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Kirkwood, Damian R., Butchering Practices at the Vore Buffalo Jump (48CK302): Investigating Organization with the Nearest Neighbor Test, MA, Department of Anthropology, May 2016.

Spatial recognition of organization at mass kill sites is often commented on in the literature but is rarely systematically investigated. The goal of this thesis is to investigate social organization of butchery with the nearest neighbor test. The lack of these sorts of methods in the literature is primarily due to ever changing methods of archaeological excavation and limited ability to easily analyze provenience data. In the literature, observations of organization and spatial patterning have relied on site maps of excavation blocks and in-field observations. In this thesis, statistical methods are applied to a mass kill site of *Bison bison* from the Vore Buffalo Jump (48CK302) to investigate the organization of butchery. Using a nearest neighbor test, pairwise bootstrapping tests, and a chi-square analysis, this study finds that these methods can give insight into dense stratified bone beds and locate patterns more confidently.

BUTCHERING PRACTICES AT THE VORE BUFFALO JUMP (48CK302): INVESTIGATING ORGANIZATION WITH THE NEAREST NEIGHBOR TEST

By

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A thesis submitted to the Department of Anthropology
and the University of Wyoming
in partial fulfillment of the requirements
for the degree of

MASTER OF ARTS
in
ANTHROPOLOGY

Laramie, Wyoming
May 2016

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ACKNOWLEDGEMENTS

I would like to thank my committee, without their help and guidance this thesis would not have been possible. Thank you Todd A. Surovell for being my chair and sharing your vast knowledge of computer simulations for statistical analyses and helping me trudge through graduate school. Thank you Charles Reher for all of your work at the Vore Buffalo Jump over the years, the result of which is an amazingly large dataset perfect for research as the limits are endless. Thank you Greg Pierce for your mentorship and friendship, both of which have been immensely invaluable. Thank you Bill Gribb for your guidance and expertise in spatial analysis.

I would also like to thank Rick Weathermon for his guidance in both my academic and professional career. The knowledge gained under your tutelage has helped shape my archaeological pursuits.

I would also like to thank my fellow graduate students: Josh and Jessie Boyd, Laura Cannon, Sean Carroll, Brigid Grund, Adam Guinard, David Howe, Connor Johnen, Maddie Mackie, Justin McKeel, Danielle Messing, Spencer Pelton, and Rachael Shimek. The ability to discuss research ideas and push each other academically has given me unique perspectives on archaeology. The passion for archaeology stems from late night discussions and debates with you all.

Finally, I would like to thank my family. The support from my parents is something that cannot be taken for granted. They have helped shape my perspective on life and given me the courage to pursue my academic goals. A special thank you to my significant other Cassidee Thornhill, without your love and support keeping me grounded, this work may have never happened.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. Introduction

Hunter-gatherers on the High Plains relied on several subsistence strategies aimed at procuring large amounts of animals at one time. For the purpose of this thesis, these strategies are referred to as mass kills. It has been argued that mass kills are large-scale operations that represent cooperation by a large group of people (Verbicky-Todd 1984; Binford 1978a and 1981; Frison 1973; Reher and Frison 1980; and Brink 2008). Because of this, aspects of social organization at mass kill sites should be spatially recognizable in the archaeological record. Using computer simulations, this thesis employs the nearest neighbor and pairwise bootstrapping tests to create methods of analysis that can be used to trace aspects of social organization through faunal remains at mass kill sites. Using the faunal assemblage at the Vore Buffalo Jump (48CK302), a *Bison bison* jump located within a natural sinkhole in the Black Hills of northeast Wyoming (Figure 1), this study investigates the organization of butchery and looks to develop methods of analysis for large faunal assemblages. For this research, I am working under the assumption that an enclosed sinkhole, like the Vore Buffalo Jump (Figure 2), represents a restricted area in which the various stages of butchery (i.e. disarticulation, skinning, marrow processing, and transport) can be carried out. This organization should be evident in the clustering of similar bone elements either in an "assembly line" fashion or in the form of anatomical partitioning (Binford 1978a:60). Clustering in this fashion would indicate that cooperative organization and decision making were occurring at the site during the butchery process.

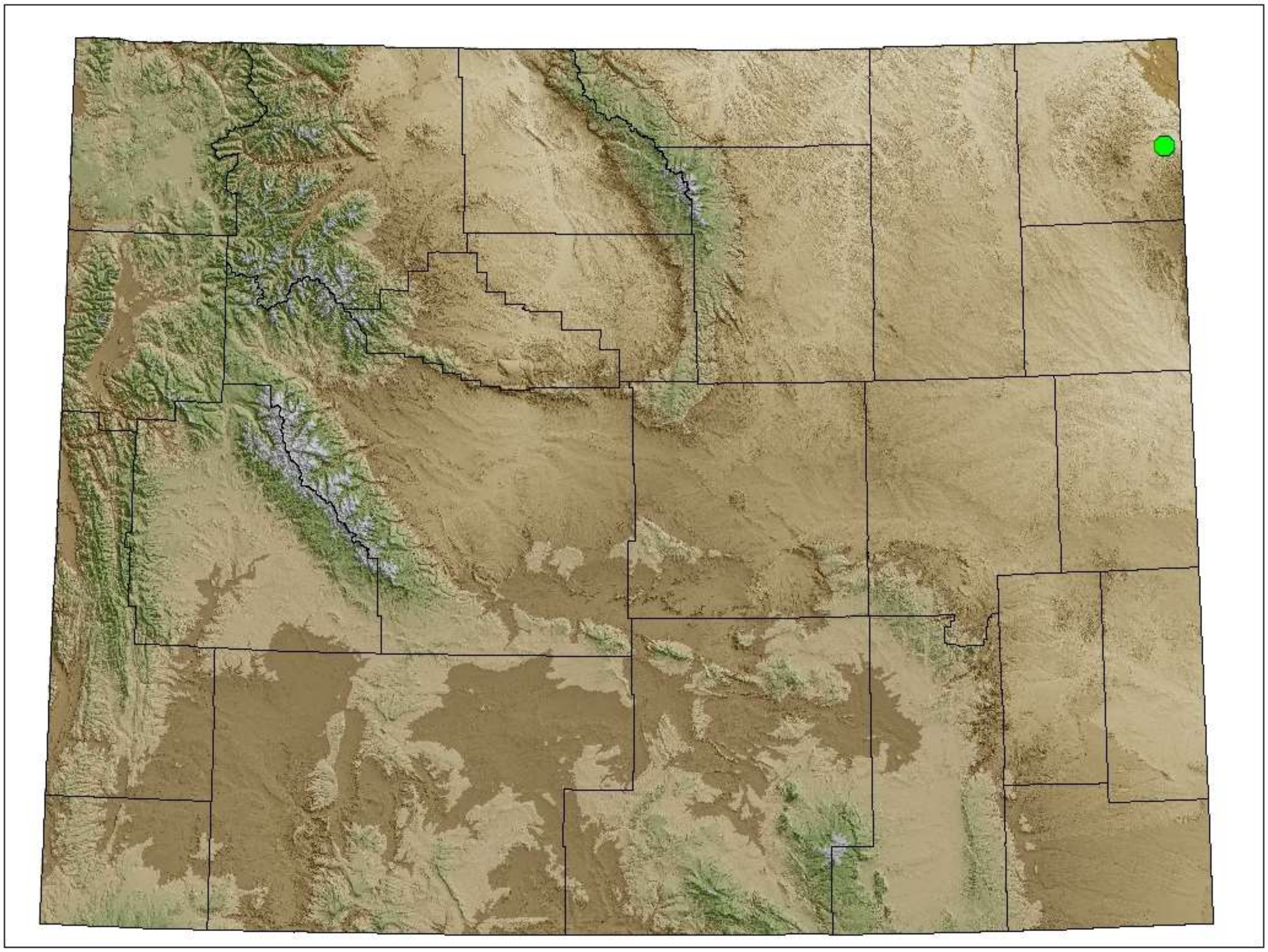


Figure 1. Vore Buffalo Jump site location.

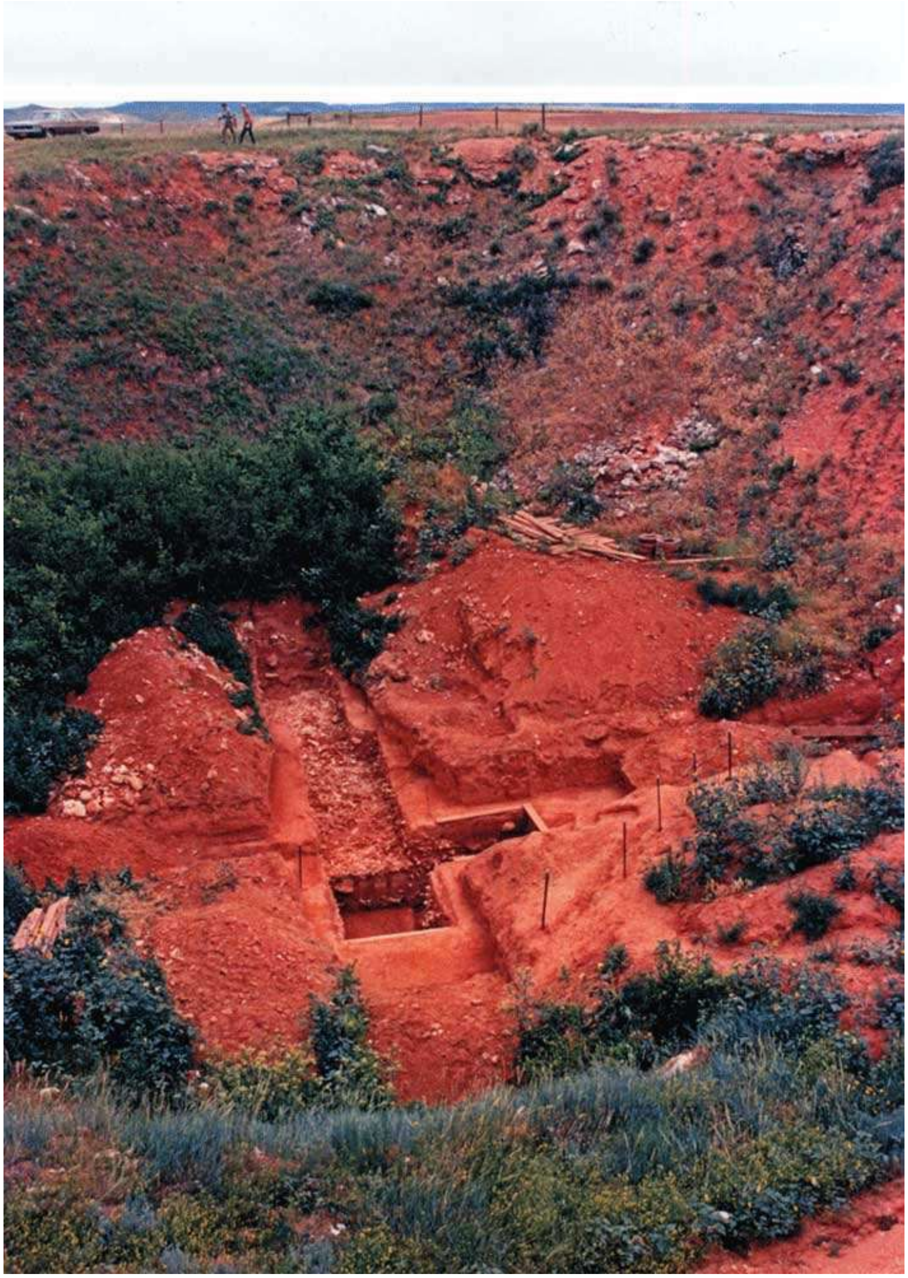


Figure 2. Overview of the Vore Buffalo Jump and excavation units (Reher 1992a)

The first section of this paper presents a brief overview of food sharing and cooperative strategies while also highlighting previous research carried out on mass kill sites, mainly focusing on spatial analysis and interpretations. The next section provides an overview of the Vore Buffalo Jump, including its discovery, geologic context, and the previous research. The third section discusses the possibility of fluvial transport (Lyman 1994) and issues related to site formation that must be considered before intrasite spatial patterning can be interpreted. After a discussion of methods, I discuss the results and implications for future research that can be employed at mass kill sites where systematic butchery takes place.

