical review of P.E.P. Deraniyagala’s work for both his contributions and inherent limitations, as many of those observations and studies were based on external morphological features (Deraniyagala 1960c) and comparative studies. Taking a step forward, he reconstructed animal species using osteological characters (Deraniyagala 1958b, 1963b, 1969) and he even attempted to cross-check between two species (Deraniyagala 1961). In his masterpiece, *The Pleistocene of Ceylon* (Deraniyagala 1958c), he describes about 20 species of vertebrates belonging to the Rathnapura fauna. Similarly, he extensively worked on the Tertiary Period in Sri Lanka, and it seems unnecessary to discuss the rest of his study as the proposed study’s limits extend only from the late Pleistocene to the early Holocene.

After P.E.P. Deraniyagala, Zooarcheology in Sri Lanka has not received much attention, primarily due to the emphasis on the expansion of historical archaeological since independence (for a general comment see Bohingamuwa 2009). After P.E.P. Deraniyagala, his disciples came forward to fill his academic lacuna. Naturalist and entomologist P.B. Karunaratne’s arrival in the zooarchaeological discipline is considered as innovative, but it is unfortunate for the nation that although he made an invaluable contribution to the Sri Lankan archaeology, his wealth of knowledge was not recorded (Manamendra-Arachchi 2012). Subsequently, his student Kelum Manamendra-Arachchi took up the flag and performed considerable research for the betterment of the discipline (Manamendra-Arachchi et al. 2005, 2013; Manamendra-Arachchi K 2010; Premarathne et al. 2011; Premarathne & Manamendra-Arachchi 2012). Manamendra-Arachchi and his colleagues’ accounts are based partly on cross-species comparison, but mainly on external morphological features. Their accounts may be regarded as generally valid for most archaeological specimens, but do not apply in relation to size and shape variation. Also, excepting taxonomical identification, no new trends of scientific advancement have been made.

Several attempts have been made to reveal the ecological correlations between man and environment (S.U. Deraniyagala 1992; Fairbridge 1997; Perera 2010). S.U. Deraniyagala (1992) was more convinced with ecological associations than with statistical approaches. However, they are merely texts written in the light of a new archeological perspective and inspired by contemporary archeological theory. S.U. Deraniyagala’s (1992) work is a comprehensive monograph on the archaeology of the entire country, which also deals with Pleistocene fauna in a broader sense. The author points out the teeth and bones of large mammals including *Elephas*, *Leo*, *Rhinoceros*, *Hexaprotodon*, *Bos*, and a freshwater snail *Paludomus* is also found, together with a *Tanalia*, and there can be no question that these fauna migrated from

peninsula India to Sri Lanka during the Pleistocene low sea level stages. S.U. Deraniyagala limits himself to the methodology throughout the study and uses traditional morphological approaches in taxonomical identifications. Perera's significant work (2010) publishes identifications carried out by field experts, based on comparisons with the reference collections available in Colombo. The level of taxonomic distinctiveness varied from the order to the family, genus, and species, as well as intermediate categories. Data are compatible with the growing trend among zooarchaeologists to turn to MNI and NISP. There are certainly occasions when NISP is misleading. Therefore, the statistical illumination that it provides is not very great.

A noteworthy publication appeared in 1987, co-authored by Kenneth Kennedy with S.U. Deraniyagala and several foreign personalities, presenting morphometric analysis of the remains of some 38 entities from two prehistoric sites dated to the upper Pleistocene. They have succeeded in reconstructing once-existed people's physical traits using measurements and morphometrics. Their methodology included mensural and morphological description of all bones and teeth while statures were drawn from measurements of long bones. (Kennedy et al. 1987).

The situation in more recent times is rather different. In the late 20th century, excavations carried out by Durham University, U.K. in collaboration with Sri Lankan scholars brought a wider archaeological context to Anuradhapura (Coningham 1991). When analysing the faunal materials, special attention was given to teeth (Young et al. 1999), but specific ages for individuals were not attempted. They specifically cited the 'grant dental attrition age estimation method' as that by which teeth were assessed. Studies that can only be considered a first step towards a more profound understanding of statistics in Sri Lankan Archeology were performed by Adikari, when he statistically analysed the changing patterns of the faunal resource utilisation of two communities over time, but he never attempted using statistical approaches to taxonomic identification of animal bones (Adikari 2010). Also, various zooarchaeological methods have been applied for the identification of bones in several publications. Chandrarathne, for example, used quantitative methods and computer applications to determine faunal remains from the Gedige Excavation in 1985. NISP and MNI were presented as a percentage of the total bone assemblage to the level of identification by fragment count of bones by weight (Chandrarathne 2015). Therefore, the proposed study argues that previous literature suffers from the lack of comparisons or osteometrics in use.

From a primatological point of view, there are a wide range of publications consisting of analyses of osteological features of the family *Cercopithecidae*. Clearly, the three species mentioned in the proposed study have not been studied in a regional perspective. More comprehensive description can be found in the scholarly works of Nahallage, who indicates the importance of cranial and mandibular measurements and dental morphology of different primate species from the bones excavated from prehistoric cave sites in the island (Nahallage 2015). Nahallage relies on traditional osteometric measurements taken from a digital sliding caliper and demonstrated the existence of statistically significant differences in various parts of the skull. Unfortunately, this study was confined only to two species, *Macaca sinica* and *Semnopithecus vetulus*. The folivores species (Molur et al. 2003), *Semnopithecus priam*, was intentionally excluded.

Osteometric research on the island has not been determined by excavated factors in the past. It has also been focused on the aboriginal people or 'Vadda' people: a group of timid human beings who loved the thick jungles of the island and who are thought to be the first inhabitants of the island. Particularly, the physical anthropology of Vadda people was mostly studied by foreign scholars. Again, two cousins, the Sarasins, excavated human bones from Nilgala cave. They identified the exhumed materials from their morphological aspects alone (Sarasin & Sarasin 1908). Various excavations followed the Sarasins, but since their basic features are not directly relevant to this discussion, it seems unnecessary to note them here. Hill in 1932 was able to collect some skeletons and measure Vaddas andromorphically. He

developed a measurement criterion independently and was able to shed some initial light on pathologies among Vadda people (Hill 1932, 1941). In addition to pathologies, a complete set of anthropometric measurements were recorded to account secular trends of physical anthropology of Vadda people (Wickramanayake & Wickramanayake 1992). Sexual dimorphism and tooth size variations among Vadda clans were estimated based on 48 dental casts (Hewapathirana et al. 2014). A complete data set of incisors, premolars, and molars of adult contemporary Uva Bintenne Vaddas were measured and statistically analysed. A conventional exploration of Sarasin's collection, the 'Vadda', comprising 22 male skulls and 19 female skulls, used a set of static measurements to evoke potential size-based sexual dimorphism. But this study lacks the in-dept measurement scales and shape and size variations, which are undoubtedly essentials in distinguishing sex in skulls. (Kulathilaka 2020). The present study is not comparable to any of these, for the first concern is not with general characteristics, but with morphometrics and osteometrics of a particular species. In sum, all previous studies in Sri Lankan Zooarchaeology have treated with descriptions of an ideal type. The present study consists of the detailed study of a particular instance.

Moving on, studies on metapodial proportions have demonstrated that limb bones can be used to identify specimens at the genus or even species level (Breyer, 1983). Solounias (2007) demonstrated that artiodactyls can be separated by metapodial characteristics, and mentioned key morphological features that identify individual species, such as the depth of the central trough, and the length of the shaft. The present study expands on these and includes additional anatomical features that define different families, which is described below. Therefore, present study provides morphological features that can be used to characterize hoofed animals at the genus level.

Morphological studies often focus on the distal aspect of metapodials (e.g., Leinders, 1979; Janis and Scott, 1987). We incorporate the anatomical features of the entire metapodial and provide detailed descriptions of the proximal and distal metapodial surfaces, which exhibit distinct characteristics distinguishable between species. In the present study, an in-depth analysis of morphological and dimensional features is used to classify the genera of hoofed animals and to create a solid base for the inclusion of the metapodial characteristics in future phylogenetic analysis, which is highly informative when it comes to zooarchaeological analysis.

Ungulates are mammals that have hooves in feet. Depending on the number of hooves, they are classified as even toed mammals (Artiodactyl) and odd toed mammals (Perissodactyl). Five families are included in the present analysis.

- 1) Family Bovidae
 - i) *Bubalus bubalis*
 - ii) *Bubalus arnee*
- 2) Family Cervidae
 - i) *Cervus unicolor*
 - ii) *Axis axis*
 - iii) *Axis porcinus*
 - iv) *Muntiacus muntjak*
- 3) Family Suidae
 - i) *Sus scrofa*
- 4) Family Tragulidae
 - i) *Moschiola meminna*
 - ii) *Moschiola kathygre*
- 5) Family Bovidae
 - i) *Bos gaurus*
 - ii) *Bos spp.* (Domesticated)

Species Description

Cervus unicolor (Artiodactyl: Cervidae)

Cervus unicolor, or sambar, is the largest Oriental deer. Seven subspecies occur in varied habitats and elevations from India and Sri Lanka throughout southeastern Asia (Leslie, 2011). Populations are vulnerable because of overexploitation for subsistence and markets in meat and antlers. *C. unicolor* was elevated by the International Union for Conservation of Nature and Natural Resources from no status in 2006 to 'vulnerable' in 2008 because of a 50% decline in many populations over the past 3 generations (Timmins et al., 2015).

Cervus unicolor can be distinguished from other species of cervids by their 'robust, rugose antlers with a long brow tine, very deep lacrimal pits, reduced auditory bullae, and dark eumelanin pelage' (Groves and Grubb, 1987).

It has a wide tolerance for different habitat types, being found from the Horton Plains at 1,800 meters elevation down to sea level in the lowland dry zone (Phillips, 1980). Habitat utilisation trends indicate that the sambar does utilise open grassland and scrub areas but generally only at night (Eisenburg and Lockhart 1972). Sambars were once plentiful, but they were slaughtered annually in the lowlands for their meat, antlers and hides which are export goods (Phillips, 1980). Animals are still present in the highland forests from the Horton Plains but are endangered and further restricted day by day. Sambars seek the seclusion of the deepest and heaviest forests (Phillips, 1980).

Their diet includes grasses together with some leaves and succulent shoots of many shrubs and trees (Phillips, 1980). They are also very fond of the fallen fruits of certain trees. Fresh grasses on patanas or riverine edges are favoured (Phillips, 1980). A cogent review of the food habits of *C. unicolor* has been provided and notes its ability to consume a wide variety of grass (Flynn, 1990). In Horton Plains National Park, Sri Lanka, nitrogen in faeces of *C. unicolor* suggested highest nutrient availability in May–June. The results show that *Pennisetum spp*, *Chrysopogon zeylanicum*, *Vulpia bromoides*, and *Agrostis spp* have been consumed by sambars from the particular location mentioned. (Padmalal, Takatsuki and Jayasekara, 2003).

In their skull, a lacrimal depression is present which is associated with two lacrimal foramina at the front edge of or outside the orbit (Lawyor, 1979). The dental formula of adult *C. unicolor* is typical of cervids: $i\ 0/3, c\ 1/1, p\ 3/3, m\ 3/3$, total 34 (Hillson, 2009). Upper canines may be absent; the cusps are relatively tall and are separated by deep clefts (Berkovitz and Shellis, 2018). They are considered grazers and browsers or mixed feeders with hypsodont dentition; 2 or 3 cusps occur on the occlusal surfaces of the premolars and molars forming sharp lingual crests (Berkovitz and Shellis, 2018). The cusps are relatively tall and are separated by deep clefts, so that a unified occlusal surface is not established until a late stage of tooth wear. The retention of spaces between cusps may enhance the cutting and shredding action of enamel ridges when browsing, but as Heywood (2010) suggested, would be a disadvantage for grazing and without support from cementum would probably lack the strength to resist the large transverse forces exerted during the shearing of grass.

Sambars are of great economic importance. *C. unicolor* is a preferred meat throughout southeastern Asia (Gardner 1993). Their meat, antlers and hides are expensive export goods and thus the local population will slaughter as many as come to drink by night at waterholes (Phillips, 1980). The flesh of sambar is dry and coarse but is much esteemed by the local population (Phillips, 1980). The flesh is dried after

being cut off in strips, since dried meat has astonishing market demand. Sambars usually have two well-developed, narrow and elongated hooves and two small non-functional dew claws in the upper position (Mattioli, 2011).

Few comprehensive ecological studies of *C. unicolor* have been conducted within its native range, and much of what is known comes from demographic assessments of *C. unicolor* as prey for highly endangered and charismatic species such as the Indian tiger or the Asiatic leopard (*Panthera pardus*) (Downes, 1983).

Timmins et al. (2015) noted that expanding urban wealth and increasing demand for exotic meat and ‘medicines’, rather than rural poverty, are having the most pernicious impacts on declining populations of *C. unicolor* and other fauna in southeastern Asia.

***Sus scrofa* (Artiodactyl: Suidae) (See Appendix 3)**

Wild pigs (*Sus scrofa*) are large terrestrial mammals with rounded bodies and short legs that show a marked degree of variation in terms of size, coat, color, tail shape, and other physical traits. They possess well-developed upper incisors and upper canines that often project outward and upward from the mouth.

The wild pig occupies a wide variety of temperate and tropical habitats, from semi-desert to tropical rain forests, temperate woodlands, grasslands and reed jungles, often venturing onto agricultural land to forage. *Sus scrofa* has also occasionally been reported to prey on larger vertebrates, such as deer fawns and (tethered) goats, though it is possible that such incidents involve only a few individuals in the population.

Wild pigs are normally most active in the early morning and late afternoon, though they become nocturnal in disturbed areas, where activity usually commences shortly before sunset and continues throughout the night.

Wild pigs are gregarious, forming herds or ‘sounders’ of varying size depending on locality and season, but usually of between 6-20 individuals, though aggregations of over 100 have been reported. The Eurasian wild pig has one of the widest geographic distributions of all terrestrial mammals, and this range has been greatly expanded by human agency. The species now occurs in pure wild or barely modified feral form on all continents excepting Antarctica, and on many oceanic islands. The wild pig may be found through almost the whole country, ranging from the coast to the highest mountain tops. Although still plentiful in many jungle areas, the majority are found in the lowlands of the island. They can be met with family parties or small herds. Their favorite haunts are swamps, damp, and muddy places (Phillips, 1980).

In most cases, wild boars are omnivores with recordings of feeding on carcasses. Phillips (1980) stated that boars will kill and eat snakes, the eggs of young of ground-nesting birds, grubs, and insects.

They can be observed within larger body sizes, associated with long, high and narrow skulls containing 44 teeth (Phillips, 1980). Their teeth reflect their diet: they retain upper incisors and only a short diastema (Meijaard et al., 2011). The lower incisors are procumbent and are used in rooting for food (Berkovitz and Shellis, 2018). The canines are rounded-triangular in cross section (Meijaard et al, 2011), are hypselodont and are well developed in males, which use them in display and in fighting (Herring, 1972). Canines usually with sharp edges; upper canines larger than lower canines. The molars increase in size from anterior to posterior. They are bunodont, with four main cusps and numerous smaller ones; the lower third molar has an extra posterior cusp. (Berkovitz and Shellis, 2018). The snout is elongated, mobile, and flattened at its end. In the skull, the paroccipital process is large and nostrils are open

anteriorly; there is no ventral flange on the angular process of the lower jaw (Lawlor, 1979). Their post orbital bar is never complete; the mastoid is not exposed. Wild pigs have 4-4 digits, but usually only two functional in locomotion (side toes are small).

Pigs are of very great economic importance as food animals. However, in the South Pacific, they also play a significant role in the culture of certain tribes, among whom they are a measure of wealth and power. The upper tusks of young boars are removed so that the lower tusks have no opposing tooth that would impede growth. With continuing growth, these teeth form into a spiral tooth that curves back and eventually forms a complete circle (Menegaz et al., 2015).

***Muntiacus muntjak* (Artiodactyl: Cervidae)**

The Muntiacus or barking deer is a small forest dwelling animal that can be classified into 9 species (Ohtaishi and Gao, 1990). Barking deer is primarily a solitary species (Kurt 1981, Heggdal 1999) and can be seen occasionally in a group of 4 or 5 animals (Kurup 1971). The skull of barking deer has a canal situated within the margin of the eye socket and leading into the nose-chamber, which has two orifices; face glands and lachrymal pits are present as usual. Antlers are present in the males.

The barking deer can be found at a range of elevated altitudes, but it appears to be rather locally distributed and is much more plentiful in some areas than in others, although it prefers hillsides at medium altitudes (Phillips, 1980). They can survive on succulent grasses with the addition of a few leaves and young shoots browsed from various shrub seedlings in the jungle (Phillips, 1980). They predominantly inhabit the jungle. Generally, they graze and browse throughout the forest during the day, where they can be slaughtered by man for various economic purposes. They are considered as a saltatorial species and their hind limbs are longer than forelimbs, permitting them to move quickly in a thick forest (Mattioli, 2011). They have particularly a distinguishing fusion of two bones, the cubonavicular and cuneiform, which is probably an adaptation to moving quickly in thick cover by leaping (Mattioli, 2011).

They have developed particular cranio-dental features that support to specialisation in grazing. The characteristics are as follows:

- A. A wide premaxilla at the tip of the muzzle;
- B. A longer snout anterior to the tooth row, associated with a long diastema;
- C. A shorter premolar row;
- D. A higher jaw joint;
- E. A deeper mandible in the cheek tooth region.
- F. Greater average crown height of molars (Berkovitz and Shellis, 2018).
- G. To maximize bite force it is therefore advantageous to shorten the premolar row. Barking Deer's molars are selenodont and brachydont. The cheek teeth are clearly very efficient in dividing plant tissues (Greaves, 1991).

***Axis axis* (Artiodactyl: Cervidae)**

Also called the chital, the axis deer lives in large herds of 100 or more, made up of mixed males, females and young. They graze in grassland and browse in open woodland, often below troops of langurs, who knock fruits to the ground and emit warning calls (Newton, 1989). The male's antler has one brow tine. *Axis axis* spend a major portion of their life in foraging, resting, and wandering within their ranges, with the extent of these activities determined by season (Lever, 1985).

Axis axis is an endemic species of south Asia, occurring in India, Sri Lanka, Nepal, and Bangladesh (Lever,

1985). *Axis axis* are essentially social animals, rarely seen as solitary individuals. The basic social unit among *Axis axis* is a matriarchal family group, normally consisting of an adult female and her offspring from the previous year (Barrette, 1991). *Axis axis* lives in lowland plains or lower hills among bushes, trees or in bamboo forests. They prefer to live in areas near a stream. In areas such as Wilpattu and Ruhunu National Parks where large areas of natural grassland allow *A. axis* to live at high densities, large herds are common, but in other areas of forest or savannah, such as the Gal Oya Valley, they live at low density and only the smaller family units are seen (Fernando, 1984).

Predominantly their diet consists of grasses, forbs, and leaves of woody plants while *Axis axis* are known to feed on more than 160 species of plants (Johnsingh and Sankar 1991).

Axis axis's skull is roughly triangular. Their molars are widely separated from the canines by a diastema, and are all markedly hypsodont, with a deep infundibulum. As a result of this positioning, it exposes a complex pattern of enamel ridges in the occlusal surface. Also, they have less robust crowns, in comparison to *Bos*. Lingual crest on all molars is sharp and pointed.

***Axis porcinus* (Artiodactyl: Cervidae)**

Axis porcinus has a wide distribution in the Asian region from Pakistan to India, Bangladesh, Nepal, Bhutan, Burma, Thailand, Vietnam and Sri Lanka where it inhabits grasslands, riverine forests and coastal areas; a well-documented introduced population is also found in Victoria, Australia. The Hog Deer is a rare and shy animal which is nocturnal in habit and is only found in the wet zone of the island. It was particularly common in the marshes round the Ambalangoda (McCarthy and Dissanayake, 1994), Telwatte and Matugama area and along the Bentota River (Vishvanath, Nanayakara and Herath, 2014).

