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Neharika Penmetcha April 9, 2019

Zooarchaeological Faunal Identifiability: Using GIS Technology to Facilitate Analysis of Gracile Long Bone Specimens

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Abstract
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Zooarchaeological analysis aims to identify the majority of represented skeletal elements within a given sample. Although research has shown that some fragments have areas with greater diagnostic value than others thanks to distinctive features, little research has been conducted to quantify that relationship. If proper analysis on how bone portion (location on bone where fragment came from) and relative size affects identifiability, then the zooarchaeological community can more accurately determine the frequency of specific skeletal elements at a site. This study attempted to quantify the ability to identify skeletal elements from bone fragments through its shape, size, and location on bone (bone portion) through GIS software and comment on the efficacy of such a strategy. Materials came from gracile goat limb bones from Stephen Merritt and Davis 2017 research on fragmentation and butchery. Each fragment was assigned to an identifiability ranking with 1 being the most identifiable to side, element and portion and 5 being the least to only class of animal such as mammalian. Each individual specimen was labeled and characterized on the geospatial template and then converted to pixelated IDcat values. Then each subsequent layer of the same element type was aggregated and averaged to visually assess which regions are more identifiable than others. Results suggest that relative specimen size (percent size of fragment relative to total bone) is positively related to identifiability, meaning the bigger the size of the fragment, the better it is to identify it. Most elements had more identifiable areas around the epiphyseal ends and less in the midshaft areas across all long bones. The data and methodology were spatial in nature, but certain calculations through the python coding language aided in the analysis of the question. Although the results obtained in the frame of this project are still at a preliminary stage, it still demonstrates the high potential of exploring and extending the methods and calculations in GIS to a possibly larger sample of specimens and case studies in zooarchaeological skeletal identifiability.

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Introduction

Archaeologist Sarah Parack once wrote, “Archaeology holds all the keys to understanding who we are and where we come from” (Leber & Leber, 2014). The collection, identification, and interpretation of material culture is the primary scope of how archaeologists interpret the past. Archaeology is defined as the study of human history through physical remains. Zooarchaeology can then be defined as the study of organisms that humans have interacted with in the past.

Zooarchaeology extracts knowledge of past remains through evidence, analogies, and methodologies. The field weaves geology, anatomy, zoology, and technology in innovative and encompassing ways. For zooarchaeology, the main goal of development is within identifying and quantifying skeletal part profiles. These profiles can reveal the biography of animal and human behavior.

However, the fragmentary nature of these skeletal parts can make identification and reconstruction challenging. Although most zooarchaeologists are equipped with enough osteology knowledge to accurately identify these fragments, this interpretive approach to faunal assemblages is argued to be too subjective (Gifford-Gonzalez, 2018). Some fragments retain enough morphological features that provide clues to which element it belongs to, while other fragments can be mistaken to the wrong element. Therefore, zooarchaeologists aim to use quantitative methods that rely less on expert opinion and more objectivity to be replicable. The degree to which fragments can be accurately identified and the number of individuals

represented within a given assemblage is still unstandardized in the field causing problems in the validity and reliability of data (Gifford-Gonzalez, 2018).

Zooarchaeologists hypothesize that the identifiability of any fragment is a function of both its shape and size (Gifford-Gonzalez, 2018). This study attempts to analyze and quantify that relationship and test how identifiable a fragment is from its shape, size, and portion on a bone by using experimental remains from butchered goats. In order to identify the relationships between fragment size, fragment location (on the bone), and fragment frequency, a specialized Geographic Information System (GIS) toolbox called Faunalyze (Fisher et al., 2017) which characterizes fragments into pixel images, was used. Rather than simply drawing out the fragments on sheets, the software allows fragments to be characterized and visually see where each piece overlaps on raster addition. This technique is valuable because it reduces the subjective biases of the researcher by characterizing fragments spatially on a computer, thereby showcasing the location of the fragment on the bone. This process has the potential to pave a more standardized path to future zooarchaeological faunal analysis.

Zooarchaeology- a vital discipline

Human beings and animals have always lived in close proximity, but with the advent of farming, their relationship has become more nuanced and complex(Gifford-Gonzalez, 2018). Zooarchaeology concerns itself with the relationship between human beings and the animals they interact with (Sutton et al., 2010). The way humans bring animals close to themselves can create a symbiotic relationship. The rise of farming and how animals were incorporated into farming lifestyle has long been the subject of study for archaeologists (Sutton et al., 2010).

Often, these animals showed very distinct changes in behavior and morphology. In a study by Cucchi et al. (2011), authors found that as Neolithic pigs were domesticated in China, their teeth became smaller, fewer in number, and lost their shaggy/rough appearance -- thereby becoming more docile and tame than their feral ancestors. Essentially, they had adapted to the human setting. By observing and analyzing these changes in animals, zooarchaeology researchers were able to infer the ways in which farming has spread and been adopted by different groups. The study of humans from the past, by definition, is the study of the world in which they were living. Animals have always played a role in humanity through consumption, predator/prey conflicts, labor, or more abstract relationships, such as for entertainment (in the context of circuses, for instance) or as pets. Therefore, if archaeologists want to understand the past, the study of animals is not only useful but vital.

Related fields

It is important to distinguish between the fields of zoology, paleontology, zooarchaeology, and archaeozoology, as they are often misunderstood. Zoology and zooarchaeology are both the study of animals. Zoologists analyze the life of animals through ecological contexts(Gifford-Gonzalez, 2018). Both study animals with detailed understandings of the anatomy, physiology, and behavior of their particular species. However, zooarchaeology focuses primarily on fossils whereas the focus of zoology is almost exclusively on living organisms (Gifford-Gonzalez, 2018).

Paleontology is often confused with zooarchaeology because the work of these professionals overlaps so frequently. Both zooarchaeology and paleontology study fossils of

animals, but paleontology studies a much older time frame than zooarchaeology. Paleontologists uncover and study fossils in an attempt to understand life before the rise of hominids and most organisms (Gifford-Gonzalez, 2018). Zooarchaeologists also study fossils, but do so specifically in relation to humans and their history.

In the literature, zooarchaeologists and archaezoologists are often interchanged as synonymous nouns. It is not entirely clear if the fields are actually different, they may be one subset of another. Both fields focus on the evaluation of faunal materials from archaeological sites, but differ slightly in their primary reasons for analysis. Zooarchaeology is described as more archaeological whereas archaeozoology is rather zoological in its interest with ecological context (Gifford-Gonzalez, 2018). Therefore, the project constructed for this thesis would be considered a more zooarchaeological study . Although these disciplines are different in their own right, they can be bridged to help inform one another. The study of archaeology and science itself is inherently collaborative. Disciplines can build on their specialized knowledge to tackle different aspects of a research question.

History and Development of Zooarchaeology

Zooarchaeology is a relatively new subfield of archaeology. Historically, animal bones found in archaeological sites were often discarded. However, scholars slowly began to understand the importance of including animal remains within analysis. Gordon Willey and Philip Phillips (1967) in their book, Method and Theory in American Archaeology, state the history of archaeology in North America can be broken up into three periods: a Formative Period (1880–1951), a Systematization Period (1950–1969), and an Integration Period (1960s–present).

The Formative Period was primarily interested in the cultures of European settlements in the North Americas such as Jamestown and Virginia (Willey & Phillips, 1967). This period analyzed how Early-European settlers developed food, weaved pottery, and transformed their technologies within agriculture. This was a period of growing institutionalism within the field of zooarchaeology. Archaeologists at the time did not collect faunal remains, but rather used the remains to document nutrition and disposed the remains afterwards (Willey & Phillips, 1967).

Slowly, the importance of faunal remains permeated within the scientific community and prompted more systematic collection . Thus, the Systemization Period was born and archaeologists began viewing faunal remains as a means toward acquiring information about culture and ecology (Willey & Phillips, 1967). This is also where one of the pioneers to zooarchaeology, Theodore E. White, introduced the quantitative concept of Minimum Number of Individuals (MNI) in a collection, while he explored the species percentage within the diets of natives in the Woodland and Upper Republican areas of Colorado (Willey & Phillips, 1967). This mode of quantification transformed zooarchaeology methodology because it showed how many individuals within one species are represented in an assemblage. Although the term "MNI" was coined by paleontologists two decades prior to White's study, he was the first to use the concept in a systematic matter to answer paleontological questions (Willey & Phillips, 1958). He demonstrated that anthropologists could deduce significant information about human behavior from the remains of modern mammals and that they were as important of a study as extinct species. This was also the time in which White and other early specialists from the University of Tennessee started training individuals as zooarchaeologists which paved the way for the profession to become legitimate (Willey & Phillips, 1958). However, this period is also heavily criticized for making broad generalizations of human subsistence based on a small

collection of data . This may have been a standard practice at the time because research methods had little to no standardization.

The shift from an inductive to a more scientific deductive approach marked the Integration Period which includes modern day study. Notable studies within this period use existing facts to explore and broaden the field of anthropology. This is the time where zooarchaeology data is supposed to be "fully" integrated into anthropological reports. This includes the 1980's development of post-processual archaeology where inquiries were webbed with alternative perspectives such as history, gender, materiality and identity. However, the Integration Period is still developing (Landon, 2009). The discrepancy lies in the fact that zooarchaeology data and analysis is not incorporated to its fullest potential (Landon, 2009). Standardization will be the key to accuracy and development of the field within archaeology. While the early generation of specialists were simply interested in the bones and not the context, almost all zooarchaeologists today are trained in anthropological analysis.

Important Terms

Some important archaeological terms should be defined for the non-analyst. A site is the location of an excavation or subject of analysis for the zooarchaeologist. A collection of objects from an archaeological site is known as an assemblage (Gifford-Gonzalez, 2018).This term is not specific to animal bones. Stones tools from archaeological sites are referred to as lithic assemblages. They separated in order for each respective specialist. Fauna is the taxa or in other words animals of a particular area (Gifford-Gonzalez, 2018). Therefore a faunal assemblage is the recovered animals from an area. Element is an anatomical unit, but a specimen is the actual

archaeological remain of an element (Gifford-Gonzalez, 2018). The goals of faunal analysis is to identify the animal remains from sites such as bones, shells, teeth etc. From this information, archaeologists can then deduce patterns in diet, environment, and culture of the humans who utilized these animals.

Theory, Methods, and Scope

Faunal analysis investigates the accumulation of bones within an archaeological site. Faunal remains, usually the table remains of prepared meat (e.g. cow, chicken, pig), can give key insights into pastoralism and identify which species were being raised as the catalysts to various economies. There are also other kinds of faunal remains called commensal species (O'Conner 2017). Commensal species or civilization followers are animals that come as a result of finding food within these populations, such as rats, rodents, and birds (O'Conner 2017). The presence of these followers commonly leads to another phenomenon coined "community in death"(Pitman, D., & Doonan, R, 2018) where various species can come together and die in one place . For instance, considering a snake that is not normally a civilization follower, but it comes to the site because there are mice. The mice are there, because the grain is there. The grain is there, because the humans are eating it. Therefore, zooarchaeology is not only interested in the bones, but in what the bones can tell about the people, ecology, and environment.

By far the most dominant species that zooarchaeologists find in domestic faunal analysis within central Asia and Africa are the bones of sheep and goats (Godwin et al., 2002). Therefore, the experimentally butchered goat is a good model organism to construct a more refined method of identification analysis. Most zooarchaeologists check their work through a comparative

collection which is characterized as an assemblage of template bones (Gifford-Gonzalez, 2018). A fragmented piece will be compared to the whole in order to see where it fits logistically. Usually, within excavation recovery, the hardest elements survive. These elements often include long bones and teeth. All mammals have long bones (humerus, femur, tibia, etc). All long bones have three parts: proximal (close to the body), distal (far away from the body), and shaft (in between). Distinguishing between the long bones of sheep and goats is a particular hardship for zooarchaeologists even with each animal's distinct morphologies (size, shape, and texture). Nevertheless, morphological criteria are extremely important within zooarchaeological analysis. Sheep have significantly longer tibia bones than goats and are generally more robust (Godwin et al., 2002). Thus, one small characteristic can be the determining factor in identifying one species from another.

Identifiability and Fragmentation

There are 206 bones in the human skeleton and approximately 189 in the average goat. The challenge would be to identify as many as possible for zooarchaeology. During identification processes, it is often rare to find bones that are complete (Gifford-Gonzalez, 2018). Most of the time the bones have been smashed, degraded, and worn down through the sediment. However, the bones can still be identifiable through their diagnostic parts. Those parts are generally investigated through diagnostic features and articulations . The shafts on most long bones are generally very rough, because these are the places where strong muscles are attached.

Another primary objective in zooarchaeological analysis is to identify the majority of the represented faunal skeletal elements (e.g., a humerus, metacarpal, femur) and determine the taxa

present within a given sample. Although it may not be possible to identify fragments all the way to species and elemental level, it is still a goal in order to extract useful information about the environmental implications of the specimen. Correct identification of animal remains can help us understand a variety of contexts in the study of butchery practices in past societies such as hunting patterns, social organization, and resource-use (Abe et al., 2002). The levels of element identifiability vary in archaeological analysis with the most general level being identification of a specific skeletal element. These identifications are based on visual clues on fauna such as zones and features. For example, Marean et al. (2001) defines features as "anatomical landmarks such as nutrient foramina" whereas zones are "larger featureless areas that nonetheless can be recognized by their shape and general configuration" (pg. 337).

Certain clues can help inform us about what skeletal part and taxon the fragment came from. For instance, a proximal humerus shaft on a goat is readily identifiable due to its surface character, shape, and texture (Merritt & Davis, 2017). Thus, certain portions and locations on the long bone are more identifiable than others. Our ability to identify skeletal elements and taxa through fragmented pieces of bone is crucial to reconstructing ancient butchery practices. Complete bones will be easier to identify than smaller ones. Determining the class of a bone helps narrow the range of possibilities of the element that it represents. Complete elements of a bone are the easiest to identify, but in many cases, even small fragments of a bone contain enough diagnostic morphology (features and zones) that allow for identification. It is therefore important to identify the element accurately to establish the quantity of each element that is actually represented in an assemblage. For example, four humeri fragments do not necessarily equate to four humeri.

What is it? And How Do We Know?

A fundamental concept to all zooarchaeologist is to identify the materials they have excavated. Within the field, there is little scrutiny with the way faunal elements are identified. Most zooarchaeologists rely on expert knowledge in identifying fragments, which is knowledge possessed by zooarchaeologists who have become experts in their domain (Landon, 2009). The knowledge is taught in academia and passed down in field projects, but is increasingly coming under criticism, because it is amorphous and difficult to quantify. This identification knowledge varies from person to person and from experience, background, and collection comparisons within the specific assemblages and animals. In principle, you could have two zooarchaeologists investigating an assemblage of 100 bones, identify 80 of them the same way and have 20 that are different. One might say a fragment is a right humerus whereas the other might say that it is simply a humerus and that side cannot be deduced. Therefore, archaeologists may identify the same animal and bone, but differ on specificity.

Often, size is presumed to affect identifiability, but it is uncertain how. Intuitively, the bigger the bone, the bigger the fragment must be in order to identify it. Reitz & Wing (2008) argue that this assumption is actually problematic and that, "one cannot assume either that small specimens are unidentifiable or that all large specimens are identifiable…[for example], the atlas of a killifish is as distinctive as the humerus of an elephant if one is familiar with morphology"(pg. 154). In short, a small fragment in a large animal can be identified depending on from where it comes.

One problem in interspecies identifiability is that some animals are more difficult to identify than others as with the case of sheep and goat mentioned earlier. In addition, constraints such as limited time or finances could prompt some researchers to put less effort into the analysis of specimens that are not as important to their research question. While it may be unrealistic to require studies to analyze all specimens equally, it is still a standard for which all zooarchaeology should strive. Moreover, some research uses restricted identification lists for comparability (Reitz & Wing, 2008). Although these restrictions are always accounted for, it still skews the representation of various species within an assemblage.

The nature of the assemblages could also affect the degree of identifiability. Each species do not fragment the same way. In the Later Stone Age site of Likoaeng, fish were less fragmented than non-fish. In the subsequent analysis, over 55% of fish remains were identified to taxon and genus; however, only 2% of non-fish remains could be identified to the taxon and genus (Badenhort & Plug, 2011). Thus, an assemblage with greater number of specimens could reduce in fragment size and become too small to be identified. Size and shape are crucial factors within the identifiability of fragmented specimens. Investigating the relationship between these factors could solve the archaeological concept of how to know a fragment is what we think it is.

Quantification in Fragmentation

In order to find patterns in bone data, most zooarchaeologists count bones in varying ways depending on their objectives. The most common quantification units for specimen counting are NISP (the Number of Identified Specimens), MNI (the Minimum Number of Individuals), and MNE (Minimum Number of Elements). The simplest and most commonly used

measure is NISP, which is the count of the number of fragmented specimens, whereas the MNI is the minimum number of individuals (Gifford-Gonzalez, 2018). For example, two left femur, one humerus, and one tibia would an NISP of four, but the MNI would be two because one person cannot have two left femur. However, NISP is often criticized as an imperfect measurement within zooarchaeological analysis. This is because it often varies with taxonomic abundance and fragmentation degrees. A humerus bone may be more fragmented than a tibia and, thus, will have a higher NISP value. However, this does not mean that the humerus is more abundant than the tibia within the collection. An experimental model developed by Cannon (2013) attempted to understand and control the effects of fragmentation on the NISP. They did so by showing the formal relationships with the NISP and experimental data. It is clear that the NISP (Number of Identifiable Specimens) is dependent on the degree to which bones become fragmented. However, this study attempted to control for the effects of fragmentation on NISP. When fragmentation increased so did the NISP, because more specimens were created (Cannon, 2013). Cannon also found that there is a peaking point where the NISP declines. In order to confer that result, there can be other variables used as fragmentation measures. These include MNI, MNE, MNI/MNE, and specimen size.

Before MNE, zooarchaeologists primarily used Minimum Number of Individuals (MNI). Many zooarchaeologists since 1990, tested the validity of the MNI by comparing the values to the ANI (Actual Number of Individuals known) (Cannon, 2013). The studies have often concluded that both the NISP and the MNI are roughly inaccurate with NISP overinflating ANI and MNI underestimating ANI. Lyman (2018) argued that the MNI still has analytical value and can be better than the NISP. However, both measurements are ordinal scale at best -meaning that

the data shown are in order of magnitude, because there is no standard of measurement for the differences (Lyman, 2018).

A famous study by Binford (1984) showed that large game hunting often used various anatomical parts in their butchering practices within the Klasies River Mouth (Morin et al., 2017). This awareness led him to create Minimum Number of Elements (MNE). MNE is simply the minimum number of individuals contributed to that skeletal number. Therefore, it is the minimum number of elements needed to account for the produced fragments. Morin et al. reviewed the accuracy in NISP and MNE by doing a case study based on an experimental blind test. The results of this study showed that NISP and MNE had replicable and accurate methods for providing measures of abundance of whole assemblages. But MNE counts and NISP counts tally parts and taxa in different ways (even though MNE uses NISP counts). They mostly failed at the ordinal level, but in general, the MNE appeared to have more reproducible estimates of relative skeletal abundances than NISP (Morin et al., 2016).

A common derivative is MNI/NISP which would reveal the representation of the element based on the MNI being the actual number of animals within the collection. However, Cannon's research showed that with MNI/NISP ratios, NISP declines and MNI does not. This suggests that this measure gives ambiguous results. Alternatively, NRSP/NISP ratios (total number of identifiable and unidentifiable specimens divided by NISP) can measure a valid fragmentation because it shows a linear relationship with increasing fragmentation (Cannon, 2017). The drawback is that NRSP/NISP cannot calculate taxon-specific values because it includes unidentifiable specimens. Finally there is specimen size, which is directly related to fragmentation because as bones become fragmented into multiple pieces, the average size of

those pieces declines. The same bone crusher experiment showed that specimen size is the most useful measure for fragmentation because size successfully declined with increasing fragmentation in a clear linear fashion (Cannon, 2017).