1.1 Background

Mass kills of *Bison bison* require efficient organization of labor “by a group of people, on either the band or tribal level, working together to secure a large number of buffalo simultaneously…for consumption by the community” (Verbicky-Todd 1984:10). Communal hunting can also facilitate a form of insurance or “reciprocal altruism” (Trivers 1971; Kelly 2013:146) for times of food shortages and stress through food sharing and cooperation. While investigating the Nunamiut, Binford (1978a) noted that “when food stores became diminished and hunting success was also reduced, the hunters would report to the head of the disadvantaged family” (Binford 1978a:141) and be given gifts of meat. The Nunamiut demonstrate how food sharing maintains kinship relationships as they “share food when engaging in communal or cooperative endeavors” (Binford 1978a:141). This is also evident with native groups in the High Plains and demonstrated at the Eden Farson (48SW304) site, a mass kill site of *Antilocapra americana* attributed to the Shoshone (Frison 1971). At this site, food sharing also maintains the social structure and it “appears that leaders received payment in the form of meat…which resulted in a receipt of better cuts of meats…(they) also received a boost in social currency among (the) primary economic unit and those participating in the hunt” (O’Brien 2013:139). Working together as a community to capture and process animals is beneficial as more food can be obtained, reciprocal relationships are formed, and social currency (O’Brien 2013) can be obtained or maintained.

With reference to the well-known bison jump, Head-Smashed-In located in Alberta, Canada, Brink states that “hundreds of people collectively found the distant herds, tricked them into the drive lanes, stampeded them to the cliff, killed them below the jump, and butchered the remains (Brink 2008:170). Because of the complex nature of driving and jumping bison, potentially hundreds of animals could be coaxed off of a precipice and “everyone had to pitch in to turn them into useable food and materials for the good of the entire group” (Brink 2008:170).

In the archaeological record, there is plentiful evidence of mass kill sites where the cooperation of individuals resulted in the capture and killing of dozens to hundreds of animals at a time (Wheat 1972; Binford 1978a and 1981; Frison 1965, 1973, and 1986; Reher and Frison 1980; and Brink 2008). According to Verbicky-Todd (1984:168), events like bison drives and jumps were often community events in which most able-bodied members participated. An event of this magnitude required the cooperation of many people and “it seems reasonable to believe that there must have been an ordered system to dismembering the spoils of the kill” (Brink 2008:171). According to Frison (1973:78), “buffalo kills appear to represent the largest economically-cooperative, socially integrated group activity during most of Plains prehistory”. For hunter-gatherer societies, a communal hunting event requires efficient social organization, which facilitates beneficial effects for all of the contributing members. Although it is only inferred based on the logistical complexity of mass kills and ethnohistoric accounts (Verbicky-Todd 1984; Brink 2008), cooperation and organization should be evident in the archaeological record.

Spatial analyses at archaeological sites are often concerned with the distribution of artifacts and the relationship of those artifacts to each other or to other features (i.e. hearths, stone circles, house pits, etc.) located within the site boundary (Carr 1984; Surovell and

Waguespack 2013; O’Brien 2013; and Brink 2008). Spatial analysis concerning mass kill sites is often commented on in the literature (Binford 1978a and 1980; Frison 1965; and Wheat 1972) but there seems to be a lack of formal statistical exploration.

Wheat (1972) describes the spatial comingling at the Olsen-Chubbuck site as appearing to represent a discard pile where “a number of bones were, for various reasons, cut apart from their related units and retained” (Wheat 1972:106). The bone piles were often “groups of the same elements, such as scapulae, femora, or cannon bones…suggesting that the elements of a group of animals were processed together” (Wheat 1972:106) and more importantly these piles indicate that “a sort of disassembly line was in operation” (Wheat 1972:106) at Olsen-Chubbuck. The work by Wheat at Olsen-Chubbuck is the best example of anecdotal interpretations of significant spatial arrangement at a mass kill site. Other work that demonstrates spatial recognition by the researcher includes Frison’s (1965) work at the Piney Creek sites, located in north central Wyoming. Frison observed some spatial patterning and areas of butchery as well as activity centers at the Piney Creek (48JO312) site. He described the distribution of bison remains at two separate areas of butchery; “in the kill area are found greater number of heads, vertebrae and proximal ends of rib bones…(suggesting) that many individuals were dismembered by detaching the hind and front quarters and removing ribs by breaking them” (Frison 1965:244). Frison also observed that the “front and hind quarters were taken to the butchering area where nearly every bone was broken…to extract fat and marrow (Frison 1965:244). Frison’s account describes two activity areas, one area where the bison were quartered and the other where to which they were transported (i.e. “butchering area”) (Frison 1965:244). Although the distribution and clustering of the faunal remains were commented on in terms of the stages of butchery, there is still a lack of statistical analysis to demonstrate that these differences in element frequencies reach the level of statistical significance. Frison made the assumptions of spatial patterning based on breakage patterns of faunal remains, locations of fire pits, chipped stone artifacts, boiling pits and the dispersion/concentrations of the bone elements in the two activity areas. It might visibly appear that the distributions of processed bison remains are separated and represent isolated activity areas, but additional analysis of these concentrations with statistics has the potential to strengthen the argument of spatial patterning.

Binford discussed site structure and spatial patterning among the Nunamiut and called for more extensive research to be made pertaining to the use and distribution of bone elements (1978a; 1981). Binford (1981) also argued that faunal remains should, in a sense, cluster or pattern based on either the anatomical association of the elements (i.e. femora, metatarsal, phalanges etc.) or based on decision-making by human agents and the type of butchery that is taking place. If there is a lack of clustering of similar bone elements, the remains can also reflect other stages of butchery or other techniques being implemented. While observing the butchering process and decision-making processes of partitioning caribou bone elements he noted that:

> Independent distributions of the metatarsals and metacarpals as well as their independence from upper leg segments of both rear and forelimbs clearly reflect…processing marrow as opposed to meat…human use of anatomical elements is apt to have certain redundant patterns (Binford 1981:95).

Patterning depends on the type of butchering taking place, but in his work with the Nunamiut, Binford witnessed how bone element dispersion may be the result of human agents rather than natural distribution. Elements high in caloric value in terms of marrow should be grouped together in one area and exhibit breakage patterns that signify marrow extraction. The bone elements that have a higher value in terms of meat should therefore be grouped together in another area indicating meat processing; and the elements low in both categories should represent discard piles.

In general, the clustering of bone piles is often discussed in the literature but not explored extensively or statistically. This is due to the changes in the methods of recordation for provenience (e.g. from hand drawn unit maps, transits, and plane tables to the use of total stations). The sites recorded by Frison and Wheat might exhibit isolated activity centers but mass kill sites like the Vore Buffalo Jump illustrate the complexity of defining organization and spatial patterning when the majority of the butchering activity is taking place in close proximity, or literally on top of, the kill location (Figure 3).

Figure 3. Unit O1 from original excavations located in the center of the site (Reher 1992a). This illustrates the difficulty of visually recognizing structure and spatial patterning.

1.2 The Vore Buffalo Jump

The Vore Buffalo Jump is located in the Red Valley of the Black Hills in northeastern Wyoming. During the construction of Interstate Highway 90 in the 1970s, the State Highway

Department drilling crew discovered the site (Reher 1980:1). Through a National Science Foundation grant, excavation by George Frison (University of Wyoming) began in the 1970s with the purpose of investigating the extent of the site and "developing sampling techniques viable in large, deep bone middens" (Reher 1980:10).

Lawrence Todd (Colorado State University) and David Rapson (University of Wyoming) continued excavations at the Vore in 1995. Charles Reher (University of Wyoming) eventually took over excavations which have been more or less continuous from 2005 to the present. The excavation blocks are separated by the era in which they were recorded (i.e. the "old" units and "new" units). The "initial excavations used 7.5'x10' units excavated in one foot arbitrary levels…(and) later units were excavated in inches with cultural breaks within larger one foot levels" (Pierce 2015:95). Excavation of the "new" units began in 1995 and the units "were placed adjacent to the south of the original 1970s excavations" (Figure 4). Data collected during the "old" and "new" excavations were both extremely detailed through the use of plan maps, overhead unit photos, and over 20 variables and codes pertaining to bone element descriptions. The result of which is a vast amount of data that can answer various questions pertaining to subsistence strategies, natural trap utilization, bison procurement, and other economic strategies.

The Vore site consists of at least 22 stratified cultural levels or "kill" events that extend approximately 5 m subsurface. Native Americans that may have utilized the jump include "Cheyenne, Crow, Kiowa, Plains Apache, Lakota Sioux, and Shoshone (Reher and Frison 1980:29-30). The "cultural material is confined to the successively layered middens of butchered bone, with sterile sediments separating the middens" (Reher and Frison 1980:9). The site has numerous strata, but this study focuses only on the top two cultural levels. The layers are separated by a relatively thin, approximately 5 to 10 cm thick, sterile level. As such it can be difficult to cleanly separate skeletal elements into cultural levels as “the cultural stratigraphy is exceedingly complex, with stacked bone middens lensing in and out, forming discrete levels in some areas and thick conglomerates in others” (Reher and Frison 1980:138).

Through the use of varved sediments, dendrochronology, radiocarbon dates, cut mark analysis and projectile point typology place the use of the site around A.D. 1500-1800 (Byerly 2007; Crago 2003; Pierce 2015; Reher and Frison 1980). This allows for spatial patterning and site usage to be tracked through time from the prehistoric to the Protohistoric and into the contact era.

The bedrock of the surrounding area consists of red siltstone, claystone, and sandstone from the Triassic Spearfish Formation. The site is nestled against a rolling prairie grassland setting (Reher 1977 and 1978a). The site is geologically unique in that the faunal assemblage is at the bottom of an enclosed sinkhole or pseudokarst (Reher 1980), as opposed to an arroyo, cliff, or constructed corral or “pound”. The sinkhole itself is the result of chemical weathering of the underlying gypsum deposits from surrounding limestone bedrock. Caving in of the ground surface has resulted in a steep sided natural enclosure, readymade for jumping and trapping bison. The site area is approximately “31 m (100ft) across the top, with steep sides 15 m (50ft) high” (Reher 1980) (Figure 4).

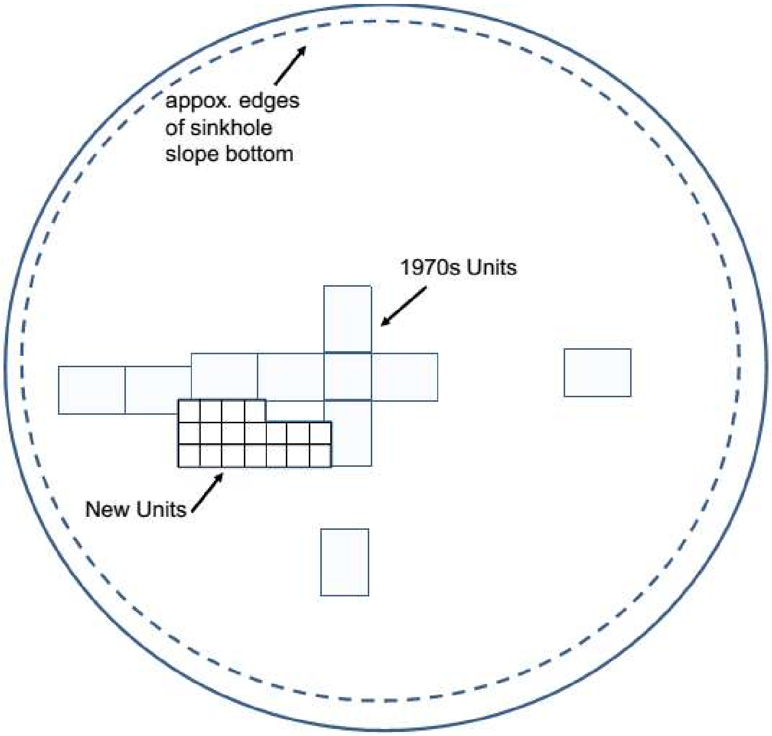


Figure 4. Plan view map of the Vore Buffalo Jump site (Reher 1992a).