Axis porcinus prefer to feed on the tender shoots of paddy and saplings and shoots of cinnamon and also various types of vegetables. As a result, they are often caught by animal traps and illegal hunting. They are also held in captivity in relevance to reduction in genetic diversity and high potential for interbreeding activities. Alternatively, traps can damage them and causes disabilities.

***Moschiola meminna* (Artiodactyl: Tragulidae)**

Tragulids, the smallest of the ungulates, are restricted to areas where dense thickets provide adequate cover. They are moderately plentiful throughout the woodlands and jungles of the entire lowland and in the lower hills (Phillips, 1980). Meijaard (2019) indicated this species as dry zoned. Because they are small, they have greater mass-specific nutrient needs, which would not be met by the slow processing times associated with ruminant digestion of leaves and grass. Therefore, they select plant foods with a low cellulose content and a relatively high nutrient content, such as young leaves, shoots, and fruits (Meijaard, 2019).

They have short, slender legs; an even number of toes; a small, pointed head; a tapered snout; large eyes; slit-like nostrils; and medium-sized, rounded ears covered with a thin layer of hair. Their backs are rounded and rise toward the rear quarters. There is no sagittal crest, and the mandibular condyle is long. Males fight with tusk-like teeth—enlarged upper canines that protrude downward from the mouth. The upper canines in the males are long and tusk like (Phillips, 1980).

The first lower incisor is large and spatulate, while the second and third, and the lower canine, are slender (Berkovitz and Shellis, 2018). The premolars are narrow and blade-like, except for the posterior upper premolar, which has a triangular shape. The molars are selenodont and brachydont. The cusps are separated by deep clefts. Also, they have no horns or antlers, and lacrimal depression (Lawyor, 1979)

The effects of forest degradation and fragmentation are probably not severe, given its ability to survive in grassland and coconut plantations (Meijaard, 2019).

***Bubalus Bubalis* (Artiodactyl: Bovidae)**

Asian water buffalo or *Bubalus arni* is a massive powerful animal, with the widest horn span of any bovid. Its large, splayed feet and flexible fetlock joints are suited to the muddy, marshy ground on which it grazes in the morning and evening. Their large horns may curl upward and inward or point straight out sideways with 'wrinkled' horn surface. The face is long and narrow, with small ears in relative to the body mass. All species of bovid have horns which often appear in both sexes and usually one lacrimal foramen present inside the orbit (Lawyer, 1979).

During midday heat, *B. arni* wallow in the water or muddy pools, sometimes almost submerged, with only their nostrils showing. In addition to keeping them cool, wallowing helps to remove skin parasites, biting flies and other pests that infect tropical swamps.

Wild water buffalo, distinguishable by colouration and horn morphology are to be found in remoter areas of Sri Lanka (Gal Oya, Wilpattu, parts of Eastern and North Central Provinces). Males are mostly solitary and female herds small. They do overlap with and probably mingle with domestic buffalo in Wilpattu (Eisenberg and Lockhart, 1972), Gal Oya and Ruhunu National Parks; wild males have been observed on several occasions with domestic herds in Gal Oya (Fernando, 1984).

Their favorite food consists of the luscious grasses and herbs growing in or beside rivers, ponds, tanks and freshwater lagoons and of grass and herbage generally. They may do damage to paddy and other growing crops as well (Phillips, 1980). Domestication has changed the buffalo bit. The main differences between the wild and the domesticated seems to be that the latter has shorter and lighter horns (Phillips, 1980).

Bubalus has a distinctive form of occlusal outline in both upper and lower third molars.

The major predators of the water buffalo appear to be the leopard (*Panthera pardus*) and two species of crocodile, namely, the swamp crocodile (*Crocodylus palustris*) and the estuarine crocodile (*C. porosus*) (de Silva et al. 1994).

129 metapodials belonging to the families outlined above were measured using the terminology stated in the methodology section below.

Methodology of the study

Measurements of bones and teeth play an important role in zooarchaeology. They are useful in distinguishing between closely related species and between their wild and domestic forms. Measurements can tell us about size and shape, and for large samples it is sometimes possible to ascertain the sex ratio of the animals from which the bones are derived. For sequences of archaeological assemblages, size changes can tell us about environmental change and economic changes such as the advent of domestication and livestock improvement.

The theory and methods advanced here are applied to artiodactyl species in Sri Lanka. Recent skeletal materials housed in the osteoarchaeological unit of the Postgraduate Institute of Archaeology, University of Kelaniya, Sri Lanka were used as samples.

The main aims of this study are as follows:

- A. To publish a set of metapodials (artiodactyl) measurements to facilitate comparisons with other bones from archaeological sites and to help the interpretation of measurement data.
- B. To gain a better understanding of metric data, i.e. how much dimensions of different bones and parts of bones vary, and how they are related to each other and also how they might reflect the condition of the animal in life. An understanding of the relations between different measurements taken on animal bones can serve as an aid in deciding which are useful and which are producing merely redundant information.

The methodology of this study draws on multiple disciplines relevant to zooarchaeological studies. Both qualitative and descriptive research methods have been adapted. Quantification of taxonomic and skeletal parts is fundamental to the investigation of the appearance and spread of animals, and their use in diet, economies, trade and social activities. Bone measurements were taken to the nearest tenth of a millimeter using vernier calipers (Inch/Metric, 0-150 mm. Range, +/-0.02 mm. Accuracy, 0.01 mm. Resolution). The study followed the set of dimensions defined by von den Driesch (1976), the rest, marked with an asterisk, were defined by the authors. Bone terminology also follows the *Nomina Anatomica Veterinaria* (2012). 129 metapodials belongs to the hoofed animals were measured using the terminology stated above. The cleaned, disarticulated metapodials available for study are housed in the reference collections of the Postgraduate Institute of Archaeology, University of Kelaniya, Sri Lanka.

Before the bones were measured, the following set of questions were considered.

- A. Concepts of validity (e.g., whether the technique measures the required data),
- B. Reliability (replicability of the measurement)
- C. Accuracy (the 'nearness' of a measurement to the target population), being central to the choice of approach.

Measurements were recorded in a consistent manner to minimize intra- and inter-observer error and enable comparative analysis. Scatter diagrams of two measurements from the same skeletal element (bivariate analysis) creates a shape index that can also be used to infer the population.

The data was plotted and analysed using Sigma Plot 14.0 software for Windows 10.1 to derive principal components and score plots representing the different aspects of the variability of metapodials, including length, depth and breadth. Principal component analysis (PCA) of the character correlation matrix was used to reduce dimensionality of the morphological variables and to identify those variables that best discriminate between species. Various axis rotations were tested and one selected for optimal

interpretability of variation among the characters. Discriminant function analysis (DFA) was used to confirm the results that were obtained from the PCA and to highlight the variables that best discriminate between groups. Both direct and stepwise methods of discriminant analysis were employed. Apart from the PCA and DFA, both Factor analysis and Item analysis were carried out to cluster observations and further confirm the results of PCA. This method calculates the logarithm of the ratio between a measurement and its standard. There are only a few published standards (e.g., Albarella and Payne 2005; Davis 1996).

A useful technique which shows (graphically) how different measurements are related is Principal Component Analysis. It sets out to determine whether several measurements are highly correlated so that a smaller number may be used in an analysis. In this study PCA variable plots were made in order to produce a graphic representation of the structure of the measurements, i.e., to see how they are associated. Thus, measurements broadly group according to the axis along which they were taken, i.e., length, breadth, and depth. These first two Principal Components account for 60% and 10% respectively of the total variation. 3D scatterplot was referred to Breadth (BP), Depth (DP) and Length (GL). These first three Principal Components account for 60%, 10% and 7% respectively of the total variation.

After identifying the orientation and articulation of the bones, they were photographed using natural light with a Samsung S7 camera. Artificial lighting methods were not used. All the illustrations included were undertaken using Photoshop, Illustrator and Adobe Spark software. Image J application was used for scaling purposes.

General description of terminology used (see Appendix 2)

- Medial epicondyle** Medial bony protrusion on the proximal-most region of the shaft, which corresponds to the third articular facet.
 - Lateral epicondyle** Lateral bony protrusion on the proximal-most region of the shaft, which corresponds to the fourth articular facet. This comprises the lateral aspect of the basis.
 - Medial ridge** Elongated elevation of bone on the medial metapodial surface.
 - Lateral ridge** Elongated elevation of bone on the lateral metapodial surface.
- The medial and lateral ridges together create a central trough that varies in depth and length; this depth is congruent with the size of the ridges.
- Pyramidal rise** Bony elevation on the metaphorical surface within the central trough. The length of the pyramidal rise is variable and can extend the length of the metapodial or be confined to the distal shaft.

List of the measurements taken, according to von den Driesch (1976) and Payne and Bull (1988)

Abbreviation	Description
BP	Breadth of the proximal articular surface in medio-lateral axis
DP	Breadth of the proximal articular surface in anterior-posterior axis
BM*	Greatest breadth of the medial edge of the proximal articular surface in medio-lateral axis

BL*	Greatest breadth of the lateral edge of the proximal articular surface in medio-lateral axis
BS	Smallest width of the shaft measured in the medio-lateral axis
GL	Greatest length taken along the long axis of the bone "in projection"
BD1	Breadth of the distal articulation measured in the medio-lateral axis
BC	Mesio-lateral breadth of the lateral condyle
BD 2*	Smallest breadth of the diaphysis

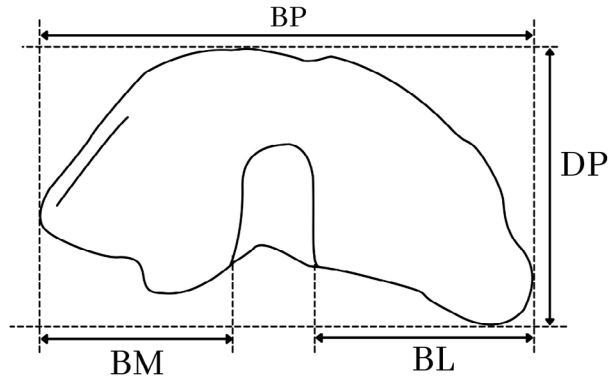


Figure 1: Bone measurement criterion - carpal view (Bovidae metacarpal, right)

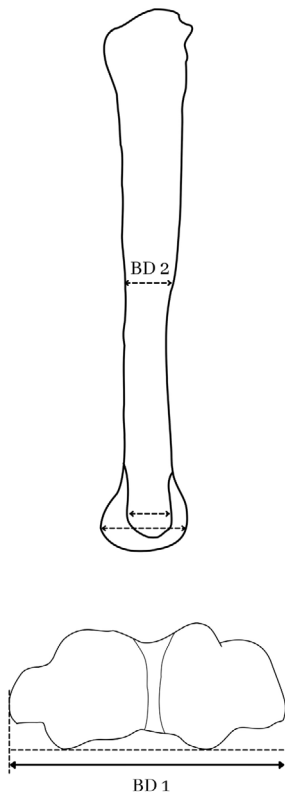


Figure 2: Bone measurement criterion - anterior view (Bovidae metacarpal, right)

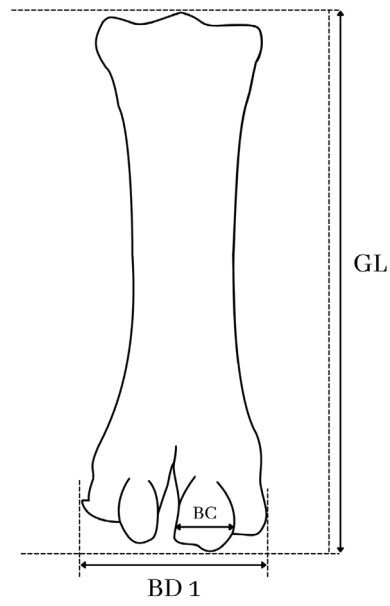


Figure 3: Bone measurement criterion – lateral and tarsal view (Bovidae metacarpal, right)

Description of the metacarpals

- A. The medial and lateral epicondyles are sub-equal in size, where the medial epicondyle is slightly larger. (*Figure 1*)

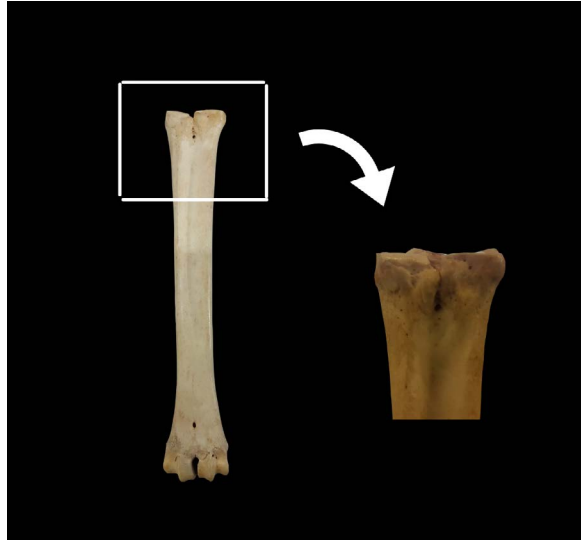


Figure 4 Metacarpal proximal morphology

- A. The lateral epicondyle is confined. There is a triangular flattened area on the lateral epicondyle, distal to the articular surface. There is an obliquely oriented groove on the lateral epicondyle separating it into two heads.
- B. The synovial fossa is open, oval, and large.
- C. The medial epicondyle is fuller, circle-sector shaped, and extends onto the medial ridge. There is a slight depression on the medial epicondyle, distal to the articular surface. (*Figure 2*)
- D. The lateral epicondyle is triangular in shape (*Figure 2*). There is an obliquely oriented groove on the surface of the medial epicondyle. Both epicondyles are notably flat.

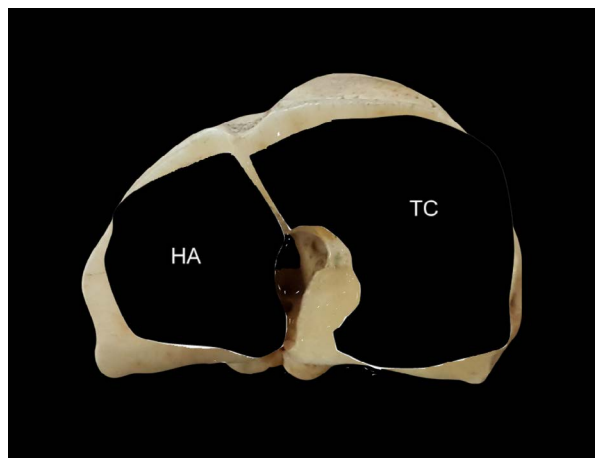


Figure 5 The medial epicondyle is circle-sector shaped and larger, and the lateral epicondyle is smaller and triangular

- A. The medial ridge has a sharp surface, whereas the lateral ridge has a dish-shaped surface where the central portion is flattened and concave. The medial ridge is rounded and extends from the medial epicondyle to the distal condyle. It is very prominent and full. The lateral ridge is sharper, and also extends from the lateral epicondyle to the distal condyle.
- B. The central trough is intermediate in depth proximally, becomes progressively shallower and is flat distally.
- C. Proximally, the lateral and medial ridges appear approximated towards the midline. The medial ridge exhibits an elongated flattened surface on the medial edge. Both ridges completely flatten at the distal third of the shaft. The distal shaft is notably flat. The keels of the distal condyles are confined and do not extend onto the distal shaft.
- D. The pyramidal rise is present most noticeably on the proximal shaft.
- E. The lateral aspect of the lateral distal condyle flares, whereas the medial aspect of the medial distal condyle is more vertical.

Description of the metatarsals

- A. There are several distinct facets at the articular surface of the metatarsals. The lateral facet articulates with the os naviculocuboideum; there is often a distinct lateral constriction. The larger medial facet articulates with the os cuneiforme intermediolaterale; it is located dorsally and may contact the os cuneiforme mediale facet. The smaller medial facet articulates with the os cuneiforme mediale (*Figure 3*).
- B. The lateral ridge is sharp and the medial ridge is rounded. The medial ridge is thickest and fullest proximally and becomes more confined throughout the shaft.
- C. Pygmaios-bony protrusion at the proximal surface of the metatarsal between the medial and lateral articular facets. It is often adjacent to the median plane.
- D. The medial and lateral epicondyles are asymmetrical in size and morphology. The medial and lateral epicondyles of the metatarsals are often split into two heads. The Lateral head is often continuous with the medial/lateral ridge, and the Medial head is often continuous with the main shaft.
- E. The medial and lateral ridges are very thin. They extend almost the entire length of the shaft and flatten close to the distal condyle.
- F. The pyramidal rise is present and faint at the distal shaft. The keels of the distal condyle extend onto the medial shaft.
- G. The lateral ridge thickens around one-third of the length of the metatarsal. The medial ridge is rounded and the lateral ridge sharp, creating a deep central trough. The medial ridge is rounded proximally, and becomes progressively flatter distally, whereas the lateral ridge remains sharp throughout the length.
- H. The distal epiphysis is slightly broader than the remainder of the shaft.
- I. The central area between the medial and lateral epicondyles is textured with many ridges, foramina, and grooves. There is a shallow groove that separates the medial and lateral epicondyles, and it continues onto the central trough. The distal edge of the medial and lateral epicondyles extends onto the medial and lateral ridges, respectively.