Approaches to Calculation

The ways in which we calculate NISP and MNE are often unstandardized in zooarchaeology, and even worse, rarely made explicit. Most zooarchaeologists use the fraction summation and the overlap approach. The fraction summation approach is very user-friendly because there is little inter-analysis variation in estimates of fractions, but its drawbacks include skewed data from taphonomic biases (Marean et al. 2001). In particular, fraction summation is highly zone dependent, which makes information about the completeness of the fragment easy to lose. Alternatively, the overlap approach provides an accurate way to estimate bone count regardless of features and zones (Marean et al. 2001). Despite its accuracy, and unlike fraction summation, the overlap approach is difficult to manage due to tedious drawing.

The new GIS approach tries to overcome the weakness of the last two, while including their strengths. The premise of the GIS approach is using each fragment as a pixel image. It can manually compare fragments by having immediate data on their sizes and spatial distribution. Calculating MNE based on the overlap method means the researcher can physically see which parts of the bone are represented multiple times. The GIS allows information to be stored as a digital image (a drawing made on a template, converted into pixels so that it has the same properties as an image). If the researchers want the MNE from a collection of 50 right humeri, then they do not have to shuffle through 50 individual drawings- the software automatically

generates the number. The GIS approach makes the process of actually computing the MNE and NISP easier and faster. Thus utilizing GIS within this project is a step towards better quantification of NISP and MNE from bone fragmentation.

There are also certain critiques of using GIS especially in MNE analysis. The method of digitizing fragments is essentially similar to the fractional summation approach where the overlapping fragments (pixels in this case) are drawn by hand. Therefore there is a human error problem and (Lyman, 2008) has suggested that it could inflate MNE values and have similar pitfalls to the fraction summation. This was his result when analyzing actual MNE counts derived from a blind study on a student utilizing GIS. Another study extended this critique to understand replicability of MNE counts based on different students except each student had previous GIS training. They found that shape and MNE counts remained consistent across all participants indicating that error can be reduced with better training (Parkinson et al., 2014). Therefore reliant replicability will be contingent upon the level of expertise of each analyst not necessarily on the approach itself.

Using GIS as a Tool

It is known that butchery often fragments bones in a way that makes certain bones or bone fragments survive better than others. For example, Pickering and Egeland (2006) conducted hammerstone fragmentation experiments and showed that white-tailed deer radii and humeri produce similar epiphyseal (end part of a long bone) and shaft (middle part of long bone) splinters, but the radii broke into more fragments than the humeri. These results exemplify an

important issue - specimen counts may be misleading if different elements are not equally identifiable (Merritt & Davis, 2017).

This research on fragmentation and identification has been previously examined by Professors Merritt and Davis (2017). They performed a fragmentation experiment to document how epiphyseal and shaft specimen identifiability impacts the minimum number of elements. They also tested if fragmentation distorts assemblage composition or underrepresents the true number of elements and individuals. Their results showed that each element had a similar number of fragments, but the specimen size across categories was positively related to identifiability. In other words, the smaller the fragment, the less identifiable it was (Merritt & Davis, 2017). They quantified the relationship through NISP and MNE. Missing epiphyses underestimated MNE and MNI in the experimental and archaeological assemblages and potentially underrepresented the behavioral richness of butchery interpretations (Merritt & Davis, 2017). Therefore, having accurate NISP or MNE in fragmentation is necessary to gain insight into hominin behaviors and cultures that are mentioned previously.

Although research has shown that it is easier to identify some fragments coming from particular locations on bones than others due to certain features and textures, little research has been conducted to quantify that relationship. If we properly analyze how bone portion -- the location of the bone fragment -- affects identifiability, then we can more accurately determine the frequency of specific skeletal elements that were present at a site. Therefore, my proposed research seeks to quantify the ability to identify skeletal elements from bone fragments through its shape, size, and location on bone (bone portion). My research is not just a replication of Merritt's premise—understanding the attributes of bone fragments that affect identification— but

an extension. I attempt to analyze how identifiable fragments are from their shape, size, and bone portion on fragment. This matters because many times it is hard for researchers to "see" the elements in the zooarchaeological record that are actually present – simply because researchers cannot identify elements based on the portions that survive. Essentially, this is the first study to utilize the technique of GIS overlap approach in what is traditionally used to calculate NISP and MNE into understanding identifiability in relation to size and shape . The software should allow such measurements to become infinitely easier by allowing myself to simply draw the fragments on a template and letting the system generate areas of each fragment and calculate the MNE. In short the GIS approach helps with faster fragmentation measurements, more reliable visualization drawings, and less tedious work flow. Success with these procedures could lead to standardization of this method within zooarchaeology.

Faunal Analysis

Zooarchaeologists must understand the variation of biology in the past and present. They are not only interested in the physical aspect of the organism, but also how biology, culture and environment interact to produce variation. The variation can be extracted through the bones because they are usually the hardest parts of the body and thus most resistant to damage against degradation. This is why long bones have the greatest potential to be found within archaeological records and form the bulk of analysis. Research into bone identification must be very specific and refined.

Structure and Function of Bones

The shape of a skeleton is a reflection of the functions that it performs. Similar to how wooden pegs provide the base for a house, bones provide the support for the body. Both the muscular and nervous systems use bones as levers for important movements. As the muscles grow, they influence the shape of the skeleton (Gifford-Gonzalez, 2018). Bones work with tendons, joints, ligaments, and skeletal muscles to produce various movements. Nutrients are provided to bones through blood vessels that are contained within canals (Gifford-Gonzalez, 2018). The muscle and blood vessels can sculpt the bones by attaching and creating projections, nodules, and ridges that help zooarchaeologists identify bones.

Bones have many important functions in the body, such as movement, support and protection of soft tissues, and bone marrow production. Bones are a subtype of connective tissue that have been mineralized with collagen and calcium phosphate. The phosphate and calcium ions can nucleate inside vesicles to form hydroxyapatite minerals that help bones become hard and sturdy (Gifford-Gonzalez, 2018). In zooarchaeology, the hydroxyapatite and other trace elements can be analyzed to understand diets and migrations patterns in animals. For example, stable isotopes with carbon and strontium in teeth analysis can used to indicate diets that are terrestrial or marine (Richards et al., 2003).

Anatomical Directions in Osteology

In research, it is vital that bones are aligned according to the correct anatomical directions. Intuitive terms like right and left are obvious, but can be confusing if not assigned. Left or right is not the analyst's left or right viewpoint, but the animal's. Therefore, many zooarchaeologists utilize standard osteology directions when categorizing the positions and features of bones. Osteological terms are important because it helps other researchers understand the positions of the body using the same reference points (Beisaw, 2013). The common human anatomy assumes that the body has a vertical axis that is in the erect face forward position. Vertebrates on the other hand have an axis that runs horizontal rather than vertical (Beisaw, 2013).

There are two main divisions of reference within the skeletal system. The axial skeleton is the core of the body and houses most of the organs. The axial skeleton of the goat consists of the ribs, skull, and vertebral column. The appendicular skeleton is the other axis that forms the outer parts for major movements -- examples include feet, legs and hip bones together with limbs and shoulder bones (Adams & Crabtree, 2011). This study focuses on the appendicular skeleton and consisting of bones from the limbs (long bones). It is important to note that anatomical terms differ when applied to quadrupeds (goats) and bipeds (humans). Anterior is towards the front and posterior is to the back. In quadrupeds this is synonymous to cranial (towards the head) and caudal (towards the tail) (Adams & Crabtree, 2011). Anterior and posterior are more similar to dorsal and ventral in humans. Medial and lateral are sides of the body. Medial is towards the inside or "middle" of the body. Lateral is towards the outside (Adams & Crabtree, 2011) .

Categories of Bones

Bones are categorized according to their shape and the way in which they develop. Traditionally skeletal elements are classed under 5 main groups: Long, Short, Sesamoid, Flat, and Irregular (Bass, 1987). Flat bones are broad flat plates such as the skull, pelvis, and rib cage. Irregular bones fit their name, irregular. They are usually bones that protect the nervous tissue like the vertebrae. Sesamoid bones are found where a tendon passes over a joint such as the patella. Pneumatic bones can develop into soft tissue and contain air filled spaces. Short bones are as wide as they are long such as the patella and tarsus (ankle bones).The focus of this study is on long bones, which are longer than they are wide. These include the femur, tibia, humerus, radius, ulna, metacarpals, and metatarsals.

Rationale for using Long Bones

There has been studies indicating that humans may prefer to exploit fat in animals for their diet (Mann, 2000). Therefore the quest for bone fats may have driven humans to select long bones which are nutritionally dense in fats, vitamins, and minerals for extraction especially in diaphyseal and shaft segments (Peres, 2018). This may be why these areas are often more fragmented than epiphyseal areas. Such is the case in Marshall and Pilgrim 1993 study where they found higher NISP frequencies (fragmented specimens) within the shaft areas of the humerus, radius, femur, and tibia, in their sheep assemblage. Other studies indicate that number of shaft fragments for bison near the articular end and shaft are positively correlated whereas the opposite is true for sheep. Different elements can fragment differently as well. In Todd and

Rapson 1988 study, sheep had a particularly large number of shaft fragments in femora and humeri than the radii and metapodials (Todd & Rapson, 1988) .

Long bones are often well preserved in archaeological records because of their strength (withstand fracture) and rigidity (Stock, 2006). In a hunter gatherer studies, Jay Stock found that certain long bones could unveil the life history of homo sapien behavior. For example their results suggested that the cross-sectional properties of the middle of the femur and tibia shaft are the strongest indicators of the mobility within different hunter gatherer populations. This was due to their observations of higher torsional strength within these two bones. Between them, the tibia was concluded to be the best bone to reconstruct mobility as its shape is a reflection of the individual's biological terrain and wear. In zooarchaeology there are also studies on long bones that showcase how biomechanical properties provide a window to the organism's function. A study by Ohman 1997 sampled faunal specimens from humans, gorillas, and chimpanzees and found different cortical bone densities in femoral heads which related to each organism's differing environmental locomotion (Ohman et al., 1997). Also there has been a growing number of 3D modeling investigations to analyze long bones. Such is the case for Houssaye et al. 2018 that analyzed humeri and femora diaphysis of various mammals to deduce differences and similarities based their evolutionary history. The same study was able to analyze posture and body weight from the structure of long bones (in addition to ribs and vertebrae). These studies highlight the utility and importance of long bone investigation. Therefore the more accurately zooarchaeologists can identify long bone specimens, the better anthropological analysis can be.

Structure of Long Bones

Long bones have 3 distinct zones: epiphysis, metaphysis, and diaphysis. The epiphysis is the enlarged region at the very ends of long bones and is usually associated with the joints. During development, the epiphysis is separated but fuses through ossification in adulthood (Beisaw, 2013). On the surfaces of the epiphyses, the bones form a joint along with a thin layer of articular cartilage, which reduces friction and absorbs impact when bones move in a joint. The elongated central part of a long bone is the diaphysis. It is extremely strong because of the strong cortical bone surrounding it. The diaphysis is connected to the epiphysis with a thin segment of bone called the metaphysis (Beisaw, 2013). The metaphysis is the most metabolically active area because it supports most of the bone marrow. The rest of the external surface of the long bones is covered in a periosteum, which is a tough connective tissue sheath. Long bone bone shafts are often damaged by carnivores to extract bone forming cells from the inner endosteum. (Beisaw, 2013).

In addition to structural roles, bones also play a crucial part in storing nutrients, lipids, and producing blood cells to nourish the body. There is a central cavity called the medullary cavity that holds adipose tissue or "yellow bone marrow" (Bass, 1987). This marrow produces fat, tissue, and more bone. A medullary surface is the inner surface of the medullary cavity, which is the surface that touches the bone marrow inside the long bone shaft (Bass, 1987). The epiphysis is made of spongy bone which is lightweight and made of irregular pieces of bone called trabeculae (Beisaw, 2013). Usually red bone marrow fill the holes within these trabeculae. Red bone marrow is mostly composed of developing red blood cells, white blood cells, and platelets.

Diagnostic Features and Zones for Long Bone Identifiability

In order to identify long bone fragments the bones themselves must be divided into the aforementioned different zones and into either the left or right side. The bones are identified according to their identifiable features (Beisaw, 2013). These are certain markings on the bones that distinguish what area and bone they come from. It can separate to identify these markings on the bone due to their subtlety and may be overlooked by the untrained eye. The markings serve as anatomic landmarks which give information about the structures that surround them. These marking are innate properties different from taphonomical markings, which are modifications of bones (e.g. burning, damage, decay). The innate properties are surface features such as articulations (where bones join together), projections, fossa (depressions), and foramen (holes). The articulation is where tendons and ligaments attach (Beisaw, 2013). A foramen is an opening or groove in the bone that allows blood vessels and nerves to enter the bone (Beisaw, 2013). The more complete a bone is, the easier it is to identify it.

There are general rules that help zooarchaeologists in identification. These are handy tells that help orient bones. For example the nutrient foramina is a key feature that helps with bone alignment. Nutrient foramina are holes that run through the outer surface into the marrow cavity to transport blood and other nutrient. They usually project downward at the proximal end but upward at the distal. This helps zooarchaeologists label the side to the bone. (Gifford-Gonzalez, 2018).

The surface features of bones can also reveal a wealth of information for identification. Usually, long bones have rough surfaces where muscles attach for movement. Some will also

have fine lines where epiphyseal or growth plate marks where the increase in the length of the bone occurred. Compact bones are also hard dense and usually cover the other layers or ends of long bones to give it strength (however compact bones were not included within this study). Intact compact bones are easily distinguishable from long because they form shells rather than long extensions. Anterior surfaces on long bones tend to be the smoothest parts of the bones and flat surfaces tend to be posterior (Beisaw, 2013). This is not universal for all bones.

There are also key features that distinguish different elements from each other. For example, in the tibia there is landmark called the medial malleolus that rests in the distal end. To side a fragment of distal tibia, the medial malleolus should be placed in the proper anatomical position, which has the anterior on the front. If the medial malleolus is on the left, it is from a right tibia because it is the medial or anterior portion of the tibia (Beisaw, 2013)

GIS

Archaeology studies materials and in order to understand that, the dsicpline must understand space. Mapping geographical data has revolutionized the understanding of location and space. Geographic Information Systems (GIS) is a popular tool for archaeologists to analyze data gathered from excavation sites such as objects, bones, and grids. Therefore, the challenge would be to collate this data into a visual conversation between analysts. The advantage of GIS is the ability to compute, analyze, and present spatial relationships and data in a way that traditional maps cannot. This is due to the system's ability to utilize the topography of mapmaking, statistical analysis, and the application of database technology.

Within archaeology, displaying data on a map can render the data immediately comprehensible for the teams and a public audience. But the real advantage of archaeology is the ability to use an extensive set of tools to analyze the data through user friendly commands in a graphical user interface (gui) rather than codes. ArcMap is where data can be displayed and explored (Gor and Kurland, 2016).

Past Use

The current primary application of GIS in archaeology is through survey mapping and analysis (Gor and Kurland, 2016). Surveys locate and preserve archaeological finds in the landscape. For analysis, GIS can make multiple layers of data available for examining spatial patterns in sites and managing data. For example, GIS can be utilized for such projects as mapping travel and exchange or predicting where archaeological sites might occur (Doyle et al. 2012; Pernice, 2014)

Aside from geographical map making, archaeologists have begun to use the GIS software in non-traditional paths by reimagining their skeletal data onto a mapped space. For example a study by Bartling and Schleyer from 2003 examined teeth to create a graphic record of a patient's oral health status. Other applications of GIS has been to analyze bone damage in hominin and carnivore damage in (Parkinson et al., 2014). Surface modification is where the bone has been modified by biological or physical forces that are different form the innate surface of the material. This is usually done by damage by carnivores and humans. Studies by Marean et al. 1999, Parkinson et al. 2014, Abe et al. 2002, Thompson 2008, Fisher 2010 and others used GIS to examine bone surface modifications and estimate minimum number of elements by

counting overlapping fragments that have been converted to pixel images (as mentioned before). The same overlapping technique is utilized in this study to integrate anatomical elements into understanding differences in identifiability across long bones. Therefore by designing a coded information system to spatially represent the elements (GIS), fragment data can be analyzed to its spatial area, identifiability, zonal portion, and map relation to other fragments. This method can increase efficiency in analysis and render the data more shareable.

Faunalyze Toolbox

The GIS toolbox is a guide on a set of instruments that can perform overlays, create buffers, calculate statistics, perform proximity analysis, and more. The specific toolbox called "Faunalyze" was utilized in this research. Eric Fisher (Fisher et al., 2017) was the creator and granted access to the Faunalyze toolbox which is still in the process of completion and has not been formally rolled out for distributive access.

Faunalyze is a collection of tools that is used to digitize whole and fragmentary bones and their surface modifications. Using Faunalyze, archaeologists can calculate the Minimum Number of Elements (MNE) by by treating each bone element as a map and overlapping areas with bones and fragments to calculate MNE.

Methods

Dr. Stephen Merritt generously provided access to his experimental research assemblage on butchery fragmentation of small ungulate long bones using hammerstones and anvils. The

assemblage consisted of 5 goat skeletons and 60 total limb bones, with only 35 long bones utilized within this study (Merritt & Davis, 2017)

Assessing Identifiability

ID category	Description
1	Side, Element, Portion
2	Element, Portion
3	Upper/Intermediate/lower limb segment, portion
4	Long, Flat, Compact, Irregular bone portion
5	Mammal/ Nonmammal

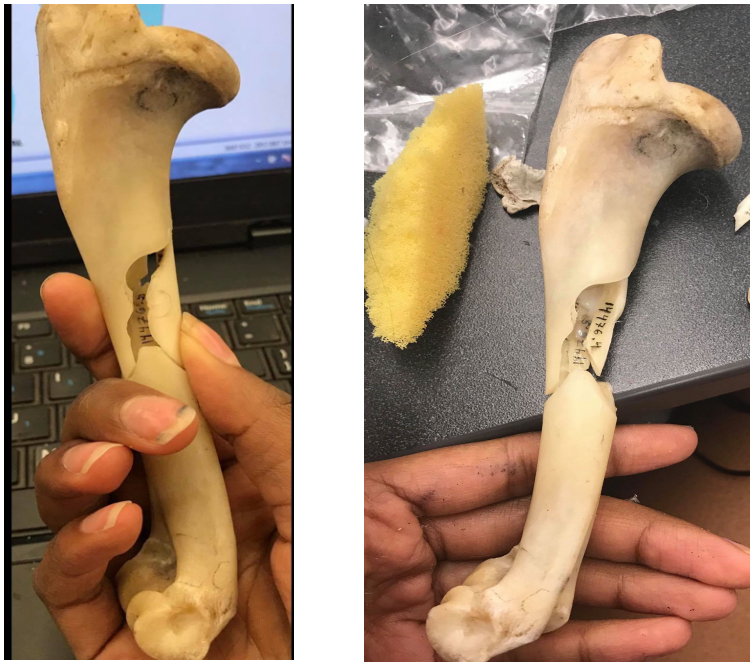
Table 1 from (Merritt & Davis, 2017)

Each specimen was previously categorized into 5 identifiability categories based on anatomical detail from the level of completeness and diagnostic features (table 1). The lower the category number, the better the identifiability criteria (ID Cat). ID Cat 1 included specimens that could be identified to side, element, and portion (Merritt & Davis, 2017). An example would be side (right) portion (proximal epiphysis), and element (humerus). ID Cat 2 included fragments that could be identified to element and portion but not side. The specimens in ID Cat 3 could not be identified to side or element, but could be identified to upper, intermediate, or lower limb elements (Merritt & Daivs, 2017). ID Cat 4 specimens could not be identified to limb segments, but still "retained cortical and medullary surfaces that could be assessed for articular vs. non-articular bone and cancellous vs. smooth medullary texture, and allowed them to be identified as

portions of long bones, such as long bone epiphyseal, near-epiphyseal, or midshaft specimens." (Merritt & Davis, 2017). ID Cat 5 specimens could only be identified as mammalian bone fragments and constituted the least identifiable category. This category is still different from a non-identifiable label or failure to be identified to any object (bone, lithic, etc).