From observations by investigators of the site, there appeared to be clusters of similar bone elements in portions of the excavated area. The most obvious clustering was evident in mandibles (Figure 5), as noted in the Vore memoir of the site (Reher and Frison 1980:15). Much like the studies previously mentioned these observations were anecdotal with no attempt at formal analysis of this spatial pattern. Although extensive research has been carried out on the faunal remains from the Vore (e.g. Byerly 2007; Crago 2003; Piece 2015; Reher and Frison 1980; St. Clair 2000), no in-depth spatial analyses have been carried out on individual cultural levels. Reher and Frison (1980:15) commented on the need for spatial analysis as there should be "a lower degree of randomization, the appearance of larger features, the appearance of greater systemization…(that) should be quite obtainable by applying a series of statistical, graphical and visual measures" to the faunal assemblage. It was also noted that "excavations revealed distinct piles of bones separated by areas of low concentration…but provided only a tantalizing glimpse of their nature" (Reher and Frison 1980:15).

Figure 5. Photo demonstrating one of the most distinctive concentrations of mandibles from Level 3 of the original excavation units at the Vore site (Reher 1992a).

St. Clair's (2000) work on the spatial arrangement of bison skulls at Vore bears some similarity to the work presented herein. St. Clair investigated the potential of ritualistic and intentional arrangement of the bison skulls at the Vore site, where it appeared that there was "specialized treatment of skulls…several clearly ceremonial alignments of bison skulls, the majority of which exhibit…similar openings of the brain cavity" and are arranged in "arc-like" concentrations (St. Clair 2000:1). These interpretations were based on plan maps and basic provenience location, photographs, and historical accounts in which other native groups ceremoniously created circles or arcs of skulls.

The Vore site provides a major advantage for this kind of study in comparison with other bison kills— there is excellent provenience data on skeletal elements. It is now possible to utilize computer simulations to investigate the statistical significance of the observed clusters of bone elements and potential activity areas. There is also a low frequency of chipped stone and an absence of metal artifacts recovered in the upper cultural levels at the Vore (Pierce 2015), hindering spatial analysis of these types of artifacts. Because of this, the faunal assemblage is more likely to produce fruitful results when examining site structure and organization.

1.3 Taphonomy and Site Integrity

Because the Vore site is located at the bottom of a natural sinkhole, the faunal assemblage is relatively well protected, but there is the possibility that alluvial processes have affected the placement of the skeletal elements. The site is enclosed on all sides by steep slopes allowing rainwater to flow into the site and pool, the result of which could be the displacement of the skeletal elements from their original locations. Historically, the Vore site has been subjected to several flooding episodes during intense thunderstorms and accelerated snowmelt that may complicate the interpretations of the clustering of bone elements.

Extensive research has been conducted on fluvial transport and sorting of skeletal elements by water (Voorhies 1969; Behrensmeyer 1975b; Korth 1979; Frison and Todd 1986). Based on this work, there are certain elements that are more subject to displacement by water than others. I used cluster analysis in conjunction with analysis of long axis orientation and the Fluvial Transport Index (FTI) as described by Voorhies (1969), Behrensmeyer (1975b), Korth (1979), Frison and Todd (1986) and Lyman (1994) to control for possible fluvial dispersion. If fluvial dispersion has affected spatial distributions, the elements most likely to be subject to the movement of water should cluster towards the center of the sinkhole. At the Vore site fluvial transport would result in many of the faunal remains having nonrandom long axis orientations (Figure 6). Random orientation would indicate the material has not been affected by the flow of water (Lyman 1994:178).

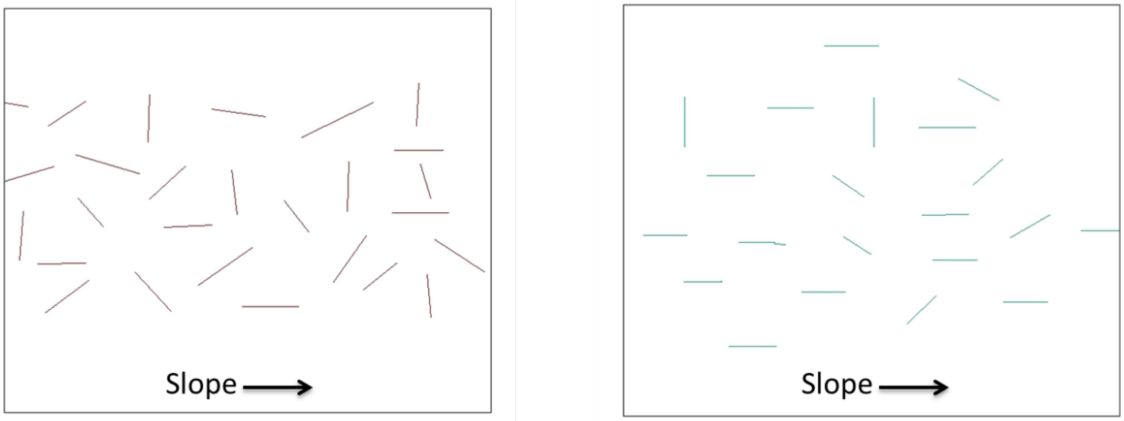


Figure 6. Hypothetical expected long axis orientation (on the left) and preferential long axis orientation indicating fluvial transport (on the right).

Voorhies (1969), Behrensemeyer (1975b), and Korth (1979) examined the settling velocities of bone elements to determine which elements are affected by fluvial transport and would settle first or last. The bones were placed into five categorical ranks (Group I, Group I and II, Group II, Group II and III, and Group III) with Group I representing bone elements most likely to be moved by fluvial transport and Group III representing the bones least likely to be moved. Frison and Todd (1986) employed a different method using remains of an Indian elephant and other fauna to determine which elements are most likely to be moved by water. Instead of grouping the bone elements into Voorhies' categories, Frison and Todd calculated a fluvial transport index (FTI) and presented three ratio classifications: ≥75 (more likely to be moved), 50 to 74, and <50 (least likely). For the ease of interpretation, I have summarized the FTIs and given my own rank based of off the work of Voorhies, Behrensemeyer, Korth, and Frison and Todd. The bone elements are ranked on a scale of 1 to 4 with 1 being elements most likely to be transported and 4 being elements least likely to be transported (Table 1). As shown in Table 1, the elements most likely to be transported by water are ribs and vertebrae. The bone elements least likely to be subject to movement are mandibles. The density of the bone is the major contributing factor to fluvial transport. For instance, mandibles are much denser than ribs or vertebrae and thus require a higher velocity for movement.

Bone Element	Voorhies (1969)	Korth (1979)	FTI Frison and Todd (1986)	FTR (Kirkwood)
Femur	Group II	Group II	24.26	3
Humerus	Group II	Group II	57.77	3
Innominate	Group II	Group II	0.00	3
Metacarpal	Group II	Group I and II	68.83	3
Mandible	Group III	Group II and III	34.56	4
Metatarsal	Group II	Group I and II	0.00	3
Rib	Group I	Group I	53.98	2
Radius	Group II	Group I and II	49.95	3
Scapula	Group I and II	Group I and II	62.95	3
Tibia	Group II	Group III	72.84	4
Vertebrae	Group I	Group I and II	Atlas 41.97 Cervical 96.64 Thoracic 76.43 Lumbar 76.21	1

*FTR=Fluvial transport rank

Table 1. Summary table of bone elements and their susceptibility to fluvial transport. The data was adapted from Voorhies (1989), Behrensmeyer (1975b), Korth (1979), Frison and Todd (1986), and Lyman (1994).

1.4 Carnivore Action at the Vore

The Vore faunal assemblage mainly comprises of *Bison bison* but remains of canids, ursids, and other large ungulates have been identified and recovered from the bone bed (Walker 1980:154-169). Walker (1980 and 1982) observed carnivore action as one of the contributing taphonomic processes affecting some of the remains at the Vore. For the purpose of this study, I chose to ignore carnivore action and other taphonomic agents (e.g. root etching, trampling, etc.) and focus primarily on fluvial action. I am working under the assumption that fluvial action is one of the main factors that could create problems for spatial patterning and potential comingling of bone elements.

2. Methods

Methods concerning spatial patterning and analysis in archaeology have been adopted "from geography and ecology" (Voorrips and O'Shea 1987:500) to investigate questions pertaining to the relationships of archaeological material through time and space. Binford (1978a) famously investigated the Nunamuiut and their utilization of caribou bone elements and where these elements were discarded. This endeavor was foundational in establishing methods of intrasite spatial analysis of faunal material and the identification of activity centers.

To investigate the potential cooperative assembly line butchering patterns at the Vore site, I conducted several nearest neighbor tests on the available provenience data. The data consists of point plots and associated portion, element, and specimen codes for each bone element that had been removed during excavation. The provenience is relative to the arbitrary grid system in which the excavations have occurred. The bones used in this study were excavated from the "new" units which were not part of the original excavations in the 1970s (Figure 7).

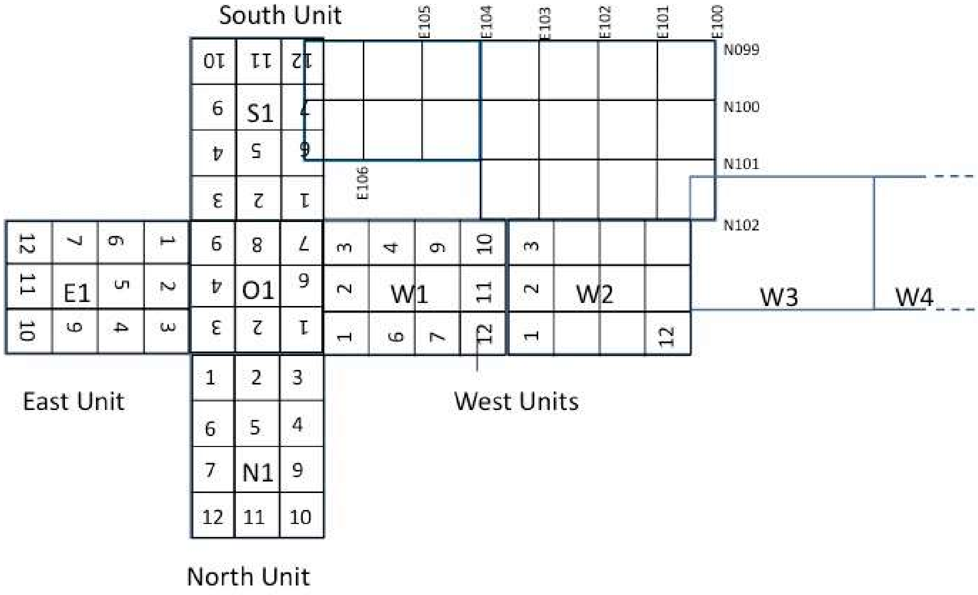


Figure 7. Grid system of the "old" and "new" block excavations at Vore (Reher 1992a). The excavation blocks comprise roughly 10 percent of the total site area.

The elements I examined include both axial and appendicular bones from Cultural Levels 1 and 2. I specifically examined ribs, vertebrae, innominate bones, scapulae, femora, humeri, tibiae, radii, mandibles, metacarpals, and metatarsals. This sample includes both complete elements and fragmentary bones. I used these elements to determine if the elements were clustering significantly and if the appendicular are clustering separately from the axial elements. Focusing on only Cultural Levels 1 and 2, I am able to control for variability in stratigraphy as discussed above. There were approximately 116 bones in Cultural level 1 (Appendicular n=73; Axial n=43). The sample for Cultural Level 2 included 81 bones (Appendicular n=50; Axial n=31). To avoid over representing potential clusters, I excluded bones that were coded as "Unknown: or "Unspecified" and only used bones that were identifiable to element.

It is also important to note that the excavated material from cultural levels 1 and 2 are sometimes necessarily coded as belonging to both because of the incline of the bone (i.e. mandible 43 is from cultural level 1/2). When this occurred, I treated the bone as if it is in both levels. While this adds to the risk of creating artificial clusters and spatial structure, I included these bones in the sample to avoid reducing sample size for each level.

2.1 Fluvial Transport

To control for the possibility of bones being transported by fluvial activity, I used several Fluvial Indices to predict which bones are most likely to be winnowed (Table 1) and also ran a chi-square test on the orientation of the complete and fragmentary bones. The orientation of the bones was plotted in rose diagram to graphically display the results. I separated the bone elements into eight different categories based on 45 degree intervals. This was done to examine whether fluvial transport was responsible for the creation of observed clusters at the site.