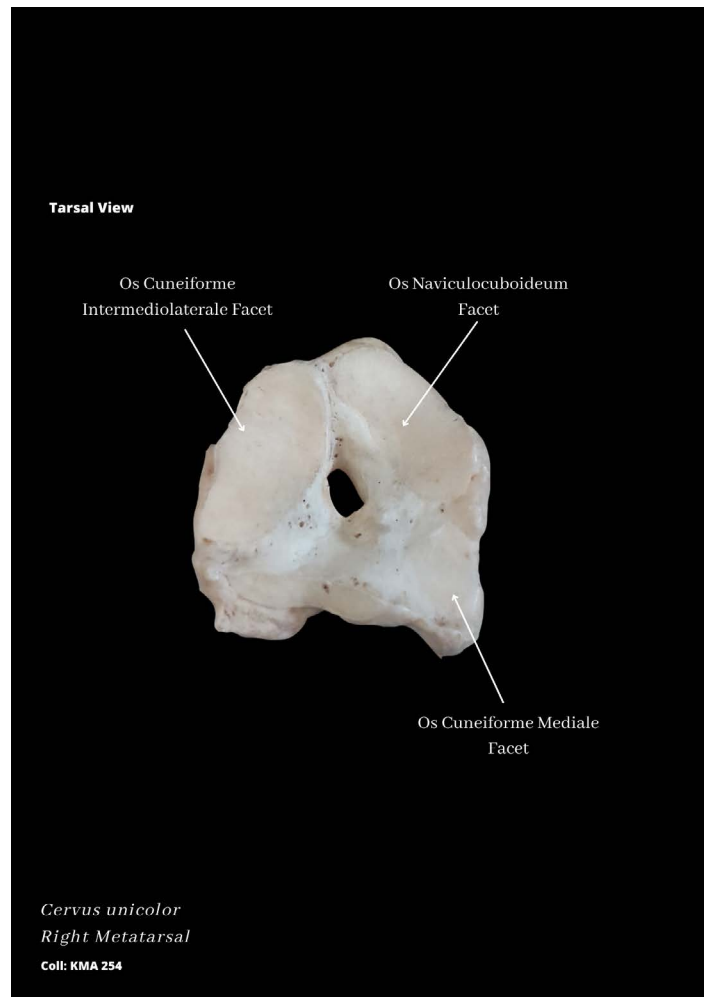


Figure 6 Capral view of metatarsal (L)

Results

Results of metacarpals

Descriptive statistics: BP, DP, BM, BL, BS, GL, BD1, BC, BD2

Statistics

Variable	Total Count	N	N*	CumN	Percent	CumPct	Mean	SE Mean	StDev	Variance
BP	69	69	0	69	100	100	51.81	2.27	18.83	354.66
DP	69	69	0	69	100	100	31.56	1.16	9.60	92.13
BM	69	69	0	69	100	100	23.147	0.985	8.181	66.926
BL	69	69	0	69	100	100	21.01	1.05	8.76	76.78
BS	69	69	0	69	100	100	32.19	1.45	12.07	145.69
GL	69	69	0	69	100	100	192.06	4.75	39.46	1556.97
BD1	69	69	0	69	100	100	54.48	2.65	21.99	483.73
BC	69	69	0	69	100	100	24.68	1.22	10.11	102.24
BD2	69	69	0	69	100	100	20.877	0.788	6.549	42.888
Variable	CoefVar	Minimum	Q1	Maximum	Range					
BP	36.35	7.41	38.30	74.05	66.64					
DP	30.41	5.41	28.07	45.01	39.60					
BM	35.34	3.410	17.550	33.620	30.210					
BL	41.71	1.19	13.48	34.41	33.22					
BS	37.50	5.55	23.01	49.29	43.74					
GL	20.54	35.69	186.10	243.20	207.51					
BD1	40.37	8.69	38.34	78.98	70.29					
BC	40.96	4.10	16.84	36.21	32.11					
BD2	31.37	2.530	18.215	30.000	27.470					

Principal component analysis: BP, DP, BM, BL, BS, GL, BD1, BC, BD2

Eigenanalysis of the correlation matrix

Eigenvalue	7.9569	0.8227	0.0744	0.0468	0.0402	0.0302	0.0165	0.0069	0.0055
Proportion	0.884	0.091	0.008	0.005	0.004	0.003	0.002	0.001	0.001
Cumulative	0.884	0.976	0.984	0.989	0.993	0.997	0.999	0.999	1.000

Eigenvectors

Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9
BP	0.352	0.097	0.020	-0.136	0.021	0.046	-0.012	-0.461	-0.795
DP	0.342	-0.137	0.752	0.534	-0.034	0.044	0.082	0.063	0.026
BM	0.349	0.054	0.081	-0.298	-0.015	-0.846	0.205	0.035	0.142
BL	0.344	0.192	0.173	-0.515	0.334	0.480	0.374	0.126	0.226
BS	0.345	0.093	-0.551	0.560	0.382	-0.020	0.309	-0.068	0.098
GL	0.193	-0.921	-0.116	-0.165	0.234	0.032	-0.135	0.005	0.006
BD1	0.349	0.159	-0.023	-0.032	-0.058	0.077	-0.606	-0.496	0.478
BC	0.348	0.183	-0.121	0.005	0.065	0.006	-0.517	0.712	-0.231
BD2	0.346	-0.130	-0.257	-0.014	-0.824	0.204	0.252	0.097	0.064

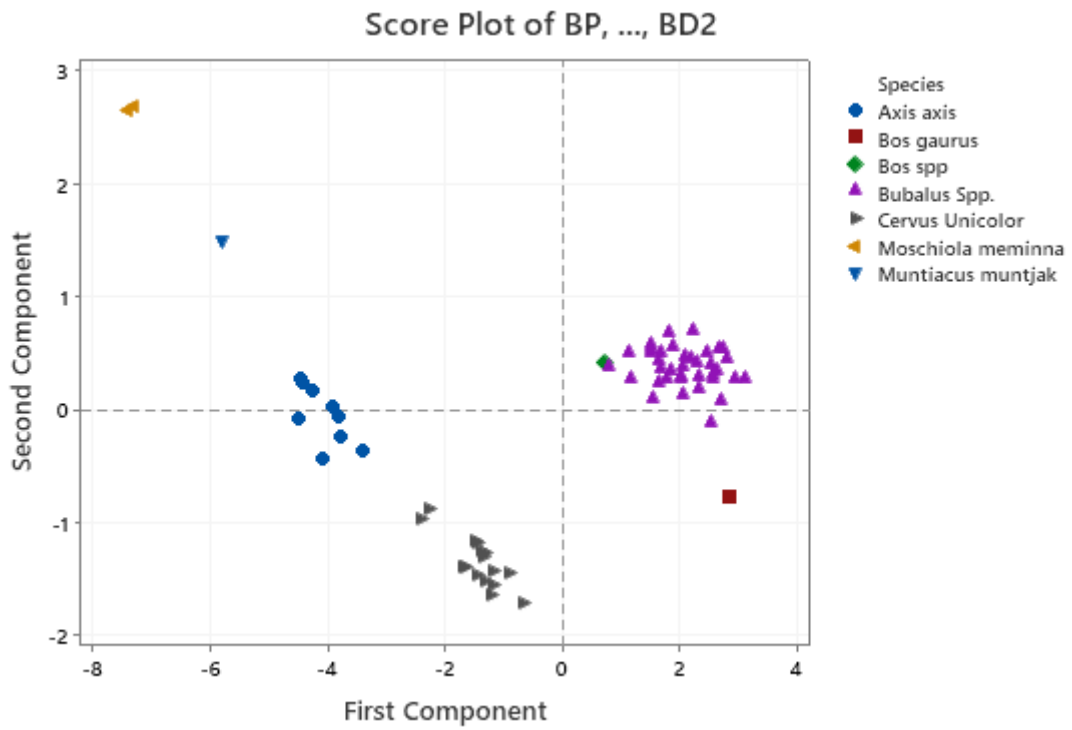


Figure 7: Score plot for metacarpals

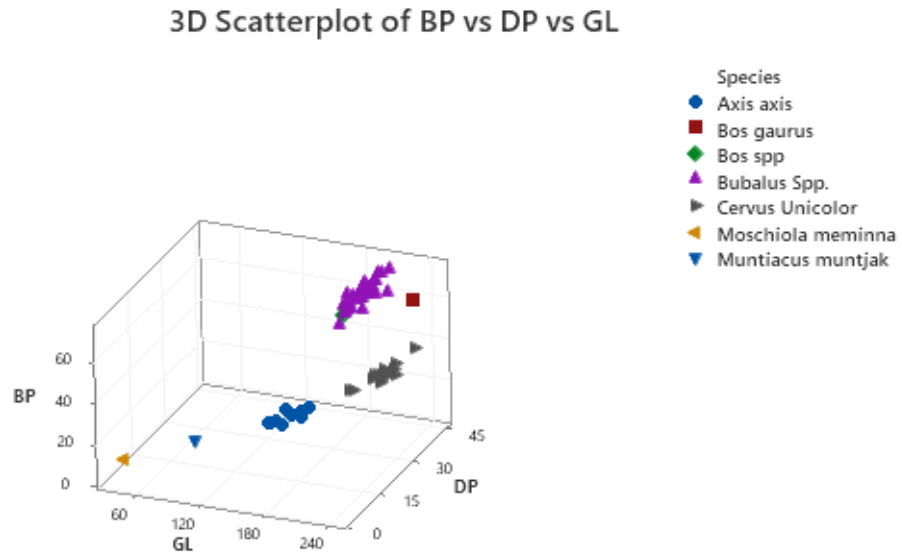


Figure 8: 3D scatterplot of BP vs DP vs GL for metacarpals

Discriminant analysis: species versus BP, DP, BM, BL, BS, GL, BD1, BC, BD2

Linear method for response: species

Predictors: BP, DP, BM, BL, BS, GL, BD1, BC, BD2

Groups

Group	<i>Axis axis</i>	<i>Bos gaurus</i>	<i>Bos spp</i>	<i>Bubalus Spp.</i>	<i>Cervus Unicolor</i>	<i>Moschiola meminna</i>
Count	9	2	2	38	16	2
Group	<i>Muntiacus muntjak</i>					
Count	2					

Summary of classification

	True Group					
	<i>Axis axis</i>	<i>Bos gaurus</i>	<i>Bos spp</i>	<i>Bubalus Spp.</i>	<i>Cervus Unicolor</i>	<i>Moschiola meminna</i>
Put into Group						
<i>Axis axis</i>	9	0	0	0	0	0
<i>Bos gaurus</i>	0	2	0	0	0	0
<i>Bos spp</i>	0	0	2	1	0	0
<i>Bubalus Spp.</i>	0	0	0	37	0	0
<i>Cervus Unicolor</i>	0	0	0	0	16	0
<i>Moschiola meminna</i>	0	0	0	0	0	2
<i>Muntiacus muntjak</i>	0	0	0	0	0	0
Total N	9	2	2	38	16	2
N correct	9	2	2	37	16	2
Proportion	1.000	1.000	1.000	0.974	1.000	1.000
	True Group					
	<i>Muntiacus muntjak</i>					
Put into Group						
<i>Axis axis</i>	0					
<i>Bos gaurus</i>	0					
<i>Bos spp</i>	0					
<i>Bubalus Spp.</i>	0					
<i>Cervus Unicolor</i>	0					
<i>Moschiola meminna</i>	0					
<i>Muntiacus muntjak</i>	2					
Total N	2					
N correct	2					
Proportion	1.000					

Correct Classifications

N	Correct	Proportion
71	70	0.986

Squared distance between groups

	<i>Axis axis</i>	<i>Bos gaurus</i>	<i>Bos spp</i>	<i>Bubalus Spp.</i>	<i>Cervus Unicolor</i>	<i>Moschiola meminna</i>
<i>Axis axis</i>	0.000	251.710	192.189	297.991	69.470	296.302
<i>Bos gaurus</i>	251.710	0.000	80.916	72.082	168.368	688.335
<i>Bos spp</i>	192.189	80.916	0.000	16.594	221.001	407.864
<i>Bubalus Spp.</i>	297.991	72.082	16.594	0.000	299.923	510.223
<i>Cervus Unicolor</i>	69.470	168.368	221.001	299.923	0.000	621.717
<i>Moschiola meminna</i>	296.302	688.335	407.864	510.223	621.717	0.000
<i>Muntiacus muntjak</i>	95.153	419.380	239.180	341.930	308.762	56.992
	<i>Muntiacus muntjak</i>					
<i>Axis axis</i>	95.153					
<i>Bos gaurus</i>	419.380					
<i>Bos spp</i>	239.180					
<i>Bubalus Spp.</i>	341.930					
<i>Cervus Unicolor</i>	308.762					
<i>Moschiola meminna</i>	56.992					
<i>Muntiacus muntjak</i>	0.000					

Linear discriminant function for groups

	<i>Axis axis</i>	<i>Bos gaurus</i>	<i>Bos spp</i>	<i>Bubalus Spp.</i>	<i>Cervus Unicolor</i>	<i>Moschiola meminna</i>	<i>Muntiacus muntjak</i>
Constant	-228.28	-461.49	-294.05	-351.69	-428.02	-10.68	-68.76
BP	-3.26	-2.71	0.78	0.85	-4.45	-0.32	-1.76
DP	-0.53	-0.90	-0.52	-0.64	-0.41	-0.01	-0.27
BM	-1.08	1.66	-1.05	-0.43	-1.46	-0.29	-0.50
BL	2.98	3.24	2.01	1.31	3.45	-0.21	1.54
BS	-1.46	-1.65	-2.15	-2.13	-1.96	-0.34	-0.58
GL	3.40	3.18	2.27	2.08	4.46	0.61	1.81
BD1	0.44	1.99	1.90	2.84	1.44	0.47	0.53
BC	0.75	3.31	3.32	3.76	1.04	0.68	0.14
BD2	-1.68	1.87	-0.81	0.08	-1.50	-0.73	-0.89

Summary of misclassified observations

Observation	True Group	Pred. Group	Group	Squared Distance	Probability
6**	<i>Bubalus Spp.</i>	<i>Bos gaurus</i>	<i>Axis axis</i>	224.323	0.000
			<i>Bubalus Spp.</i>	8.186	0.408
			<i>Cervus Unicolor</i>	196.696	0.000
			<i>Bos gaurus</i>	7.445	0.592
			<i>Moschiola meminna</i>	447.095	0.000
			<i>Muntiacus muntjak</i>	289.169	0.000

32**	Bubalus Spp.	Bos gaurus	Axis axis	278.579	0.000
			Bubalus Spp.	8.824	0.386
			Cervus Unicolor	224.914	0.000
			Bos gaurus	7.893	0.614
			Moschiola meminna	533.478	0.000
			Muntiacus muntjak	362.022	0.000
21**	Bubalus Spp.	Bos spp	Axis axis	207.23	0.000
			Bos gaurus	65.44	0.000
			Bos spp	10.26	0.927
			Bubalus Spp.	15.36	0.073
			Cervus Unicolor	220.99	0.000
			Moschiola meminna	445.09	0.000
			Muntiacus muntjak	267.35	0.000

Factor analysis: BP, DP, BM, BL, BS, GL, BD1, BC, BD2

Principal component factor analysis of the correlation matrix

Unrotated factor loadings and communalities

Variable	Factor1	Factor2	Factor3	Factor4	Factor5	Factor6	Factor7	Factor8	Factor9
BP	0.993	0.088	0.005	-0.029	0.004	0.008	-0.002	-0.038	-0.059
DP	0.964	-0.124	0.205	0.115	-0.007	0.008	0.010	0.005	0.002
BM	0.985	0.049	0.022	-0.064	-0.003	-0.147	0.026	0.003	0.011
BL	0.970	0.174	0.047	-0.111	0.067	0.083	0.048	0.010	0.017
BS	0.974	0.084	-0.150	0.121	0.076	-0.003	0.040	-0.006	0.007
GL	0.546	-0.835	-0.032	-0.036	0.047	0.006	-0.017	0.000	0.000
BD1	0.985	0.145	-0.006	-0.007	-0.012	0.013	-0.078	-0.041	0.035
BC	0.981	0.166	-0.033	0.001	0.013	0.001	-0.066	0.059	-0.017
BD2	0.975	-0.118	-0.070	-0.003	-0.165	0.036	0.032	0.008	0.005
Variance	7.9569	0.8227	0.0744	0.0468	0.0402	0.0302	0.0165	0.0069	0.0055
% Var	0.884	0.091	0.008	0.005	0.004	0.003	0.002	0.001	0.001
Variable	Communality								
BP	1.000								
DP	1.000								
BM	1.000								
BL	1.000								
BS	1.000								
GL	1.000								
BD1	1.000								
BC	1.000								
BD2	1.000								
Variance	9.0000								
% Var	1.000								

Rotated factor loadings and communalities

Quartimax rotation

Variable	Factor1	Factor2	Factor3	Factor4	Factor5	Factor6	Factor7	Factor8	Factor9
BP	0.997	-0.012	-0.017	-0.026	0.016	0.001	0.013	-0.040	-0.054
DP	0.947	-0.205	0.245	-0.028	0.013	-0.006	0.004	-0.001	-0.000
BM	0.985	-0.048	-0.018	-0.043	0.026	-0.023	-0.154	-0.003	-0.001
BL	0.982	0.072	-0.025	-0.058	0.050	0.153	0.023	-0.003	-0.001
BS	0.977	-0.016	-0.050	0.205	0.010	-0.021	0.017	-0.000	-0.000
GL	0.461	-0.887	0.002	0.001	0.000	-0.000	-0.000	0.000	0.000
BD1	0.994	0.046	-0.023	-0.029	0.020	-0.041	0.044	-0.024	0.059
BC	0.993	0.065	-0.040	0.000	0.030	-0.036	0.033	0.072	-0.003
BD2	0.960	-0.206	-0.030	-0.013	-0.187	-0.025	0.014	-0.001	-0.000
Variance	7.8884	0.8858	0.0667	0.0495	0.0399	0.0281	0.0279	0.0074	0.0064
% Var	0.876	0.098	0.007	0.006	0.004	0.003	0.003	0.001	0.001
Variable	Communality								
BP	1.000								
DP	1.000								
BM	1.000								
BL	1.000								
BS	1.000								
GL	1.000								
BD1	1.000								
BC	1.000								
BD2	1.000								
Variance	9.0000								
% Var	1.000								

Factor score coefficients

Variable	Factor1	Factor2	Factor3	Factor4	Factor5	Factor6	Factor7	Factor8	Factor9
BP	0.142	0.069	-0.856	-1.411	1.459	-2.625	2.164	-5.804	-9.814
DP	0.109	0.064	3.778	0.422	-0.165	0.110	0.067	0.619	0.155
BM	0.131	0.069	-0.406	-0.309	0.304	-0.315	-5.470	0.166	1.285
BL	0.130	0.067	-0.309	-0.104	-0.114	5.647	-0.005	0.907	1.947
BS	0.124	0.068	0.106	4.460	0.086	0.919	-0.578	-0.995	0.746
GL	-0.036	-1.147	-0.926	-0.247	1.284	0.029	0.512	0.277	0.305
BD1	0.143	0.072	-0.826	-1.350	1.381	-2.385	2.014	-4.750	7.951
BC	0.140	0.071	-0.737	-1.236	1.164	-1.974	1.625	9.109	-2.651
BD2	0.118	0.060	-0.152	-0.271	-4.888	0.727	-0.119	0.696	0.331

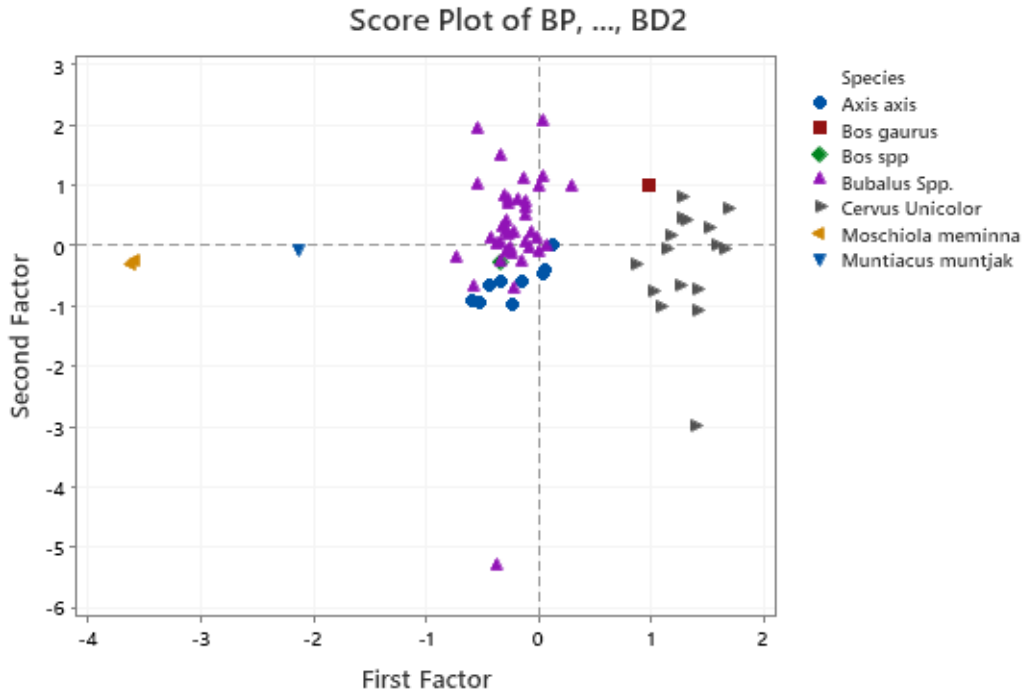


Figure 9: Score plot for factor analysis (quartimax rotation)