Reconstruction

The purpose of this research was designed to work on fragments of six long bone elements: femur, humerus, ulna, radius, metacarpal, and metatarsal. Each fragment was reconstructed to the complete bone. All specimens were already grouped and bagged with the element it originated from. There were over two hundred and eighty-nine fragments total, each of which was analyzed and reconstructed to its respective bone element. Fragments < 2cm were also included, however, most were incomprehensible due to their small size. However, the fragments < 2cm were not included in Merritt et al's data and therefore could not be matched to an ID category. These incomprehensible fragments were instead labeled as ID Cat 5 to indicate that the fragment was still existent as a mammal bone. Fragments were glued together using white glue and clay, then removed. Although superglue could have been efficient for assembly and tight holds, it was not used as it is often unforgiving for adjustability. After reconstruction, each fragment was drawn and characterized into the geospatial templates.



Figures 2: Reconstruction of Right Humerus Specimen 14476

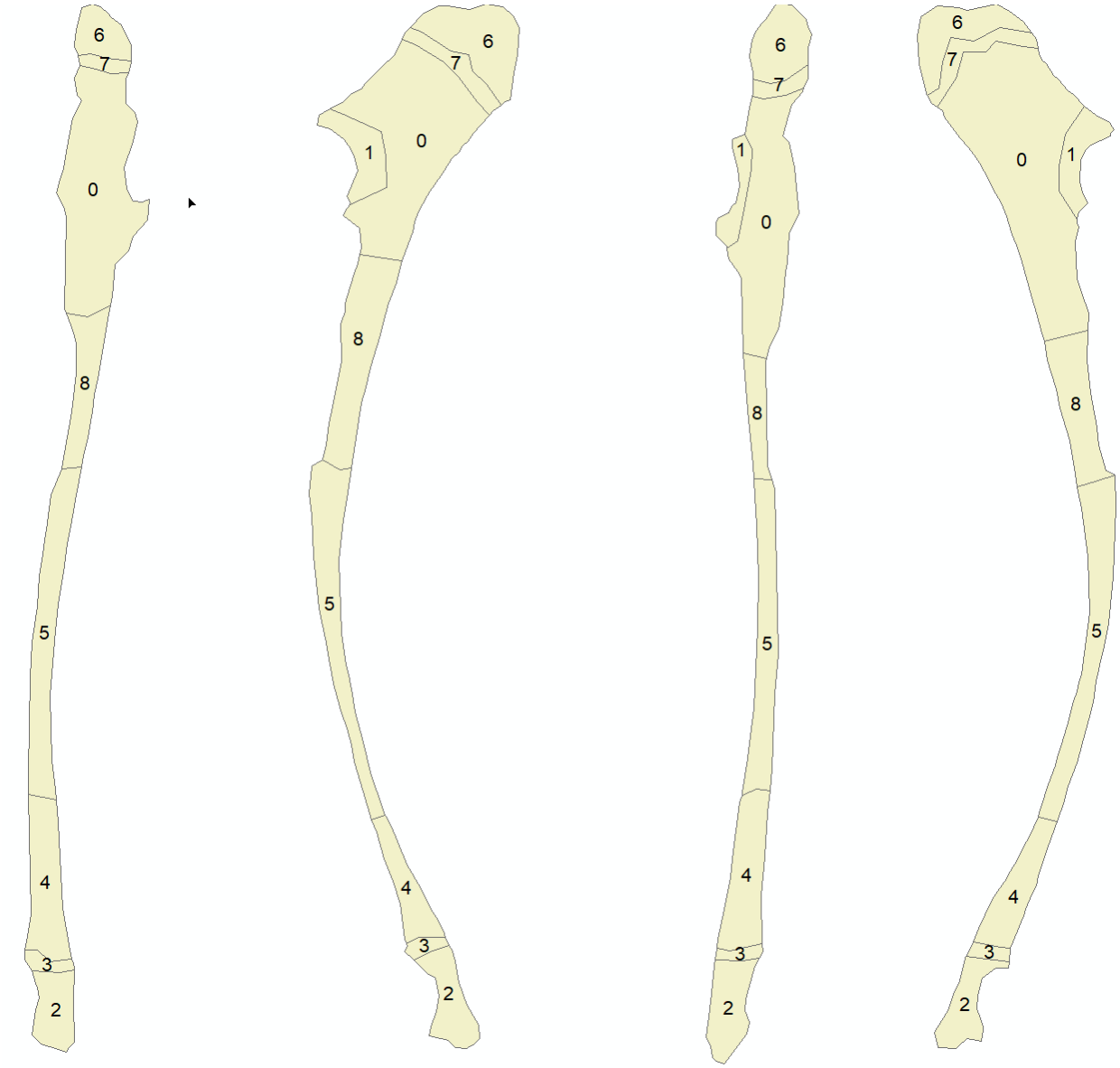
Figure 3: Reconstruction of Radio Ulna (fused) 14486

Feature Maps

In order to landmark identifiable features of the different long bone elements in analysis, feature landmarks were created by expert zooarchaeological analyst Dr. Jessica Thompson. Areas with identifiable features were given ID cat scores of 1 to signify most identifiable. Any areas outside of these landmarks were coded as 5 to indicate little to no identifiability.

Feature Maps with coded landmark regions

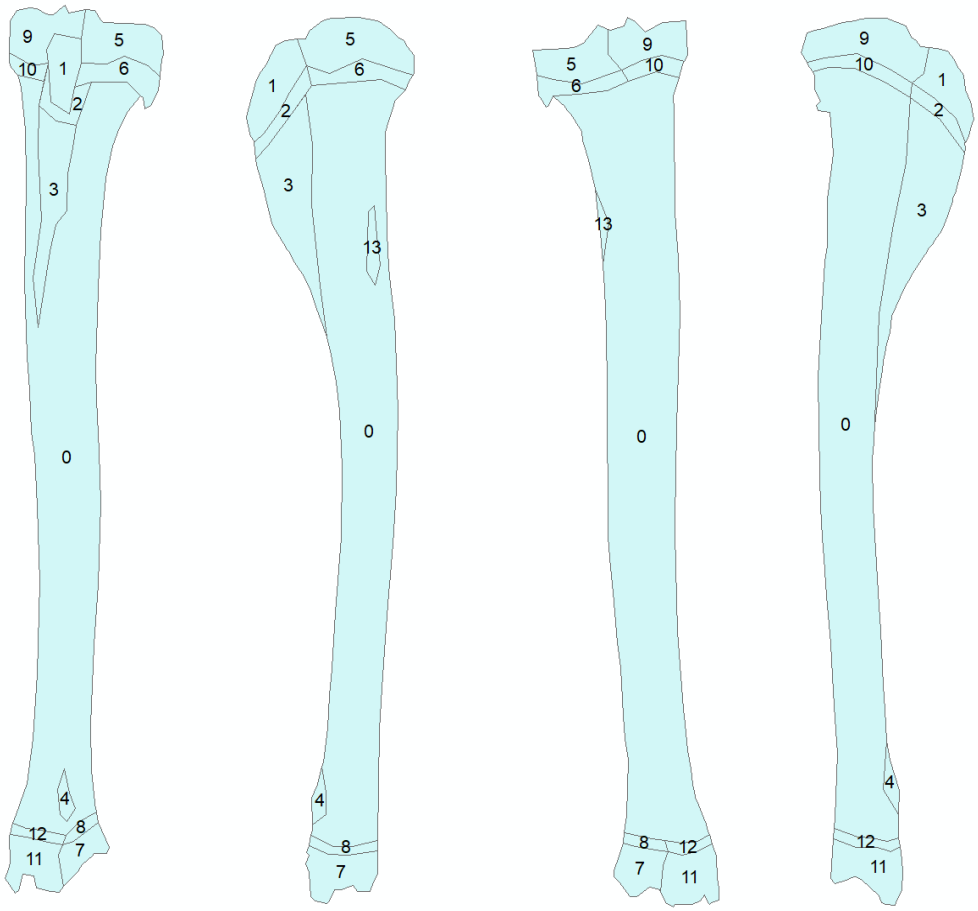
Figure 3: Ulna with coded landmark regions



ID	Feature

0	No Feature
1	Anconeal process
2	Distal epiphysis
3	Distal metaphysis
4	Distal radial articulation
5	Midshaft radial articulation
6	Olecranon process epiphysis
7	Olecranon process metaphysis
8	Proximal radial articulation

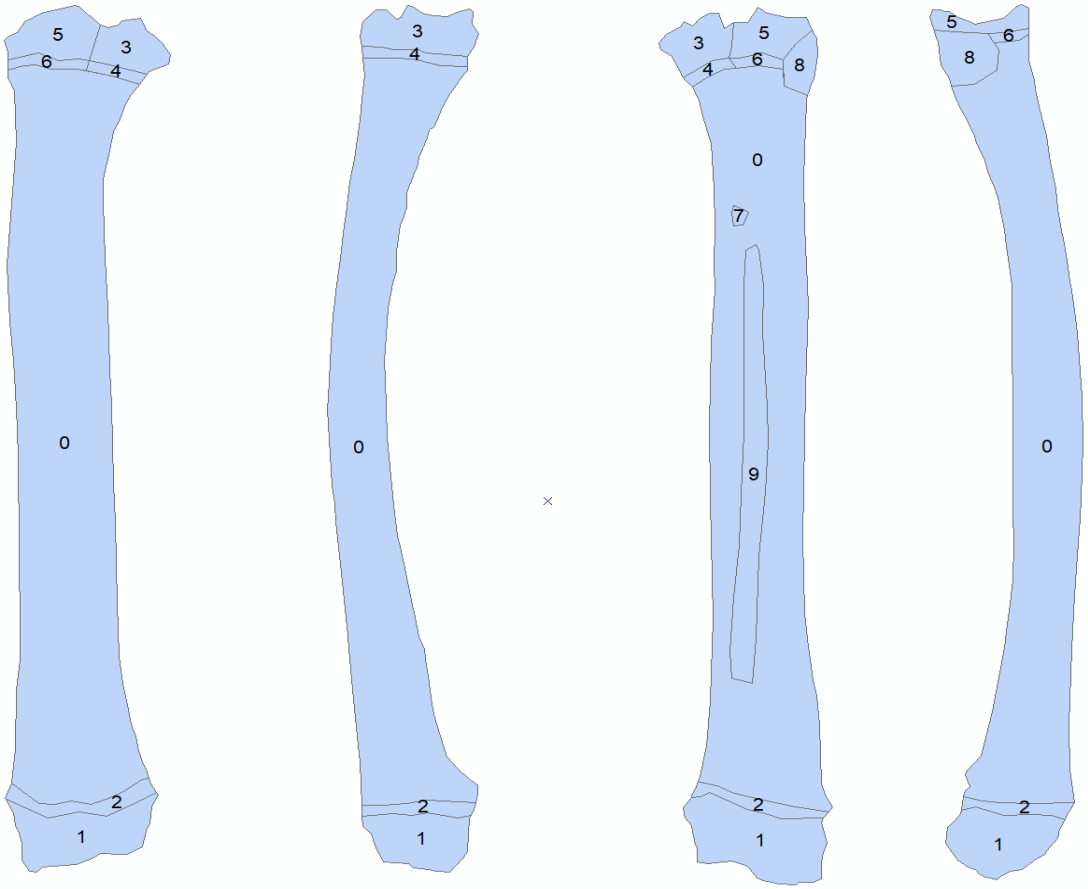
Figure 4: Tibia with coded landmark regions



ID	Feature
0	No Feature
1	Anterior crest epiphysis
2	Anterior crest metaphysis
3	Anterior crest midshaft
4	Anterior distal tuberosity

5	Lateral condyle epiphysis
6	Lateral condyle metaphysis
7	Lateral groove epiphysis
8	Lateral groove metaphysis
9	Medial condyle epiphysis
10	Medial condyle metaphysis
11	Medial groove epiphysis
12	Medial groove metaphysis
13	Nutrient foramen

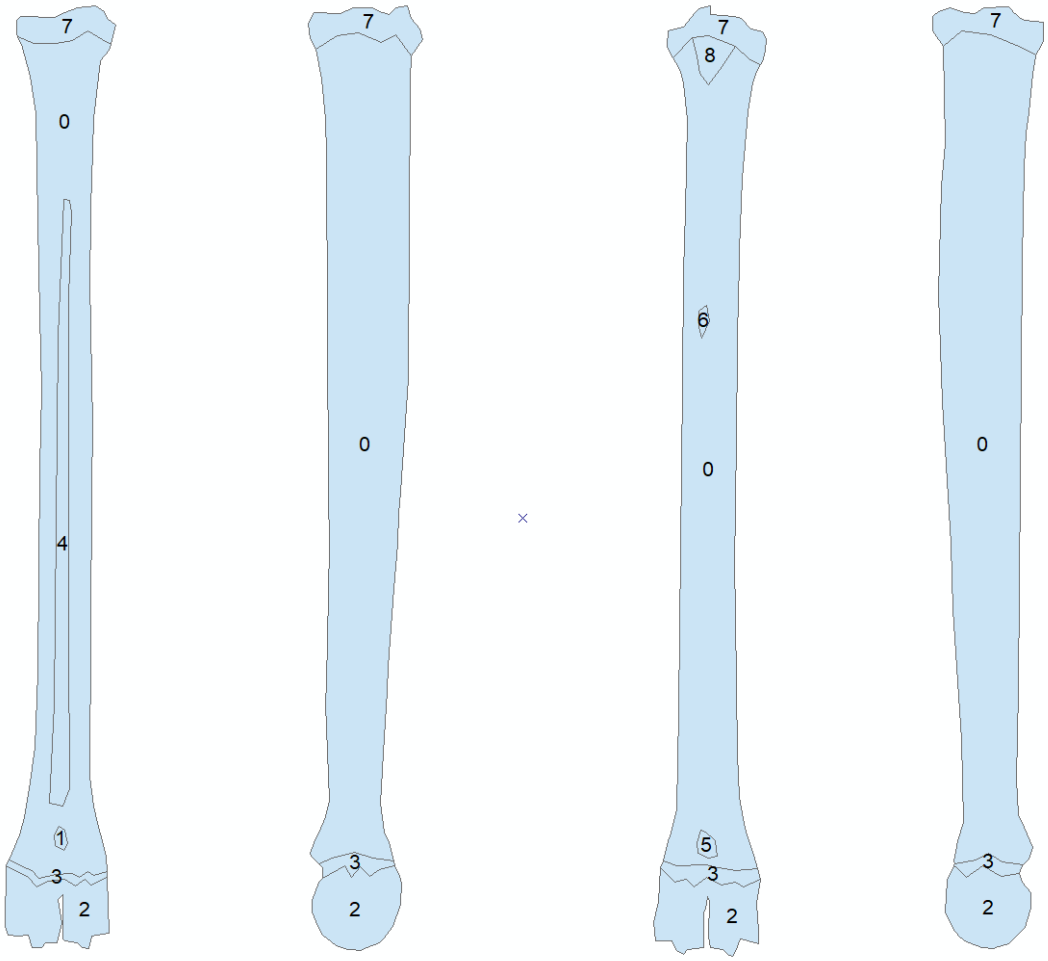
Figure 6: Radius with coded landmark regions



ID	Feature
0	No Feature
1	Distal epiphysis
2	Distal metaphysis

3	Lateral epiphysis
4	Lateral metaphysis
5	Medial epiphysis
6	Medial metaphysis
7	Nutrient foramen
8	Radial tuberosity
9	Ulnar scar

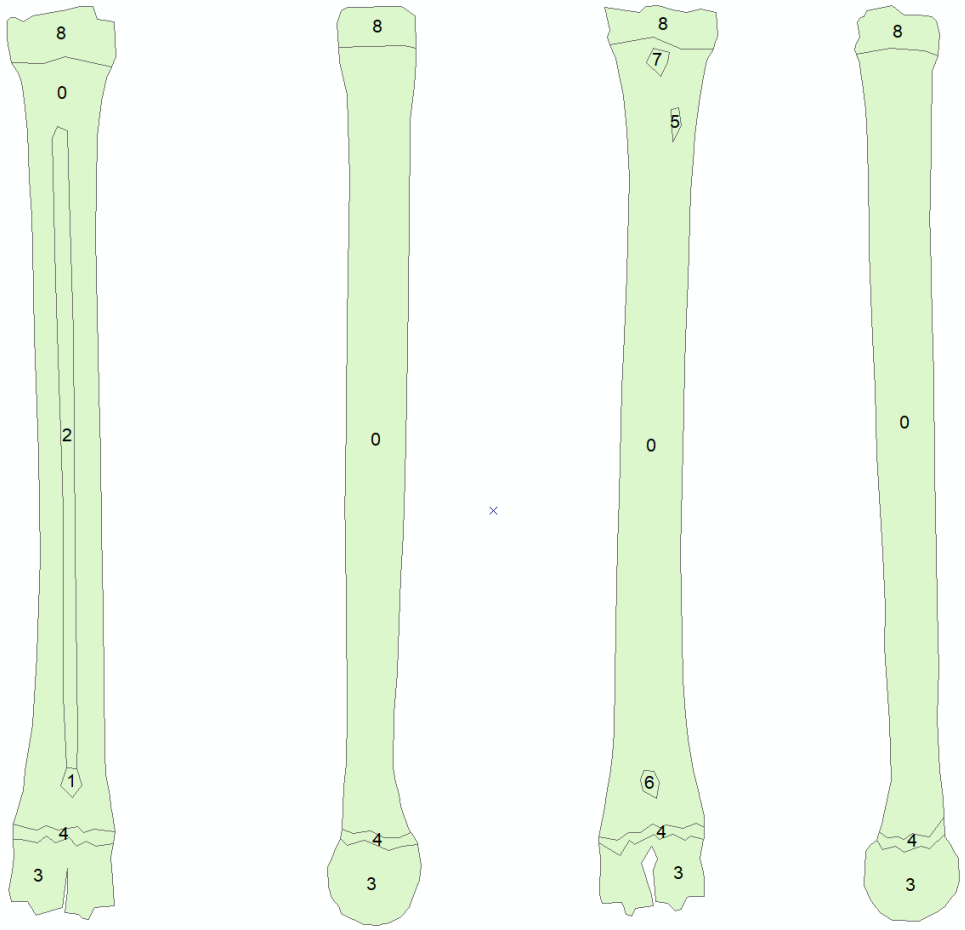
Figure 7: Metatarsal with coded landmark regions



ID	Feature
0	No Feature
1	Anterior distal foramen
2	Both distal epiphyses
3	Both distal metaphyses
4	Midshaft anterior groove