2.2 Clustering and Spatial Segregation

According to Carr (1984:108) "an assessment of the form of spatial arrangement of entities using the nearest-neighbor statistic does depend on the size of the area chosen for analysis". For a good representation of potential spatial patterns, I chose to examine all of the excavated material from the "new" units that had point plotted provenience. I omitted the faunal remains excavated from the "old" units as the provenience is only spatially referenced to excavation unit, and in the best case, the bone was accompanied by a sketch map of the unit before the bone was removed. I wanted to avoid artificially creating clusters and therefore did not digitize the "old" material for this study.

To test whether there is clustering or random distributions of the same bone type (Figure 8), I used nearest neighbor analysis which is based on the total set of distances from each element to its closest neighbor. For the faunal remains, I compare the observed mean nearest neighbor distances to the expected distribution of nearest neighbor distances for the same number of elements distributed randomly within the excavation area. The observed nearest neighbor distance is compared to 10,000 randomized averaged nearest neighbor distances. By doing this, the actual (or observed) northing and easting could be compared to random distributions that simulate what one would expect to see if no human agency was affecting the distribution of the material. The nearest neighbor test was carried out on all of the bone elements for both cultural levels as a whole and then broken into two categories (complete and fragmentary) and run again to ensure that significant clustering was occurring and not being skewed by fragmentary bone elements.

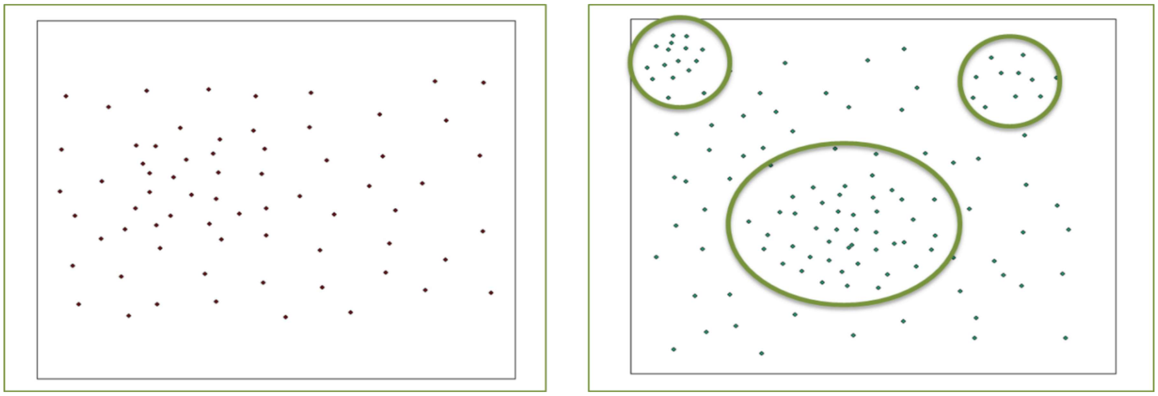


Figure 8. Hypothetical random distribution (on the left) versus clustering (on the right).

Next, I ran pairwise bootstrapping tests on distances between complete bone centroids (mean provenience) values for each pairing of skeletal elements to examine degree of spatial separation. I only used the bones coded as complete bones because the fragmentary bones may create unrealistic representations of the data. Due to the size of some of the fragmentary bones, I determined that the dispersion might be overestimated if fragments were included. In this method, all bones from each pair of elements are randomly assigned to proveniences from the actual proveniences for the total set of bones and a distance between the mean centroid positions is calculated. This procedure is repeated for 10,000 iterations. Probability is calculated by comparing the distribution of randomized centroid distances to the observed distance between the centroids with a null hypothesize of distance is equal to zero. For example, I tested the distance between the centroids of mandibles and scapulae in Cultural Level 1. The bootstrap test was used to determine the significance of spatial segregation of this pair of elements. If mandibles were clustering together and away from scapulae that would indicate that assembly line and organization may have been taking place at the Vore site.

The first category was appendicular bones: humeri, femora, scapulae, tibiae, radii, metacarpals, metatarsals, and mandibles. I included mandibles in this category as they are part of the intensive butchering process during tongue extraction and exhibit the highest frequency of cut marks (Pierce 2015:119). The second category included the axial elements: vertebrae and rib bones.

2.3 Breakage Patterns of Long Bones

After statistics were run on the faunal assemblages in each level, I investigated breakage patterns of the long bones. Breakage was recorded in the field on the coding forms, which I used as a reference for the provenience and description of the bones. I focused on breakage patterns that would indicate marrow processing (i.e. green breaks, or breaks along the shaft or distal and proximal ends). Animal butchery typically occurs in three stages (Binford 1978a:48; Lyman 1978:247; and Pierce 2015:131). The stages as described by Binford (1978:48) can be summarized as follows: Stage 1 is the kill stage where the animal is reduced to transportable parts, Stage 2 is where the animals are further reduced to edible or storable units, and Stage 3 is where consumption and discard take places. Examining the breakage patterns in the clusters of bones might indicate which stage or stages of butchery created the piles. In Stages 1 and 2, the bone piles could be articulated or the most valued cuts could be missing if they have been transported away from the kill. If the bone pile represents a Stage 2 or 3 butchery episode, there could be butchery marks in the form of green bone breaks for marrow extraction similar to those observed by Frison (1965). In this case, the bones would represent consumption and discarded material. To investigate the nature of the bone piles, I recorded the percentage of green bone breakage for the long bones for each cultural level.

3. Results

3.1 Long Axis Orientation

According to Lyman (1994:179), the long axis orientation of the bones should be represented by an asymmetrical shape in a rose diagram if fluvial processes have affected the bones. The null hypothesis is that there is random orientation, indicating that fluvial transport is not affecting the assemblage of bones at the Vore site.

A chi-square test assuming random orientation was used to determine if the bones in each cultural level were being affected by fluvial transport. The long axis orientation was also plotted in a rose diagram to determine if there was any asymmetry indicating fluvial transport (Lyman 1994:178). The bones in Cultural Level 1 had a p-value that was not significant ($X^2=13.79$, $df=7$, $p=.055$). Therefore the null hypothesis could not be rejected. This indicates that the bones in Level 1 have likely not been affected by fluvial processes and are randomly oriented (Figure 9). The chi-square results for Cultural Level 2 are significant ($X^2=30.77$, $df=7$, $p<.001$), suggesting that the bones are not randomly oriented and have an asymmetrical distribution of orientations with southern and eastern orientations being overrepresented (Figure 10). These results can be interpreted in three ways: (1) fluvial transport has affected the orientation of the bones, (2) the bones represent anatomical position indicating that the elements are aligned in the same direction as they were deposited, and (3) is the result of excavation bias. The orientation of the long axis for each bone can be represented by "two orientations, such as 160° and 340°, if measured from the proximal end and from the distal end" (Lyman 1994:178). This can result in a "mirrored" representation of the data that over represents the orientation. Even though the Vore site is often flooded, it does not appear that the faunal assemblage in Cultural Level 1 has been significantly affected by fluvial transport. The clustering of bones in Cultural Level 1 is also largely comprised of mandibles (n=31). According to the Fluvial Transport indices, mandibles would be the element least likely to be transported by water. Therefore, the integrity of this cultural level has likely not been significantly affected by fluvial action and the clusters are the result of a different process. In Cultural Level 2, the bones are not randomly oriented and the null hypothesis is rejected and fluvial action cannot be ruled out.

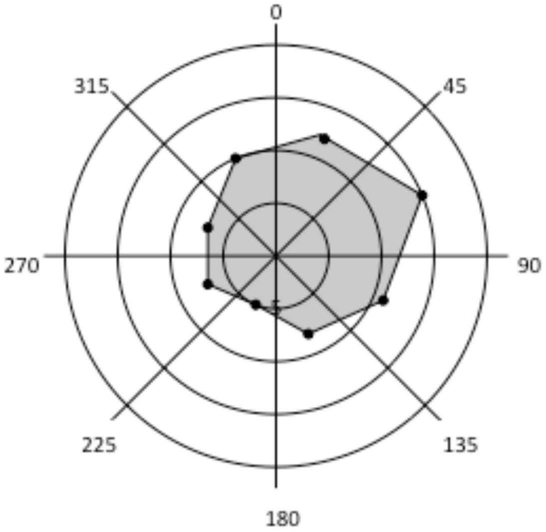


Figure 9. Rose diagram demonstrating the long axis orientation of bones in Cultural Level 1 (n=68).

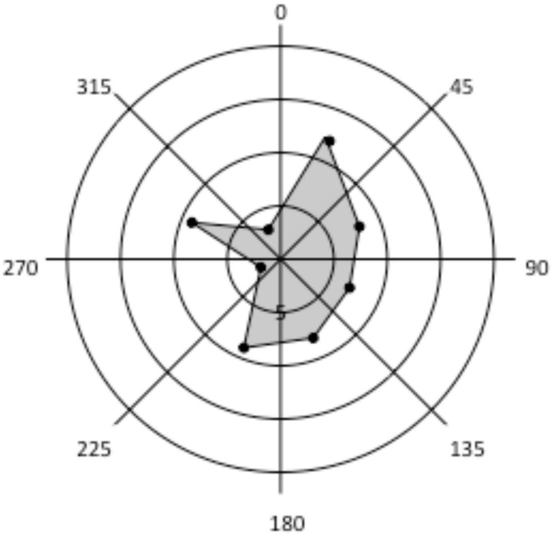


Figure 10. Rose diagram demonstrating the long axis orientation of bones in Cultural Level 2 (n=56).

3.2 Spatial Structure

Statistical analysis presents compelling insights into the Vore site's structure. The first nearest neighbor test was conducted on the appendicular elements in Cultural Level 1. The nearest neighbor test was run for the entire sample of appendicular bones and then separated into fragmentary and complete elements. In comparison to the randomized (expected) distributions, the appendicular bones are clustering significantly (R=.8 and p<.001), as a result the null hypothesis was rejected (Figures 11 and 12). The fragmentary and complete bones are both clustering significantly (R=.71 and p<001) (Figures 13 and 14). The distribution of axial elements is also nonrandom (R=.72 p<.001), and the null hypothesis was again rejected (Figures 15 and 16). The results indicate that the faunal remains in Cultural Level 1 are not randomly distributed. Therefore, it appears that the bones are clustering in some fashion and most likely due to human agency (Figure 17). The same tests were run on Cultural Level 2, first on the entire sample of appendicular and axial elements and again separately on fragmentary and complete bones (Figure 18). The fragmentary bones in Cultural Level 2 appear to cluster (R=.38 and p<.001) indicating non-random distribution and rejection of the null hypothesis. The results for the complete appendicular elements were not significant (R=1.36 and p =.16) (Figures 19 and 20). Axial elements in Cultural Level 2 are significantly clustered (R=.48 and p<.001) (Figures 21 and 22). The axial elements are clustering significantly in both levels and appendicular elements only cluster in Level 1. Even though the bone elements are clustering nonrandomly, I could not make confident inferences concerning the extent to which the bone piles were clustering by specific elements. The structure is visibly more apparent in Cultural Level 2 (Figure 23), but the patterning can still be the result of fluvial transport.

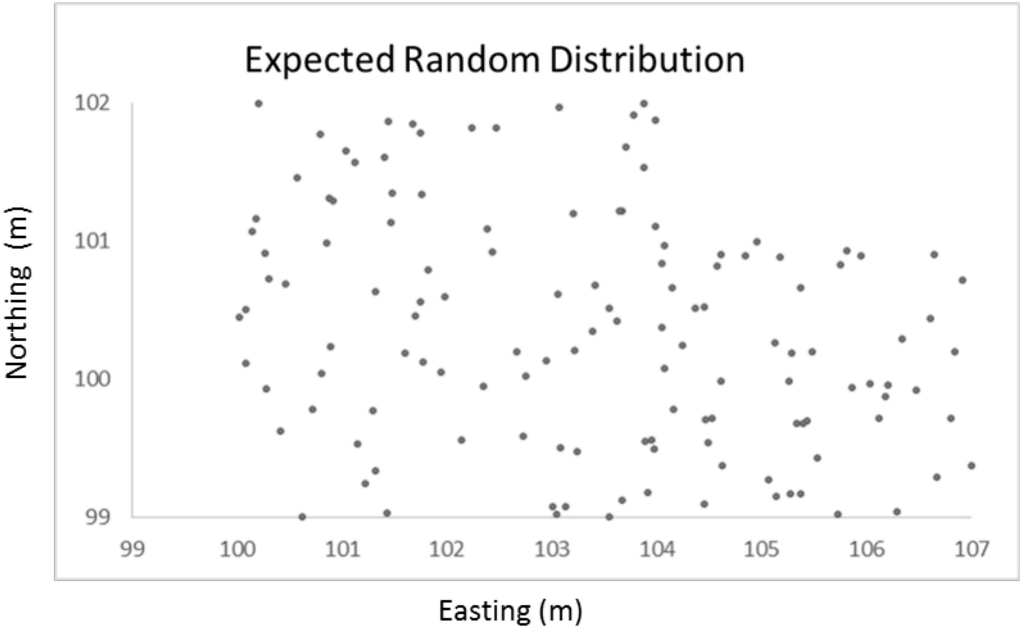


Figure 11. Expected random distribution of appendicular elements in Cultural Level 1.