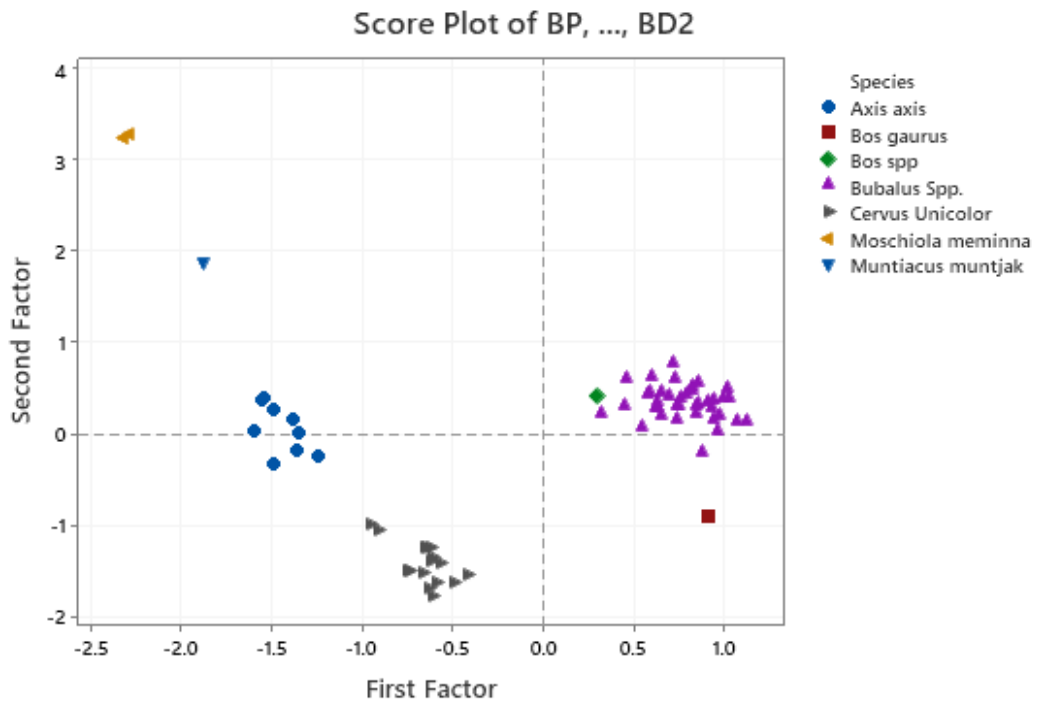


Figure 10: Score plot for factor analysis (equimax rotation)

Item analysis of BP, DP, BM, BL, BS, GL, BD1, BC, BD2*Correlation matrix*

	BP	DP	BM	BL	BS	GL	BD1	BC
DP	0.944							
BM	0.983	0.940						
BL	0.982	0.911	0.961					
BS	0.970	0.911	0.954	0.945				
GL	0.470	0.619	0.497	0.389	0.465			
BD1	0.990	0.928	0.974	0.978	0.968	0.418		
BC	0.988	0.918	0.972	0.977	0.973	0.400	0.993	
BD2	0.957	0.942	0.950	0.916	0.939	0.625	0.944	0.936

Cell Contents

Pearson correlation

Covariance matrix

	BP	DP	BM	BL	BS	GL	BD1	BC	BD2
BP	354.7								
DP	170.6	92.1							
BM	151.4	73.8	66.9						
BL	162.0	76.6	68.9	76.8					
BS	220.5	105.6	94.2	100.0	145.7				
GL	349.2	234.3	160.4	134.6	221.3	1557.0			
BD1	410.3	195.9	175.2	188.4	256.9	362.7	483.7		
BC	188.1	89.1	80.4	86.6	118.7	159.6	220.7	102.2	
BD2	118.0	59.2	50.9	52.6	74.2	161.6	135.9	62.0	42.9

Item and total statistics

Variable	Total Count	Mean	StDev
BP	69	51.81	18.83
DP	69	31.56	9.60
BM	69	23.15	8.18
BL	69	21.01	8.76
BS	69	32.19	12.07
GL	69	192.06	39.46
BD1	69	54.48	21.99
BC	69	24.68	10.11
BD2	69	20.88	6.55
Total	69	451.82	118.59

Cronbach's alpha

Alpha
0.9809

Omitted item statistics

Omitted Variable	Adj. Total Mean	Adj. Total StDev	Item-Adj. Total Corr	Squared Multiple Corr	Cronbach's Alpha
BP	400.0	100.8	0.9850	0.9932	0.9757
DP	420.3	109.4	0.9588	0.9330	0.9767
BM	428.7	110.8	0.9768	0.9688	0.9760
BL	430.8	110.7	0.9508	0.9727	0.9770
BS	419.6	107.4	0.9605	0.9559	0.9766
GL	259.8	94.5	0.4952	0.7684	0.9942
BD1	397.3	98.4	0.9709	0.9900	0.9762
BC	427.1	109.3	0.9656	0.9900	0.9764
BD2	430.9	112.2	0.9735	0.9602	0.9761

NOTE : Cronbach's alpha and omitted-variable correlations calculated with standardized data.

Matrix Plot of BP, DP, BM, BL, BS, GL, BD1, BC, BD2

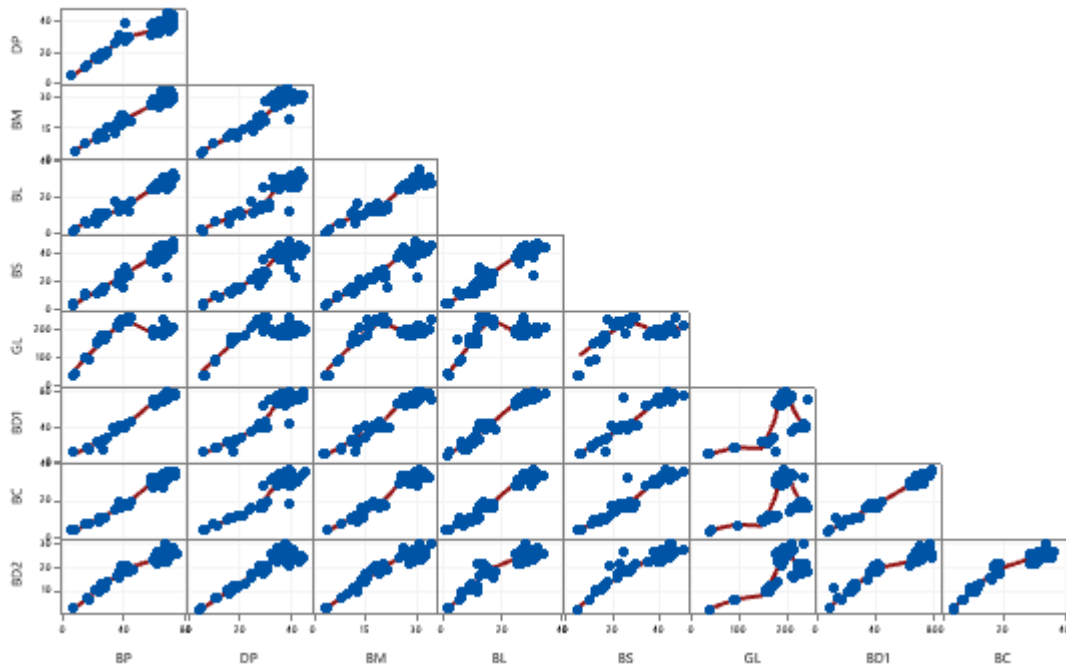


Figure 11: Matrix plot for metacarpal measurements

Results of metatarsals

Descriptive statistics: BP, DP, BM, BL, BS, GL, BD1, BC, BD2

Statistics

Variable	Total Count	N	N*	CumN	Percent	CumPct	Mean	SE Mean	Tr.Mean	St.Dev
BP	61	61	0	61	100	100	45.33	1.60	46.37	12.51
DP	61	61	0	61	100	100	40.40	1.31	41.34	10.25
BM	61	61	0	61	100	100	16.653	0.681	16.718	5.322
BL	61	61	0	61	100	100	18.463	0.737	18.751	5.758
BS	61	61	0	61	100	100	28.80	1.02	29.37	7.93
GL	61	61	0	61	100	100	225.05	5.00	229.83	39.02
BD1	61	61	0	61	100	100	53.81	2.23	55.07	17.41
BC	61	61	0	61	100	100	24.04	1.05	24.44	8.19
BD2	61	61	0	61	100	100	24.911	0.853	25.450	6.666
Variable	Variance	Coef. Var	Sum	Minimum	Q1	Median	Q3	Maximum	Range	
BP	156.49	27.60	2765.14	8.81	37.81	50.69	53.56	59.39	50.58	
DP	104.98	25.36	2464.34	8.01	36.41	45.01	47.20	52.23	44.22	
BM	28.321	31.96	1015.810	3.130	13.175	18.290	19.890	28.820	25.690	
BL	33.158	31.19	1126.260	2.190	15.290	20.040	23.000	28.400	26.210	
BS	62.88	27.54	1756.69	5.63	24.67	30.39	35.20	38.79	33.16	
GL	1522.32	17.34	13727.76	57.11	221.25	230.81	242.10	264.50	207.39	
BD1	303.22	32.36	3282.18	10.72	38.36	61.70	67.67	70.19	59.47	
BC	67.07	34.07	1466.17	5.29	16.38	27.71	30.07	38.97	33.68	
BD2	44.432	26.76	1519.570	3.720	22.100	27.180	29.010	34.320	30.600	

Principal component analysis: BP, DP, BM, BL, BS, GL, BD1, BC, BD2

Eigen analysis of the correlation matrix

Eigenvalue	7.8091	0.6666	0.1852	0.1190	0.1031	0.0575	0.0371	0.0155	0.0067
Proportion	0.868	0.074	0.021	0.013	0.011	0.006	0.004	0.002	0.001
Cumulative	0.868	0.942	0.962	0.976	0.987	0.993	0.998	0.999	1.000

Eigenvectors

Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9
BP	0.354	0.049	-0.006	0.095	0.167	-0.252	0.133	0.766	0.409
DP	0.350	-0.014	-0.006	0.122	0.239	-0.513	-0.670	-0.301	0.038
BM	0.329	0.180	0.736	0.459	-0.241	0.190	0.057	-0.098	-0.022
BL	0.335	0.145	0.300	-0.864	-0.169	-0.006	-0.033	-0.021	0.012
BS	0.337	-0.116	-0.446	0.118	-0.809	-0.054	-0.029	-0.027	0.046
GL	0.242	-0.893	0.152	-0.037	0.136	-0.056	0.283	-0.126	-0.039
BD1	0.348	0.221	-0.175	0.054	0.171	-0.189	0.312	0.086	-0.791
BC	0.342	0.272	-0.270	0.031	0.275	0.123	0.439	-0.511	0.436
BD2	0.347	-0.099	-0.207	0.006	0.226	0.762	-0.397	0.167	-0.100

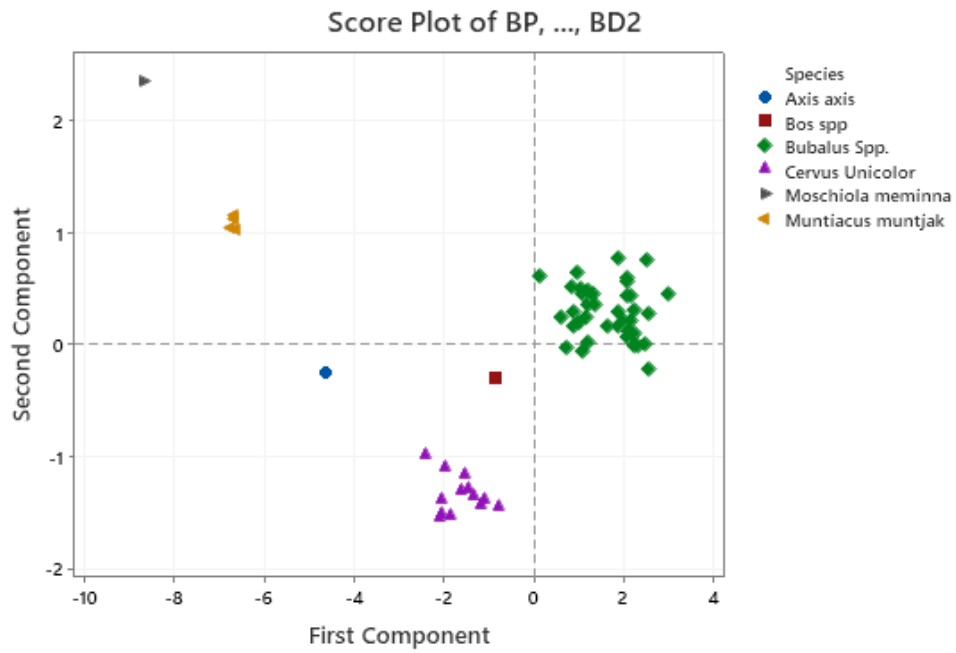


Figure 12: Score plot for metatarsals

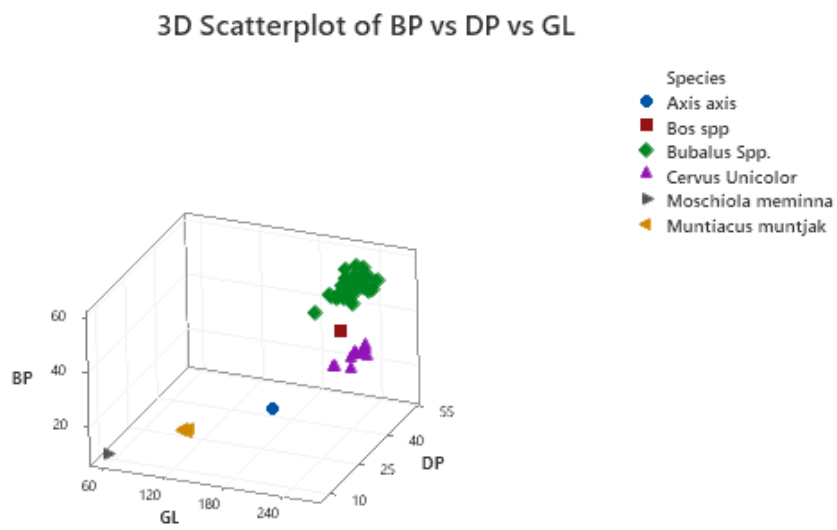


Figure 13: 3D Scatterplot of BP vs DP vs GL for metatarsals

Discriminant analysis: species versus BP, DP, BM, BL, BS, GL, BD1, BC, BD2

Linear method for response: species

Predictors: BP, DP, BM, BL, BS, GL, BD1, BC, BD2

Groups

Group	<i>Axis axis</i>	<i>Bos spp</i>	<i>Bubalus spp.</i>	<i>Cervus unicolor</i>	<i>Moschiola meminna</i>
Count	2	2	40	13	2
Group	<i>Muntiacus muntjak</i>				
Count	4				

Summary of classification

	True Group					
	<i>Axis axis</i>	<i>Bos spp</i>	<i>Bubalus spp.</i>	<i>Cervus unicolor</i>	<i>Moschiola meminna</i>	<i>Muntiacus muntjak</i>
Put into Group						
<i>Axis axis</i>	2	0	0	0	0	0
<i>Bos spp</i>	0	2	0	0	0	0
<i>Bubalus spp.</i>	0	0	40	0	0	0
<i>Cervus unicolor</i>	0	0	0	13	0	0
<i>Moschiola meminna</i>	0	0	0	0	2	0
<i>Muntiacus muntjak</i>	0	0	0	0	0	4
Total N	2	2	40	13	2	4
N correct	2	2	40	13	2	4
Proportion	1.000	1.000	1.000	1.000	1.000	1.000

Correct classifications

N	Correct	Proportion
63	63	1.000

Squared distance between groups

	<i>Axis axis</i>	<i>Bos spp</i>	<i>Bubalus spp.</i>	<i>Cervus unicolor</i>	<i>Moschiola meminna</i>	<i>Muntiacus muntjak</i>
<i>Axis axis</i>	0.000	98.565	257.685	78.561	289.847	78.929
<i>Bos spp</i>	98.565	0.000	69.155	45.273	524.806	245.582
<i>Bubalus Spp.</i>	257.685	69.155	0.000	199.450	588.329	358.698
<i>Cervus Unicolor</i>	78.561	45.273	199.450	0.000	617.659	280.479
<i>Moschiola meminna</i>	289.847	524.806	588.329	617.659	0.000	69.180
<i>Muntiacus muntjak</i>	78.929	245.582	358.698	280.479	69.180	0.000

Linear discriminant function for groups

	<i>Axis axis</i>	<i>Bos spp</i>	<i>Bubalus spp.</i>	<i>Cervus unicolor</i>	<i>Moschiola meminna</i>	<i>Muntiacus muntjak</i>
Constant	-285.66	-445.87	-471.12	-504.13	-25.87	-114.41
BP	0.97	4.81	5.66	3.98	0.73	1.30

DP	3.84	4.82	5.00	4.87	1.13	2.39
BM	-0.80	-0.94	-1.25	-1.61	-0.17	-0.61
BL	-1.10	-1.37	-1.24	-1.69	-0.61	-0.64
BS	-1.97	-3.64	-3.76	-2.63	-0.67	-1.24
GL	3.04	3.07	2.28	3.74	0.82	1.87
BD1	-5.39	-5.20	-2.28	-7.40	-1.37	-3.55
BC	5.20	5.97	5.45	5.84	2.15	3.08
BD2	0.03	0.93	1.71	1.46	-0.46	0.09

Factor analysis: BP, DP, BM, BL, BS, GL, BD1, BC, BD2

Principal component factor analysis of the correlation matrix

Unrotated factor loadings and communalities

Variable	Factor1	Factor2	Factor3	Factor4	Factor5	Factor6	Factor7	Factor8	Factor9
BP	0.991	0.040	-0.000	0.030	0.052	-0.057	0.022	-0.089	0.033
DP	0.982	-0.017	-0.002	0.036	0.073	-0.114	-0.120	0.036	0.003
BM	0.925	0.138	-0.309	0.147	-0.077	0.042	0.010	0.011	-0.002
BL	0.944	0.104	-0.119	-0.282	-0.057	-0.001	-0.005	0.002	0.001
BS	0.946	-0.081	0.195	0.045	-0.240	-0.015	-0.004	0.004	0.004
GL	0.727	-0.681	-0.058	-0.010	0.042	-0.011	0.055	0.015	-0.003
BD1	0.974	0.184	0.071	0.017	0.054	-0.043	0.054	-0.012	-0.061
BC	0.957	0.228	0.110	0.010	0.087	0.030	0.077	0.060	0.033
BD2	0.974	-0.077	0.086	0.003	0.065	0.170	-0.072	-0.020	-0.008
Variance	7.9312	0.5936	0.1758	0.1061	0.0915	0.0497	0.0322	0.0138	0.0061
% Var	0.881	0.066	0.020	0.012	0.010	0.006	0.004	0.002	0.001
Variable	Communality								
BP	1.000								
DP	1.000								
BM	1.000								
BL	1.000								
BS	1.000								
GL	1.000								
BD1	1.000								
BC	1.000								
BD2	1.000								
Variance	9.0000								
% Var	1.000								

*Rotated factor loadings and communalities**Quartimax rotation*

Variable	Factor1	Factor2	Factor3	Factor4	Factor5	Factor6	Factor7	Factor8	Factor9
BP	0.992	-0.039	0.003	0.037	0.042	-0.053	0.012	-0.089	0.034
DP	0.979	-0.088	0.015	0.044	0.046	-0.037	-0.168	-0.001	0.004
BM	0.928	0.041	-0.368	-0.007	0.041	-0.010	0.002	-0.000	0.000
BL	0.947	0.018	-0.012	-0.319	0.035	-0.010	0.006	-0.000	0.000
BS	0.939	-0.117	0.067	0.037	-0.315	-0.002	0.006	-0.000	0.000
GL	0.673	-0.740	0.005	0.002	-0.007	0.001	-0.000	0.000	0.000
BD1	0.987	0.107	0.052	0.046	0.033	-0.059	0.040	-0.000	-0.065
BC	0.973	0.152	0.083	0.060	0.051	-0.014	0.083	0.092	0.028
BD2	0.967	-0.136	0.066	0.043	0.008	0.201	0.021	0.002	0.001
Variance	7.8878	0.6256	0.1546	0.1139	0.1099	0.0483	0.0374	0.0164	0.0062
% Var	0.876	0.070	0.017	0.013	0.012	0.005	0.004	0.002	0.001
Variable	Communality								
BP	1.000								
DP	1.000								
BM	1.000								
BL	1.000								
BS	1.000								
GL	1.000								
BD1	1.000								
BC	1.000								
BD2	1.000								
Variance	9.0000								
% Var	1.000								