5	Posterior distal foramen
6	Posterior midshaft foramen
7	Proximal end
8	Proximal posterior foramen

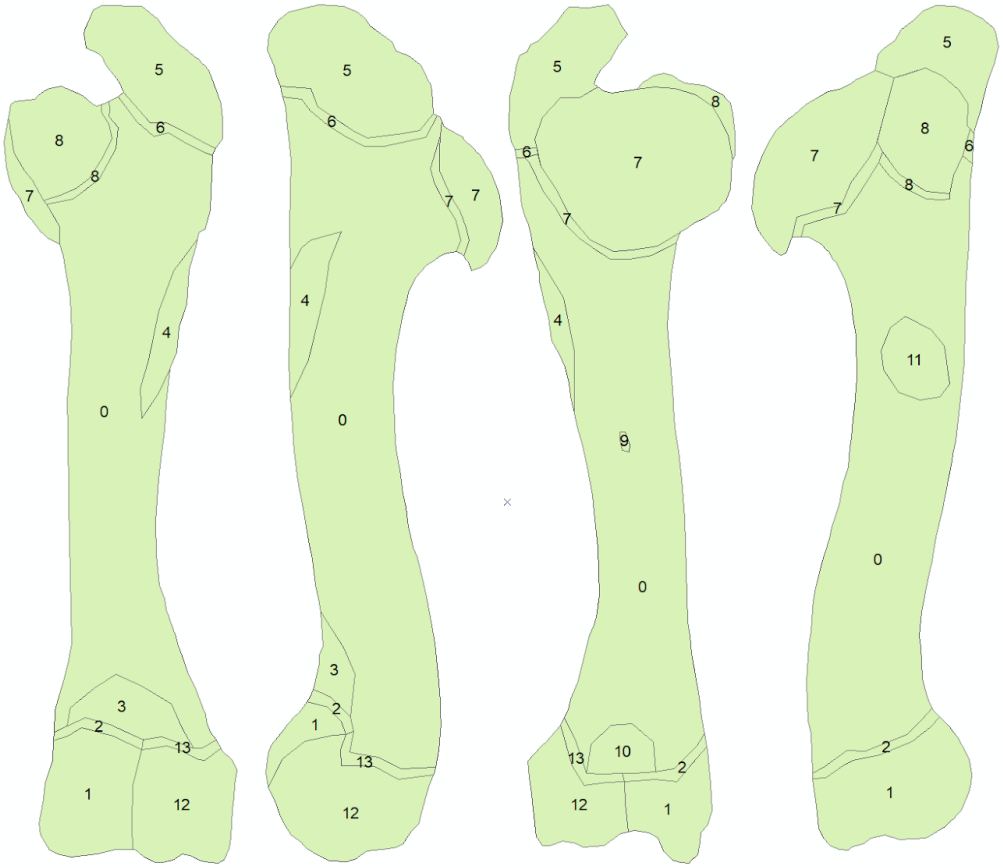
Figure 9: Metacarpal with coded landmark regions



ID	Feature
0	No Feature
1	Anterior distal foramen
2	Anterior groove at midshaft
3	Both distal epiphyses

4	Both distal metaphyses
5	Nutrient foramen
6	Posterior distal foramen
7	Posterior proximal foramen
8	Proximal end

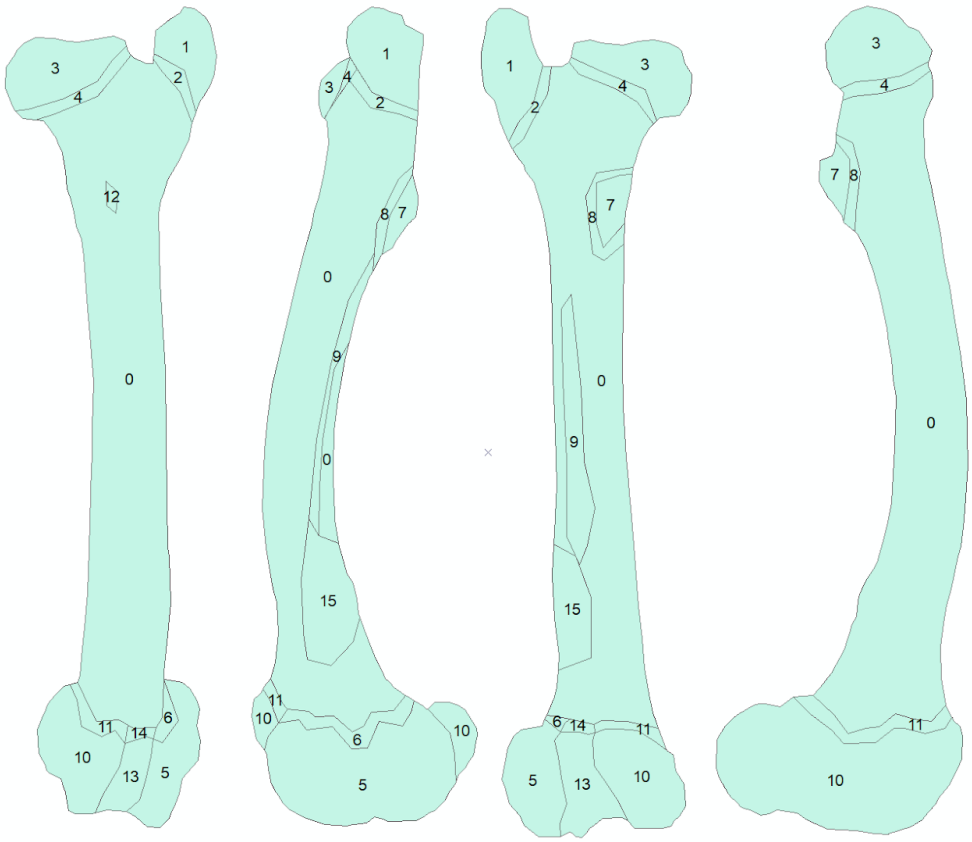
Figure 9: Humerus with coded landmark regions



ID	Feature
0	No Feature
1	Capitulum epiphysis
2	Capitulum metaphysis
3	Coronoid fossa
4	Deltoid tuberosity
5	Greater tubercle epiphysis
6	Greater tubercle metaphysis
7	Head epiphysis

8	Lesser tubercle epiphysis
9	Nutrient foramen
10	Olecranon fossa
11	Terres major
12	Trochlea epiphysis
13	Trochlea metaphysis

Figure 10: Femur with coded landmark regions



ID	Feature
0	No Feature
1	Greater trochanter epiphysis
2	Greater trochanter metaphysis
3	Head epiphysis
4	Head metaphysis
5	Lateral condyle epiphysis
6	Lateral condyle metaphysis
7	Lesser trochanter epiphysis
8	Lesser trochanter metaphysis
9	Linea aspera
10	Medial condyle epiphysis
11	Medial condyle metaphysis
12	Nutrient foramen
13	Patellar groove epiphysis
14	Patellar groove metaphysis
15	Supracondyloid fossa

Work Flow

The GIS workflow for this project is summarized into the steps below:

1) Create template samples
2) Edit features and digitize the fragments onto each element
3) Join the corresponding fragments to Merritt et al. 2017 ID category ranking
4) Create spatial reference
5) Convert shapefile layers to rasters
6) Add and merge each element raster into single layer
7) Use python code to aggregate raster data and perform map algebra functions

Detailed description and theory of methods is described below:

Loading the files:

Each fragment was drawn and characterized. Then, the template and skeletal element was selected and named according to the following naming convention based on Object ID name and element name, ex: KB5_Right_Femur_14525. With KB5 representing the Merritt et al. butchery trial, right femur is the element name, and 1425 is the object ID. Subsequently, each fragment within the element was named according to the object ID such as 14525.1, 14525.2, etc. Once layers were added, they were edited by using the cut polygon tool. This tool split the bone template shape into its corresponding fragments by creating new polygons. This tool allowed each fragment to join together to reflect how the fragments exist in reality. Therefore, each newly created polygon represented a single fragment on the template. The edge snapping feature ensured that the cut went across the polygon by digitizing the line segment to the edges of the

wall of the particular bone side. Then if the fragment continued on the next angle (example posterior to anterior. All polygons together (present or not present) compromised one shapefile layer. These layers could then be turned on and off easily by checking or unchecking the box next to their entry in the list pane. This made maneuvering through different templates efficient and simple.

Each shapefile contains data tabular about the location, shape, size of each fragment within one element layer. Within the table, each row corresponded to every polygon cut from the template. Each fragment that corresponded to the polygon was labeled to the specimen number (spec number). Each separate polygon is treated as a new data row with its own area. Polygons shape areas with the same spec number were added together and divided by the total area of the summed rows to generate percent area of each fragment relative to the total bone. The advantage here is that the exact size of the fragment in proportion to the total bone is calculated. This is more precise and reliable measure of size compared to the traditional length/width measurement in Merritt and Davis 2017 research.

Each polygon (fragment) that was edited as a shapefile layer and was saved into the larger geodatabase for the project. After each fragment was labeled to the specimen name, the resulting attribute table generated the spatial area that the fragment occupied. However, the data coded the same fragments as different entries even when drawn on different views. For example, 14525.1 on the posterior would be a separate feature than 14525.1 on the medial. Therefore, the resulting ID labels of the same name were aggregated to compute the sum area and divided by the total area of all the fragments of the same Object ID to get percent size of each fragment

relative to the whole bone. The resulting image shows each fragment relative to size and shape on the complete bone with 4 views: Medial, Posterior, Lateral, and Anterior.

Table

KB1_Right_Humerus_14470

OBJECTID *	Shape *	ID	SPECNUMBER	Shape_Length	Shape_Area	comment
1	Polygon	0	14470.2	7271.22621	2451087.194397	<Null>
2	Polygon	0	14470.2	7666.022442	2299295.64186	<Null>
3	Polygon	0	14470.1	10156.972008	3971967.102327	<Null>
4	Polygon	0	14470.1	10702.454723	3632681.628708	<Null>
5	Polygon	0	14470.4	3722.400211	312618.721339	<Null>
6	Polygon	0	14470.1	8244.06617	3224818.240151	<Null>
7	Polygon	0	14470.4	3870.571404	556050.636815	<Null>
8	Polygon	0	14470.9	1027.388438	62849.546839	<Null>
9	Polygon	0	14470	3784.713752	397449.636674	not present
12	Polygon	0	14470.1	9219.214573	3273078.701035	<Null>
13	Polygon	0	14470	4687.812815	1157602.117653	not present
14	Polygon	0	14470.2	6334.910245	2093387.541266	<Null>
15	Polygon	0	14470.3	2812.306108	336806.379489	<Null>
16	Polygon	0	14470.8	1480.569456	54340.50455	<Null>
17	Polygon	0	14470.6	1494.805322	107448.665044	<Null>
18	Polygon	0	14470	3091.982702	306819.979846	not present
20	Polygon	0	14470.2	8502.871705	2222278.486534	<Null>
21	Polygon	0	14470.3	3738.492703	574115.927674	<Null>
22	Polygon	0	14470.11	406.134551	6689.867731	<Null>

1 (0 out of 19 Selected)

KB1_Right_Humerus_14470

Figure 11 Example of Right Humerus 14470 Attribute Data

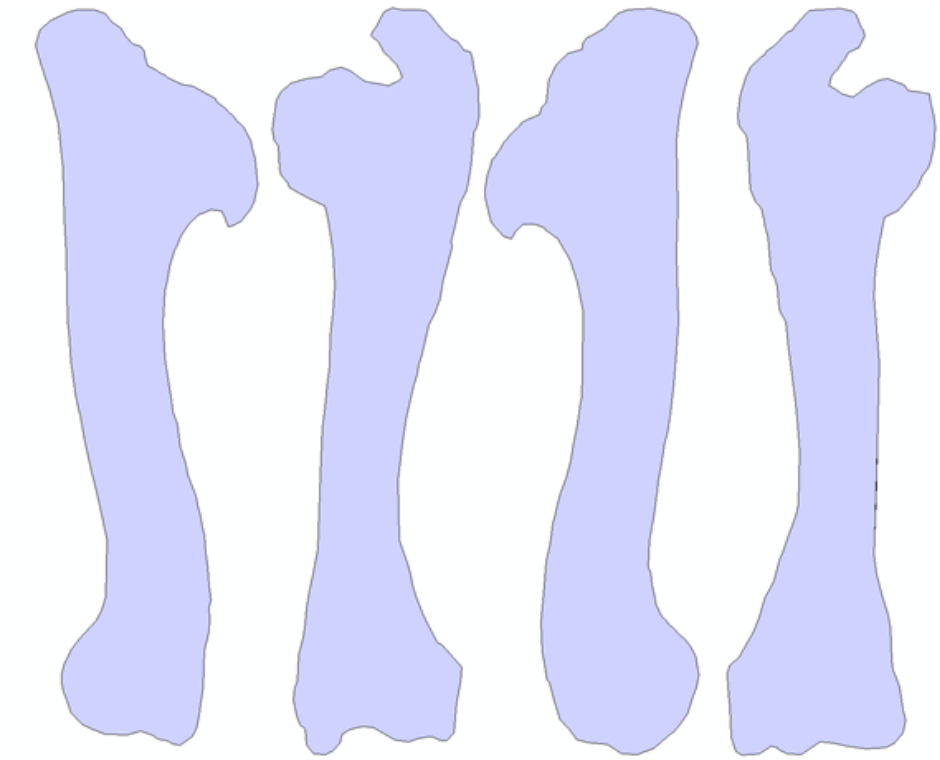


Figure 12: Right Humerus unedited template

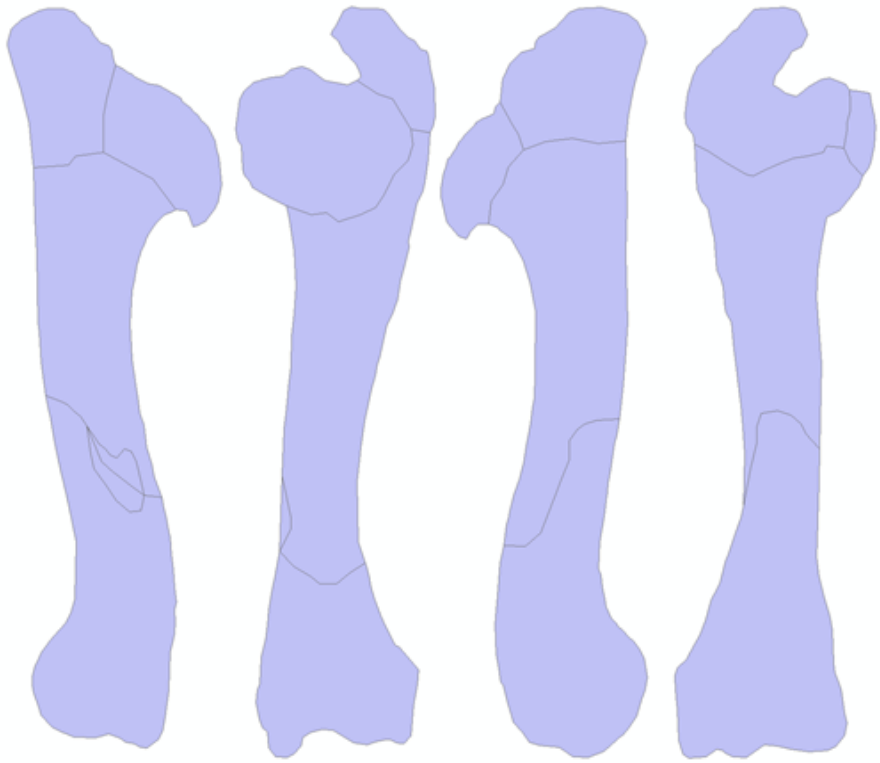


Figure 13: Right Humerus Specimen number 14483 with fragments drawn in

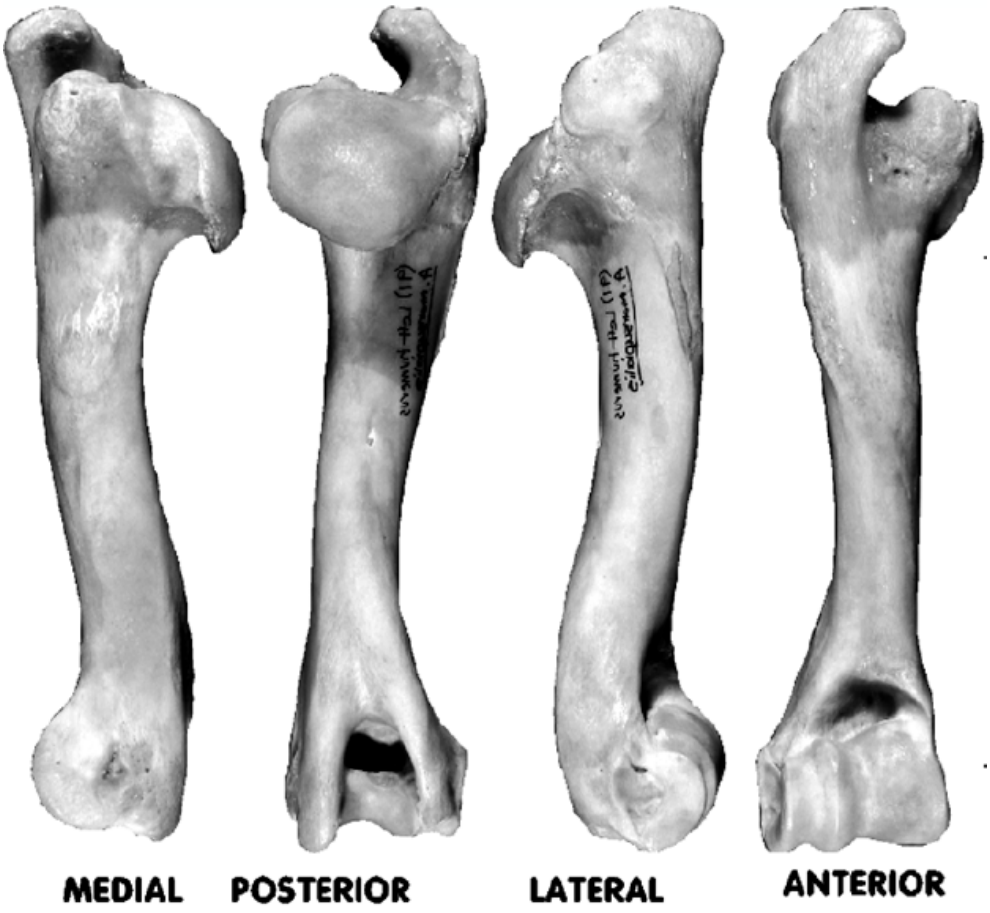


Figure 14: The 3D images within the toolbox helped guide the placement of fragmentary pieces into the anatomically correct spaces on the template and visualize the fragments corresponding size and shape.

Any missing fragments were coded as null data to indicate the absence of the specimen. Merritt and Davis 2017 did not include fragments smaller than 2cm because they are often difficult to analyze. This is consistent with most standard zooarchaeological practices (Thompson, 2008). However, small fragments often constitute a large portion of the number specimens in analysis. In the Thompson 2009 study from the assemblage in Blombos, removing

fragments <2cm reduced the assemblage analysis from 5856 specimens to 2969 (Thompson 2008). Such a large reduction in data could be buffered if smaller fragments are included and reliable analysis stays consistent. Although such small specimens are difficult to analyze, including them will render a more comprehensive data set and allow the attribute data to be more complete.

Fragments smaller than (<2cm) were still drawn on the template the system then generated corresponding areas of each labeled fragment. When fragments were found as the reconstruction advanced, the old shapefiles were re-edited to match the existing bones. Again, the template provided by faunalyze is the average mold or template mesh that captures the average shape of the gracile bone element.

Linking data

In order to link the digitized fragments to Merritt et al. ID category data, each element attribute table was linked to corresponding ID category data. The object ID corresponded to the name of the same ID on the attribute table. However, since the names were formatted as text, the linked data needed to be the same field type. Each feature was then linked to the same name that corresponded to the object ID.

Definition queries

Rasters to Vectors:

There are two main ways data is represented in GIS: raster and vector modeling. These are essentially two ways of capturing and presenting real world data. A vector model uses points, lines and areas to represent spatial data(Barsai, 2018). This is great for representing non-continuous data such as boundaries and binary relationships. Raster, on the other hand, is an image file and modeling that is based on square cells and pixels, and is great for representing continuous data such as frequency of artifacts and changes in vegetation (Barsai, 2018). Different values are offered different colors or shades. Rasters are advantageous because map algebra functions can be quick on pixelated images. Therefore, shifts in data can be easily understood. For the purposes of identifiability overlays, rasters files were selected as the most proficient.