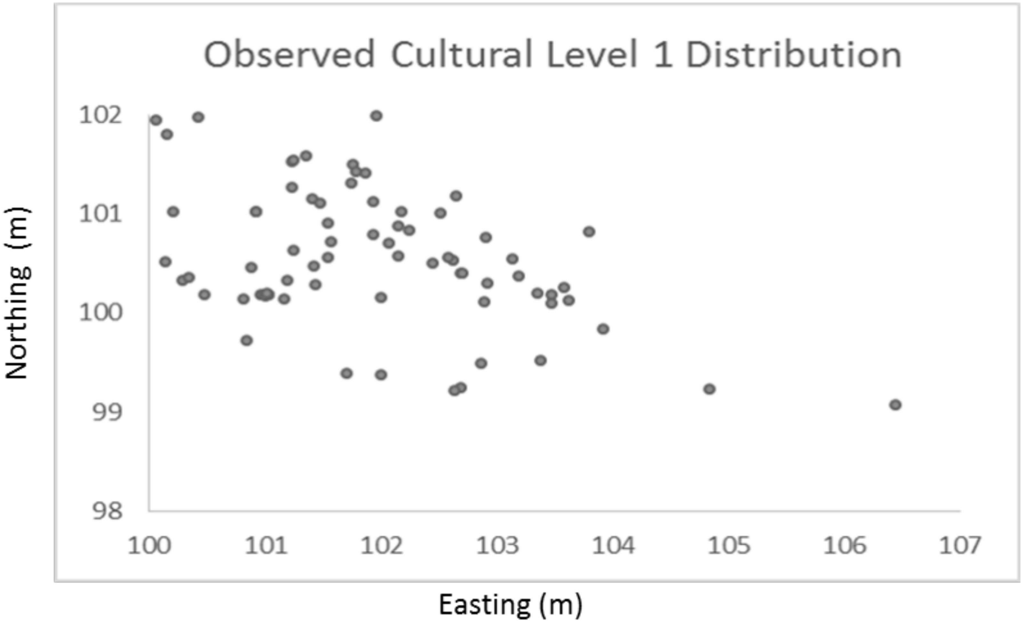


Figure 12. All of the appendicular bone elements (n=73) from Cultural Level 1 plotted within the excavated area (the nearest neighbor mean is 20 cm, R=.8 and p<.001).

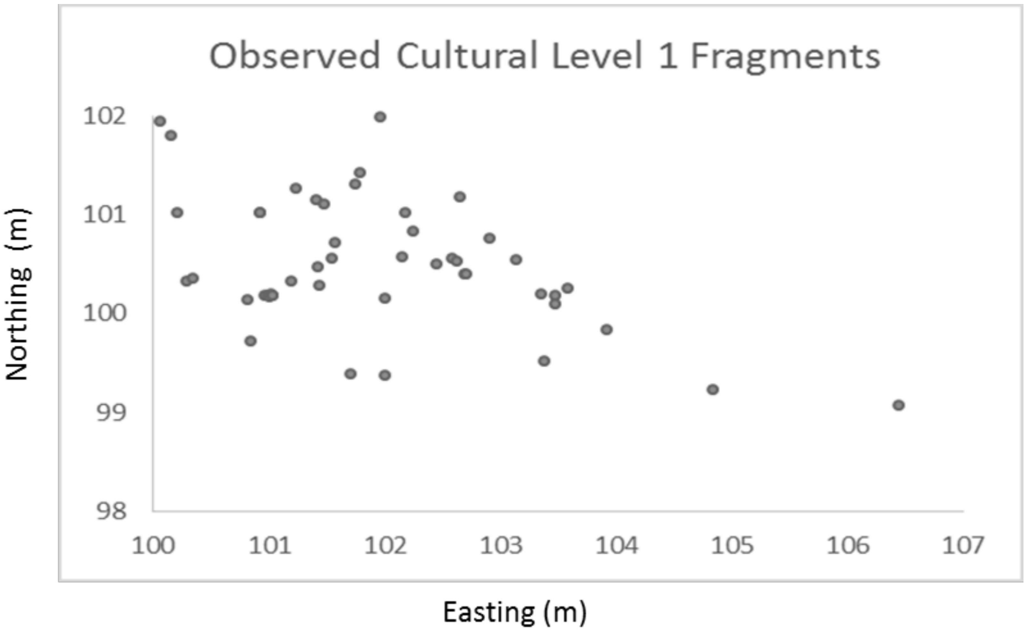


Figure 13. A nearest neighbor test was run on the fragmentary bone (n=48) to see if they were clustering significantly in Cultural Level 1 (the nearest neighbor mean is 23 cm, R=.71 and p<.001).

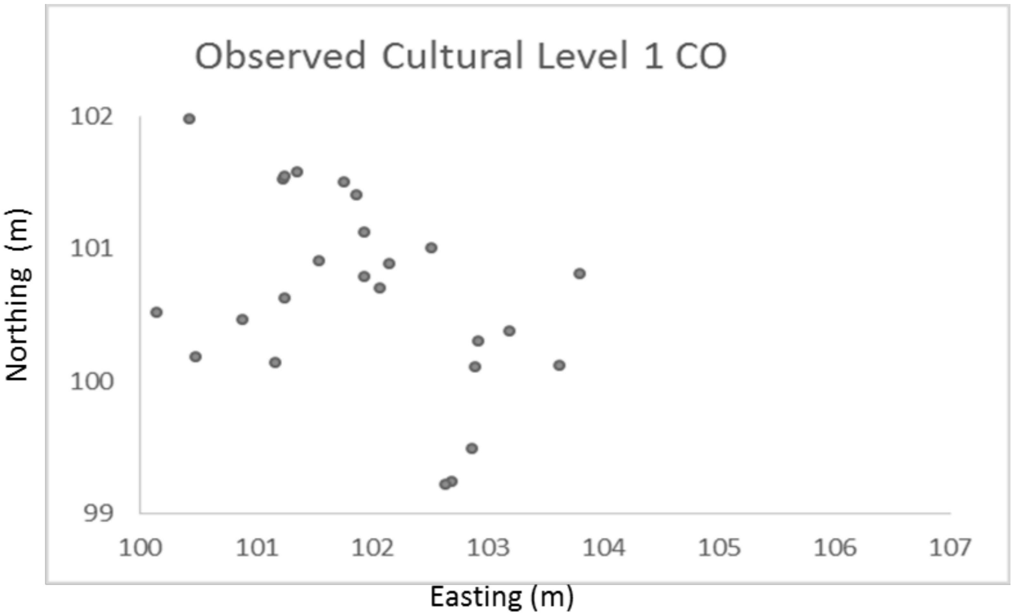


Figure 14. A nearest neighbor test was run on the complete bones in Cultural Level 1 (n=25) to determine if they were clustering (nearest neighbor mean is 29 cm, R=.63 and p<.001).

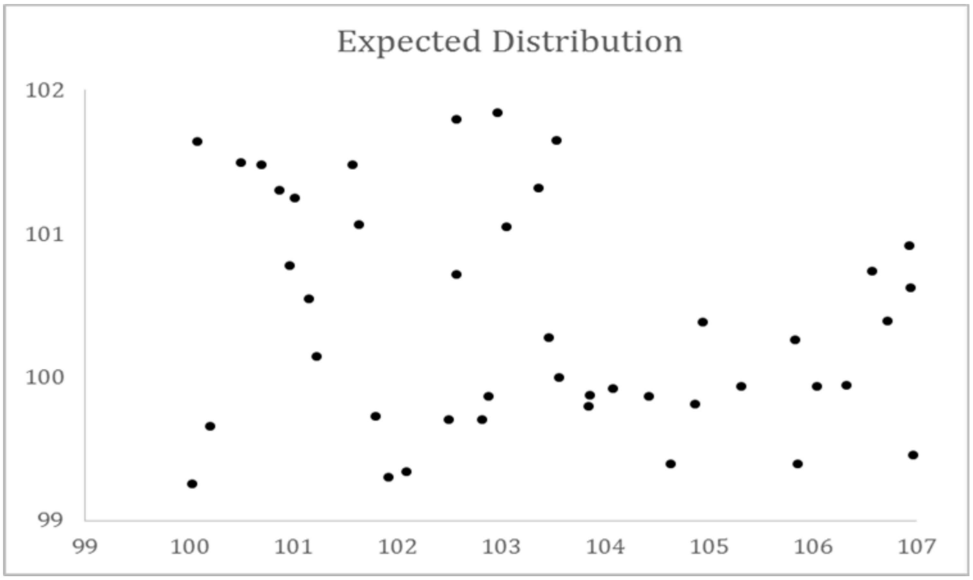


Figure 15. Expected distribution of axial elements in Cultural Level 1 (n=43).

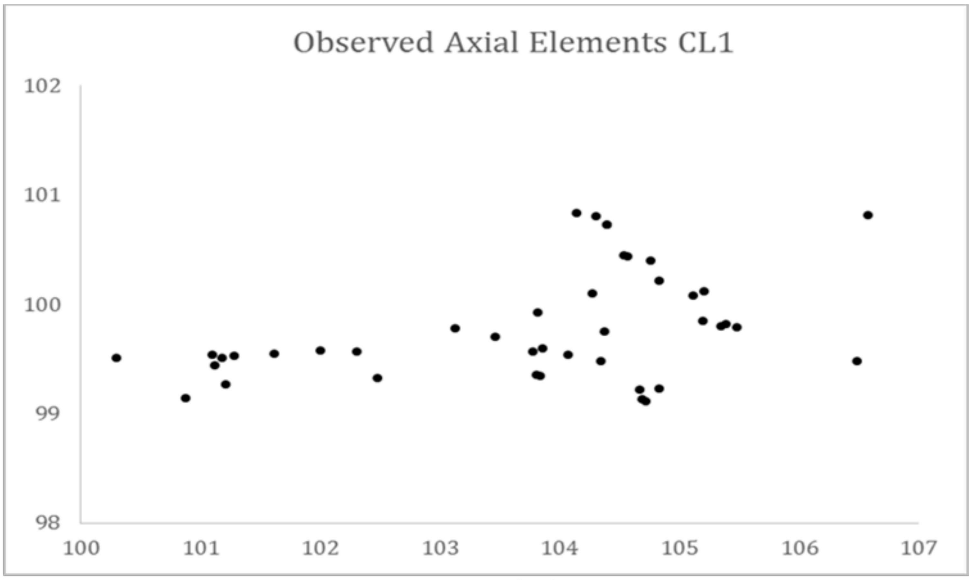


Figure 16. Observed distribution of axial elements in Cultural Level 1 (n=43). A nearest neighor test was run to see if the axial elemts were clustering significatly (nearest neighbor mean is 24 cm, R=.72 and p<.001).