Factor score coefficients

Variable	Factor1	Factor2	Factor3	Factor4	Factor5	Factor6	Factor7	Factor8	Factor9
BP	0.149	0.130	0.491	0.568	0.611	-1.068	1.569	-6.184	5.543
DP	0.141	0.129	0.396	0.383	0.413	-0.338	-4.865	1.623	0.483
BM	0.100	0.078	-2.494	0.370	-0.219	0.291	0.284	0.813	-0.304
BL	0.113	0.099	0.358	-2.803	0.051	0.000	-0.074	0.124	0.151
BS	0.109	0.128	-0.027	0.019	-2.901	-0.301	-0.143	0.164	0.567
GL	-0.006	-1.364	-0.082	0.008	0.497	-0.998	0.998	1.253	-0.634
BD1	0.151	0.132	0.469	0.540	0.582	-1.006	1.115	-0.955	-10.181
BC	0.143	0.130	0.468	0.544	0.581	-1.101	1.455	4.924	5.295
BD2	0.132	0.125	0.271	0.297	0.408	4.280	-0.040	-1.216	-1.083

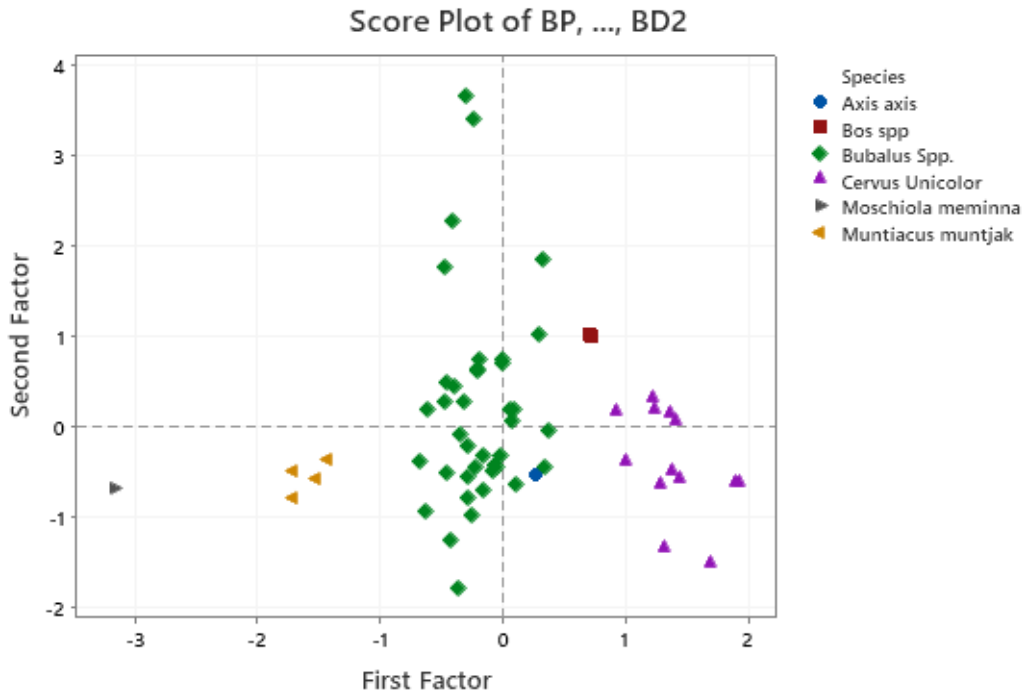


Figure 14: Score plot for factor analysis (quartimax rotation)

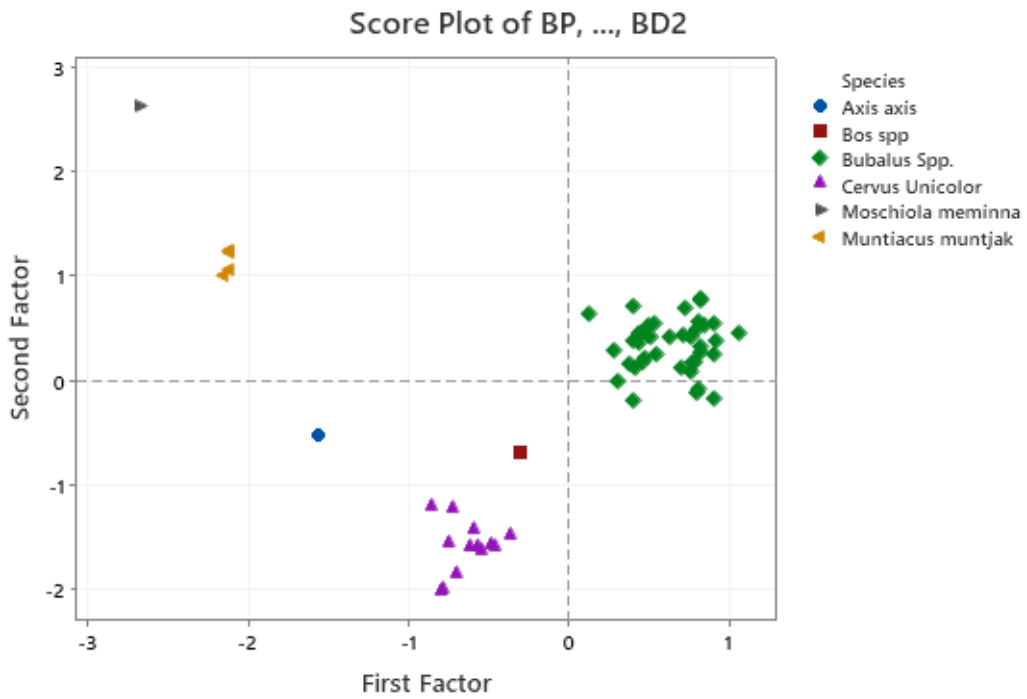


Figure 15: Score plot for factor analysis (equimax rotation)

Item analysis of BP, DP, BM, BL, BS, GL, BD1, BC, BD2*Correlation matrix*

	BP	DP	BM	BL	BS	GL	BD1	BC
DP	0.978							
BM	0.920	0.901						
BL	0.928	0.912	0.888					
BS	0.924	0.916	0.828	0.863				
GL	0.695	0.723	0.592	0.622	0.721			
BD1	0.979	0.956	0.902	0.923	0.909	0.584		
BC	0.958	0.932	0.881	0.907	0.888	0.542	0.988	
BD2	0.956	0.951	0.865	0.897	0.926	0.751	0.934	0.928

Cell Contents

Pearson correlation

Covariance matrix

	BP	DP	BM	BL	BS	GL	BD1	BC	BD2
BP	172.7								
DP	139.8	118.3							
BM	66.6	54.0	30.3						
BL	73.5	59.8	29.5	36.3					
BS	101.6	83.4	38.2	43.5	70.0				
GL	400.8	344.9	142.9	164.4	264.5	1923.3			
BD1	231.5	187.1	89.4	100.0	136.8	461.1	323.7		
BC	105.9	85.3	40.8	45.9	62.5	199.9	149.4	70.7	
BD2	89.0	73.3	33.8	38.3	55.0	233.6	119.1	55.3	50.3

Item and total statistics

Variable	Total Count	Mean	St. Dev
BP	63	44.70	13.14
DP	63	39.85	10.88
BM	63	16.45	5.51
BL	63	18.19	6.03
BS	63	28.32	8.37
GL	63	222.54	43.86
BD1	63	53.00	17.99
BC	63	23.67	8.41
BD2	63	24.52	7.09
Total	63	471.24	109.53

Cronbach's alpha

Alpha
0.8628

Omitted item statistics

Omitted Variable	Adj. Total Mean	Adj. Total StDev	Item-Adj. Total Corr	Squared Multiple Corr	Cronbach's Alpha
BP	426.5	97.0	0.9483	0.9864	0.8242
DP	431.4	99.1	0.9532	0.9632	0.8314
BM	454.8	104.8	0.8579	0.8637	0.8549
BL	453.1	104.2	0.8843	0.8758	0.8522
BS	442.9	101.8	0.9224	0.8877	0.8420
GL	248.7	75.2	0.6711	0.8355	0.9664
BD1	418.2	93.4	0.8773	0.9907	0.8190
BC	447.6	102.2	0.8673	0.9823	0.8444
BD2	446.7	102.7	0.9577	0.9531	0.8455

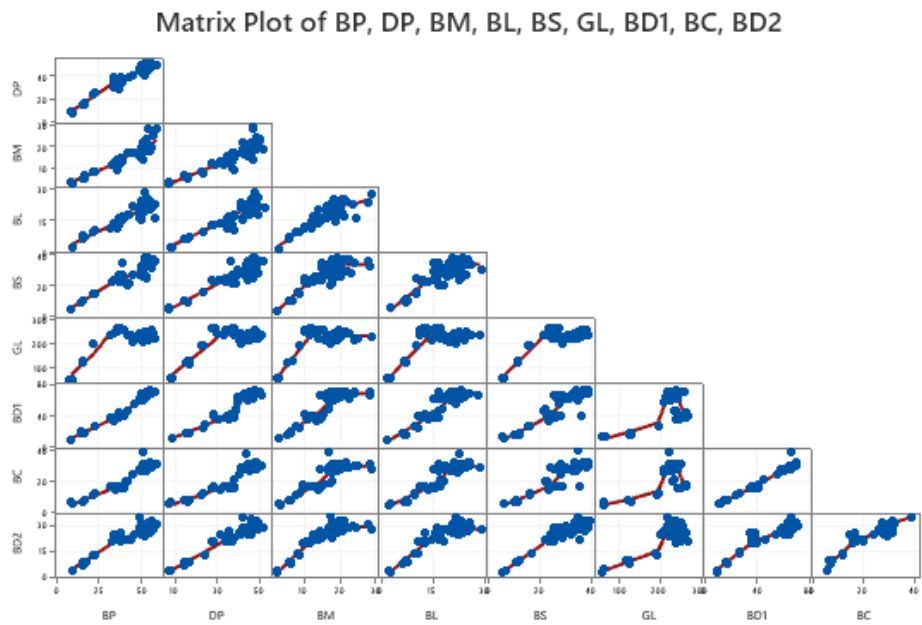


Figure 16: Matrix plot for metatarsal measurements

Interpretation of the Results

Appendix 1 gives the individual bone measurements (raw data) of all 129 metapodials (62 metatarsals and 67 metacarpals). In order to understand how different measurements vary, the coefficients of variation are given in the previous section. The advantage of the coefficient of variation is that, in addition to characterising the amount of variation, it is dimensionless and allows a comparison of variability of small and large data sets.

In zooarchaeology, it is important to distinguish the differences among species. PC analysis focuses on larger data sets to summarise multivariate data. It tells us about the structure of the data and provides us with a way of displaying it in a reduced number of dimensions. It helps us to see data clustering that might indicate distinct species types.

As the first two components were detailed into a score plot diagram, some clusters became visible, clusters that have been plotted into species groups. Even within these species groups, it is possible to plot a phenomenon that could be in part related to environmental differences between geographic regions of *Cervus unicolor* and *Bubalus bubalis*.

E.g. (Refer to the Metacarpals section, Figure 7)

<i>Bubalus bubalis</i>	Row 19	Yala National Park	1.62073 (1 st Comp.)	0.07064 (2 nd Comp.)
<i>Bubalus bubalis</i>	Row 38	Sirinandanapura, Thanamalwila	2.11122 (1 st Comp.)	0.35515 (2 nd Comp.)
<i>Cervus unicolor</i>	Row 53	Sirinandanapura, Thanamalwila	-2.01832 (1 st Comp.)	1.14293 (2 nd Comp.)
<i>Cervus unicolor</i>	Row 50	Horton Plains	-1.27227 (1 st Comp.)	1.622339 (2 nd Comp.)

It is clearly possible to identify two sub-groups within the main shaft group based on variables as defined by the PCA; two sub-groups belongs to different geographical regions can also be clearly observed.

Therefore, results of PCA can be used in differentiating between species that are closely related with very similar morphological features. A further example can be adduced from *Cervus unicolor* and *Bos spp.* Metapodials of both spp share most of the same characteristics and cannot be separated simply by looking at their external morphological characters. The only character that can be distinguished is the midline groove's continuity. It can be identified in the final PCA results as it is classified by two factors.

E.g. (Refer to the Metatarsals section, Figure 9)

<i>Bos spp</i>	Row 41		-0.52348 (1 st Comp.)	-0.30827 (2 nd Comp.)
<i>C unicolor</i>	Row 46		-2.11906 (1 st Comp.)	-0.99896 (2 nd Comp.)

Different measurements show, as expected, different variability. Obviously, measurements of unfused and fusing bones (see methodology for clarifications) are excluded, thus giving a better estimate of

adult variability. Pearson's coefficient of variation (V) in the metapodials ranges between 3.7 and 10.6, the mesio-lateral breadth of the lateral condyle being the least variable measurement and the greatest length taken along the long axis of the bone 'in projection' the most. Most measurements have a coefficient of variation that shows very similar linear discriminant function between groups, which is the kind of value that would be expected from a single population for each species; see also, the sub-groups above mentioned. A similar group of coefficients of variation was reported by Payne and Bull, (1988) in a study of a very large pig bone assemblage from the Czech Republic. Measurements with low coefficients of variation are likely to be of particular value for this purpose, and are likely to be less affected by dietary and other environmental changes rather than being in different ecological niches. Within the assemblage, BP and DP tend to have low coefficients of variation and probably belong to this category of measurements, as Payne and Bull (1988) have already pointed out. This makes them well-suited for comparing populations, specially as they are often relatively common in archaeological assemblages.

A small number of large specimens (in the metacarpals section, rows 19, 1, 32 etc.) from *Bubalus spp* are remarkable but they could equally represent tails of the main distribution and thus be unusually large specimens. Whichever the case, their frequency is low and thus they have relatively little effect on assemblage means. As they represent the tails of the main distribution, we can postulate that different ages were present within the population; as they get older, their bones get bigger. Our final picture is thus that of a young population, accompanied by several older animals. The explanation of the functions of principal component analysis will help to determine the density of the animal population of the past. It could also sum up a great deal of other information, including the economics of ancient man. A similar analysis was conducted by Reitz and Ruff (1994) in reference to North America and the Caribbean region.

E.g. (Refer to the Metacarpals section, Figure 7)

<i>Bubalus bubalis</i> (Older)	Row 25	Yala National Park	2.28036 (1 st Comp.)	-0.81760 (2 nd Comp.)
<i>Bubalus bubalis</i> (Older)	Row 4	Yala National Park	3.27758 (1 st Comp.)	-0.65791 (2 nd Comp.)
<i>Bubalus bubalis</i> (Younger)	Row 8	Yala National Park	1.97008 (1 st Comp.)	-0.49194 (2 nd Comp.)
<i>Bubalus bubalis</i> (Younger)	Row 37	Yala National Park	1.85501 (1 st Comp.)	-0.34396 (2 nd Comp.)

When we come to the general conclusion of metacarpals vs metatarsals measurements, forelimb measurements in the assemblage tend to be more variable than hindlimb measurements, and this can only partly be explained by age-related increase. This may support Payne and Bull's (1988) hypothesis that forelimb bones are more sexually dimorphic than those from the hind limb.

The matrix of correlation coefficients between all measurements is presented to facilitate further work on this aspect of the osteometry of Sri Lankan hoofed animals (excluding *Sus scrofa* – See appendix 4). Close study of the correlation matrix reveals the following.

A. Intra-axis Measurements taken along the same axis such as lengths, breadths and antero-posterior depths are all highly correlated.

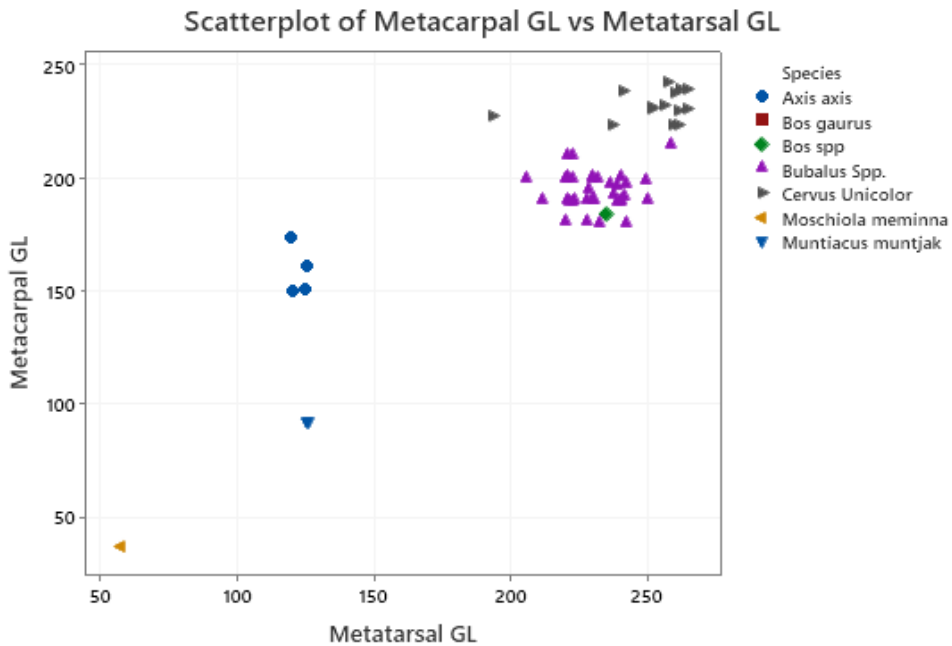


Figure 17: Scatterplot of metacarpal GL vs metatarsal GL in tenths of millimetre taken along same axis

B. Inter-axis By contrast, comparison of measurements taken in different axes such as widths versus antero-posterior depths, indicates that some are not very highly correlated.

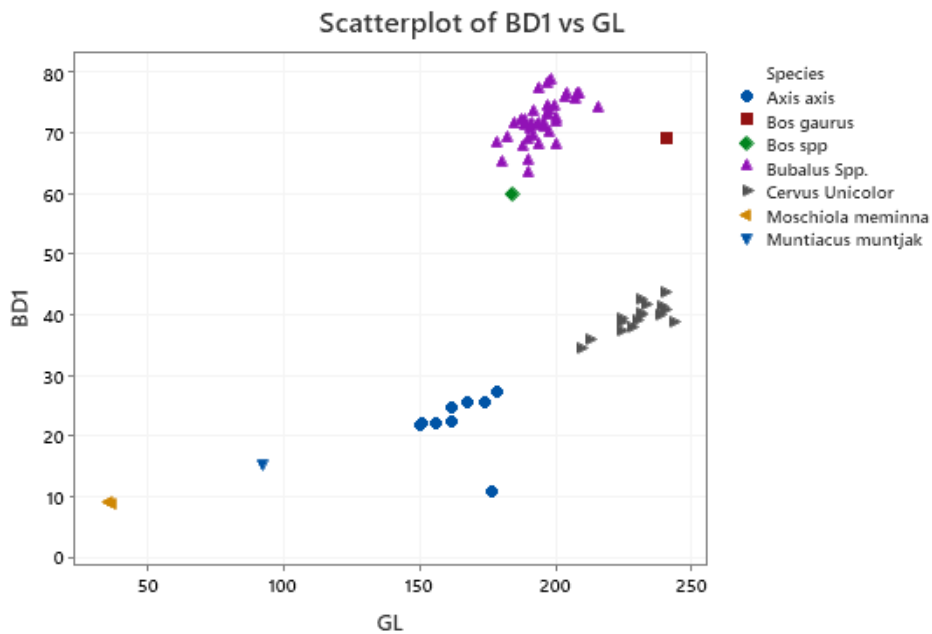


Figure 18: Scatterplot of metacarpal BD1 vs metacarpal GL in tenths of millimetre taken along same axis

The high correlations between measurements taken on the distal metacarpal and distal metatarsal condyles are noteworthy. These high correlations of both metacarpal and metatarsal condyles may reflect very intense selection pressures in the course of Cervidae’s evolution. These condyles articulate with phalanges and their efficient movement is vital for rapid locomotion as the Cervidae’s main strategy in escaping from predators.