Rasters

In order to create rasters, the layers need a projected coordinate system. Therefore, each shapefile was converted to a World Geodetic System (WGS-1984) spatial reference from the map toolbar. World Geodetic System (WGS-1984) is familiar to many non-geographers because it is used by GPS devices to describe locations all over the Earth (Barsai, 2018). This is the default spatial reference and was chosen because the spatial areas within this analysis were only relative to each other and no real-world measurements were linked to the templates. Therefore, none of the areas are in meters, inches, etc., but rather in pixel counts because the analysis utilizes percent area of each fragment relative to total. Therefore, coordinate measurements were

not needed and not included.

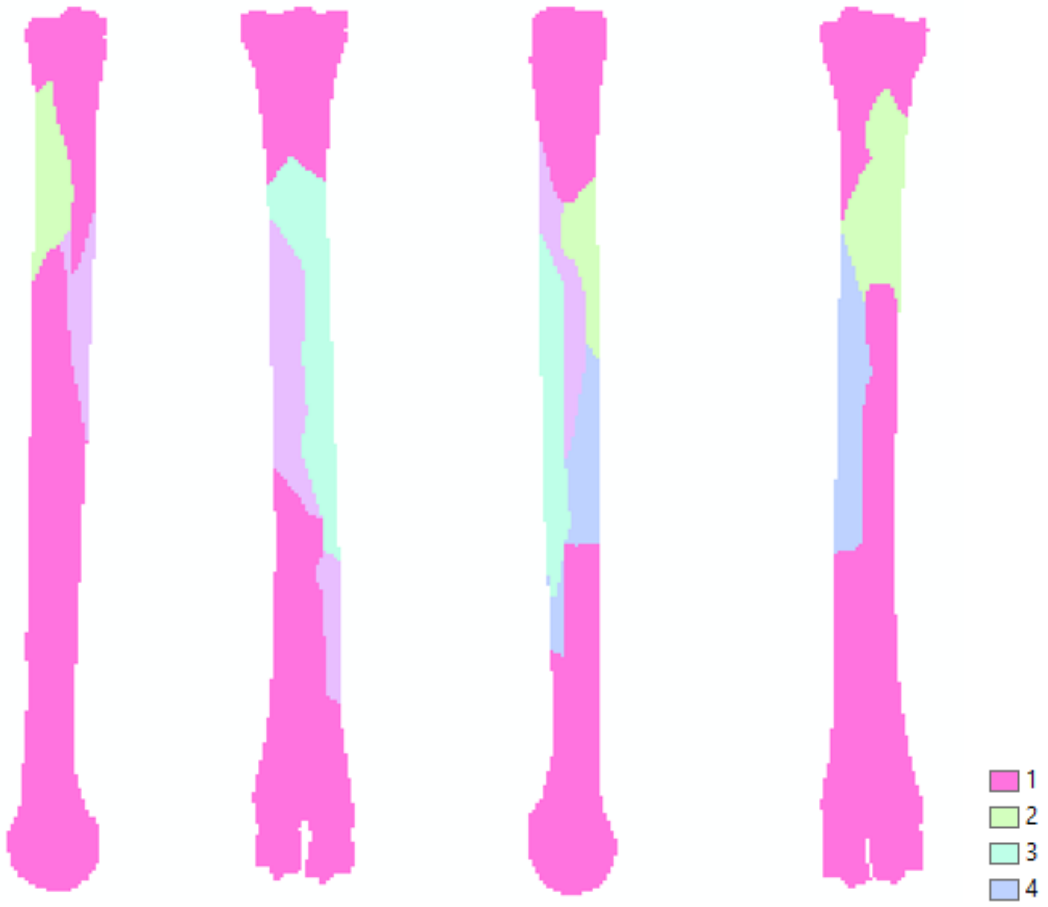


Figure: 15 Right Metacarpal 14511 Raster

In any case, the resulting layers were converted to rasters based on their ID categories. Then the ID categories were added on top of each bone by raster addition. The template guaranteed point to point overlay which allowed for accurate calculation of the sum of ID categories on areas for fragments on each raster. This technique of converting layers to rasters and overlaying them is usually used to determine MNE as with the case studies mentioned earlier. The pixel images that overlap would be added and the map calculation would signify the highest number of overlapped fragments and thereby give the MNE. The present study utilizes

that technique, but instead of generating MNE, the overlapping fragments are added in order to visually zone which areas are more identifiable than others.

On top of each aggregate raster elemental, was also a feature map of the element that had specific zones where osteological features were present. For example, the linea aspera on the femur indicates a specific ridge on the posterior midshaft region. Any fragment that had this mark, would make immediately identifiable. Therefore, these zones were coded as IDcat 1 to indicate the highest identifiability. Areas outside any key zones were coded as 5 to indicate the least identifiable zone.

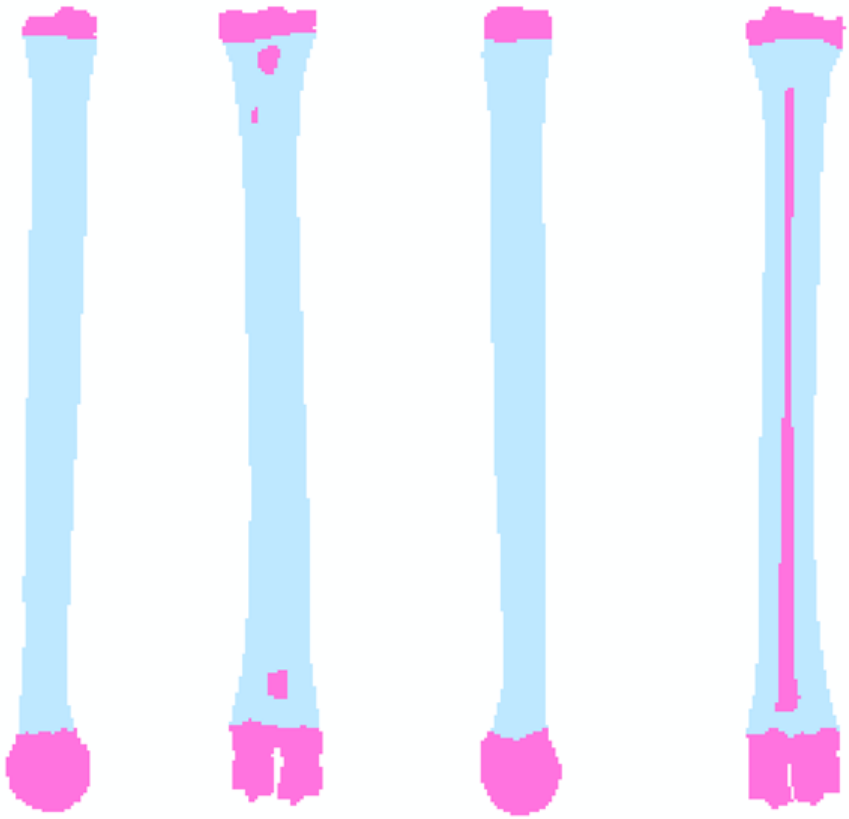


Figure 16: Raster of Right Metacarpal Feature Map

Problems with missing fragments

The present study undertook several corrective measures to accommodate for missing fragments and missing ID cats. For example, specimens <2cm that had no ID category ranking were given values of 5 to signify the least identifiability. Fragments that were missing were initially coded as nulls to indicate a nonexistent portion. However, the raster calculator tool could not analyze null values and essentially projected it as no data segments on the resulting raster. The missing fragments should not be included within the resulting raster addition, so this seemed to be a good method to characterize the data. However, the raster calculator cannot add a "no data" segment and instead leaves the area as a 'hole' on the raster and prevents any raster area that falls on top of it to be excluded in the addition. This leaves significant holes in analysis as shown below.

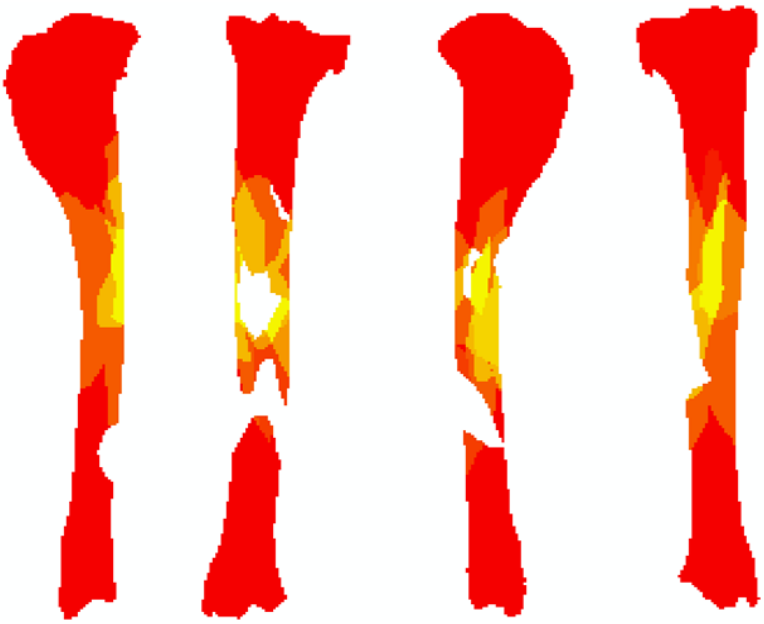


Figure: 17 Resulting Raster of Right Tibia

Nulls can usually be filled in by the field calculator. However, that function can only be done on the shapefile and not on the raster. This is because the raster still needs a value to create a pixelated image. Therefore, the missing fragments were coded as 0's. This allowed the area to have an actual integer expression and spatial coordinate. However, a 0 would render that area to look more identifiable than it actually was. Same is the case if the missing fragment was coded as a high number 5, which would render the resulting raster area to look less identifiable. The identifiability should not be included because the fragment simply is not there. Therefore, to circumvent this problem, a mean was calculated by totaling all the overlaid values by only the number of template areas with fragments. This was done by giving the missing fragments an arbitrary value of 0 and excluding that layer with any fragmented portion that overlaid it. Ordinal data for this project was rated according to a category where a low score indicated a better identifiability than a higher score. Generally, a mean value is an inappropriate measure for data on an ordinal scale because the information conveyed is relative but not equal between the ranks. For example, an average ID scored area of 1 compared to one that is 5 does not mean that the lowered scored area is 5 times more identifiable. However, because the systematic errors (missing fragments) skews the final visualization, the best way to rid the missing fragments was to use the mean (avg). This was needed because missing pieces were frequent within reconstruction and although the arbitrary 0's will affect individual bone rasters, they will not affect the average of their overlay additions. Therefore, the resulting calculations will be a fractional ranking average (3.66) rather than rounding to their original ordinal scales.

Data analysis

Unfortunately, both the entry and analysis were a time-consuming process, and the outdated ArcMap 10.2 edition corrupted certain files. Those subsequent files were not included in raster analysis, but were included in data analysis as the attribute tables were saved before corruption.

Executing Raster Average

Creating the differentiated average was difficult to execute on the raster calculator tool as it is not a simple raster addition and division. This proved to be the most difficult aspect of the project as a simple SQL code on the calculator could not carry out the right output. For the following description, r# is the type of raster file needed for bone element average.

The following SQL code could not function because the function was unrecognizable to the software

Con("r1" + "r2" + "r3">0,(("r1" + "r2" + "r3")/3), ("r1" + "r2" + "r3")/3-1))

Con is a geoprocessing tool in the spatial analyst toolbox that tests a condition, so if the condition raster is the integer raster then the query is true and will return pixel values from the integer raster. If the query is false, it will return values of zero. Here the query is the pixel values set to 1,3, or 5. Once that statement is executed, a new raster object will be created. Therefore, everywhere there is a zero will be excluded from the average of the computed total raster files.

The set null geoprocessing tool is similar to the con tool and will test the condition. So, for pixel values =0, and the query is true and will set that value to no data. No data is missing

values and will be ignored in subsequent operations. If false will return original pixel values that was in the input raster. There is a geoprocessing tool called IsNull and it looks at every pixel in the new raster and if the pixel is no data then it returns a value 1. However, setting the data as nulls will exclude all the data on top of the frame as stated before.

Python code

```
import arcpy
from arcpy.sa import *
f1 = arcpy.Raster(""Snapme2/Faunalyze/Feature_KB3_Right_Radius_14497/value")
f2 = arcpy.Raster("C:/ ")
f3 = arcpy.Raster("C:/ ")
if value > 1:
outraster = (f1 + f2 + f3)/3
else:
outraster = (f1 + f2 +f3)/3 - 1
```

The if value > 1 didn't work. Therefore, Con was used to replace it.

```
f123 = f1 + f2 + f3 outraster = Con(f123 > 0, f123 / 3, f123 / 3 - 1)
outraster.save('S:/npenme2/Faunalyze/rasterCalc')
```

However, the function still didn't work. Possible reasons could be due to the slow processing power of the older version of arcmap, etc.

Therefore, the data was executed on the desktop terminal instead

Python code

```
#!C:filepath

import arcpy


if arcpy.CheckExtension("Spatial") == "Available":
    arcpy.AddMessage("Checking out Spatial")
    arcpy.CheckOutExtension("Spatial")
else:
    arcpy.AddError("Unable to get spatial analyst extension")
    arcpy.AddMessage(arcpy.GetMessages(0))
    sys.exit(0)


from arcpy.sa import *


def run(path):
    arcpy.env.workspace = path
    rasters = arcpy.ListRasters()
    avg_r = sum(Raster(r) for r in rasters) / sum(Con(r, 1, 0, 'Value > 0') for r in rasters)
    avg_r.save('avg_r')
```

```
    print('done: '+path)


if __name__ == '__main__':
    run(sys.argv[1])
```

The strength of GIS is that many of the tools are simple and straightforward. However, behind the program are other powerful toolboxes for various functions most of which is difficult to use without proper training.

Future Directions and Use of ArcPro

A frustrating aspect of this project was the slow processing of the data. Simple functions such projections, transformations, and conversions took several minutes to carry out for single layers. Therefore, archaeologists may want to consider turning to Arcgis Pro which is the latest desktop version of GIS. It claims to modernize the user experience and carry functions more efficiently. The layout is more user friendly and many archaeologists would appreciate the better learning curve that comes with Pro.

Results

Raster Analysis

Composite GIS images of the (a) femur, (b) humerus, (c) ulna, (d) tibia, (e)radius, (f) metatarsal, and (g)metacarpal. Darker red areas indicate regions of lower ID cat averages (higher identifiability) and lighter yellow areas indicate areas of higher ID cat averages (lower identifiability). Each stretched color area is relative to the identifiability of its perspective bone element with different values of higher vs lower identifiability scores depending on the element and side. Number of element rasters within aggregation is defined as n excluding the feature the map that was also included. There n=3 means 3 elements in addition to the feature map.

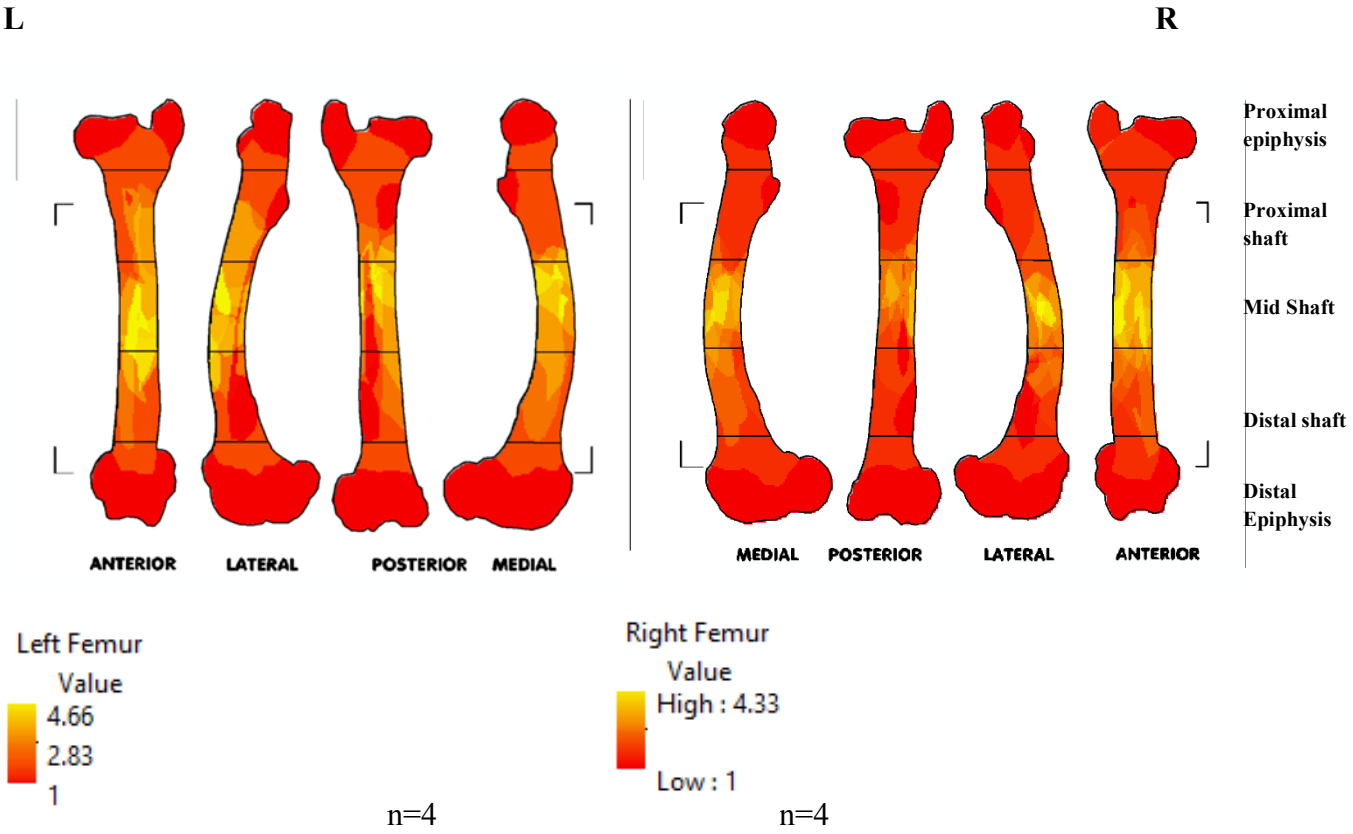


Figure 18

Less identifiable regions tend to aggregate in the midshaft across all views for Right Femur. Same is the case for the Left Femur with some stretching into the distal and proximal shaft zones.