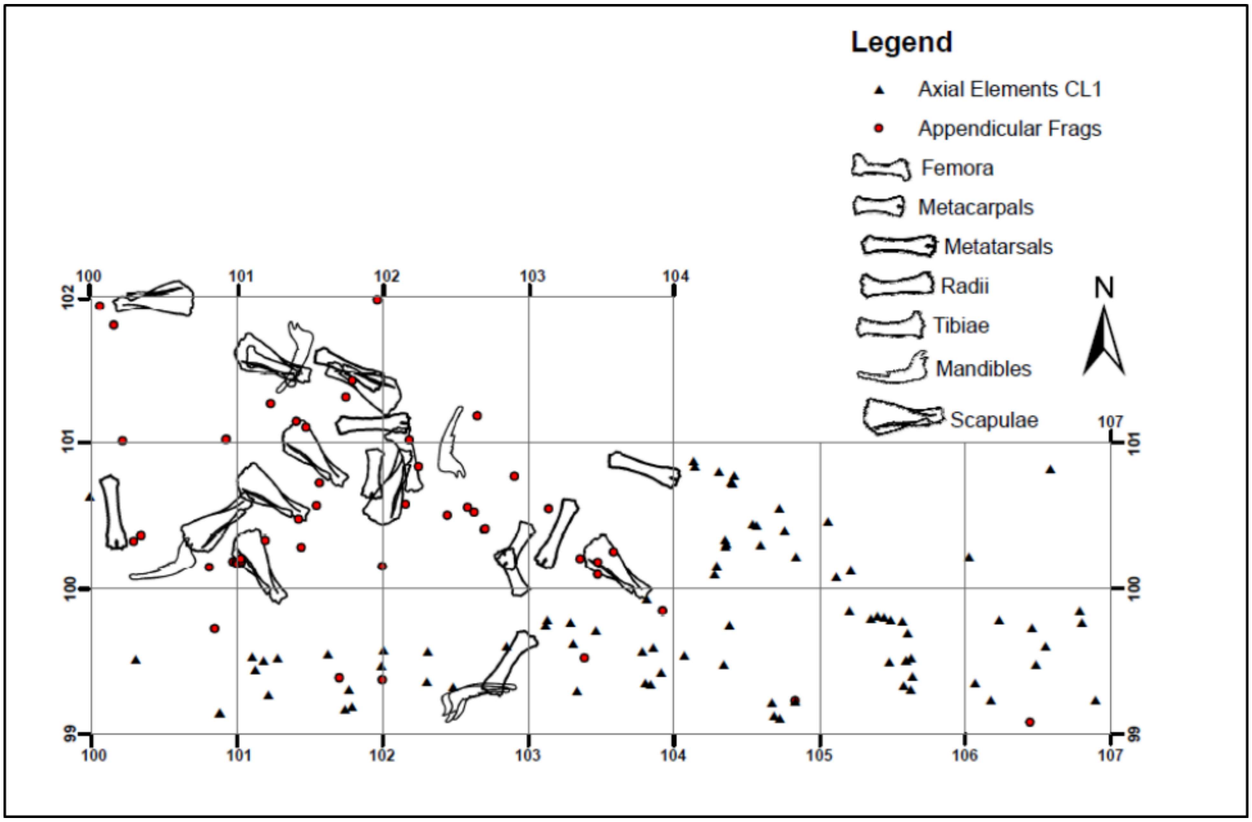


Figure 17. Appendicular and axial bone elements from Cultural Level 1 mapped together in the excavated area. The axial elements coded as "Unknown" or "Unspecified" are included in this plot.

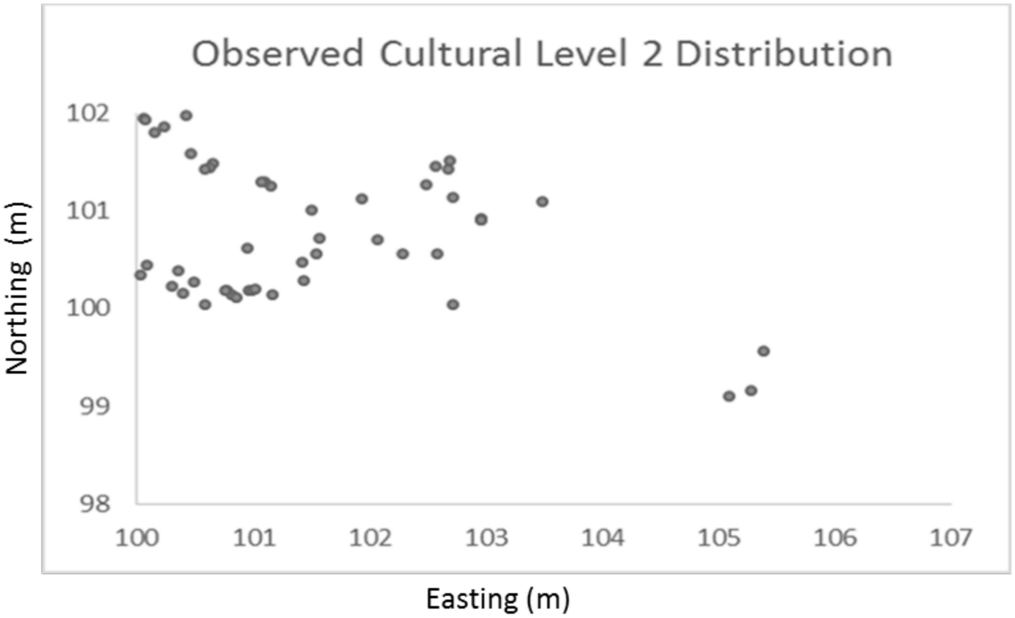


Figure 18. All of the appendicular bone elements (n=50) from Cultural Level 2 plotted within the excavated area (the nearest neighbor mean is 15 cm, R=.48 and p<.001).

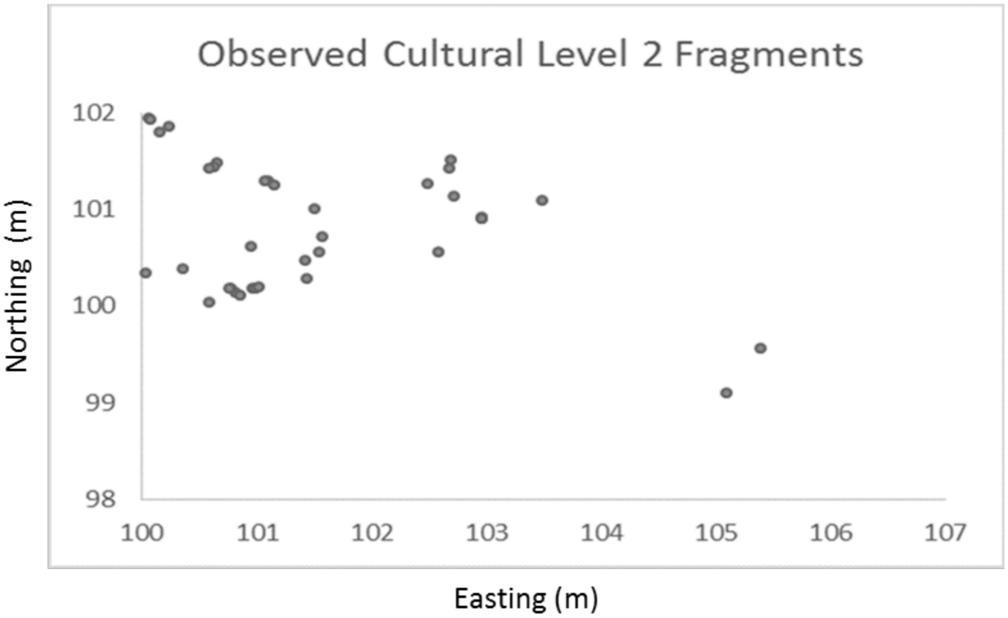


Figure 19. A nearest neighbor test was run on the fragmentary bone (n=37) to see if they were clustering significantly in Cultural Level 2 (the nearest neighbor mean is 15 cm, R=.38 and p<.001).

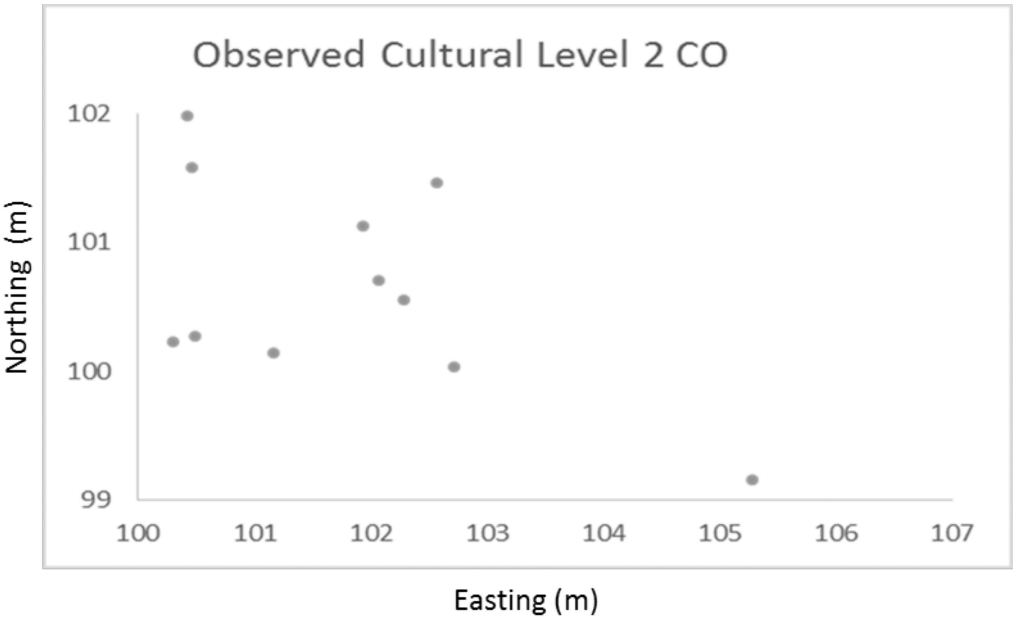


Figure 20. A nearest neighbor test was run on the complete appendicular bones in Cultural Level 2 (n=25) to determine if they were clustering (nearest neighbor mean is 63 cm, R=1.36 and p=.16). The bones are not clustering significantly.

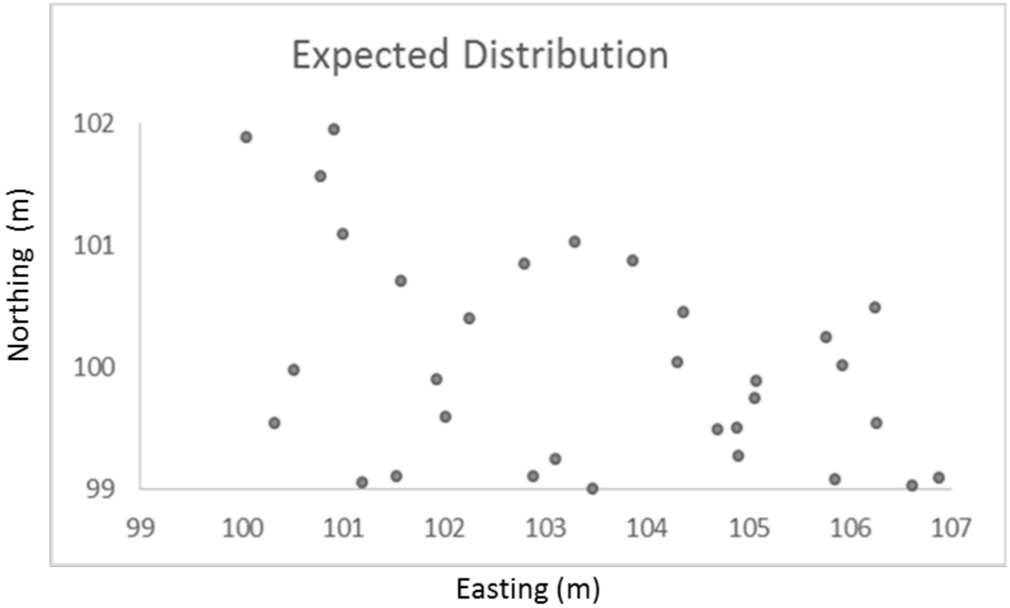


Figure 21. Expected distribution of axial elements in Cultural Level 2 (n=31).