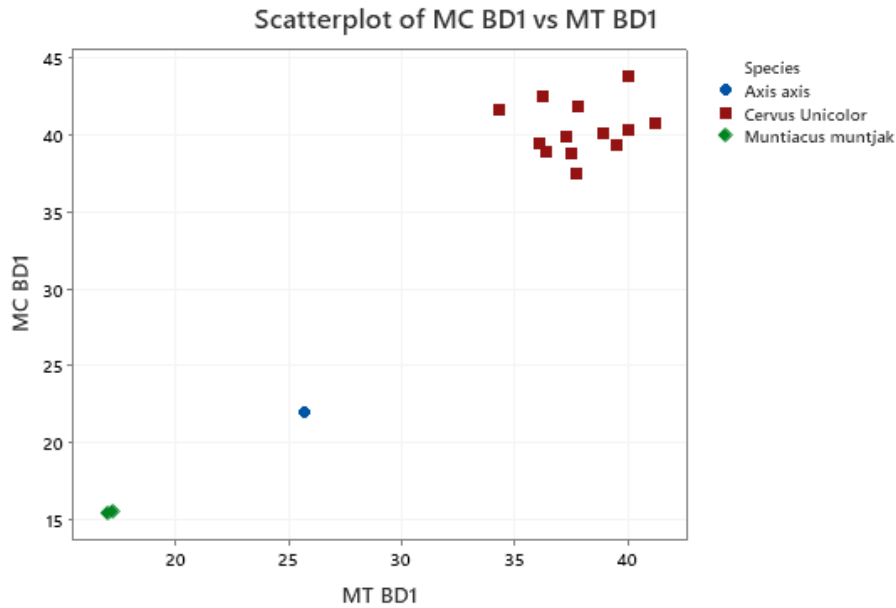


Figure 19: Scatterplot of MC BD1 vs MT BD1

A most noteworthy observation would be to identify differences between *Bubalus* spp, *Bos* spp (domesticated) and *Bos gaurus*. As presented under misclassified observations in the metacarpals section, the system signifies some correlations between *Bubalus* and *Bos gaurus* metacarpals. Gaura is a massively built animal relative to *Bubalus*. Mis-observations has classified three *Bubalus* bones that can be postulated as *Bos gaurus*. It has a 0.592 and 0.614 probability of being a gaurus bone. *Bos gaurus* was last seen in Ceylon during the British rule, and these misclassified observations could lead us to an idea of *Bubalus* that had grown close to the size of a *Bos gaurus*, like a mini-*Bos gaurus*.

It is hoped that this study highlights the importance of using and interpreting measurements in a critical way. Biometry can provide important archaeological information, but for this to work we need to be aware of patterns of variability and the causes of variation in different measurements. The understanding of biological factors related to growth, dimorphism and polymorphism in animal populations is essential for a reliable reconstruction of ancient techniques of animal exploitation.

Appendix 1: Primary data set of bone measurements

Metacarpals

<i>Species</i>	<i>Side</i>	<i>Cat. N</i>	<i>BP</i>	<i>DP</i>	<i>BM</i>	<i>BL</i>	<i>BS</i>	<i>GL</i>	<i>BD1</i>	<i>BC</i>	<i>BD2</i>
<i>Bubalus Spp.</i>	Left	YNP 92	66.01	40.11	31.29	27.67	40.2	190.15	71.81	32.61	2.61
<i>Bubalus Spp.</i>	Left	YNP 77	66.59	39.35	30.11	31.1	45.21	190.98	78.19	36.21	25.11
<i>Bubalus Spp.</i>	Left	YNP 80	70.11	39.97	32.81	30.91	42.87	210.19	75.91	34.79	27.01
<i>Bubalus Spp.</i>	Left	YNP 73	76.13	45.51	33.91	35	49.29	200.95	75.71	35.54	28.02
<i>Bubalus Spp.</i>	Right	YNP84	66.29	40.31	32.19	27.19	41.81	190.69	73.29	32.63	26.19
<i>Bubalus Spp.</i>	Right	YNP 98	65.59	45.9	30.01	29.4	38.91	190.93	68.01	30.49	25.9
<i>Bubalus Spp.</i>	Left	YNP 87	70.73	39.71	29.98	31.1	43.51	200.01	77.29	35.79	27.39
<i>Bubalus Spp.</i>	Right	YNP 91	65.98	38.88	30.7	28.9	39.42	190.61	71.35	32.61	26.8
<i>Bubalus Spp.</i>	Left	YNP 78	64.31	42.19	29.9	26.35	38.55	190.65	65.61	28.32	24.89
<i>Bubalus Spp.</i>	Right	YNP74	66.72	42.19	28.71	26.65	41.29	190.41	71.29	32.44	25.28
<i>Bubalus Spp.</i>	Left	YNP 88	65.89	38.89	29.81	29.51	39.81	190.41	67.91	31.39	22.7
<i>Bubalus Spp.</i>	Left	YNP 79	66.21	39.5	30.09	26.78	41.52	200.89	71.71	34.81	25.55
<i>Bubalus Spp.</i>	Left	YNP 76	68.12	41.56	29.21	30.49	43.41	190.71	73.5	33.5	25.69
<i>Bubalus Spp.</i>	Left	YNP 75	65.91	38.81	28.29	28.15	37.1	190.55	69.55	31.12	23.93
<i>Bubalus Spp.</i>	Right	YNP 86	72.59	42.02	33.02	28.29	45.1	200.21	76.85	34.22	27.19
<i>Bubalus Spp.</i>	Left	YNP 71	63.9	37.22	27.2	29.31	45.28	190.19	71.39	32.86	26.02
<i>Bubalus Spp.</i>	Right	YNP 81	67.8	42.77	29.28	28.91	39.5	190.83	70.32	32.39	24.31
<i>Bubalus Spp.</i>	Left	YNP 99	70.63	45.82	32.01	28.83	43.52	210.65	70.09	34.61	30.15
<i>Bubalus Spp.</i>	Right	YNP 89	60.12	38.61	28.05	25.8	34.38	180.32	65.29	28.23	22.01
<i>Bubalus Spp.</i>	Right	YNP 85	66.12	40.21	29.29	29.38	39.11	200.38	71.89	28.32	25.89
<i>Bubalus Spp.</i>	Right	YNP 90	60	32.67	26.29	23.96	35.49	190.19	63.4	29.22	21.31
<i>Bubalus Spp.</i>	Right	YNP 85	67.23	39.98	29.09	28.31	38.95	200.39	72.01	31.62	25.6
<i>Bubalus Spp.</i>	Left	YNP 94	68.51	39.83	29.15	27.69	40.71	200.39	72.52	33.29	27.69
<i>Bubalus Spp.</i>	Right	YNP 96	67.77	41.4	30.4	30.72	24.98	190.62	70.69	31.23	25.71
<i>Bubalus Spp.</i>	Right	YNP 82	70.05	41.4	30.5	31.1	44.71	180.8	72.21	32.42	24.32
<i>Bubalus Spp.</i>	left	YNP 93	71.69	41.42	33.17	29.69	45.03	200.49	74.44	34.81	24.39
<i>Bubalus Spp.</i>	Right	YNP 95	74.05	43.69	31.55	34.41	46.2	200.83	76.42	33.94	25.8
<i>Bubalus Spp.</i>	Left	YNP 72	64.48	38.73	29.51	27.98	39.05	180.31	68.29	31.84	25.01
<i>Bubalus Spp.</i>	Left	YNP 100	61.89	35.91	28.11	25.12	41.29	180.85	69.29	30.82	26.82
<i>Bubalus Spp.</i>	Right	KMA 673	67.43	40.31	29.09	30.4	40.79	190.05	69.11	32	26.13
<i>Bubalus Spp.</i>	Left	KMA 696	70.05	45.01	31.09	30.91	43.42	198.1	78.98	36.04	23.67
<i>Bubalus Spp.</i>	Right	KMA 573	67.29	39.98	29.69	26.83	44.79	215.5	74.19	34.09	27.21
<i>Bubalus Spp.</i>	Right	KMA 700	69.97	44.26	28.98	28.91	42.92	197.2	73.16	34.59	25.99
<i>Bubalus Spp.</i>	Right	KMA710	63.72	40.29	28.92	25.71	40.29	192	69.49	31.06	21.91
<i>Bubalus Spp.</i>	Left	KMA 701	63.49	39.32	29.29	27.73	40.48	193.2	71.28	33.53	25.37
<i>Bubalus Spp.</i>	Right	KMA 697	69.05	39.52	32.33	29.57	43.48	199.5	74.49	34.69	24.55
<i>Bubalus Spp.</i>	Right	KMA 698	67.79	43.41	29.61	26.3	39.09	195.5	71.52	32.02	22.72
<i>Bubalus Spp.</i>	Left	KMA 669	68.01	37.79	31.25	27.94	43.39	197.8	74.06	34.6	23.93
<i>Cervus Unicolor</i>	Right	KMA 856	39.6	28.4	20	14.5	25.68	223.9	38.81	17.13	18.32
<i>Cervus Unicolor</i>	Left	KMA 857	38.79	27.39	19.69	13.92	26.51	224.1	37.41	18.29	18.23
<i>Cervus Unicolor</i>	Right	KMA 858	39.05	29.63	19.13	14.03	27.47	230	39.28	18.52	17.89
<i>Cervus Unicolor</i>	Right	KMA 859	40.04	28.5	20.75	14.03	18	233	41.8	17	20.02

AN EXPERIMENTAL APPROACH TO ARCHAEO-MORPHOMETRICS

<i>Cervus Unicolor</i>	Right	KMA 860	42	39.7	19.6	12.15	29.7	238.6	41.6	18.05	21.3
<i>Cervus Unicolor</i>	Left	KMA 861	42.41	29.4	18.1	13.05	27.7	231.5	42.5	16.85	21.2
<i>Cervus Unicolor</i>	Right	KMA 862	41.6	30.48	18.55	14.88	27.1	238.5	39.9	17.12	19.6
<i>Cervus Unicolor</i>	Right	KMA 863	41.32	28.71	19.52	13.98	27.88	243.2	38.9	17.14	19.32
<i>Cervus Unicolor</i>	Left	KMA 864	44.5	30.81	18.32	16.9	27.45	240	43.82	19.2	18.95
<i>Cervus Unicolor</i>	Left	KMA 865	40.08	28.3	19.4	14.52	23.5	224.2	39.45	16.83	20.8
<i>Cervus Unicolor</i>	Left	KMA 867	42.2	28.2	18.56	15.02	25.85	240.05	40.76	17.34	18.5
<i>Cervus Unicolor</i>	Right	KMA 254	37.81	28.25	15.5	14	23.23	231	40.12	17.61	18.2
<i>Cervus Unicolor</i>	Left	KMA 254	37.05	27.95	17	13.05	22.79	231	40.23	18.43	18.4
<i>Cervus Unicolor</i>	Right	KMA 868	40.25	28.3	21.06	16.23	24.25	228.05	37.88	16.7	19
<i>Axis axis</i>	Right	KMA 778	23.78	16.1	10.1	11.05	12.8	151	22	9.6	9.8
<i>Axis axis</i>	Left	KMA 843	28.08	18.75	11.5	10.41	15.5	161.5	24.63	10.73	12.1
<i>Axis axis</i>	Left	KMA 845	23.55	16.1	11.85	9	13	150	21.83	9.2	10.64
<i>Axis axis</i>	Left	KMA 779	27.5	19.89	11.1	11.68	16.2	173.8	25.49	10.71	12
<i>Axis axis</i>	Left	KMA 780	27.05	17.9	12.2	10.91	16.3	167.2	25.61	11.39	12.48
<i>Axis axis</i>	Right	KMA 777	28.4	21.1	14.72	10.21	17.7	178	27.19	11.2	13.61
<i>Axis axis</i>	Right	KMA 842	23.5	17.09	11.7	10.08	14.6	155.5	22.2	10.6	10.52
<i>Axis axis</i>	Left	KMA 781	23.73	16.07	12.13	5.6	12.75	161.8	22.39	10.01	10.12
<i>Axis axis</i>	Left	KMA 776	26.38	18.2	12.2	9.23	16.51	176.5	10.9	11	12.29
<i>Cervus Unicolor</i>	Left	KMA 774	35.34	24.41	15.6	11.5	21.68	209.2	34.5	15	16.4
<i>Cervus Unicolor</i>	Right	KMA 773	35.33	25	13.18	17.3	21	212.3	36	16	15.2
<i>Muntiacus muntjak</i>	Left	KMA 870	16.16	11.02	7.48	5.86	11.12	92.29	15.35	6.91	7.01
<i>Muntiacus muntjak</i>	Right	KMA 870	16.09	10.82	7.38	6.21	11.15	92.33	15.52	6.7	7.03
<i>Moschiola meminna</i>	Right	KMA 359	7.59	5.41	3.41	1.19	5.55	36.52	8.69	4.1	2.53
<i>Moschiola meminna</i>	Left	KMA 359	7.41	5.51	3.59	2.19	5.72	35.69	8.91	4.11	2.94
<i>Bubalus Spp.</i>	Left		59.88	35.88	25.67	26.37	40.30	190.80	69.22	32.27	23.41
<i>Bos gaurus</i>	Left		66.14	38.77	33.62	27.22	45.79	240.40	69.29	32.82	30.00
<i>Bos spp</i>	Left		59.35	34.60	25.10	26.10	34.17	184	59.88	27.80	21.21

Metatarsals

Species	Side	CatalogNumber	BP	DP	BM	BL	BS	GL	BD1	BC	BD2
<i>Bubalus Spp.</i>	Left	YNP 67	54.82	46.02	20.41	24.73	37.30	240.32	68.31	30.61	26.81
<i>Bubalus Spp.</i>	Right	YNP 66	55.61	48.01	20.79	20.56	37.93	230.81	69.50	31.39	30.40
<i>Bubalus Spp.</i>	Right	YNP 63	50.81	44.41	19.19	21.00	29.46	220.81	62.00	28.39	27.61
<i>Bubalus Spp.</i>	Left	YNP 61	52.31	41.31	18.29	23.69	30.39	220.80	61.60	27.97	26.10
<i>Bubalus Spp.</i>	Right	YNP 68	53.51	49.01	23.74	23.00	28.20	220.61	65.13	30.12	29.01
<i>Bubalus Spp.</i>	Left	YNP 59	53.61	48.41	28.82	28.40	32.00	230.17	65.91	27.94	27.18
<i>Bubalus Spp.</i>	Right	YNP 60	50.39	44.40	19.89	22.51	32.49	220.59	61.41	28.12	28.20
<i>Bubalus Spp.</i>	Left	YNP 69	54.59	48.49	18.60	25.70	33.61	230.30	68.00	31.00	28.77
<i>Bubalus Spp.</i>	Left	YNP 50	51.51	47.10	18.20	23.39	26.00	230.10	61.06	27.00	28.61
<i>Bubalus Spp.</i>	Right	YNP 70	52.69	47.32	19.97	24.40	34.01	249.90	68.90	31.32	30.10
<i>Bubalus Spp.</i>	Right	YNP 57	50.15	42.12	21.79	16.70	30.13	240.01	61.07	27.69	29.03
<i>Bubalus Spp.</i>	Right	YNP 62	50.69	46.39	19.89	18.30	27.59	230.10	61.51	27.69	28.10
<i>Bubalus Spp.</i>	Right	YNP 47	51.16	46.00	20.10	18.91	27.28	223.50	66.10	29.61	28.90
<i>Bubalus Spp.</i>	Left	YNP 64	50.01	44.28	19.69	19.40	27.20	227.60	61.09	27.90	27.31
<i>Bubalus Spp.</i>	Left	YNP 65	54.10	45.29	18.10	22.89	24.49	222.60	65.01	29.82	24.00
<i>Bubalus Spp.</i>	Left	YNP 52	55.72	48.52	20.03	21.23	32.89	239.20	67.60	30.01	27.51
<i>Bubalus Spp.</i>	Left	YNP 54	53.19	46.62	18.42	23.98	26.62	229.80	63.49	28.50	28.61
<i>Bubalus Spp.</i>	Right	YNP 53	50.62	46.39	14.41	19.59	32.92	222.50	63.38	27.69	27.11
<i>Bubalus Spp.</i>	Left	YNP 42	50.11	46.33	16.31	17.20	31.71	232.50	61.70	27.52	25.01

APPENDIX 1: PRIMARY DATA SET OF BONE MEASUREMENTS

<i>Bubalus Spp.</i>	Right	YNP 58	53.02	52.23	19.49	21.01	35.69	231.52	66.50	29.82	29.09
<i>Bubalus Spp.</i>	Left	YNP 45	50.62	43.70	18.95	15.09	30.61	221.50	60.09	27.71	25.91
<i>Bubalus Spp.</i>	Right	YNP 56	57.35	48.37	19.29	21.97	34.52	220.05	69.72	30.69	30.13
<i>Bubalus Spp.</i>	Right	YNP 83	52.30	46.02	17.51	20.21	33.88	230.05	59.29	27.00	28.31
<i>Bubalus Spp.</i>	Left	YNP 55	50.35	44.94	16.15	20.04	33.02	211.80	62.22	28.43	25.81
<i>Bubalus Spp.</i>	Right	YNP 44	50.50	45.79	19.01	18.89	34.21	220.01	64.82	27.69	27.31
<i>Bubalus Spp.</i>	Right	YNP 46	46.02	40.55	17.70	21.42	28.02	205.30	54.52	24.62	24.46
<i>Bubalus Spp.</i>	Right	YNP 48	55.01	45.91	19.30	24.39	35.79	240.05	67.72	29.82	29.30
<i>Bubalus Spp.</i>	Right	YNP 97	55.71	49.29	20.03	22.62	35.11	242.30	67.63	29.61	28.03
<i>Bubalus Spp.</i>	Left	YNP 43	53.08	47.26	18.29	22.29	33.29	227.90	63.19	26.97	31.31
<i>Bubalus Spp.</i>	Left	YNP 41	51.10	43.02	16.72	21.88	34.59	222.75	66.90	38.97	34.32
<i>Bubalus Spp.</i>	Left	YNP 49	53.09	46.81	17.79	23.00	37.89	236.50	69.50	30.67	32.10
<i>Bubalus Spp.</i>	Left	YNP 102	56.11	47.98	19.33	22.82	36.70	258.50	70.01	31.92	32.42
<i>Bubalus Spp.</i>	Right	YNP 51	56.39	48.32	19.41	23.49	37.78	238.70	67.62	29.61	29.01
<i>Bubalus Spp.</i>	Left	KMA 668	55.81	47.14	18.72	23.01	38.79	241.90	70.19	31.04	32.72
<i>Bubalus Spp.</i>	Right	KMA 667	51.42	48.91	21.72	24.78	36.89	237.50	69.15	31.62	31.68
<i>Bubalus Spp.</i>	Right	KMA 695	52.92	46.01	22.19	24.93	37.32	249.50	67.97	29.34	28.48
<i>Bubalus Spp.</i>	Left	KMA 674	57.59	50.48	24.49	17.12	35.69	228.30	67.91	30.60	28.34
<i>Bubalus Spp.</i>	Left	KMA 675	59.39	48.19	28.30	23.32	36.61	242.30	68.98	30.99	30.98
<i>Bubalus Spp.</i>	Left	KMA 695	53.08	45.01	18.29	21.82	35.28	232.60	69.07	31.00	30.51
<i>Bubalus Spp.</i>	Left	KMA 699	64.29	40.72	30.91	26.54	41.52	195.20	70.59	30.61	26.39
<i>Cervus Unicolor</i>	Right	KMA 765	37.61	36.3	12.92	16.62	26.67	259.5	37.49	15.92	25.61
<i>Cervus Unicolor</i>	Left	KMA 772	39.98	37.52	14.69	16.1	28.02	261.1	37.72	16.09	22.59
<i>Cervus Unicolor</i>	Right	KMA 768	38.98	36.51	14.92	15.29	35.69	261.1	39.5	17.11	22.25
<i>Cervus Unicolor</i>	Left	KMA 770	37.79	34.99	12.75	15.29	23.65	255.9	37.81	15.89	22.83
<i>Cervus Unicolor</i>	Left	KMA 769	35.32	31.19	13.39	13.29	23.41	240.89	34.29	15	24.91
<i>Cervus Unicolor</i>	Right	KMA 766	36.48	35.09	14.21	15.91	24.89	251.5	36.22	16.34	22.07
<i>Cervus Unicolor</i>	Left	KMA 771	38.39	37.68	12.96	16.71	24.86	260	37.25	16.5	22.13
<i>Cervus Unicolor</i>	Right	KMA 767	38.05	35.19	14.08	16.14	25.61	257.5	36.38	16.41	21.71
<i>Cervus Unicolor</i>	Right	KMA 764	37.81	28.25	11.5	12.6	23.8	264.5	40	15.69	20.75
<i>Cervus Unicolor</i>	Left	KMA 866	32.82	34	11.6	11.35	23.05	236.9	36.11	16	20.04
<i>Cervus Unicolor</i>	Left	KMA 254	35.75	37.5	10	12.25	24.1	262	41.2	16.8	20.9
<i>Cervus Unicolor</i>	Right	KMA 871	36.5	37	10	10.6	25.45	251.5	38.9	16.15	20.5
<i>Cervus Unicolor</i>	Right	KMA 254	37.81	28.25	11.5	12.6	23.8	264.5	40	16.69	20.75
<i>Axis axis</i>	Right	KMA 775	22.79	23.72	8.41	9.87	16.05	193.1	25.69	11.4	13.5
<i>Muntiacus muntjak</i>	Right	KMA 869	16.11	16.28	6.01	6.93	10.69	124.89	16.92	7.02	8.92
<i>Muntiacus muntjak</i>	Left	KMA 869	15.69	15.36	6.29	6.79	10.41	125.5	17.19	6.88	7.72
<i>Muntiacus muntjak</i>	Left	KMA 870	16.16	16.31	5.59	7.21	11.1	119.91	16.59	7.06	9.01
<i>Muntiacus muntjak</i>	Right	KMA 870	16.08	15.16	6.12	6.94	11.16	119.24	16.32	7.21	9.16
<i>Moschiola meminna</i>	Right	KMA 359	8.81	8.01	3.13	2.19	5.63	57.11	10.72	5.29	3.72
<i>Bos spp</i>	Right	KMA 872	43.1	37.92	17.6	17.3	21.4	235	46.11	20.3	21.6