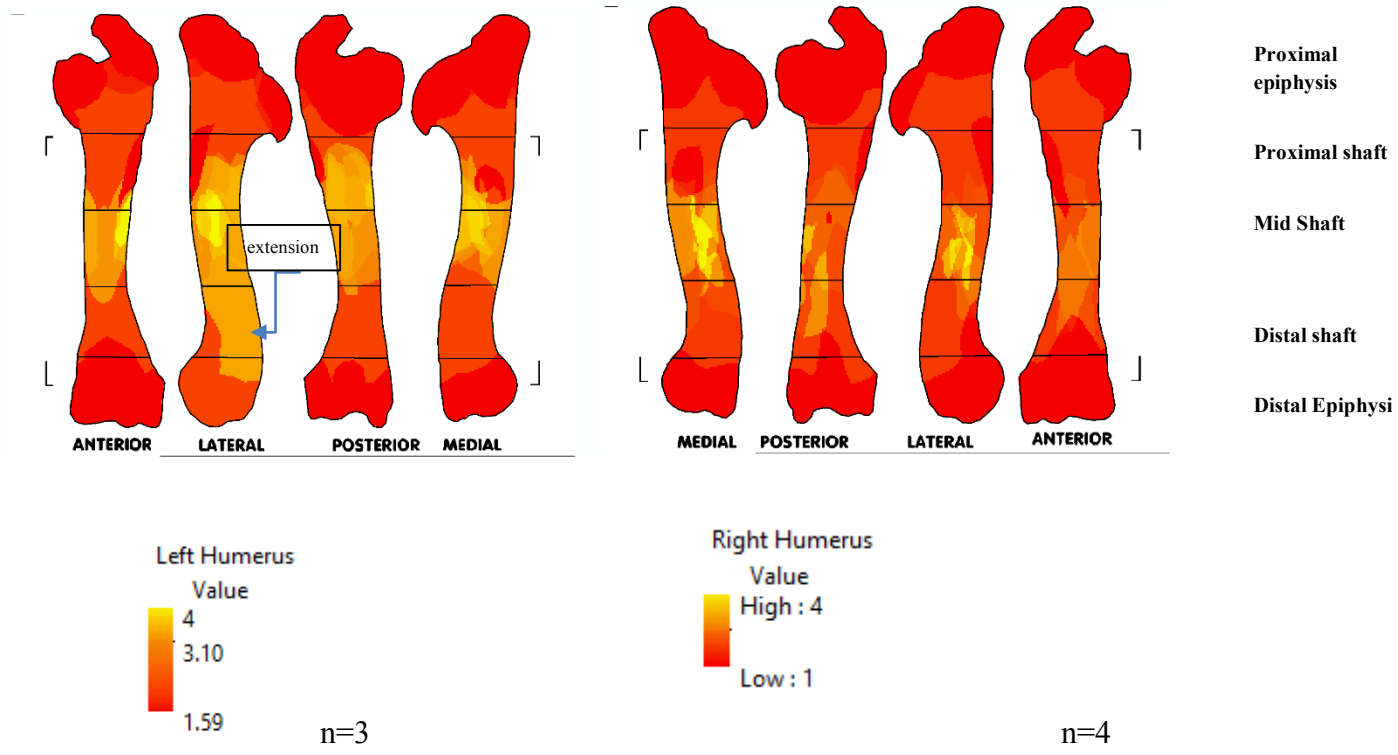


Figure 19

Left Humerus shows less identifiable areas within the medial mid shaft, posterior midshaft to distal shaft, lateral midshaft, and anterior distal midshaft. Exceptions occurs in the lateral side of the Left Humerus where less identifiable extension occurs towards the distal epiphysis. This may be due to lower sample number (n=3). Across all views, less identifiable areas overlap at the midshaft with some extending to the posterior and anterior distal shaft in

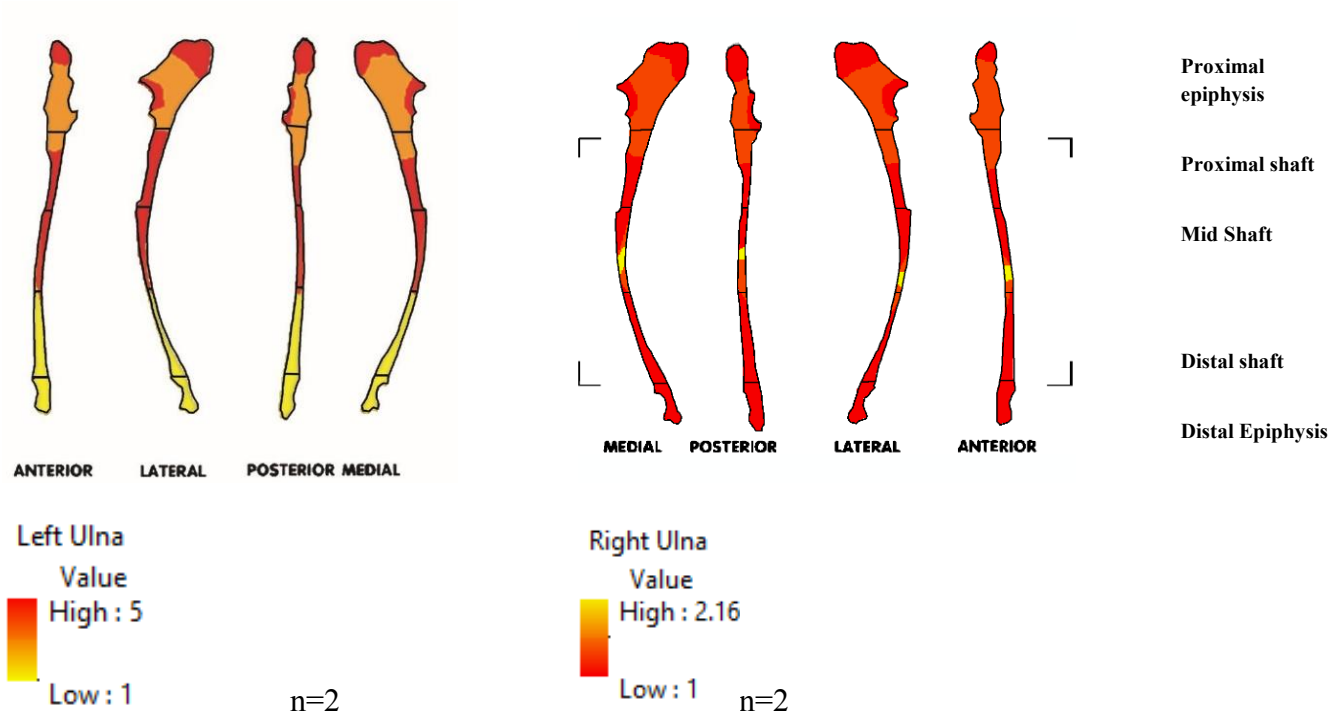
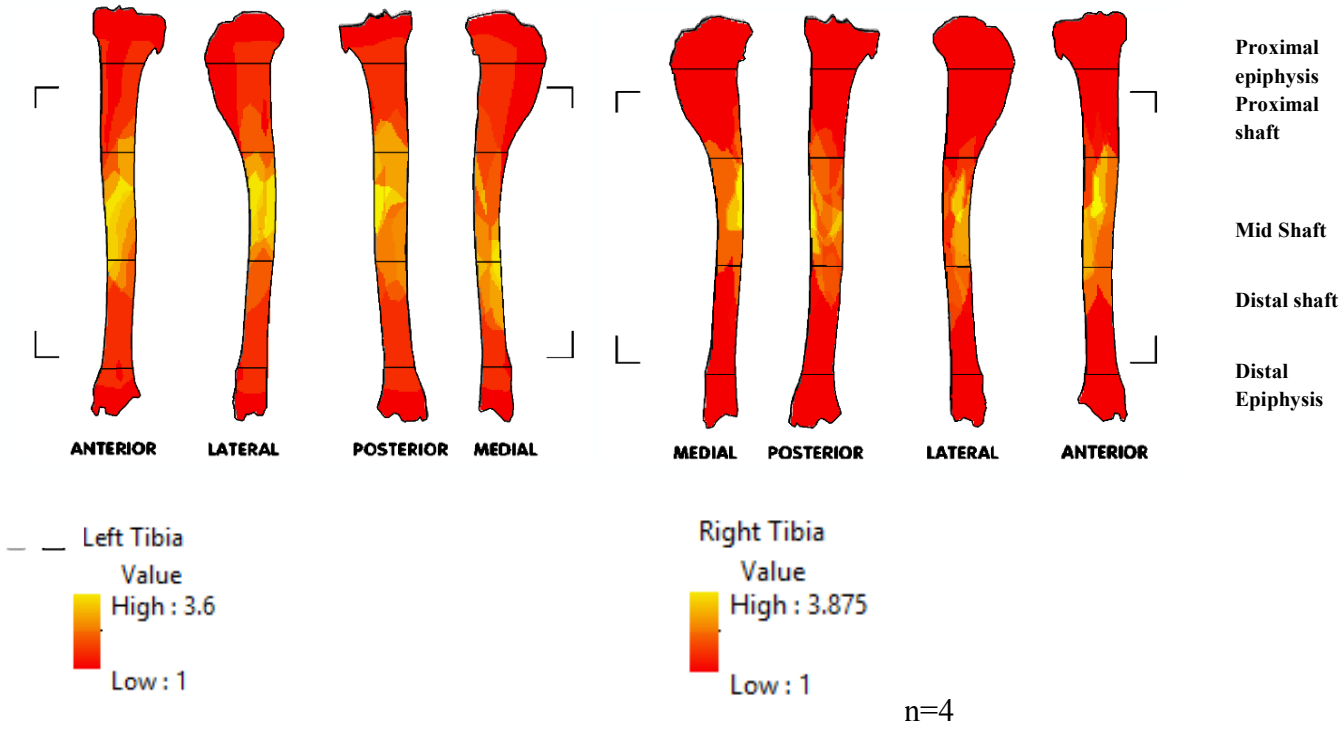


Figure 20

Left Ulna is less identifiable in the distal epiphysis for all zones. Right Ulna is less identifiable in the mid shaft. This is most likely due to the low sample size and NISP



n=4

Figure 21 - Tibia with Raster Analysis

Both the Left and Right Tibia show the bulk of the less identifiable areas towards the midshaft of the bone while some areas creep into the proximal and distal shaft as well.

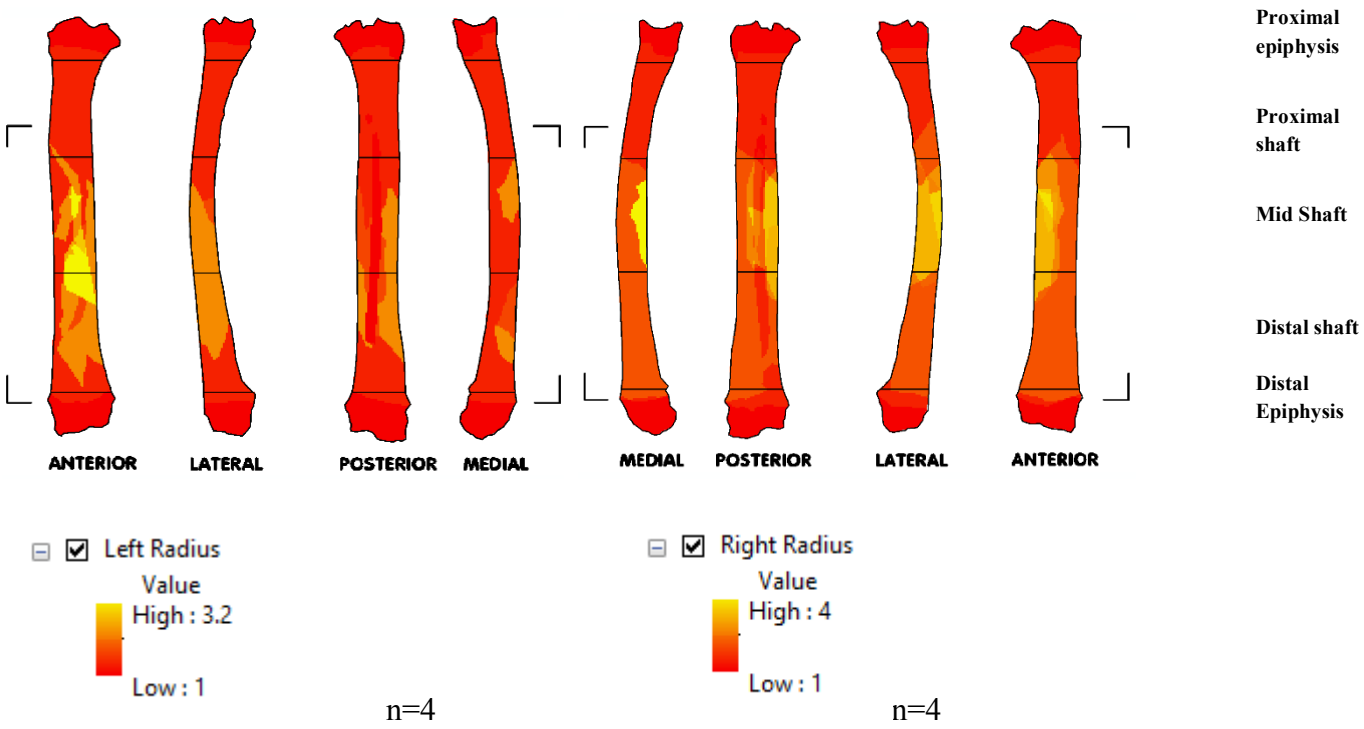
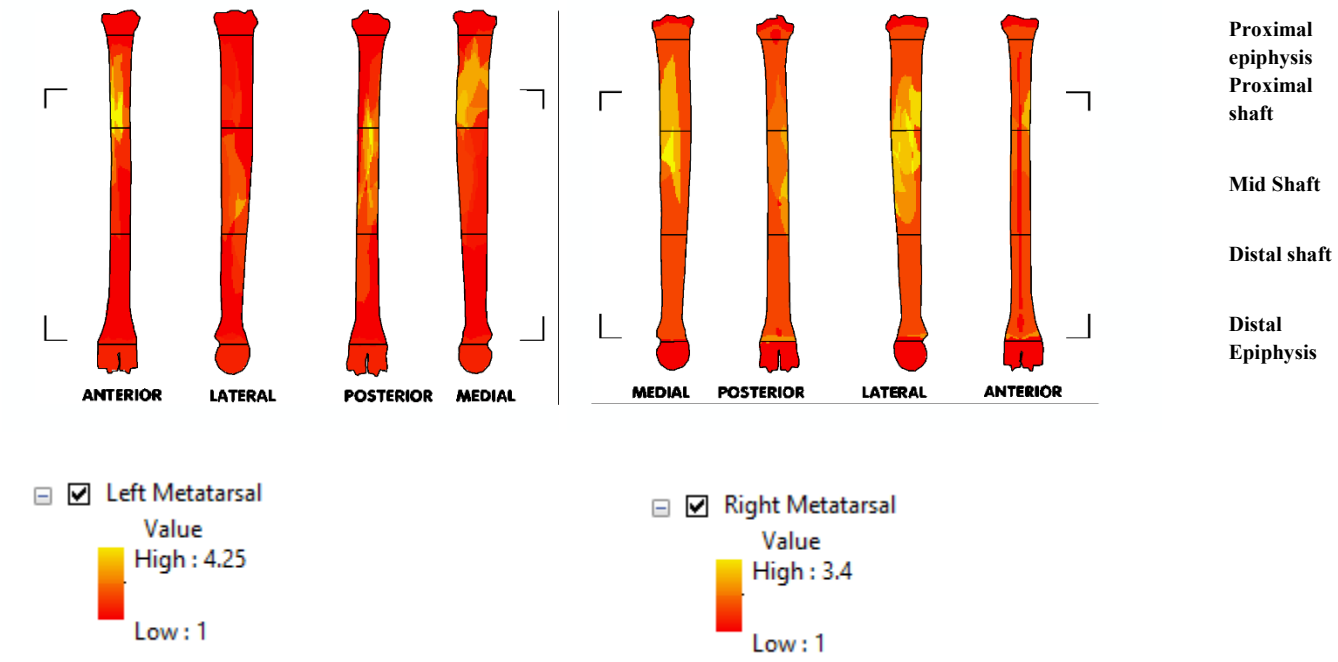


Figure 22

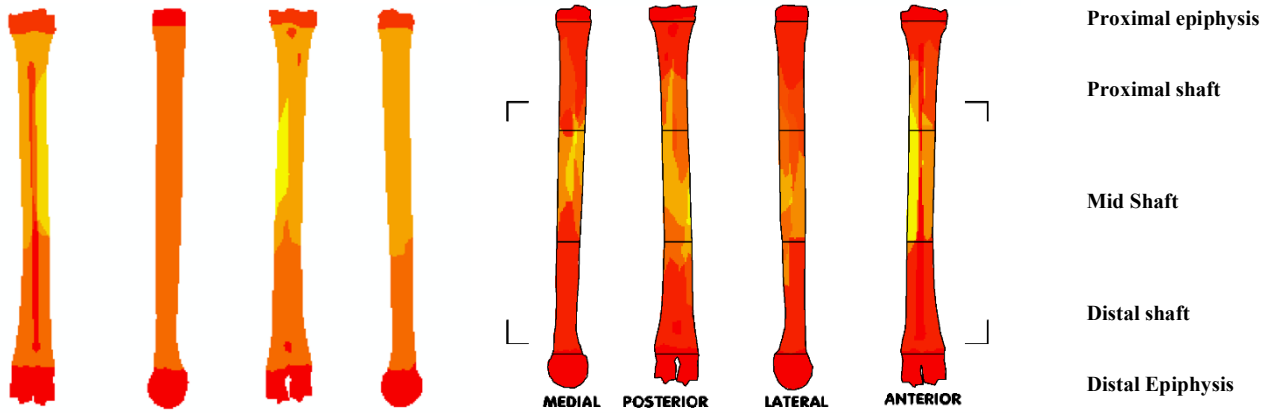
Left Radius show lower identifiable areas within the midshaft to distal shaft zones. However, less identifiable areas are concentrated within the midshaft for the Right Humerus

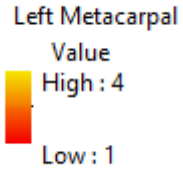


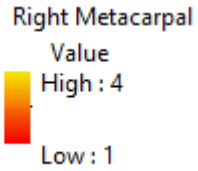
n=4 n=4

Figure 23

Left Metatarsal shows shows smaller identifiable areas especially within the midshaft to proximal shaft zones. There is only a small area located in the proximal epiphysis. The Right Metatarsal has much bigger areas, located in the proximal and mid shaft.







n=2 n=3

Figure 24 Left Metacarpal shows the most area of less identifiability, the area ranges from parts of the distal shaft to almost the top of the proximal epiphysis. Sections were not zones as there were only two shapefiles within the total raster (excluding feature map). The Right Metacarpal is much better, with only a slim of less identifiable fragments within the midshaft to proximal shaft zones.

Although corrupted long bone files were excluded in raster analysis, the attribute data was still saved and used for percent size analysis.

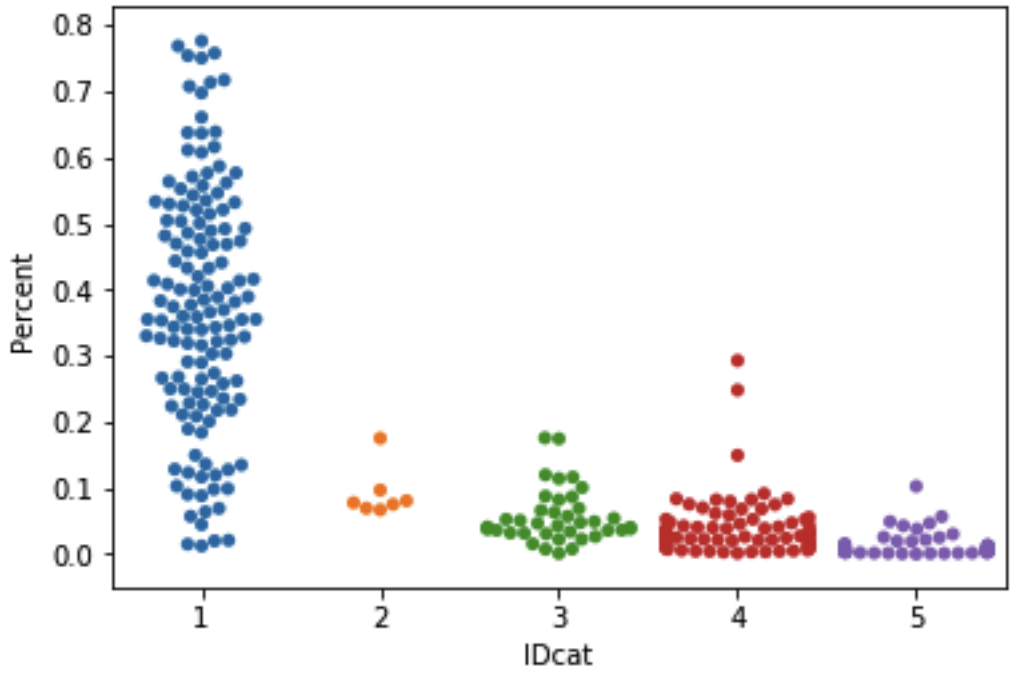


Figure. 25 -- Distribution of each ID category across all bones. Abundantly clear that most bones fall under the ID category of 1

The swarm plot shows the data distribution of each ID category. By observing this graph, it is apparent that ID cat 1 can range from the tiniest sizes to the largest. However, any sizes in percent of total bone over 34% only falls under ID cat 1.