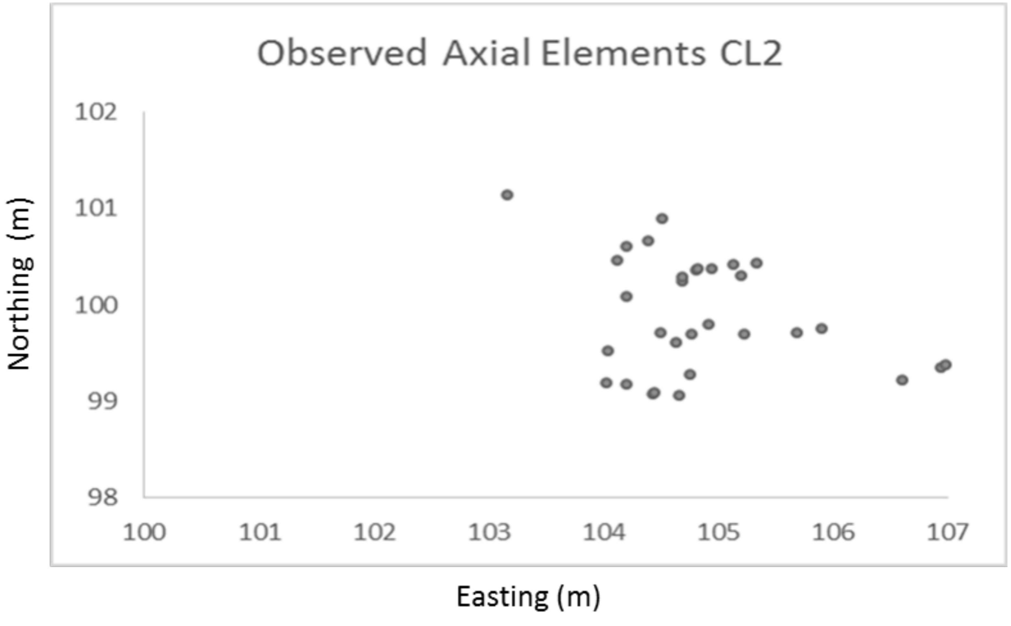


Figure 22. Observed distribution of axial elements in Cultural Level 2 (n=31). A nearest neighor test was run to see if the axial elemts were clustering significatly (nearest neighbor mean is 19 cm, R=.48 and p<.001).

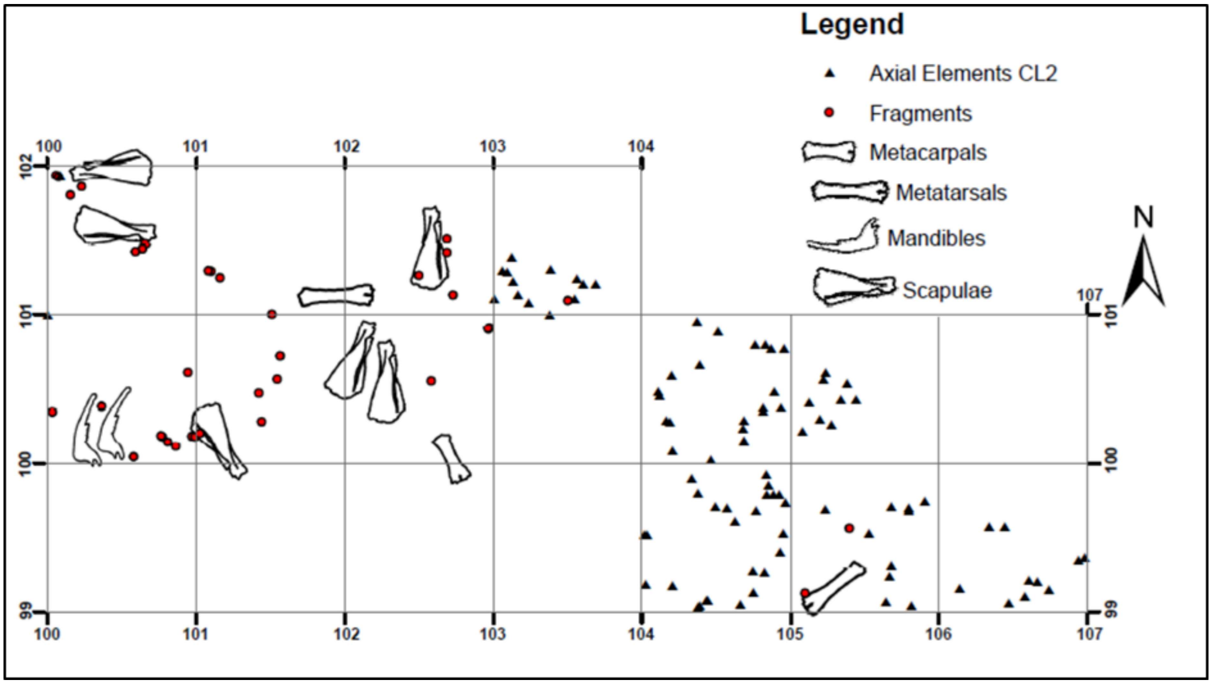


Figure 23. Appendicular and axial bone elements from Cultural Level 2 mapped together in the excavated area. The axial elements coded as "Unknown" or "Unspecified" are included in this plot.

The nearest neighbor test demonstrated that the bones were clustering significantly in a nonrandom distribution, but the organization by anatomical relation or by similar bone elements could not be tested due to a small sample of each bone element. Through the use of the bootstrap test, the distance between centroids for each pair of the skeletal elements can be evaluated. If the p-value in the bootstrap test is significant, it indicates that each bone element pairing, (e.g. humeri, femora, axial, appendicular etc.), is clustering in their own respective areas within the larger cluster. In Cultural Level 1, femora and tibiae are significantly spatially segregated, as are femora and humeri, humeri and mandibles, and finally scapulae and femora (Table 2). The rest of the pairings of bones in Cultural Levels 1 and 2 were dispersed relatively in the same general areas. As a result, the null hypothesis could not be rejected in the remaining tests (Tables 3 and 4).

Centroids	Observed Distance (cm)	Expected Distance (cm)	p value
Femora vs Tibiae	0.957	0.666	<.001
Femora vs Humeri	1.399	0.698	0.0083
Humeri vs Mandibles	1.407	0.613	<.001
Scapulae vs Femora	0.727	0.557	0.002

Table 2. The significant results from the bootstrap test in Cultural Level 1. The bone elements have significantly distanced centroids.

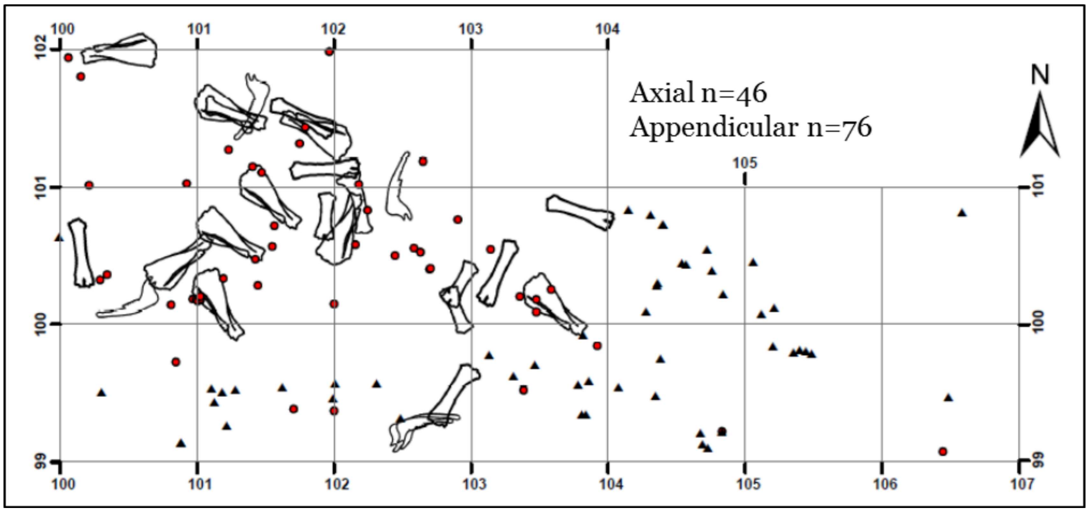
Centroids	Observed Distance (cm)	Expected Distance (cm)	p value
Scapulae vs Tibiae	0.705	1.01	0.3698
Humeri vs Tibiae	1.148	0.901	0.2749
Metatarsals vs Tibiae	0.853	0.843	0.2979
Mandibles vs Tibiae	0.758	0.452	0.1213
Mandibles vs Scapulae	0.758	0.551	0.279
Metatarsals vs Scapulae	0.853	0.61	0.0985
Metatarsals vs Humeri	1.273	1.166	0.0988
Mandibles vs Metatarsals	0.778	0.617	0.1214
Femora vs Metatarsals	0.764	0.762	0.163
Complete vs Fragmentary	0.41	0.42	0.4812

Table 3. The results of the bootstrap test that are not significant in Cultural Level 1. These elements are dispersed in the same portion off the site.

Centroids	Observed Distribution (cm)	Expected Distribution (cm)	p value
Mandibles vs Radii	0.688	0.842	0.496
Mandibles vs Scapulae	0.596	0.586	0.476
Complete vs Fragmentary	0.532	0.827	0.718

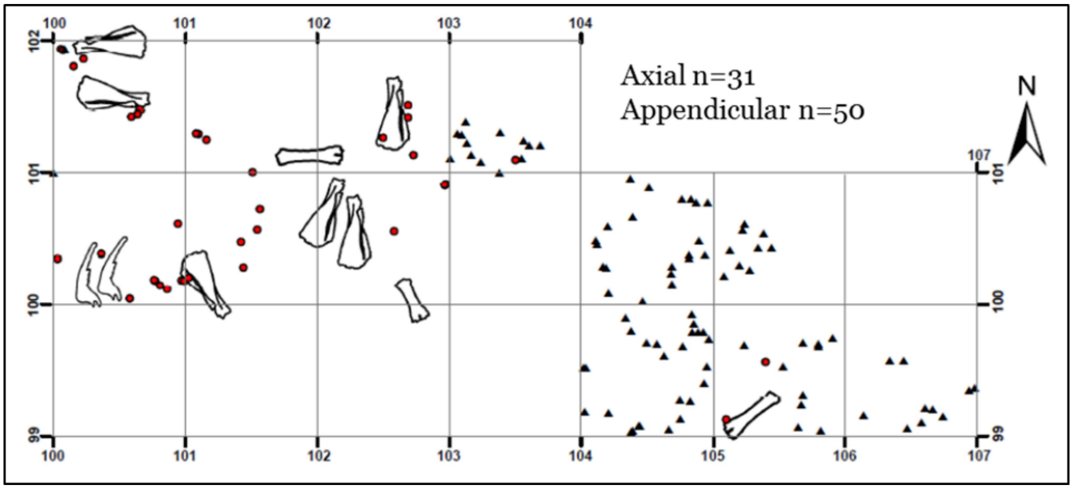
Table 4. The bootstrap test results from Cultural Level 2. These results indicate that the bones are discarded in the same portion of the site.

Based on the pairwise bootstrapping test and the nearest neighbor test, it appears that the bone elements in Cultural Levels 1 and 2 are clustering entirely by bone element. The axial bones seem to be clustering based on anatomical association. These results indicate that there is organization and it may be in an assembly line fashion where the piles comprise similar elements. The bone piles are clustering based on axial and appendicular elements and indicate the three stages of butchery and disarticulation mentioned above. The most striking results were reached when running the bootstrap test between the two general categories of bone (i.e. appendicular and axial) (Figure 25 and 26). The centroids for the appendicular and axial elements are observed clustering away from one another and seem to be restricted to their own respective areas within the excavation area. The results of the bootstrap and nearest neighbor tests might indicate that the clusters elements represent all of the stages of butchery (Binford 1978a:48; Lyman 1978:247).



Centroids	Observed Distribution (cm)	Expected Distribution (cm)	p value
Axial vs Appendicular	1.332	1.221	<.001

Figure 24. The results of the bootstrapping test for Cultural Level 1. The image shows the appendicular elements (represented by bones or dots) clustering away from the axial elements (represented by triangles).



Centroids	Observed Distribution (cm)	Expected Distribution (cm)	p value
Axial vs Appendicular	1.853	1.482	<.001

Figure 25. The results of the bootstrapping test for Cultural Level 2. The image shows the appendicular elements (represented by bones or dots) clustering away from the axial elements (represented by triangles). The distance is more prominent here compared to level 1.

The appendicular pile in Cultural Level 1 and 2 comprises of a higher frequency of mandibles (n=31 in Cultural Level 1; n=26 in Cultural Level 2) than any other element (Figure 26 and 27). This indicates that mandibles are being discarded in the same portion of the site. The low frequency of bone elements with high meat and marrow values are low in frequency and exhibit breakage patterns. Not only are the animals being disarticulated for transportable parts, but they're being reduced to edible parts, and being consumed and discarded on site.