Appendix 2: Bone terminology

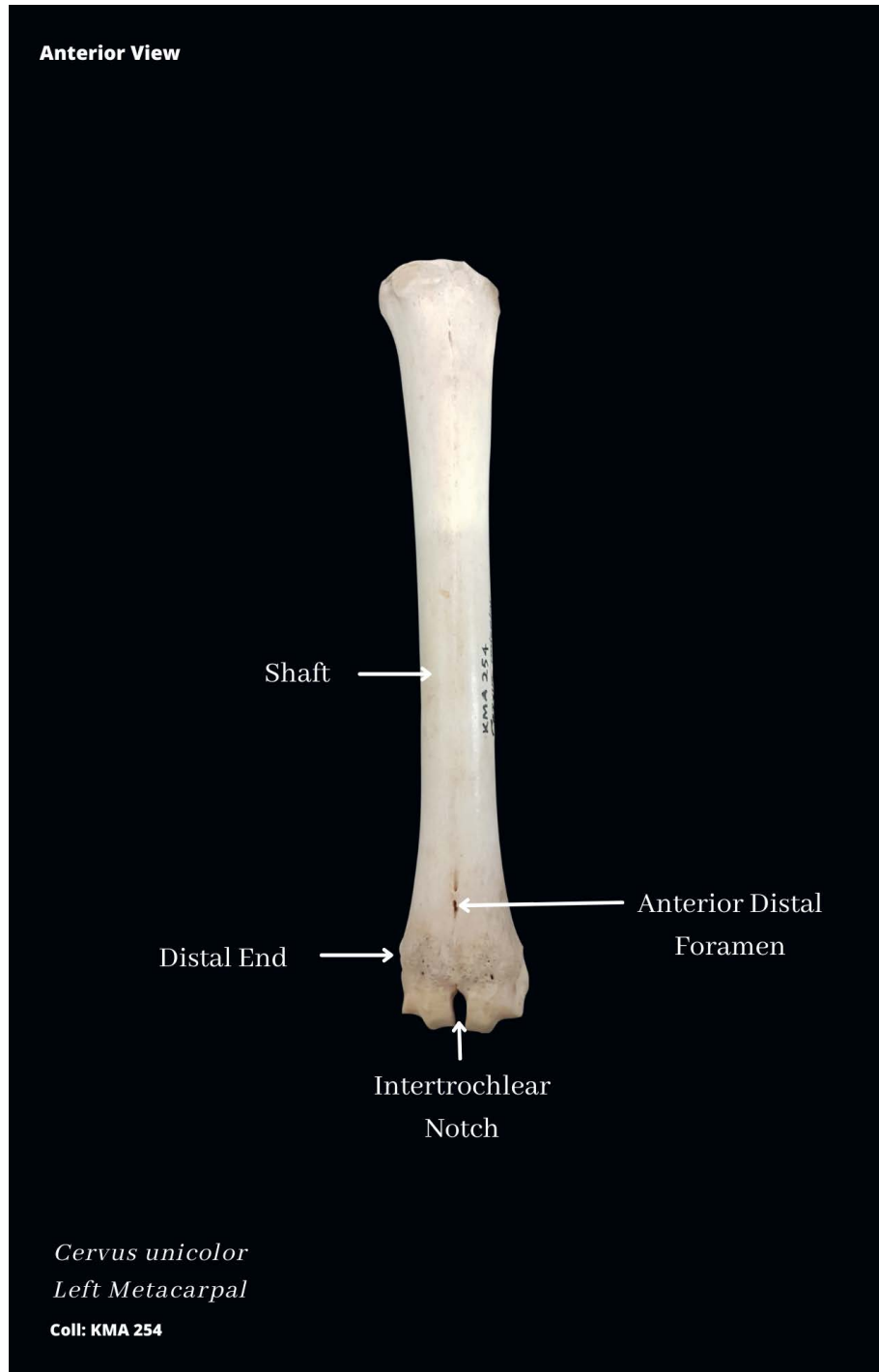


Figure 20: *Cervus unicolor* metacarpal - anterior view (L)

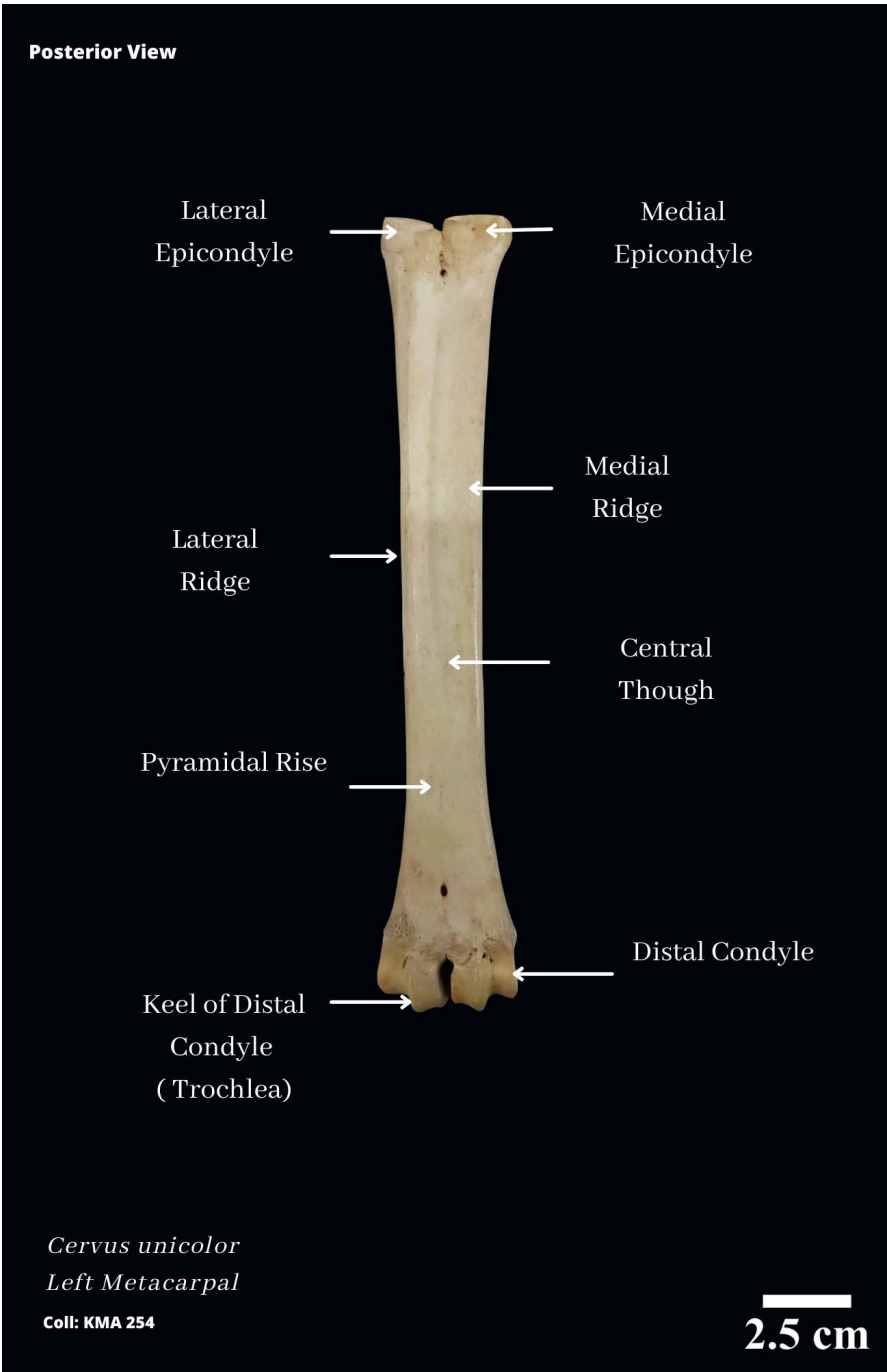


Figure 21: Cervus unicolor metacarpal - posterior view (L)

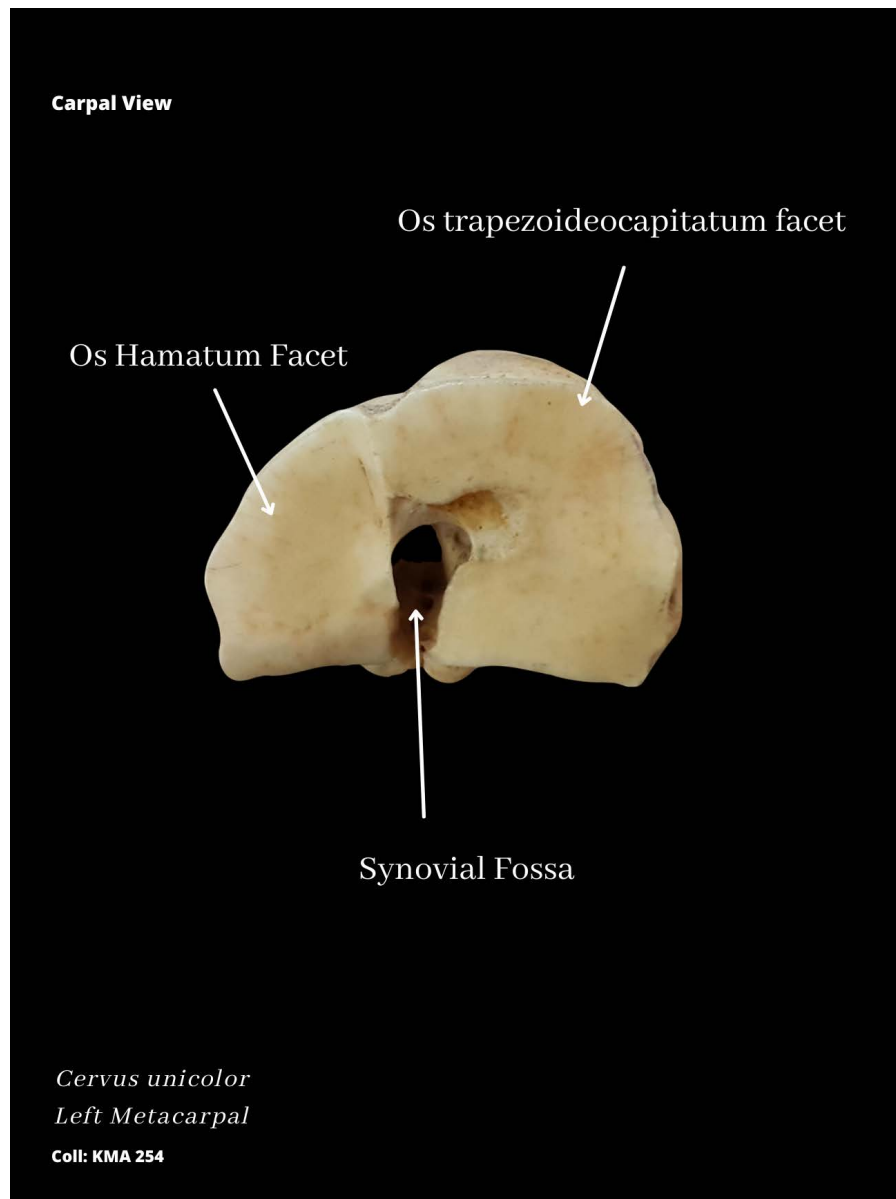


Figure 22: *Cervus unicolor* metacarpal - carpal view (L)

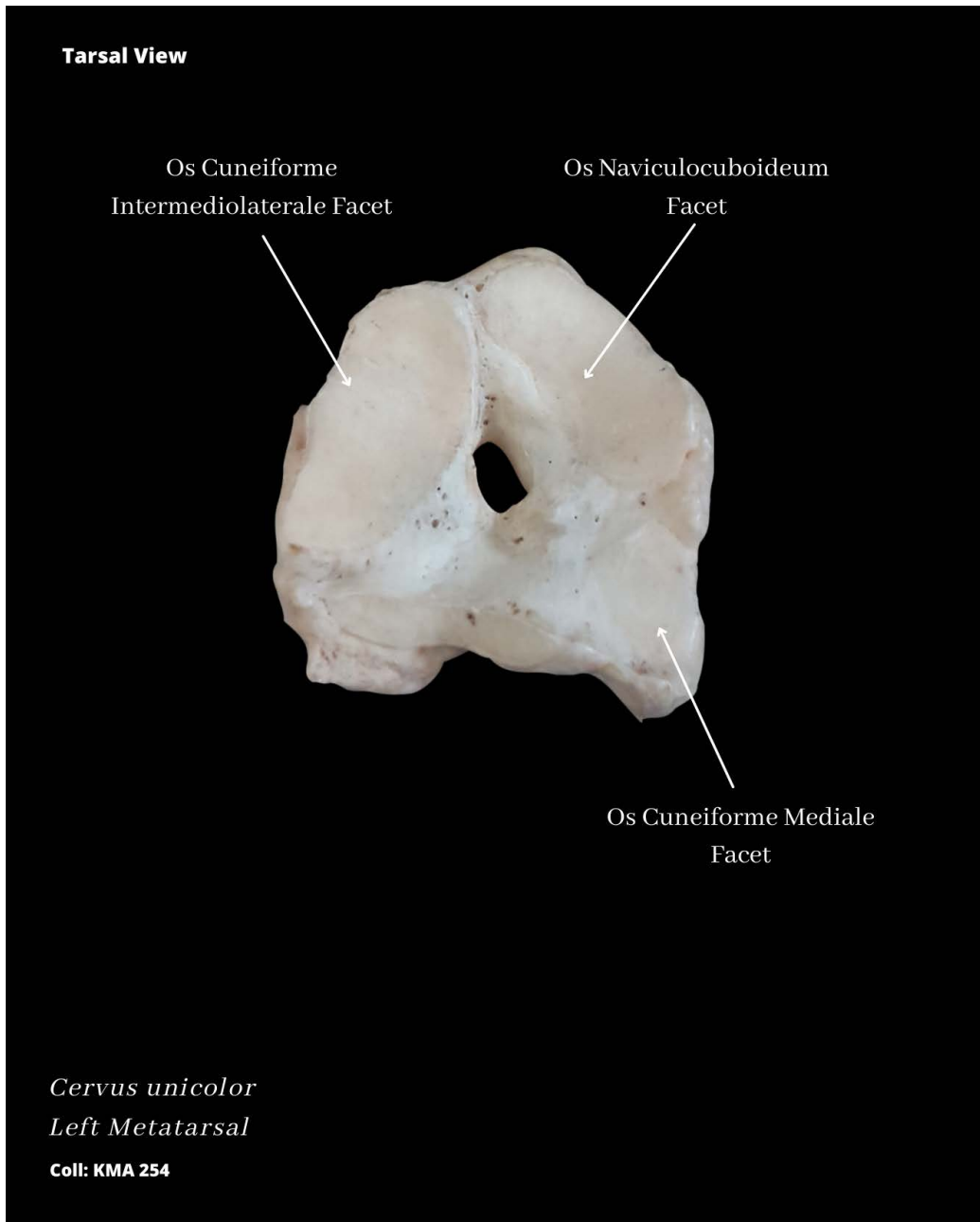


Figure 23: *Cervus unicolor* metatarsal - tarsal view (L)

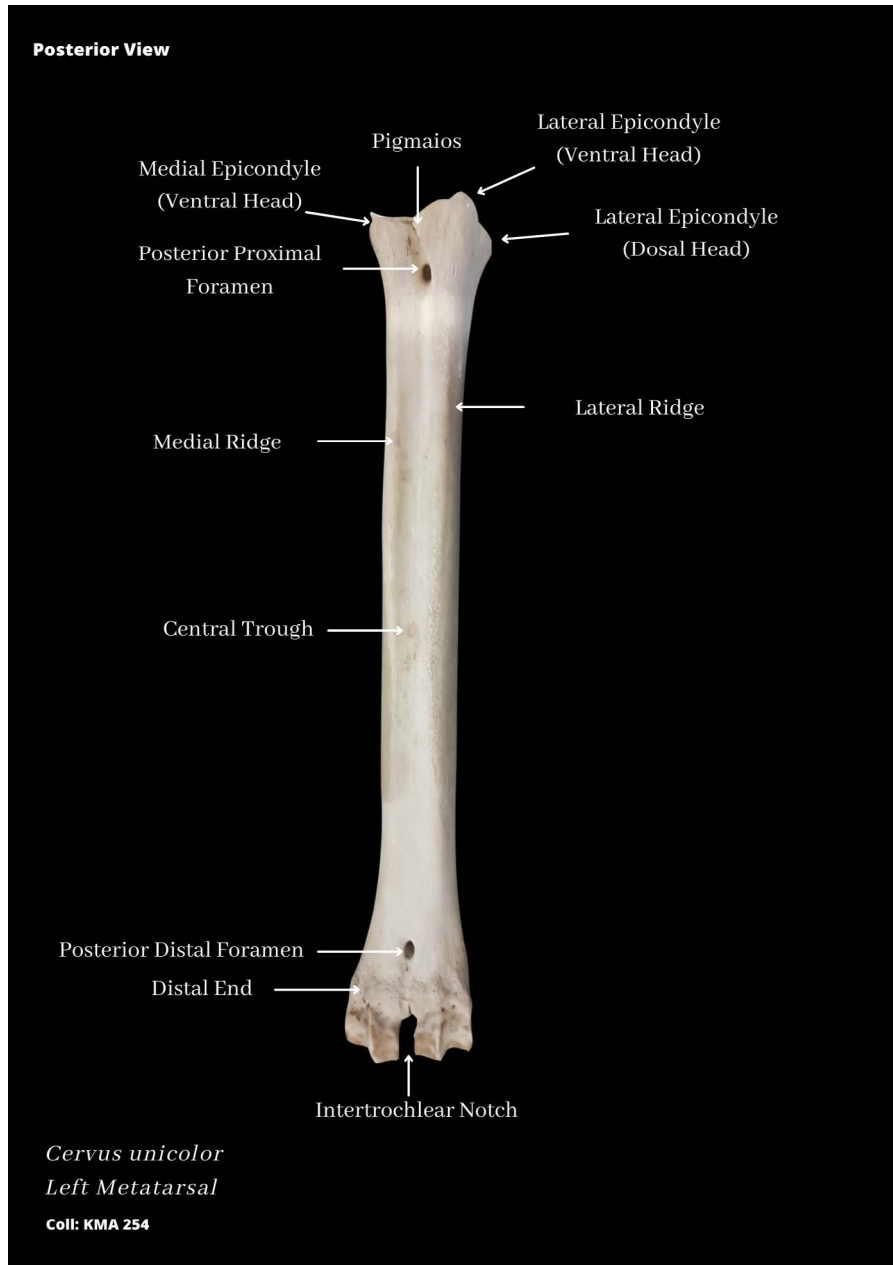


Figure 24: *Cervus unicolor* metatarsal - posterior view (L)