The same data were then broken down to their respective bone elements. However, ulnas had large variances and were subsequently excluded in graphical analysis. This may be due to inherently unique morphology of the Ulna opposed to the rest of the long bones. Ulna in mammals are often more narrow, long, and less thick than the other bones. Right and Left elements were included simply as a quality control measure to test if the data is consistent between sides.

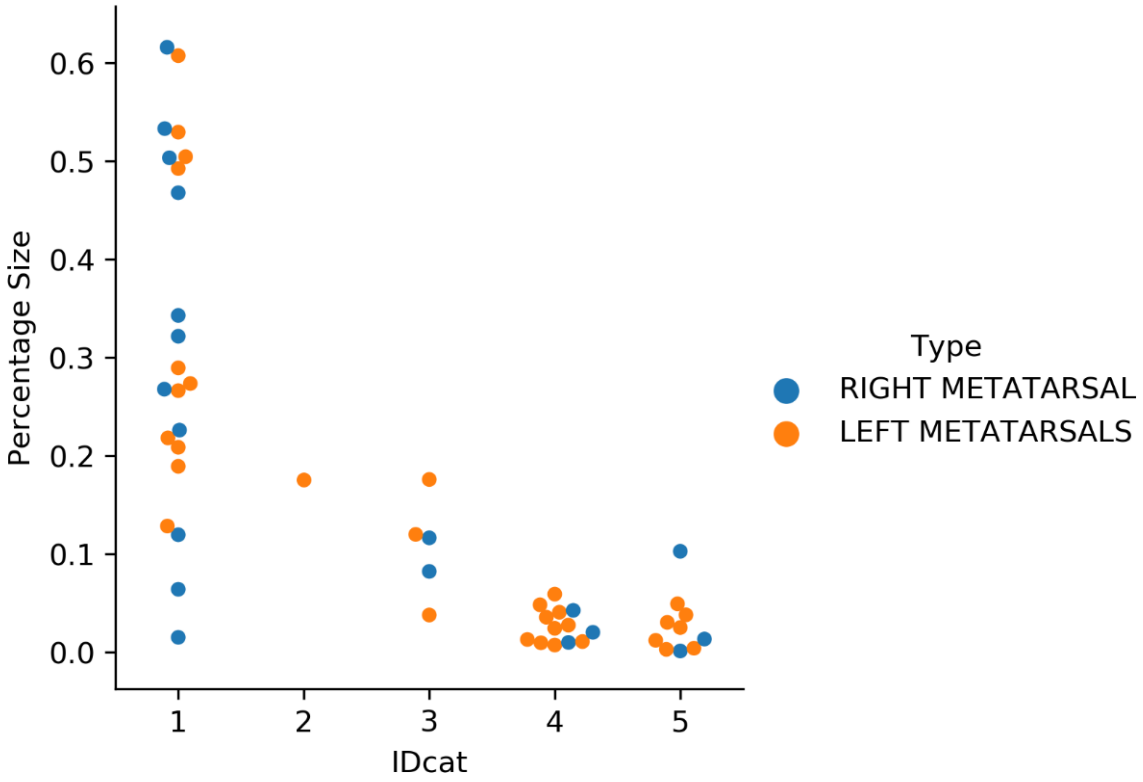


Figure 26 -- ID category distribution for the metatarsals. Evenly distributed between the right and left metatarsals.

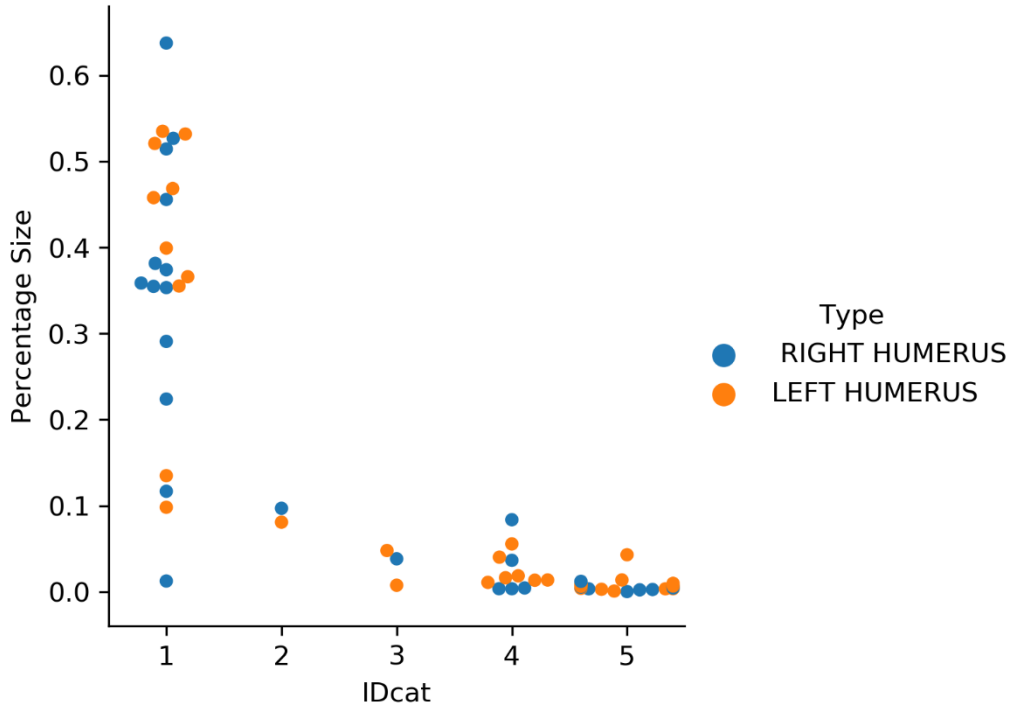


Figure 27 -- ID category distribution for the Humerus

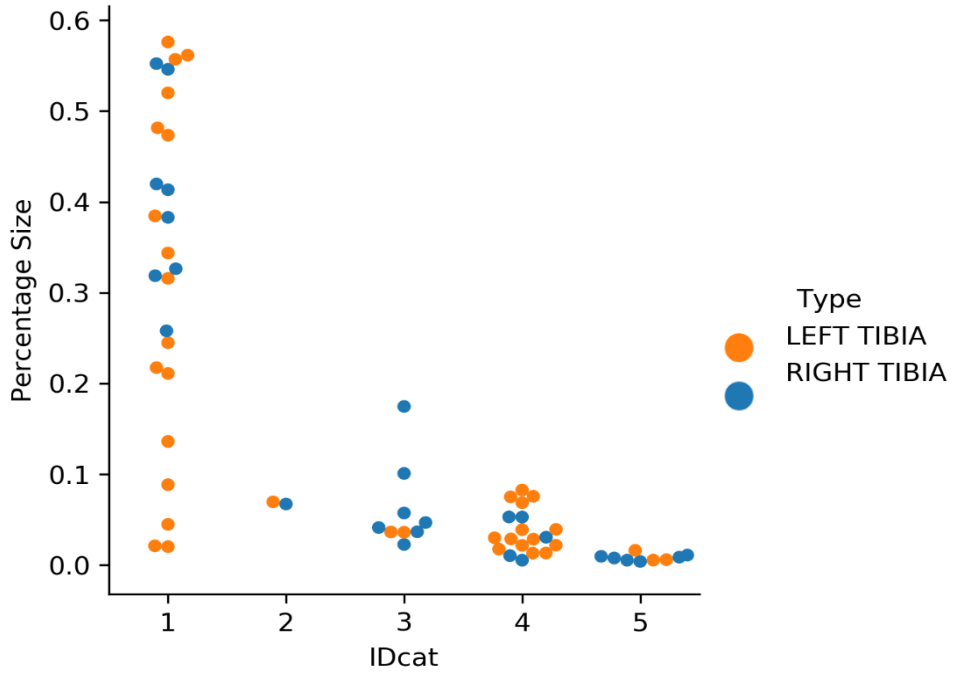


Figure 28 -- ID category distribution for the Tibia

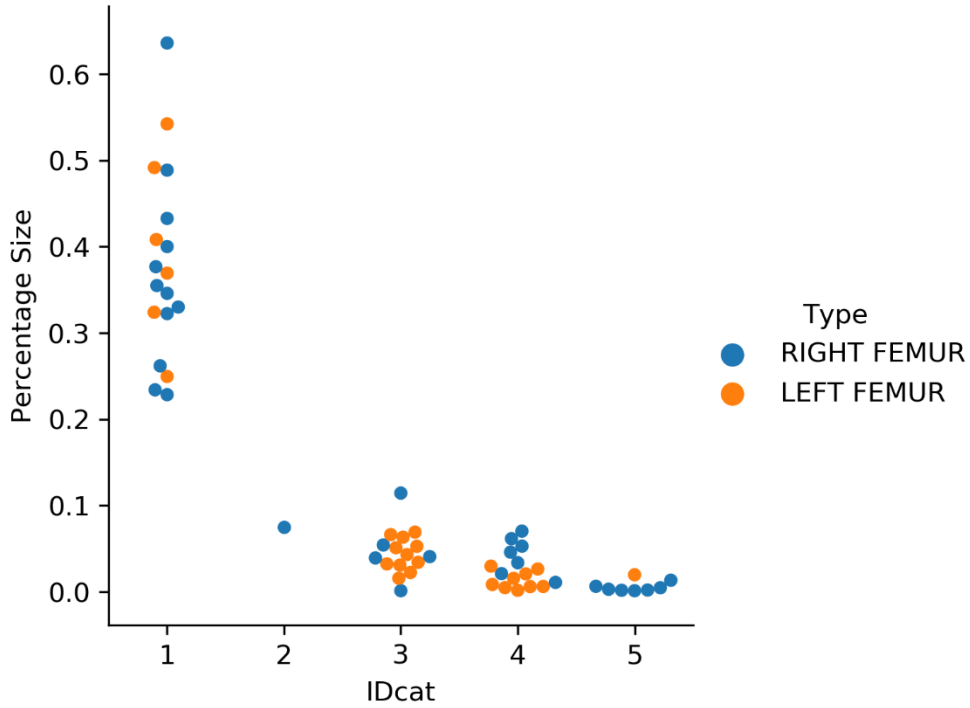


Figure29 -- ID category distribution for Femur. The bone areas under the 1 ID category carry a much larger percentage size than others.

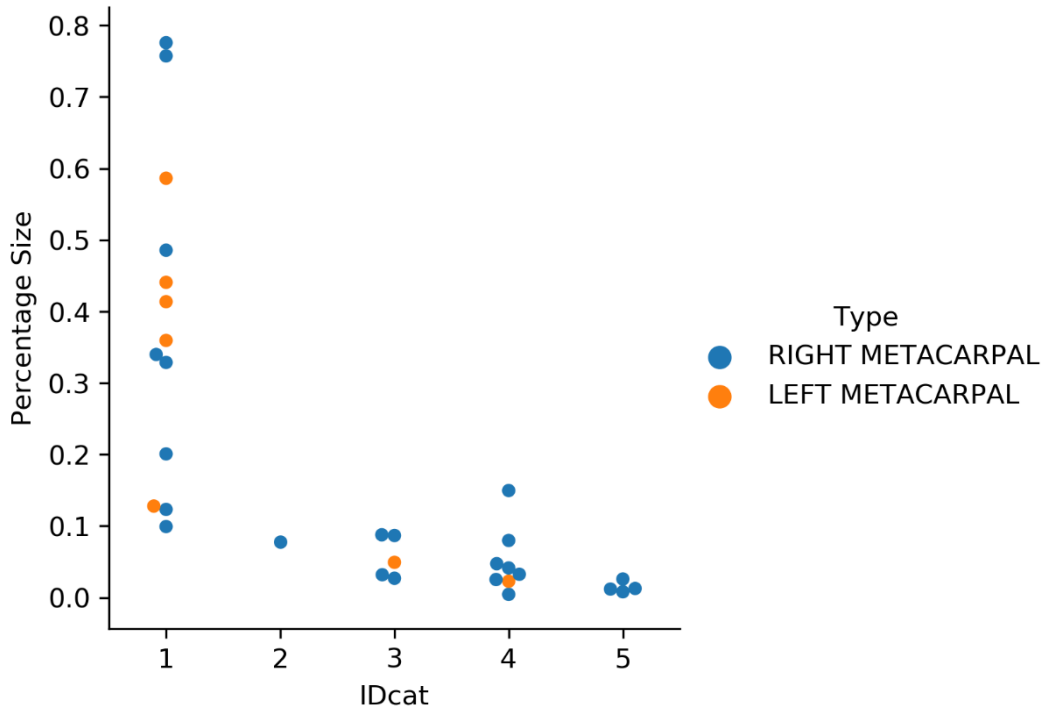


Figure 30 -- ID category distribution for Metacarpal.

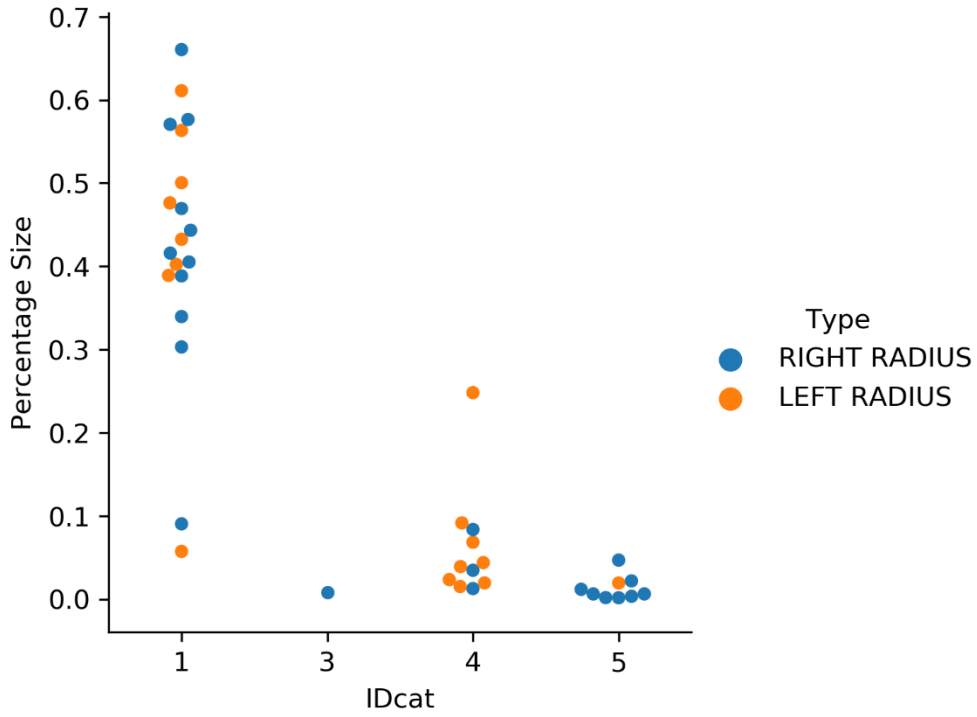


Figure 31 -- Id category distribution for the radius

There are no large differences from the trends observed in the aggregated data with each element. However, the femur is especially sensitive to fragment size. Everything below 20% is 2 or greater in IDcat. Same is the case for femurs below 10% and may be outliers with the IDcat concentration around 4-5.

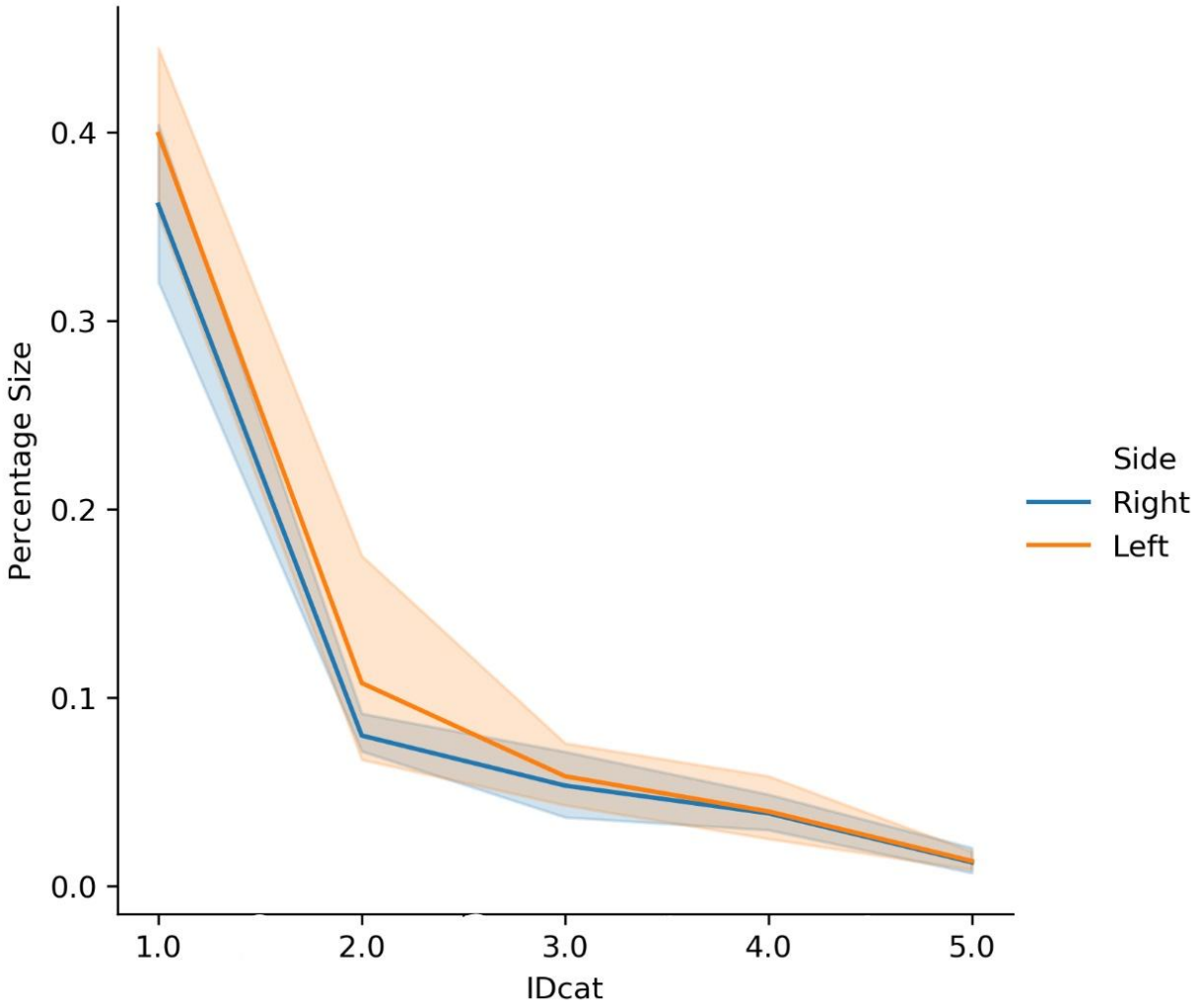


Fig. 32 shows the linear regression of how percent fragment size and ID cat are related. Representation is zoomed to percent sizes below 45% as areas above constitute only to IDcat 1. In, general as the size of the fragment decreases, the identifiability decreases (increase in ID cat #). There were no significant differences between the right and left sides of each element which is what is to be expected. Mann Whitney U Test: statistic=12212.0, p value=0.097 validates the side consistency. Therefore, the method is working and is consistent.