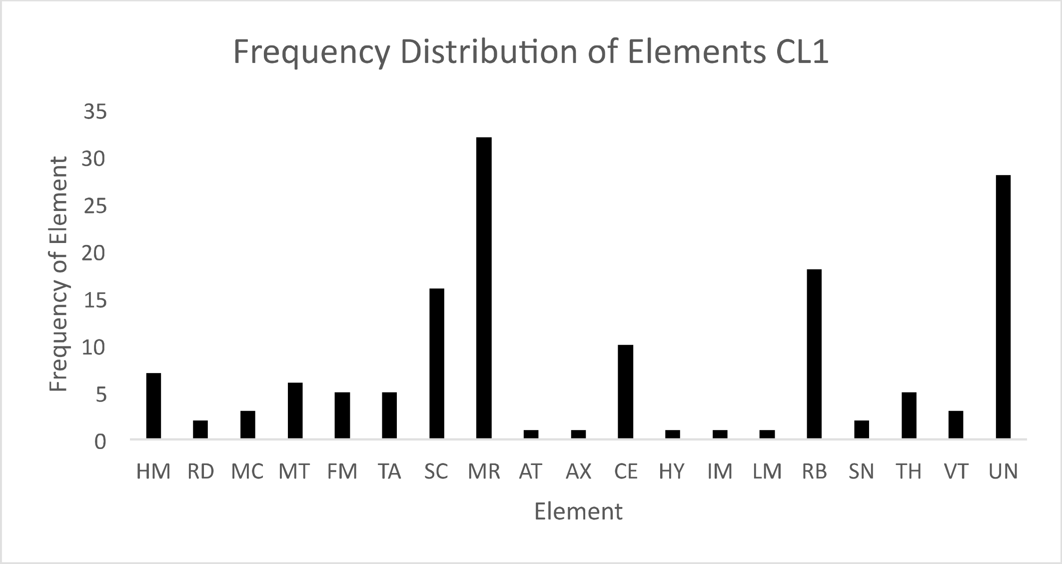


Figure 26. The frequency distribution of the bone elements: radii (RD), metacarpals (MC), metatarsals (MT), tibiae (TA), scapulae (SC), mandibles (MR), innominate (IM), lumbar vertebrae (LM), ribs (RB), sternal bodies (SN), thoracic vertebrae (TH), vertebrae unknown (VT), and unknown bone specimens (UN) recovered from Cultural Level 1.

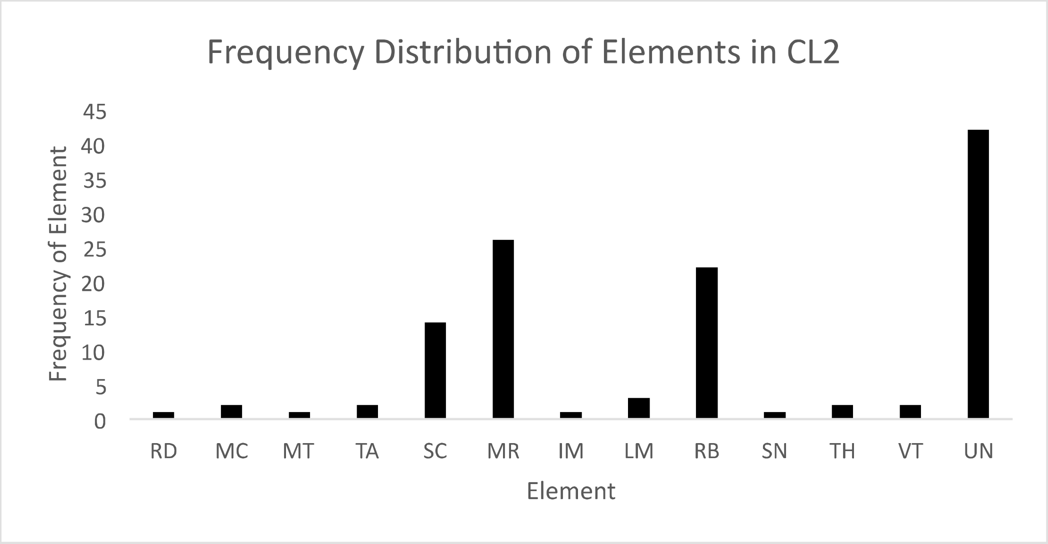


Figure 27. The frequency distribution of the bone elements: radii (RD), metacarpals (MC), metatarsals (MT), tibiae (TA), scapulae (SC), mandibles (MR), innominate (IM), lumbar vertebrae (LM), ribs (RB), sternal bodies (SN), thoracic vertebrae (TH), vertebrae unknown (VT), and unknown bone specimens (UN) recovered from Cultural Level 2.

3.3 Long Bone Breakage

I graphed the frequency distribution and the breakage percentage of the bone elements for each level. Cultural Level 2 has a low frequency of long bones and because of this I ignored the long bones in this level and focused on the breakage percentage in Cultural Level 1. If the long bones in Cultural Level 1 demonstrate a high percentage of green bone breakage, it may indicate that the piles of long bones are remnants of consumption and discard during this kill event.

Marie (1990) quantified the caloric value of bone marrow in the long bones of *Bison bison*. According to Marie, the metacarpals and metatarsals have the lowest caloric value for bone marrow. The low caloric return of marrow from metatarsals and metacarpals has also been noted in other species including *Odocoileus virginanus* (White-tailed deer) (Madrigal and Holt 2002) and in *Antilocapra americana* (Pronghorn) (O'Brien and Liebert 2013). As such, these elements should exhibit the lowest percentage of breakage at a mass kill as they do not yield much in terms of marrow. These authors also agree that greater quantities of marrow are derived from the tibia and the femur. As Figure 28 illustrates, the metatarsals in Cultural Level 1 exhibit the least amount of breakage. Additionally, the tibiae and the femora have a relatively high percentage of green bone breakage. Although the sample sizes of each of these elements are low (Femora=5, Humeri=7, Metatarsals=6, Radii=2, and Tibiae =5), they still exhibit the behavior one might expect to see based on caloric value by element. The bone pile in Cultural Level 1 appears to not only represent Stage 1 and 2 but also Stage 3 butchering patterns for consumption and discard. The pile is comprised of bones with high caloric value in terms of marrow, coupled with mandibles which are exploited for tongue extraction. Historically the tongue was highly valued and considered a delicacy by native groups and Euro-Americans (Lewis 1942:29; Smits 1994).

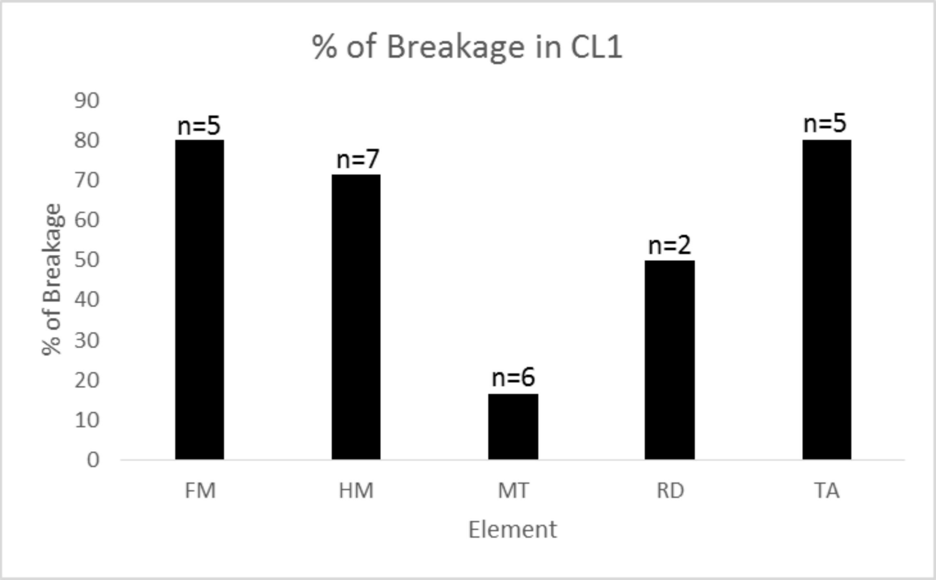


Figure 28. The percentage of breakage in Cultural Level 1: femora (FM), humeri (HM), metatarsal (MT), radii (RD), and tibiae (TA). Elements rich in marrow have a high percentage and elements with a low value have a low percentage.

4. Conclusion

While the nearest neighbor test demonstrated significant clustering of appendicular elements in Cultural Level 1 and clustering of axial elements in both levels, one statistical analysis is not enough to make confident inferences about site structure. However, using a bootstrap test and examining the green bone breakage of long bones that comprise the clusters, it allows for inferences about the nature of the faunal assemblage to be made. The clusters do not appear to be the result of fluvial transport at least in Cultural Level 1. The organization of bones and people at the site may represent an assembly line style of butchery as predicted. The patterns may represent decision-making about secondary discard, or where the people working chose to discard skeletal elements after butchery. The long bone breakage in Cultural Level 1 indicates that consumption (or snacking) and discard was taking place during the butchering process. To reiterate, the faunal remains at the Vore site are not randomly distributed across the site. The appendicular and axial elements are significantly separated indicating organization and human agency.

I argue that this study contributes to the discussion of intrasite spatial analysis promoted by Binford (1978a; 1981). Stapert (1989:3) argued “any meaningful spatial analysis must attempt to establish parts of the sites where at least some relation exists between artefact (sic) locations and former activity areas”. The search for activity locations and spatial patterning has been an integral part of archaeology, and using these methods with point plotted provenience data, it becomes easier to apply statistical methods of analysis.

This research serves as a step in the right direction to understanding the benefits of a statistical approach at mass kill sites. Previous work done on mass kills, have relied on spatial recognition by the researcher in the field or observations on patterns in plan maps. This was the case for the Vore site until the 1990s when a total station was used for better recording of the excavated material. Applying a statistical approach supports interpretations of structure and organization at mass kill sites.

The Vore site presents a unique dataset that is comprised of hand-drawn maps, point plotted material, and unit- or subunit-scale provenience. For the material recovered in the pre-total station and GPS era, not all is lost. The nearest neighbor, and bootstrap methods used for this study could incorporate the data that lacks point plotted provenience. Whallon (1974:16) employed a dimensional analysis of variance for material that only had subunit data or was “collected in the form of counts per grid unit”. With these methods, Whallon was able to statistically analyze distributions within blocks or excavation units that lacked data adequate for nearest neighbor tests. For future research, Whallon’s methods coupled with the methods presented here can offer insight into the reality of the organization observed at the Vore site on a larger scale. By doing this, the patterns observed here could be expanded upon through the various cultural levels to determine if the methods and techniques of butchery at Vore have remained consistent through time.

Lastly, it is important to note that “spatial distribution within an archaeological context can only rarely be ascribed to the effects of a single, strong factor” (Voorrips and O’Shea 1987:500). By ruling out fluvial transport as a taphonomic process affecting the integrity of the bone bed, the argument that the faunal assemblage is not random is strengthened. But there are several other taphonomic agents that could be investigated in the future. For example, this study ignores carnivore action and scavenging which have been noted as being factors to have likely affected the faunal remains at the Vore site by Pierce (2015) and Reher and Frison (1980). It would strengthen the argument of the breakage patterns that were observed in this study if the faunal remains that had a high percentage of breakage were fully examined to rule out carnivores as the main agents of breakage.

Although there are several aspects that could be investigated in the future, the methods presented here allow inferences to be made about site structure and organization at the Vore Buffalo Jump. Through a nearest neighbor test, a pairwise bootstrapping test, and a look into the breakage patterns at the Vore, it is apparent that the individuals who utilized the site did so to procure massive amounts of meat and marrow and display organizational patterns. Cooperation and social organization does not cease at the killing and capture of the animals, but continues through the butchering process. The spatial patterning and difference in the dispersion of the appendicular and axial elements indicates that there is conscience decision-making being made concerning the use of available space at the bottom of a sinkhole. Additionally, mass kill sites with dense bone beds and complicated stratigraphy have the potential to be analyzed with statistical and intrasite spatial analyses.

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