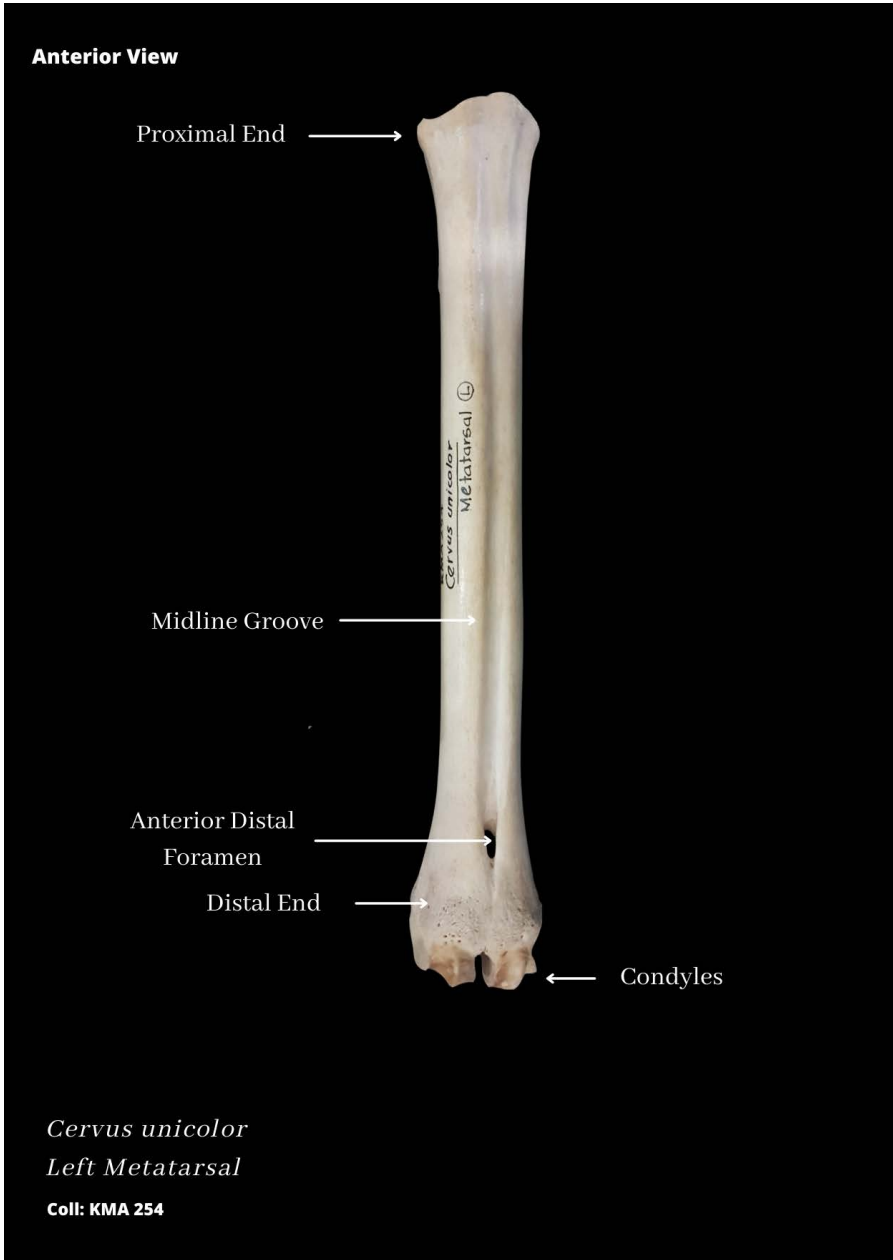
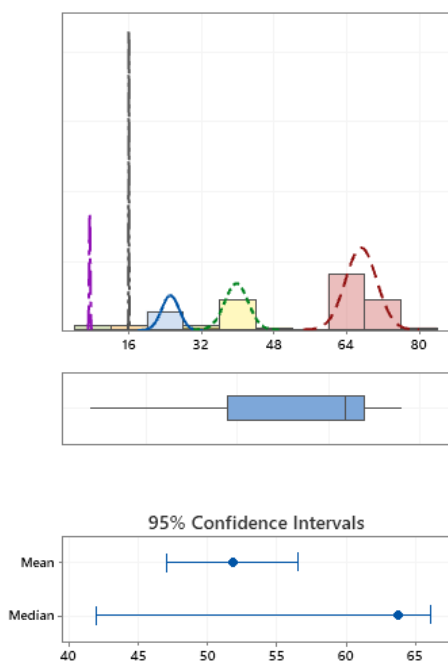


Figure 25: Cervus unicolor metatarsal - anterior view (L)

Appendix 3: Summary report for BP, DP, BM, BL, BS, GL, BD1, BC, BD2

Summary Report for BP



Anderson-Darling Normality Test

A-Squared	4.13
P-Value	<0.005
Mean	51.786
StDev	19.402
Variance	376.444
Skewness	-0.649413
Kurtosis	-0.936012
N	67

Minimum	7.410
1st Quartile	37.810
Median	63.720
3rd Quartile	67.770
Maximum	76.130

95% Confidence Interval for Mean

Lower Bound	47.053
Upper Bound	56.519

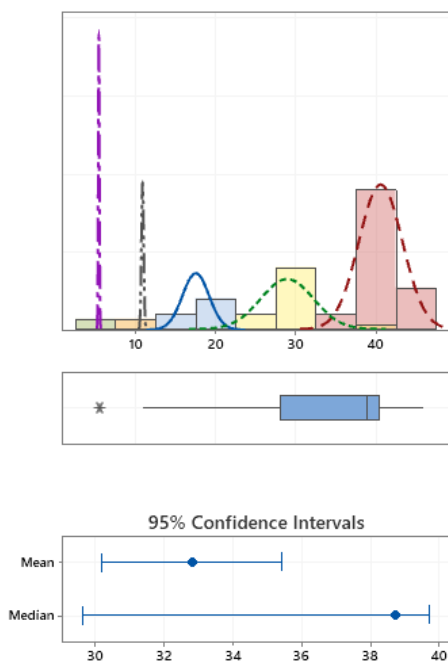
95% Confidence Interval for Median

Lower Bound	41.993
Upper Bound	66.012

95% Confidence Interval for StDev

Lower Bound	16.583
Upper Bound	23.385

Summary Report for DP



Anderson-Darling Normality Test

A-Squared	3.19
P-Value	<0.005
Mean	32.809
StDev	10.724
Variance	115.001
Skewness	-0.914983
Kurtosis	-0.174159
N	67

Minimum	5.410
1st Quartile	27.950
Median	38.730
3rd Quartile	40.310
Maximum	45.900

95% Confidence Interval for Mean

Lower Bound	30.193
Upper Bound	35.425

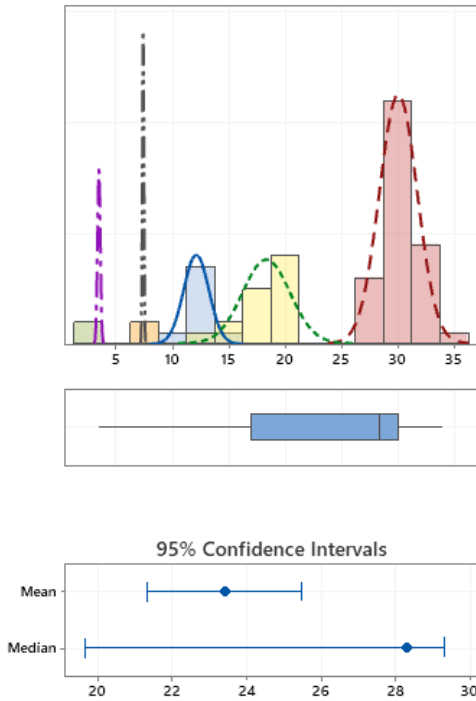
95% Confidence Interval for Median

Lower Bound	29.626
Upper Bound	39.700

95% Confidence Interval for StDev

Lower Bound	9.166
Upper Bound	12.925

Summary Report for BM



Anderson-Darling Normality Test

A-Squared	3.58
P-Value	<0.005
Mean	23.413
StDev	8.476
Variance	71.848
Skewness	-0.691670
Kurtosis	-0.793704
N	67
Minimum	3.410
1st Quartile	17.000
Median	28.290
3rd Quartile	30.010
Maximum	33.910

95% Confidence Interval for Mean

21.346 25.481

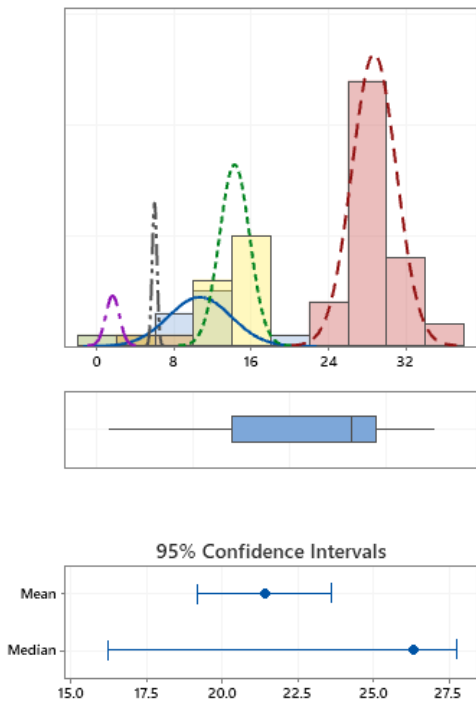
95% Confidence Interval for Median

19.689 29.280

95% Confidence Interval for StDev

7.245 10.217

Summary Report for BL



Anderson-Darling Normality Test

A-Squared	3.44
P-Value	<0.005
Mean	21.397
StDev	9.099
Variance	82.791
Skewness	-0.46919
Kurtosis	-1.17399
N	67
Minimum	1.190
1st Quartile	13.920
Median	26.300
3rd Quartile	28.910
Maximum	35.000

95% Confidence Interval for Mean

19.177 23.616

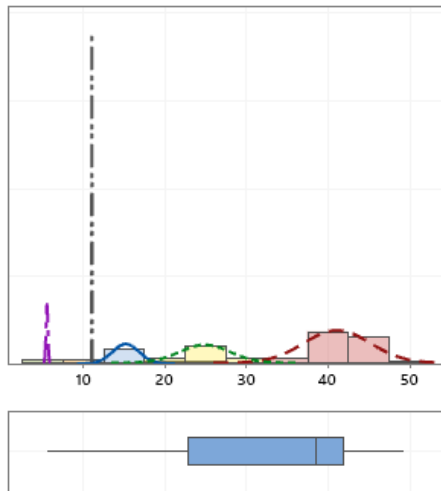
95% Confidence Interval for Median

16.210 27.733

95% Confidence Interval for StDev

7.777 10.967

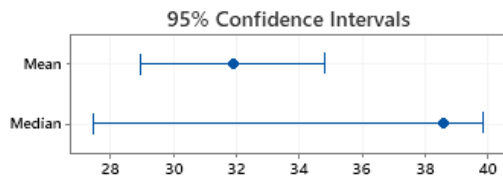
Summary Report for BS



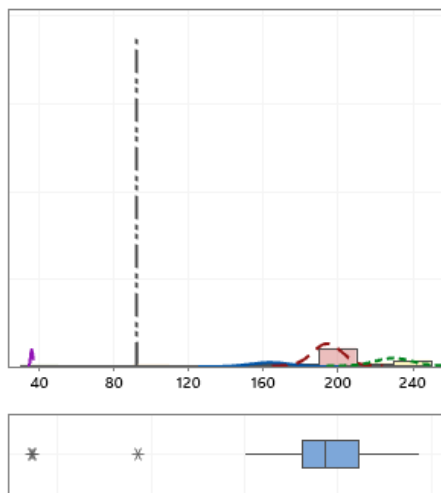
Anderson-Darling Normality Test

A-Squared	2.71
P-Value	<0.005
Mean	31.872
StDev	12.033
Variance	144.784
Skewness	-0.54497
Kurtosis	-1.02810
N	67
Minimum	5.550
1st Quartile	22.790
Median	38.550
3rd Quartile	41.810
Maximum	49.290

95% Confidence Interval for Mean	28.937	34.807
95% Confidence Interval for Median	27.444	39.816
95% Confidence Interval for StDev	10.284	14.503



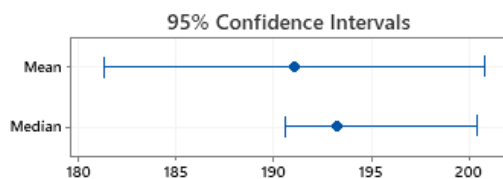
Summary Report for GL



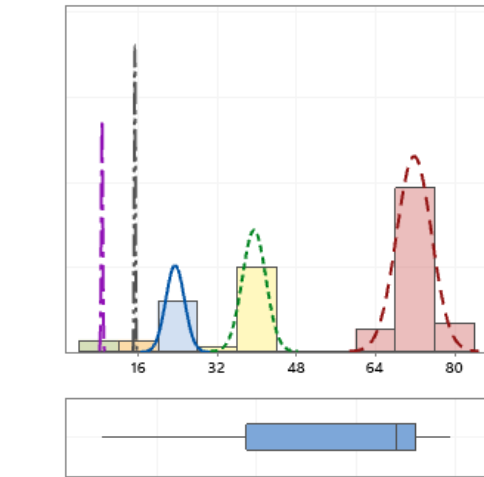
Anderson-Darling Normality Test

A-Squared	3.93
P-Value	<0.005
Mean	191.05
StDev	39.62
Variance	1570.11
Skewness	-2.13407
Kurtosis	6.28953
N	67
Minimum	35.69
1st Quartile	180.85
Median	193.20
3rd Quartile	210.65
Maximum	243.20

95% Confidence Interval for Mean	181.39	200.72
95% Confidence Interval for Median	190.62	200.38
95% Confidence Interval for StDev	33.87	47.76



Summary Report for BD1



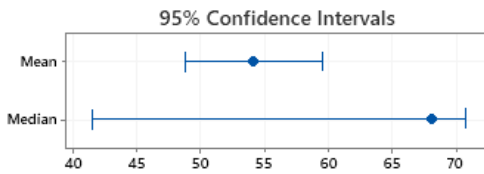
Anderson-Darling Normality Test

A-Squared	4.65
P-Value	<0.005
Mean	54.113
StDev	21.853
Variance	477.563
Skewness	-0.56418
Kurtosis	-1.21564
N	67
Minimum	8.690
1st Quartile	37.880
Median	68.010
3rd Quartile	72.010
Maximum	78.980

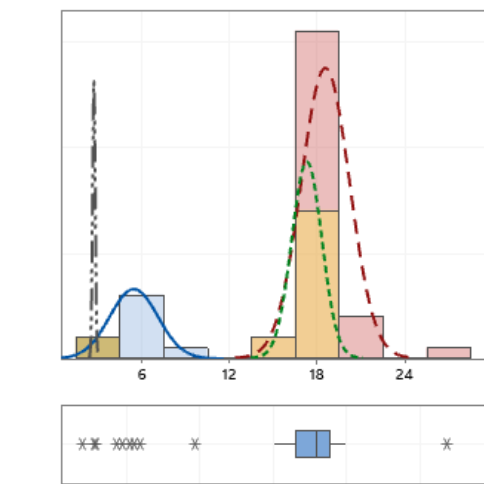
95% Confidence Interval for Mean
 48.782 59.443

95% Confidence Interval for Median
 41.586 70.700

95% Confidence Interval for StDev
 18.678 26.340



Summary Report for BC



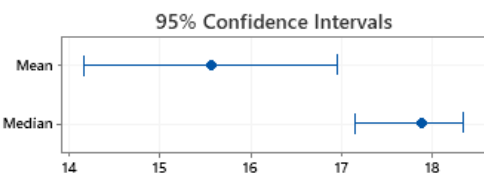
Anderson-Darling Normality Test

A-Squared	9.42
P-Value	<0.005
Mean	15.558
StDev	5.715
Variance	32.658
Skewness	-1.37315
Kurtosis	0.71398
N	67
Minimum	1.910
1st Quartile	16.490
Median	17.880
3rd Quartile	18.810
Maximum	26.910

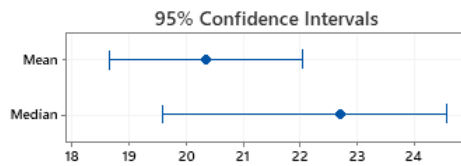
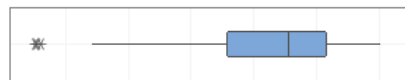
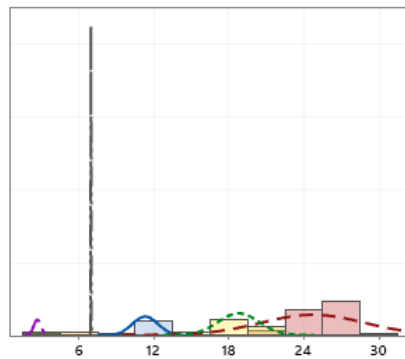
95% Confidence Interval for Mean
 14.164 16.952

95% Confidence Interval for Median
 17.140 18.331

95% Confidence Interval for StDev
 4.884 6.888



Summary Report for BD2



Anderson-Darling Normality Test

A-Squared	2.83
P-Value	<0.005
Mean	20.351
StDev	6.916
Variance	47.834
Skewness	-1.03561
Kurtosis	0.21194
N	67
Minimum	2.530
1st Quartile	17.890
Median	22.700
3rd Quartile	25.710
Maximum	30.150

95% Confidence Interval for Mean

18.664	22.038
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95% Confidence Interval for Median

19.595	24.556
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95% Confidence Interval for StDev

5.911	8.336
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Appendix 4: Exclusion of *Sus scrofa*

Although *Sus scrofa* belongs to the same order, artiodactyl, they have different metapodials from other animals that are mentioned in the text. Their metapodials are related to the structure of *Homo sapiens*.

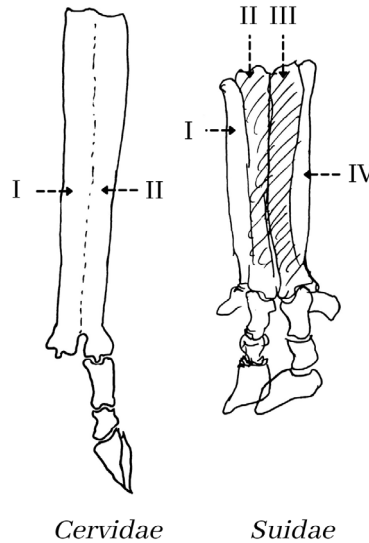


Figure 26: Articulation of metapodials: Cervidae vs Suidae (K. Manamendra-Arachchi del)

It has four metapodia (II–V present) on each foot. The third and fourth metapodia are larger central metapodia, while the second and fifth metapodia are smaller.



Figure 27: Human third and fourth left metacarpals (anterior views) are compared to adult pig left third and fourth metacarpals (dorsal views)



Figure 28: Human third and fourth left metatarsals (superior views) are compared to adult pig left third and fourth metatarsals (dorsal views)

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