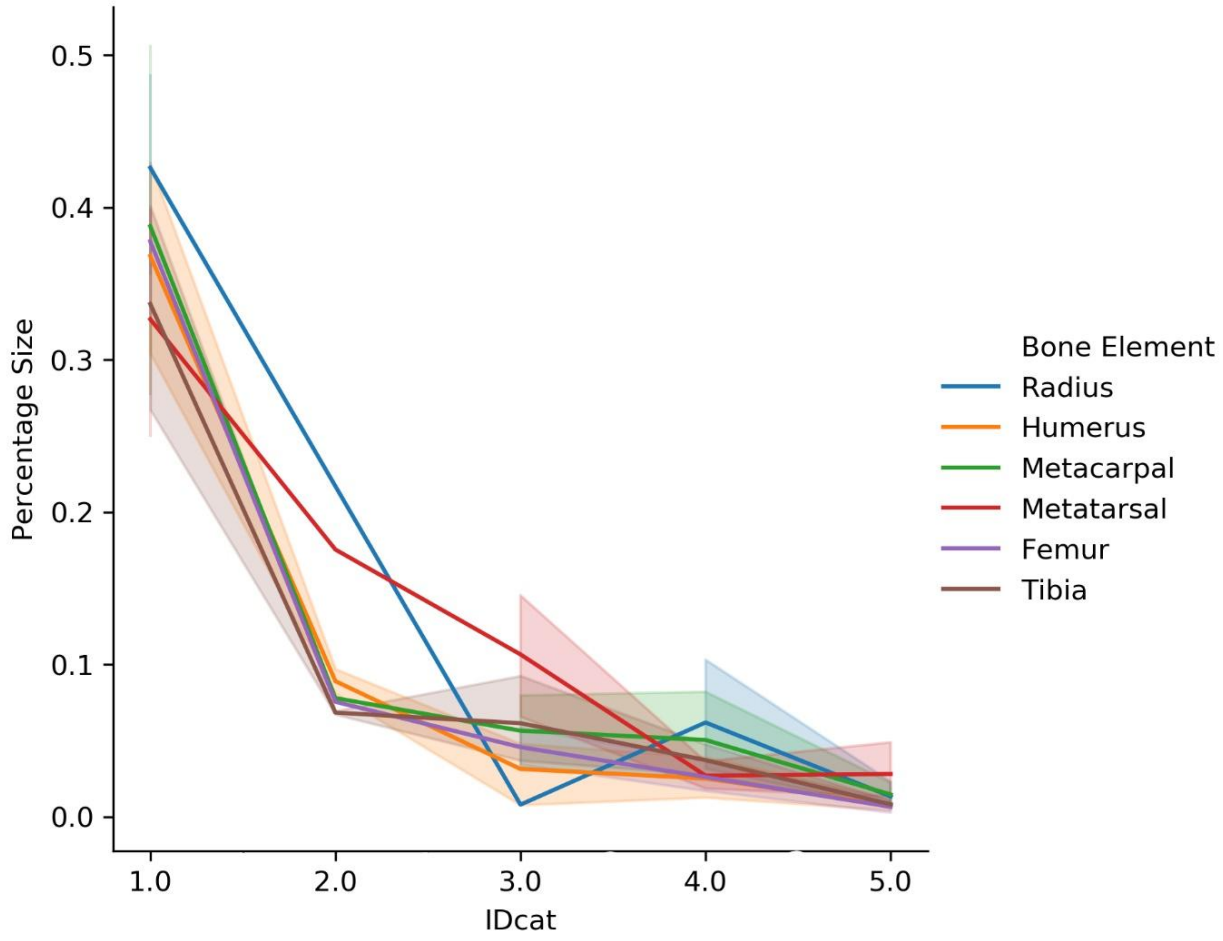


Fig. 32

The following lines are corroborating the above analysis on the relationship between the Percent Size and Identity on each element. Variance trends indicate that some bones such as the Metatarsal, Radius, and Femur are more sensitive to fragmentation than others.

Table-1

ID cat	Max-Percentage Shape	Min-Percentage Shape	Mean-Percentage Shape
1	0.775	0.0125	0.376
2	0.175	0.0671	0.0918
3	0.176	0.00117	0.0563
4	0.292	0.00167	0.0391
5	0.102	0.000281	0.0128

Table 2 (33) indicates that the minimum percent size of a fragment must be in order to be completely identifiable is 1.25% of the complete bone. ID 2 cat is higher and must be 6.75% of the total bone. All other categories fall under smaller sizes. The minimum size a fragment must be in for identifiability falls within ID cat 5 with a size of .0281% of total bone.

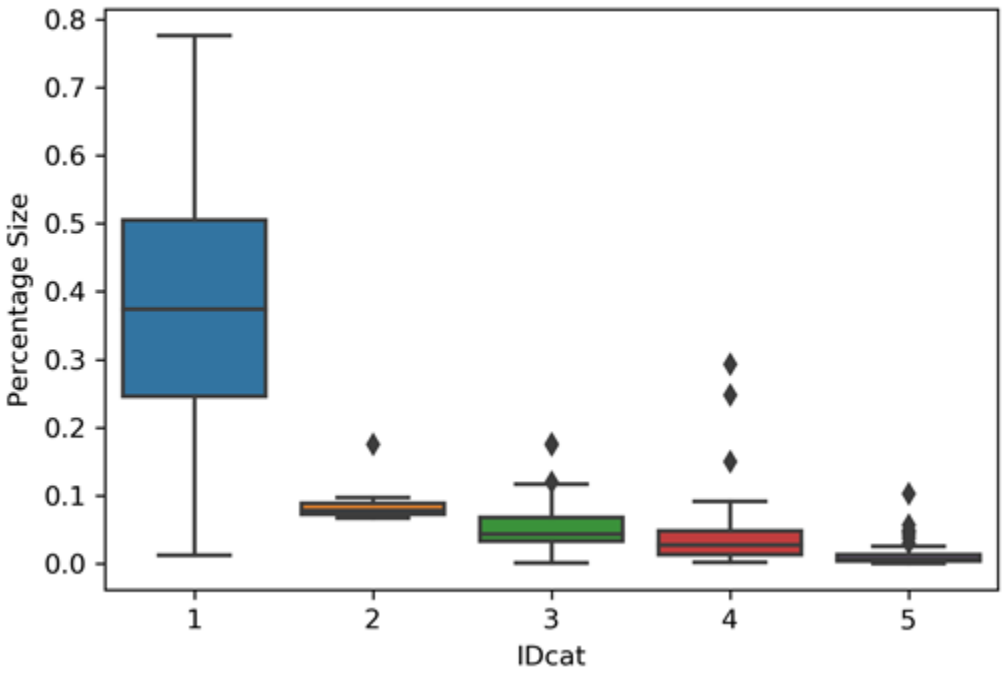


Figure 34
Boxplot visualizing the percent size of fragments within each ID category. Box and whisker plots show the median value (line), interquartile range (box), and outliers(circles).

By observing the above box plot, there are no outliers for ID category 1; however, there are outliers for other categories. If the percent size of fragment is above 13%, the bone can fall into ID category 1. The maximum possibility of ID Cat 1 falls between 25% and 50% percentage of shape. The median percent specimen size is much higher in IDcat 1 than all other categories. This is consistent with Merritt and Davis 2017 data with size of fragment within each ID category

*Outliers were excluded for the analysis

By observing the boxplot and quantile values in the table-1, the following insights are observed:

- When the value of % area is above 12.9% then it falls under category 1
- Category 2 percentage is between 12.8% and 6.9%
- Category 3 percentage is between 11.4% and 2%
- Category 4 percentage is between 7.9% and .6%
- Category 5 percentage is between 3% and .1%
- If the percentage is below .6% then the fragment falls under category 5

Table-3 (Fig 35)

IDcat	**Bone Element**	**MAX-Percentage Size**	**MIN-Percentage Size**	**MEAN-Percentage Size**
1	Femur	0.636180529	0.228476342	0.377680173

1	Humerus	0.637258884	0.012531082	0.368097373
1	Metacarpal	0.775873881	0.099178097	0.387600549
1	Metatarsal	0.615764581	0.015208075	0.326562471
1	Radius	0.660442414	0.057315656	0.426008504
1	Tibia	0.57606346	0.02015888	0.336555382
1	Ulna	0.768181818	0.06927966	0.444093272
2	Femur	0.075367938	0.075367938	0.075367938
2	Humerus	0.096980049	0.08086328	0.088921665
2	Metacarpal	0.077815517	0.077815517	0.077815517
2	Metatarsal	0.175348609	0.175348609	0.175348609
2	Tibia	0.069448598	0.067104095	0.068276346
3	Femur	0.114351079	0.001172697	0.045627092
3	Humerus	0.047926973	0.007620008	0.031290687
3	Metacarpal	0.087652796	0.02684954	0.056419178
3	Metatarsal	0.175879933	0.037912419	0.10650017
3	Radius	0.007866753	0.007866753	0.007866753
3	Tibia	0.174583124	0.022594857	0.061316679

4	Femur	0.070223719	0.001671352	0.025939296
4	Humerus	0.083699643	0.003566473	0.025059647
4	Metacarpal	0.149537766	0.00434382	0.050307827
4	Metatarsal	0.059160387	0.007353346	0.026904832
4	Radius	0.248108216	0.012601634	0.061790429
4	Tibia	0.08249419	0.005225035	0.03709646
4	Ulna	0.292755527	0.003149238	0.098394534
5	Femur	0.01966823	0.001166807	0.006454962
5	Humerus	0.043067428	0.000281462	0.007438487
5	Metacarpal	0.025792612	0.007919623	0.01450424
5	Metatarsal	0.102780549	0.001297179	0.027966426
5	Radius	0.046824917	0.00159744	0.013202906
5	Tibia	0.016054678	0.003834396	0.008083856
5	Ulna	0.056836236	0.056836236	0.0568362

Table Additional breakdown of fragment sizes between each long bone specimen

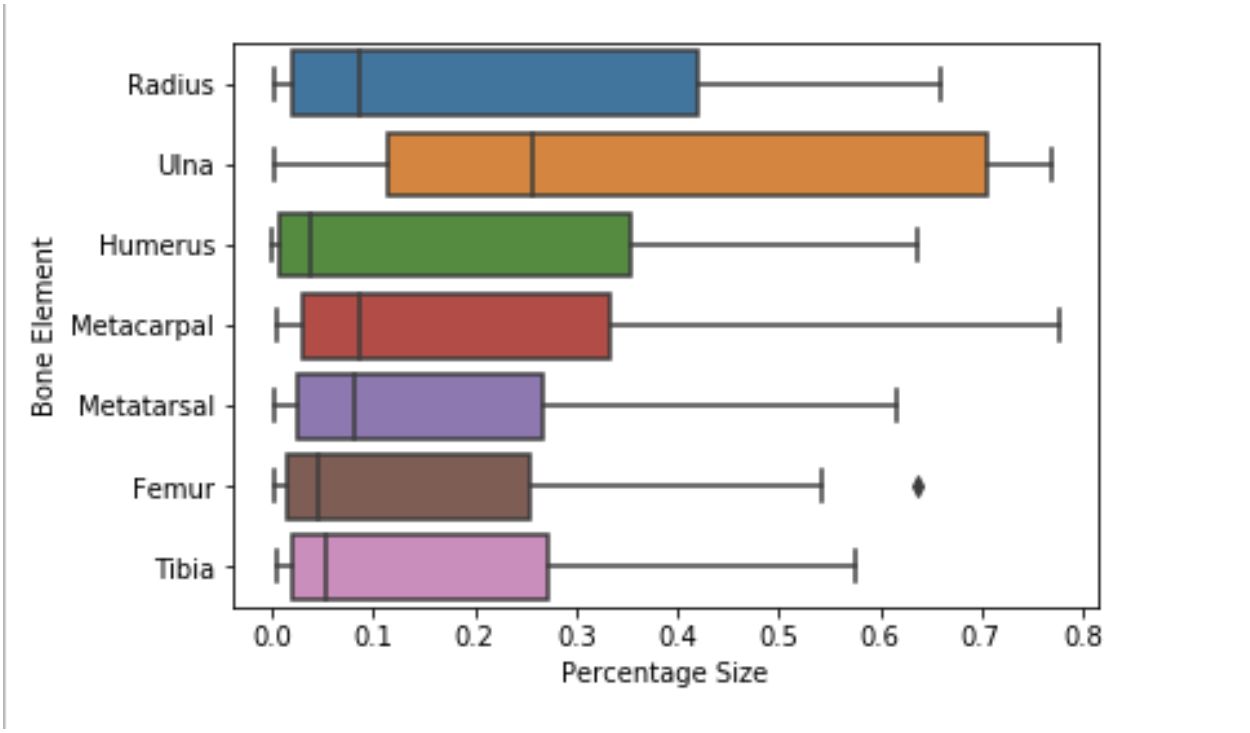


Figure 36

Boxplot visualizes the range in date shown for percent size of fragments within each long bone element. Box and whisker plots show the median value (line), interquartile range (box), and outliers(circles).

Discussion:

The composite rasters show that the highest areas of identifiability across all long bone elements occurs primarily at the epiphyseal ends. The Right and Left Ulna are exceptions to this trend because of their small raster aggregation (each with only 3 raster additions including feature map). This was due to some of the raster files being corrupted during data transfer. It is worth noting that many of the epiphyseal specimens are relatively complete in circumference and therefore can be more precisely identified. It is also worth noting that the epiphyseal ends generally tend to remain intact during breakage due to the jointed ends being able to withstand a larger amount of force (Godwin et al., 2002). However, in the observation of actual carnivore assemblages, the epiphyseal ends are rarely preserved. In a study by Pickering et al. 2003, NISP counts are much lower than in post ravage vs pre ravage. Shafts on the other hand have higher post ravaged NISP counts than pre ravaged. Although experimental research may indicate that epiphyseal fragments are more identifiable than shafts due their features, the actual research may not be concerned with their identifiability as shaft specimens may be more useful for data analysis as they are more represented (Osterholtz, et al. 2004. Pg. 224).

Based on raster analysis, most of the zones with less identifiable areas occur in the midshaft to proximal shaft zones with the exception of the Left and Right Radii where less identifiable areas occur in the midshaft and distal shaft zones. However, in general there are fewer distinctive features in the midshaft areas that could help constitute where the fragment is located and what element and side it belongs to.

Size in relation to identifiability

The less identifiable regions mostly occurred towards denser specimen counts (higher fragmented areas). This may be because smaller fragments are less likely to retain diagnostic features to accurately categorize them into the higher ranked identifiability categories. In actualistic research, Atici 2014 found that fragment size and specimen count were inversely related. Therefore, smaller fragments are more common within an assemblage than larger ones.

This theory is generally conserved during the regression analysis of identifiability vs percent size t graphs. The results indicate that the larger percent size of fragment is positively correlated with better identifiability, and bones greater than 34% size are likely to be easily identifiable.

Analyzing percent size may be more important for elemental identifiability than actual measurement size. For example, a 22 cm^3 size fragment of an Ulna may be more identifiable than a Radius because the $22cm^3$ area might constitute 20% of the total area of the ulna, but only 10% of the radius. Therefore, relative size can be a valuable measurement for identification. Although this study did not have a large enough sample size to quantify the differences between each element, Figures 29-34 show general trends of each respective bone.

Caveats

Overshoot Bias

When characterizing fragments into the geospatial software, there is a bias towards the ability of the analyst to correctly draw out each specimen. Therefore, the shape of each fragment will always have a human subjectivity error. But more so than shape, size can be heavily skewed by the way the GIS templates characterize the data. After all, converting a 3d object to a 2d template will be skewed based on the angle and view of the analyst. The different angles in the template (medial, posterior, lateral, and anterior) attempt to capture the 360 view of the bone element, but due to physiological optics and human error, there may be a tendency to overshoot the size of the fragment when characterizing it on the template. Therefore, the physical space the specimen occupies is different than the visual space characterized on the template.

Future Directions:

As analyzed in this project, identifiability and size are positively related. However future research should delve into how both size and identifiable features are also related. What exact percent of the fragment overlaps with a featured attribute. For example, a large fragment (30% of long bone) may only be identifiable if at least 10% of it overlaps with a featured area. This may not be that difficult to execute, as the percent size of a featured areas could be overlapped to the fragments above it. The fragment is not identifiable because of its larger percent size per se but because it happened to overlap on a feature. The elemental rasters for this study were overlaid with the feature maps as to assess identifiable areas in combination with landmarks on the bone.

Again, future studies can use the aggregated rasters as one raster file and compare it to the feature map raster. This technique could showcase the relation between landmark preservation, fragment size, and identifiability. This type of study could showcase differences within featured areas. For example, an epiphysis may be a better marker to identity than a small nutrient foramen.

Because the mammal sample size is so small, it may be useful to continue research on multiple different specimens per element and on different mammal skeletons. As stated before, relative size is important in analysis. Therefore, it would worthwhile to research if the percent size between the elements makes a significant difference in analysis or if different animals have differing identifiably. For example, would a 10% sized humerus fragment of a gracile goat be equally identifiable to the same percent sized humerus of a small bird? Also, age may be another area of significance. Often young mammals can lose epiphyseal ends during degradation, causing identifiability at the end to be harder to identify. Although there are often distinct features on epiphyseal ends of long bones due to limb attachments, most of the ridges may not be fully developed for correct identification (Liu et al., 2013).

Use of ArcGIS Pro

A frustrating aspect of this project was the slow processing of the data. Simple functions such projections, transformations, and conversions took several minutes to carry out for single layers. This may be due to the slower processing power as the software was not completely updated in the beginning of the project. Therefore, archaeologists may want to consider turning

to the latest desktop version of ArcGIS to best utilize their system's RAM. ArcGIS Pro claims to modernize the user experience and carry functions more efficiently (Barsai, 2018). The layout is more user friendly and many archaeologists would appreciate the better learning curve that comes with Pro.

Importance of Analogy

One of the fundamental philosophies that zooarchaeology depends on is analogy which assumes that the processes of the past and present are comparable and similar. This serves as the basis for modern experimental observations to understand the archaeological record. (Gifford-Gonzalez). Although analogy can be misinterpreted, it is still necessary in order to understand the archeological record. Simply identifying fragments from an assemblage is not enough, analogues are needed to reduce uncertainty in identification.

The analog of identifiability in this study showcases how fragments from regions in proximal to midshaft zones are often less identifiable than epiphyseal ends. This observation can help analysts reconsider their accuracy when identifying fragments coming from those regions. Also, the observations could aid inter analyst disagreements in identification. For example, if two analysts disagree to the level of identifiability (IDcat1 or 2) of a midshaft specimen with a size <34%, then it may be wise to error on the side of caution and place the fragment in the lower ranked category as that size may be rarely identifiable to side, element, and portion.

Experimental design must find a balance between this realism and analogy (Levins, 1966), therefore archaeologists should explore the efficacy of GIS mediated analysis, individual influence of the analyst, and how differential zones and relative size impacts fragmentary specimen identification. Identification of fragments is subjective to the analyst, but placing emphasis on what areas of bones are less identifiable and why could help in developing predictive modeling. The ID categories attributed to each fragment was primarily based on the data ranking of the analysts in the Merritt et al. 2017 study. However, certain mislabeled fragments were recoded and refitted to the present analyst's expertise. Essentially identification is a craft specialism and fundamentally flawed. Although the knowledge of experts is valuable, by pointing to certain conditional identifiability differences (size and bone portion), researchers can more accurately determine the fragment and analyze how accurate their identification labels are.

Conclusion

The small sample size prevents the study from making general conclusions about identifiability of long bone specimens. However, three important observations can be drawn. First, fragment size and portion seem to be a positive contributor in faunal identifiability. Second, highest ranking identifiability categories where specimens can accurately be assigned to side, element, and portion, can range from varying different sizes although larger sizes are much more identifiable than smaller ones. However lower ranked ID categories often include much smaller specimens and do not include anything past a relative size of 34%. Third, several subjective biases are innate when quantifying identifiability in this project, such as osteological

expertise, analyst drawing bias, and area overshoot bias from 3D to 2D digitalization. Also, the described techniques and fallbacks when utilizing GIS in the present study can aid in more efficient future projects and reliable interpretations.

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